SPT-BASED PROBABILISTIC ASSESSMENT OF SEISMIC SOIL LIQUEFACTION TRIGGERING

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ABSTRACT

SPT-BASED PROBABILISTIC ASSESSMENT OF SEISMIC SOIL LIQUEFACTION TRIGGERING

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The in-situ tests are proven to be a reliable approach to assessing the resistance against seismic soil liquefaction triggering. The scope of this research is to enrich previous SPT-based databases with new case histories from events that occurred in the last 25 years and employ an updated processing perspective with a new set of parameters and correction terms. The new SPT-based liquefaction triggering field case history database is based upon a large field case history from seismic events between 1964 and 2018. The suite of 334 case histories covers normal, reverse, and subduction zone events with site-specific event term parameters presented individually. The critical layers are composed of occasional gravelly and silty critical layers in addition to sandy layers, which enables the introduction and the assessment of new and/or updated corrections schemes (fines correction, etc.). The database documents the available case history data consistently with ongoing CPT and V_s case history data processing. Site response analyses are conducted to estimate the PGA and r_d, when possible. An updated set of factors is used for the correction of SPT N values. The updated database is used to develop a probabilistic model for liquefaction triggering. The resulting relationships provide an updated understanding of the effects of durational, overburden stress, and fines corrections.

Keywords: Liquefaction, Earthquake, Standard penetration test, Site response

ÖZ

SPT-ESASLI OLASILIKSAL SİSMİK ZEMİN SIVILAŞMASI TETİKLENME DEĞERLENDİRMESİ

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Sismik zemin sıvılaşması tetiklenmesi direncinin belirlenmesinde saha deney sonuçlarının kullanılması yaygın bir şekilde kullanılagelmektedir. Bu araştırma bünyesinde, mevcut SPT esaslı sıvılaşma veri tabanları son 25 yılda meydana gelen yeni deprem vaka örnekleri ile zenginleştirilmiş ve yeni parametreler ve düzeltme terimleri kullanılarak güncellenmiş bir bakış açısı geliştirilmiştir. Yeni SPT esaslı veritabanı 1964-2018 yılları arasında oluşmuş vaka örneklerini kapsar. Bu çalışma 334 vaka örneğini ve normal, yanal atımlı depremleri ve bu depremlere özgü yeni parametre terimlerini içerir. Vaka örneklerindeki kritik tabakalar kumlara ek olarak, çakıllı ve siltli kritik tabakaları da bünyesinde barındırır ve bu tabakaları tanımlamaya yardımcı parametreler içerir (ince dane düzeltmesi, vb.). Mevcut vaka örnekleri, V_s ve CPT saha deneyleri verilerini de kullanarak incelenmiştir. Veritabanı kapsamında, yapılması mümkün olan sahalar için, 1-boyutlu saha tepki analizleri gerçekleştirilmiş ve PGA ve r_d parametreleri sahaya özel olarak hesaplanmıştır. Bu çalışma kapsamında, SPT-N darbe sayılarının düzeltilmesinde yeni ve geliştirilmiş düzeltme katsayıları kullanılmıştır. Oluşturulan yeni bağıntı gelişmiş ve güncellenmiş süre, gerilme, ince dane düzeltmelerinin etkilerinin içerir.

Anahtar Kelimeler: Sıvılaşma, Deprem, Standart penetrasyon deneyi, saha tepki analizi

...to my family
who always loves and supports me...

"Our true mentor in life is science."
Mustafa Kemal Atatürk

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TABLE OF CONTENTS

ABSTRACT v

ÖZ vii

ACKNOWLEDGMENTS x

TABLE OF CONTENTS xii

LIST OF TABLES xvi

LIST OF FIGURES xviii

LIST OF SYMBOLS xxiv

CHAPTERS

1 INTRODUCTION 1

1.1 Overview 1

1.2 Organization of the Dissertation 4

2 ENGINEERING APPROACHES TO SEISMIC-SOIL LIQUEFACTION 7

2.1 Introduction 7

2.2 Definition of Seismic-Soil Liquefaction 8

2.3 Seismic Soil Liquefaction Triggering 12

2.3.1 Standard Penetration Test (SPT) 14

2.3.2 Cyclic Stress Ratio, CSR 39

2.3.3 SPT-Based Seismic Soil Liquefaction Triggering Relationships 51

3 DATABASE PROTOCOL & SELECTION OF INPUT PARAMETERS 57

3.1 Introduction 57

3.2 Case History Database Protocol and Selection of Input Parameters 58

3.2.1 Selection of Case History Data 58

3.2.2 General Information Related to Case History Data....58
3.2.3 Field Performance....59
3.2.4 GNSS (GPS) Coordinates....60
3.2.5 Geological Unit....61
3.2.6 Event Parameters....62
3.2.7 Critical Layer Selection and Associated Uncertainty....63
3.2.8 Ground Water Table and Associated Uncertainty....64
3.2.9 Unit Weight and Associated Uncertainty....65
3.2.10 Total and Effective Overburden Stress and Associated Uncertainty....66
3.2.11 Mass participation Ratio and Associated Uncertainty....67
3.2.12 Maximum ground acceleration and Associated Uncertainty....67
3.2.13 Cyclic Stress Ratio and Associated Uncertainty....68
3.2.14 Moment Magnitude, $M_{w,}$ & Associated Uncertainty....69
3.2.15 Shear Wave Velocity, ($V_{s,30m}$ and $V_{s,12m}$)....69
3.2.16 Liquefiable Soil Layer Type and Properties....70
3.2.17 Standard Penetration Test Blow Counts and Associated Uncertainty....71
3.2.18 Reasons for Excluding Case Histories....75
3.2.19 Data Class....76
4 DEVELOPMENT OF FIELD CASE HISTORY DATABASE....79
4.1 Introduction....79
4.2 History of Compilation of Field Case History Data....80
4.3 Compilation of New Case History Database....82
4.3.1 An Illustrative Example of Case History Processing....85
4.3.2 An Overview of the New Case Histories....93

4.4 Re-evaluation of Legacy Case History Database of Cetin et al. (2004, 2018a, b) 101

4.4.1 Modification of Cetin et. al. (2018a, b) Database 101

4.4.2 Excluded Case History Data from Cetin et al. (2004, 2018a) 103

4.4.3 An Overview of the Updated Case Histories from Cetin et al. (2004, 2018a, b) 109

4.5 An Overview of the Case History Database 117

5 SEISMIC SITE RESPONSE ANALYSIS 139

5.1 Introduction 139

5.2 1-D Seismic Site Response Analysis 140

5.3 Subsurface Characterization 140

5.4 Parameter Selection 141

5.5 Selection of Analyses Type and Input Ground Motion 146

5.6 Site Response Analysis for New Zealand Case Histories 147

5.7 Site Response Analysis: Wildlife USA Case Histories 173

6 DEVELOPMENT OF SEISMIC SOIL LIQUEFACTION TRIGGERING RELATIONSHIPS 177

6.1 Introduction 177

6.2 Development of Probabilistic Liquefaction Triggering Curves 177

6.2.1 Development of Mathematical Expression for Seismic Soil Liquefaction 178

6.2.2 Likelihood Function for Seismic Soil Liquefaction Triggering 178

6.2.3 Sampling Bias of the Observations 180

6.2.4 Parametrical Error Terms 181

6.3 Probabilistic Liquefaction Triggering Curves 183

6.4 Recommended Use of the Correlation 203
6.5 Comparison of the New Liquefaction Triggering Relationships with the Available Literature 206
7 SUMMARY & CONCLUSIONS 209
7.1 Summary and Conclusions 209
7.2 Future Recommendations 212
REFERENCES 215
APPENDICES 245
A. Site Response Analysis 245
B. Liquefaction Case History Database 301
CURRICULUM VITAE 967

LIST OF TABLES

TABLES

Table 2.1. Recommended SPT correction for use in liquefaction correlations (NCEER 1997) 15
Table 2.2. Recommended C_R correction proposed by Cetin et al. (2004, 2018)..... 16
Table 2.3. Recommended SPT overburden corrections 19
Table 2.4. Donut 25
Table 2.5. Safety Hammers 26
Table 2.6. Automatic trip..... 26
Table 2.7. Fines Content Correction Terms 36
Table 2.8. Overburden Stress Correction 44
Table 3.1. An illustrative example of the summary of the event parameters listed in each case history data 63
Table 3.2. Unit weights 65
Table 3.3. Recommended SPT sampler correction for use in liquefaction correlations (NCEER 1997) 72
Table 3.4. Recommended SPT borehole diameter correction for use in liquefaction correlations (NCEER 1997) 72
Table 4.1. The summary of the current SPT-based liquefaction triggering database. 82
Table 4.2. The summary of the calculation of $N_{1,60}$ for Avondale Playground (NZGD BH-ID 57217). 89
Table 4.3. Statistics of input parameters for the new case histories (163 data) 94
Table 4.4. The excluded case histories from the Cetin et al. (2018a, b) database. 104
Table 4.5. A summary of the average input parameters (171 case history) 116
Table 4.6. Summary of the SPT-based case history database. (334 case histories) 118
Table 4.7. A summary of the average input parameters for the final database. 132

Table 4.8. Comparison of the mean, mean of the standard deviation, minimum and maximum values input parameters of Cetin et al. (2018a, b) and this study. 137
Table 5.1. Field performance of the SMS sites after the 2010 Darfield and 2011 Christchurch Earthquakes. 149
Table 5.2. Recorded peak ground acceleration values during the 2010 Darfield and 2011 Christchurch Earthquakes 150
Table 5.3. Summary of the information related to gravel for SMS soil profiles .. 152
Table 5.4. Site response analysis profile for CBGS..... 153
Table 5.5. Summary of the deconvolution analysis at SMS. 155
Table 5.6. Rupture distance of the SMS for the 2010 Darfield and 2011 Christchurch earthquake events. 157
Table 5.7. Scaling factors calculated to transfer CACS deconvolved motion to the listed sites for the 2010 Darfield and 2011 Christchurch events 158
Table 5.8. Scaling factors calculated to transfer RHSC deconvolved motion to the listed sites for the 2010 Darfield and 2011 Christchurch events 158
Table 5.9. Average of the residuals for the two horizontal components of the 2010 Darfield and 2011 Christchurch Earthquakes by using CACS within motions.... 161
Table 5.10. Average of the residuals for the two horizontal components of 2010 Darfield and 2011 Christchurch Earthquakes by using RHSC within motions.... 163
Table 5.11. Summary of the results for SMS in Christchurch area. 164
Table 5.12. Rupture distance for the case history sites in Christchurch for the 2010 Darfield and 2011 Christchurch Earthquakes. 165
Table 5.13. 20 Corhampton Street site response analysis model. 168
Table 5.14. Wildlife site response analysis model. 175
Table 6.1. Limit state function alternatives for Model-1, 2, and 3. 185
Table 6.2. Probability of liquefaction and the cyclic resistance ratio functions for Model-1, 2, and 3. 185
Table 6.3. Resulting parameters (i.e.: θ_1, θ_2, ... σ_e) using Model-1, -2, and -3. ... 186
Table 7.1. Summary of the proposed seismic soil liquefaction triggering model equations. 210

LIST OF FIGURES

FIGURES

Figure 2.1. a) Graphical representation of the Seed et al. (2003), b) Bray and Sancio (2006), c) Boulanger and Idriss (2006) criteria. 11
Figure 2.2. Standard Penetration Test (SPT) setup. 14
Figure 2.3. Chamber test results by Marcuson and Bieganousky (1977) for two coarse sand specimens. 17
Figure 2.4. Stress normalization exponent estimations by Cetin and Isık (2007) based on field data. 18
Figure 2.5. Comparison of overburden corrections proposed for SPT. 20
Figure 2.6. Hammer Types. 25
Figure 2.7. Short rod correction database and developed C_R model by Deger (2014) 31
Figure 2.8. Comparison of short rod corrections based on F^2 and F-V methods. ... 32
Figure 2.9. Comparative illustration of fines correction 34
Figure 2.10. Schematic diagram of the theoretical variation of minimum void ratio in binary packings with % fines. (After Lade et al., 1998) 34
Figure 2.11. Influence of fines content on the packing of sand-silt mixtures variation of index void ratios with fines content for Cambria sand – Nevada silt mixtures (Cubrinovski, 2019) 35
Figure 2.12. Comparative illustration of fines correction 37
Figure 2.13. CRR boundary curves by Seed et al (1985) for different fines content values. 38
Figure 2.14. The recommended K_σ relationship of Idriss and Boulanger (2010) and Cetin et al. (2004, 2018) along with laboratory data of Montgomery et al. (2014) and Cetin and Bilge (2012) 45
Figure 2.15. a) Representative curve for the relationship between cyclic stress ratio and number of cycles to liquefaction (Seed et al., 1975), b) Equivalent numbers of

uniform stress cycles based on strongest components of ground motion (Seed et al., 1975) 46
Figure 2.16. Comparison of magnitude (duration) scaling factors 50
Figure 2.17. Liquefaction triggering database and boundaries of a) Seed et al. (1985), b) Cetin et al. (2004), c) Boulanger and Idriss (2012), and d) Cetin et al. (2018a). 55
Figure 2.18. Curves of $CRR_{M=7.5,\sigma'v=1\ atm}$ versus $N_{1,60,CS}$ for probabilities of liquefaction of 15 and 50 proposed by Seed et al. (1985), Cetin et al. (2004, 2018a) and Idriss and Boulanger (2010). 56
Figure 3.1. An illustrative example of the cover page for Wufeng Site C, WCS-1 (Yue-The Rd. Rice Paddy, Wufeng) 59
Figure 3.2. The map of the new database on Google Earth. 61
Figure 3.3. Fault plane of 1999 Chi-Chi Earthquake and the case history data on Google Earth and an example calculation of $R_{jb.}$ 62
Figure 3.4. Short rod correction data given by Deger (2014) and developed C_R model. 73
Figure 4.1. The location of the new earthquake events. 83
Figure 4.2. Plan view of the Avondale Playground park along with the in-situ test locations and field performance after the 2011 Christchurch earthquake (McLaughlin, 2017). 86
Figure 4.3. Plan view of the Avondale Playground along with the in-situ test locations and test results of SCPT57354 and SPT57217 (Map on the left and data on the right are retrieved from NZGD). 87
Figure 4.4. Summary of the SPT results (NZGD ID: BH 57217) 87
Figure 4.5. Summary of the CPT results. (NZGD ID: CPT 57534) 88
Figure 4.6. Summary of the V_s profile obtained from SCPT data given by a) NZGD (NZGD ID: CPT 57534) and b) McLaughlin (2017). 88
Figure 4.7. a) Corrected $N_{1,60}$ profile, b) r_d plot with respect to depth, and c) summary of the input parameters for Avondale Playground case history. 91

Figure 4.8. The summary page of the site response analyses results for Avondale Playground case history. 92
Figure 4.9. Summary page for Avondale Playground case history. 92
Figure 4.10. The second page of the summary for Avondale Playground case history. 93
Figure 4.11. Comparison of input parameters a) $d_{crt.}$, b) γ_{moist}, c) γ_{wet}, d) GWT, e) σ_v, f) σ'_v, g) FC, h) a_{max}, i) M_w, j) $V_{s,12m}$, k) r_d, l) $CSR_{\sigma'v,Mw}$, m) C_N, n) C_R, o) C_E, p) $N_{1,60}$, r) $N_{1,60,CS}$, s) K_σ, t) K_{Mw}, u) $CSR_{\sigma'v=1atm,Mw=7.}$ 95
Figure 4.12. New case histories (163) on corrected $N_{1,60}$ versus $CSR_{\sigma'v,Mw}$ 100
Figure 4.13. Comparison of input parameters according to case history numbers. 110
Figure 4.14. Comparison of input parameters on this study versus Cetin et al. (2018a, b) plot. 113
Figure 4.15. Comparison of updated Cetin et al. (2018a, b) and the re-processed case histories within this thesis (171) on corrected $N_{1,60}$ versus $CSR_{\sigma'v, Mw}$. 117
Figure 4.16. Comparison of input parameters a) $d_{crt.}$, b) GWT, c) γ_{moist}, d) γ_{wet}, e) σ_v, f) σ'_v, g) C_E, h) C_R i) C_N, j) $N_{1,60}$, k) FC, l) $N_{1,60,CS}$, m) $V_{s,12m}$, n) a_{max}, o) M_w, p) r_d, r) $CSR_{\sigma'v,Mw}$, s) K_σ, t) K_{Mw}, u) $CSR_{\sigma'v=1atm,Mw=7.5}$. 126
Figure 4.17. The distribution of the parameters a) $d_{crt.}$, b) σ'_v, c) $N_{1,60}$, d) a_{max} , e) M_w, f) $CSR_{\sigma'v,Mw}$ 133
Figure 4.18. Updated SPT catalog (334) case histories on corrected $N_{1,60}$ versus $CSR_{\sigma'v,Mw}$. 135
Figure 4.19. a) Seed et al. (1985), b) Cetin et al. (2018a, b), c) Idriss and Boulanger (2010), and d) this study. 136
Figure 5.1. Normalized modulus reduction and damping factors for gravels proposed by Rollins et al. (2020). 142
Figure 5.2. Normalized modulus reduction and damping factors for cohesionless soils proposed by Seed et al. (1984) for mean effective stress of σ'_m <1 atm, 1<σ'_m<3 atm and σ'_m>3 atm. 143

Figure 5.3. Normalized modulus reduction and damping factors for cohesive soils proposed by Vucetic and Dobry (1991) as a function of plasticity index..... 144
Figure 5.4. Normalized modulus reduction and damping factors for rocks proposed by Idriss (1990). 145
Figure 5.5. Schematic sketch of forward site response and deconvolution analyses. 147
Figure 5.6. Strong ground motion network in Christchurch (purple pins indicated the epicenter of the 2010 Darfield and 2011 Christchurch events)..... 148
Figure 5.7. The geological cross-section of Christchurch (Deschenes, 2017)..... 151
Figure 5.8. V_s profile given by Wotherspoon et al. (2015) for CBGS..... 151
Figure 5.9. Site response analyses result for CBGS 154
Figure 5.10. The comparison of predicted and calculated 5% damped response spectra at CBGS for the two horizontal components (dashed line represents the calculated motion by ProShake and the solid lines are the recorded surface motions at CBGS)..... 159
Figure 5.11. Residual plot at CBGS buT using CACS as input motions for the two horizontal components. 160
Figure 5.12. 20 Corhampton Street site plan after the 2011 Christchurch Earthquake showing the field test data (McLaughlin, 2017)..... 166
Figure 5.13. 20 Corhampton Street CPT and V_s test data along with sonic borehole data shown on the left (McLaughlin, 2017)..... 167
Figure 5.14. 20 Corhampton Street borehole data (NZGD ID: BH_57244) retrieved from NZGD. 167
Figure 5.15. 20 Corhampton Street V_s profile along with soil layering. 169
Figure 5.16. Site response analysis result at 20 Corhampton Street for the 2011 Christchurch Earthquake. (P1M3L14, P1M4L14 are within motions, P1M3L1, and P1M4L1 are soil outcrop motions estimated with the site response analysis at 20 Corhampton Street by using CACS as input motion)..... 170

Figure 5.17. Response spectra comparing the estimated surface motions and within motion used as input at 20 Corhampton Street for the 2011 Christchurch Earthquake. 170
Figure 5.18. a_{max}, r_d, CSR, and τ_{max} plots versus depth for the two horizontal components at the 20 Corhampton Street site for the 2011 Christchurch earthquake. 171
Figure 5.19. Summary of 20 Corhampton Street site response analysis results for the 2011 Christchurch earthquake. 172
Figure 5.20. Cross-section and the top view of the Wildlife site http://www.nees.ucsb.edu/facilities/wla 174
Figure 5.21. Wildlife V_s profile along with soil layering. 175
Figure 5.22. Summary of Wildlife site response analysis results for the 2012 Brawley earthquake M_w=4.61. 176
Figure 6.1. Mean and ± one standard deviation the database a) liquefied and marginal, b) non-liquefied case histories. 183
Figure 6.2. Liquefaction triggering curves (Model-1) for the new database. 187
Figure 6.3. Liquefaction triggering curves (Model-2) for the new database. 188
Figure 6.4. Liquefaction triggering curves (Model-3) for the new database. 189
Figure 6.5. Comparison between the probability of liquefaction 50% curve for Model-1, -2, and -3. 191
Figure 6.6. Comparison of K_{Mw} corrections for Model-1, -2, and -3. 192
Figure 6.7. Comparison of fines corrections for Model-1, -2, and -3. 192
Figure 6.8. Comparison of K_σ corrections for Model-1, -2, and -3. 193
Figure 6.9. Comparison of the regressed overburden correction factor (C_N) for clean sands and silty soils as a function of N_{60} in Model-1, 2, and 3. 194
Figure 6.10. Seismic soil liquefaction triggering relationships (Model-3) is developed by a) not incorporating, and b) incorporating errors in input parameters. 196

Figure 6.11. Seismic soil liquefaction triggering relationships (Model-3) developed by a) applying, b) not applying weighting factors liquefied and non-liquefied field case histories. 197
Figure 6.12. Proposed K_σ correction (Model-3) along with laboratory data by Montgomery et al. (2014) and Cetin and Bilge (2013). 198
Figure 6.13. Proposed K_σ correction with the available literature and cyclic laboratory test data. 199
Figure 6.14. Proposed K_{Mw} correction (Model-3). 200
Figure 6.15. Proposed K_{Mw} correction with available literature. 201
Figure 6.16. Proposed fines content correction (Model-3) 201
Figure 6.17. Proposed fines content correction with the available literature. 202
Figure 6.18. A “typical" potentially liquefiable layer. 203
Figure 6.19. Comparison of the new seismic soil liquefaction triggering relationship (Model-3) with CEA 2004, CEA 2018, and IB 201) for P_L=50%, and the deterministic model of SEA 1985. 206
Figure 6.20. Comparison of the new seismic soil liquefaction triggering relationship (Model-3) with CEA 2004, CEA 2018, and IB 2012) for P_L=15%, and the deterministic model of SEA 1985. 207
Figure 7.1. Liquefaction triggering curves (Model-3) for the new database. 209

LIST OF SYMBOLS

SYMBOLS

SPT	Standard penetration test
CPT	Cone penetration test
DPT	Dynamic cone penetration test
BHT	Becker hammer test
$\mathbf{V_s}$	Shear wave velocity
$\boldsymbol{\gamma_{moist}}$	Unit weight above the ground water table
$\boldsymbol{\gamma_{sat}}$	Unit weight below the ground water table
$\mathbf{D_{50}}$	Mean grain size diameter
FC	Fines content
PI	Plasticity index
$\mathbf{a_{max}}$	Peak horizontal acceleration
a(t)	Ground surface acceleration at time t
PGA	Peak ground acceleration
GWT	Ground water table
$\mathbf{r_d}$	Stress reduction coefficient, mass participation ratio
CSR	Cyclic stress ratio
$\mathbf{R_{rup}}$	Closest distance to coseismic rupture
$\mathbf{R_{jb}}$	Closest distance to surface projection of coseismic rupture
$\mathbf{Z_{tor}}$	Depth to coseismic rupture
$\mathbf{K_\sigma}$	Correction for overburden stress
$\mathbf{K_\alpha}$	Correction for sloping sites
$\mathbf{K_{Mw}}$	Magnitude (duration) scaling factors
$\mathbf{CSR_{Mw,\sigma'v}}$	Cyclic stress ratio for M_w and σ'_v
$\mathbf{CSR_{Mw=7.5,\sigma'v=100kPA}}$	Cyclic stress ratio for M_w =7.5 and σ'_v=100 kPa
CRR	Cyclic resistance ratio
$\mathbf{CRR_{Mw,\sigma'v}}$	Cyclic resistance ratio for M_w and σ'_v

$\mathbf{CRR_{Mw=7.5,\sigma'v=100kPA}}$	Cyclic resistance ratio for M_w =7.5 and σ'_v=100 kPa
$\mathbf{q_{t1}}$	Normalized cone tip resistance
$\mathbf{q_t}$	Cone tip resistance
RF	Friction ratio
$\mathbf{M_w}$	Moment magnitude
USL	Ultimate state line
$\mathbf{w_n}$	Natural water content
N, N_m	Measured standard penetration resistance
$\mathbf{C_B}$	Correction for borehole diameter
$\mathbf{C_N}$	Overburden correction
$\mathbf{C_S}$	Correction for sampling method
$\mathbf{C_R}$	Correction factor for the rod length
$\mathbf{C_E}$	Correction for hammer energy ratio (ER)
$\mathbf{N_{1,60}}$	Normalized SPT-N values for σ'_v =1 atm and SPT hammer energy efficiency of 60%
$\mathbf{N_{1,60,cs}}$	Clean sand corrected $N_{1,60}$
$\mathbf{\Delta N_{1,60}}$	Fines content correction
$\mathbf{P_a}$	Atmospheric pressure (1 atm)
$\mathbf{\sigma'_v, \sigma'_{vo}}$	Vertical effective stress
$\mathbf{\sigma_v, \sigma_{vo}}$	Vertical total stress
L	Rod length (borehole depth and stick up)
F(t)	Force measured as a function of time
V(t)	Particle velocity measured as a function of time
$\mathbf{\Delta t}$	Sampling interval
E	Modulus of elasticity of the drilling rod
A	The cross-sectional area of the drilling rod
c	Stress wave propagation velocity for steel
$\mathbf{D_R}$	Relative density
e	In-situ void ratio

$\mathbf{e_{min}}$	Minimum void ratio
$\mathbf{e_{max}}$	Maximum void ratio
$\boldsymbol{\tau(t)_{ave}}$	Average shear strength
$\boldsymbol{\tau(t)_{max}}$	Maximum shear strength
g	Acceleration of gravity
$\boldsymbol{\gamma}$	Unit weight
h	Soil block height
$\boldsymbol{\tau(t)_{rigid}}$	Shear stresses at the base of the rigid soil block
$\boldsymbol{\tau(t)_{deformable}}$	Shear stresses at the base of the deformable soil block
z	Depth
$\mathbf{d_{cr}}$ **or d**	Critical depth for liquefaction
f	Exponent that is a function of relative density D_R
OCR	Overconsolidation ratio
$\boldsymbol{\sigma'_c}$	Preconsolidation pressure
N	Number of cycles
$\mathbf{r_u}$	excess pore water pressure ratio
$\boldsymbol{\gamma_{max}}$	maximum shear strain
$\mathbf{S_1}$	spectral acceleration
$\mathbf{T_s}$	period of soil layer
b	weighting factor (b)
$\mathbf{P_L}$	Probability of liquefaction in decimals
$\boldsymbol{\Phi}$	Standard cumulative normal distribution
$\boldsymbol{\Phi^{-1}(P_L)}$	The inverse of the standard cumulative normal distribution
G	Shear modulus
$\mathbf{G_{max}}$	Maxiumum shear modulus
$\mathbf{S_{a,observed}}$	Observed spectral acceleration
$\mathbf{S_{a,predicted}}$	Predicted spectral acceleration
W	Fault rupture width
$\boldsymbol{\sigma^2_{e_{N_{1,60,i}}}}$	Standard deviation of the $N_{1,60}$ for the i^{th} observation

$\sigma^2_{e_{\ln(CSR_i)}}$	Standard deviation of the ln(CSR) for the ith observation
$\sigma^2_{e_{M_{w,i}}}$	Standard deviation of the moment magnitude for the ith observation
$\sigma^2_{e_{FC_i}}$	Standard deviation of the fines content for the ith observation
$\sigma^2_{e_{\ln(\sigma'_{v,i})}}$	Standard deviation of the ln(σ'_v) for the ith observation
σ_e^2	Observation variance
$\sigma_{tot,i}^2$	Total varience
Φ	Normal cumulative distribution function
x_i	descriptive variables
$\hat{g}$	Limit state function
θ	Unknown model parameters
$f_\theta'(\theta)$	Prior distribution of parameters
$L(\theta\|x)$	Likelihood Equation
c	Normalization constant
$f_\theta(\theta\|x)$	Posterior distribution calculated by Bayesian analysis
$\sigma\varepsilon$	Standard deviation of the model uncertainty
ε	Model uncertainty
w_{liq}	Weighting factor for the liquefied data
w_{nonliq}	Weighting factor for the non-liquefied data
$\delta_{(N_1)_{60}}$	Coefficient of variation of $N_{1,60}$
δ_{C_N}	Coefficient of variation (cov) of C_N
δ_{C_E}	Coefficient of variation (cov) of C_E
δ_{C_B}	Coefficient of variation (cov) of C_B
δ_{C_R}	Coefficient of variation (cov) of C_R
δ_{C_S}	Coefficient of variation (cov) of C_S

$\boldsymbol{\mu_{N_{1,60}}}$	Mean value of $N_{1,60}$
$\boldsymbol{\mu_{N}}$	Mean value of N
$\boldsymbol{\mu_{a_{max}}}$	Mean value of a_{max}
$\boldsymbol{\mu_{\sigma_v}}$	Mean value of σ_v
$\boldsymbol{\mu_{\sigma'_v}}$	Mean value of σ'_v
$\boldsymbol{\mu_{r_d}}$	Mean value of r_d
$\boldsymbol{\mu_{CSR}}$	Mean value of CSR
$\boldsymbol{\delta_{\sigma_v}}$	Variance of σ_v
$\boldsymbol{\delta_{\sigma'_v}}$	Variance of σ'_v
$\boldsymbol{\zeta_s}$	Standard deviation of the ln(CSR)
$\boldsymbol{\lambda_s}$	Mean value of the ln(CSR)
$\boldsymbol{\sigma_{h_w}}$	Standard deviation of the h_w
$\boldsymbol{\sigma_{\gamma_{wet}}}$	Standard deviation of the γ_{wet}
$\boldsymbol{\sigma_{\gamma_{sat}}}$	Standard deviation of the γ_{sat}
$\boldsymbol{\sigma_{lnPGA}}$	Standard deviation of the ln(PGA)
$\boldsymbol{\sigma_{D_{50}}}$	Standard deviation of the D_{50}
$\boldsymbol{\rho_{\sigma'_{vo}\sigma_{vo}}}$	Correlation of coefficient between σ_v and σ'_v

CHAPTER 1

INTRODUCTION

1.1 Overview

Seismic soil liquefaction became the subject of research interest in the field of geotechnical earthquake engineering over 50 years ago due to the worldwide extent of induced damage to structures including natural and man-made fills and slopes, buildings, and bridges, dams, buried structures, etc. In addition to experimental and theoretical soil and fluid mechanics principles, researchers have also benefitted from well-documented field case history databases to understand and assess seismic and monotonic soil liquefaction behavior. The pioneering deterministic empirical correlation to estimate the seismic soil initiation was suggested by Seed and Idriss (1971) and Seed et al. (1984, 1985). The study is followed by the proposals of many other research groups (e.g. Christian and Swiger, 1975, Liao et al., 1988, Youd and Noble, 1997, Andrus and Stokoe, 1997, Liao and Lum, 1998, Toprak et al., 1999, Youd et al., 2001, Cetin, 2000, Cetin et al., 2004, 2018a, Juang et al., 2002, Moss et al., 2006, Idriss and Boulanger, 2004, 2006, 2008, 2010, Boulanger and Idriss 2012, 2014, 2016, Kayen et al., 2013, etc.) which are based on different in-situ test methods to estimate the vulnerability against seismic soil liquefaction initiation. Owing to the increasing demand for risk assessments in engineering applications, probabilistic evaluations of seismic soil liquefaction triggering relationships were urged starting with the pioneering study of Liao et al. (1988), which was followed by Youd and Noble (1997), Cetin (2000), Cetin et al. (2004, 2018a), Juang et al. (2002), Moss et al. (2006), Idriss and Boulanger (2006, 2008, 2010), Boulanger and Idriss (2004, 2012, 2016), Kayen et al. (2013), etc.

Empirical seismic soil liquefaction correlations are developed based on the field case history catalogs. These datasets are compiled from sites where the reconnaissance studies were conducted preferably immediately after major earthquake events. The field performances of the sites are reported by the research teams based on the presence or lack of surface manifestations (e.g. sand boil, lateral spread, etc.). Liquefaction triggering boundary curves are developed to define the boundary that separates liquefied and non-liquefied case history performances. For this purpose, each case history was represented by a demand and capacity term by Seed et al. (1985). The capacity of the soil site is represented by in-situ field test (e.g. SPT, CPT, $V_{s,}$ etc.) results, and the demand (the intensity of shaking) is represented by cyclic stress ratio, CSR as proposed by Seed and Idriss (1971) which is called as "simplified procedure". The Standard Penetration Test (SPT) based methods have been used for over 100 years in civil engineering applications, and it is the scope of this dissertation.

The topic has been in continuous progress for nearly 50 years in the field of geotechnical engineering. The widely used SPT-based field case history models (e.g.: Seed et al., 1985, Cetin et al., 2004, 2018a, Idriss and Boulanger, 2010, etc.) are based on catalogs that cover events until the 1995 Kobe earthquake. More recently, Boulanger and Idriss (2014) processed additional 24 case histories from the 1999 Kocaeli and 1999 Chi-Chi earthquakes and revised magnitude scaling factors. The updated database was used to test the performance of the model but not to update the model. Now, there are other means to process and interpret available information to understand soil liquefaction initiation. The significant findings from recent events that occurred between 1995-2022 urge the need for updated seismic soil liquefaction triggering databases and models.

Recent earthquake events caused extensive liquefaction manifestations (e.g. 2010-2011 New Zealand Sequence, 2011 Tohoku Earthquake, etc.), and widen the perspective of researchers with the new information and lessons learned from those events. The scope of this research involves enriching the previous SPT-based databases with the new earthquake events as recent as 2022, the number of which

reach twice the number of pre-1995 case history sites. Additionally, it is intended to re-visit these legacy case histories to populate a more complete field case history database by employing an updated perspective in field case history processing as well as implementing a new set of parameters and correction terms along with harmonizing the dataset with the new developments and understanding of the liquefaction engineering. The improved and extended data processing efforts were tied together to develop a probabilistic framework to estimate the initiation of soil liquefaction triggering, which is the primary motivation of this dissertation.

The database and the corollary model introduce new parameters that were identified to govern the liquefaction response of soils but were not addressed by earlier liquefaction triggering relationships. For example, the previous database compilations efforts were based on surface manifestations. Recent studies proved that liquefaction might occur at a site that might not produce manifestation due to the presence of a crust layer or dilative surrounding layers. The availability of seismometer or piezometer recordings reveals that without the occurrence of surface manifestations, the occurrence of liquefaction manifested with frequency shifts in ground shaking or increased excess pore pressures is likely (Greenfield, 2017). These cases were also incorporated into the database with special treatment to consider the lack of surface manifestation. This study additionally collects some new parameters that may affect the triggering of liquefaction: e.g.: the geological and depositional setting, gravel content, rupture distance, and event types.

Ongoing discussions (e.g. NCEER, 2001, NGL, 2019, etc.) have addressed the need to update the case history database i) at lower and higher magnitude events and PGA levels, ii) with gravelly and silty critical layers, iii) with better ground motion characterization, and iv) event mechanism. The development of more precise estimation of the soil liquefaction triggering boundary urges the need for a good quality case history database that is assessed with the current state of knowledge and data. The new SPT-based liquefaction triggering field case history database is a collection of a larger suite of case histories compiled from 334 sites, and includes new earthquake events that occurred between 1996-2018 including the 2001

Nisqually, 2010-2011 New Zealand Earthquake sequence, 2011 Tohoku earthquakes) along with re-investigated and -assessed legacy case histories. The database covers normal, reverse, and subduction zone earthquake events along with documented event parameters of R_{rup}, R_{jb}, z_{tor}, etc., which have a wider range of moment magnitudes (M_w=4.6-9.1). As part of site response analyses, forward and deconvolution analyses were performed after site characterization and idealization. The most extensive site response analyses were performed for case histories from New Zealand reaching approximately 92 for the Christchurch events.

The database is processed with improved knowledge and understanding of standard penetration test data; more specifically new short rod length (C_R) correction and updated hammer energy ratios (C_E) terms were used. As part of the proposed model, the overburden effects were assessed within a probability-based framework. New research studies also revealed that short rod corrections change with rod length in a less pronounced way at shallower depths than what was proposed by NCEER (2001). On the basis of discussions regarding the validity of automatic and safety hammers delivering 73 %, and 60 % of theoretical potential energy, an updated average hammer energy scheme was implemented in this study.

The updated database is then used to develop probability-based liquefaction triggering boundary curves utilizing the maximum likelihood analysis statistical framework. The resulting relationship provides an improved correction scheme for magnitude correlated durational, K_{Mw}, overburden stress, K_σ, and fines correction.

1.2 Organization of the Dissertation

The following chapters are organized to present the discussions included within the scope of this thesis:

Chapter 2 presents a comprehensive summary of seismic soil liquefaction behavior and liquefaction triggering relationships available in the literature. The current state of practice prevails advancements in terms of capacity ($N_{1,60}$) and demand terms

(CSR). Those advancements discussed herein have formed the basis of the new insight of case history processing and model development efforts.

Chapter 3 introduces a database protocol, which is established to achieve a high-standard data processing scheme, and process the case histories in an unbiased manner. It presents the discussion of the implemented probabilistic case history processing methodology. A data processing protocol consisting of a strict screening criterion is set to achieve a high-quality dataset. A new set of parameters were introduced, which were significantly helpful to understand the triggering of soil liquefaction behavior.

Chapter 4 presents an updated liquefaction performance case history database, which consists of significantly extended database size. The first part of the chapter introduced the new case history catalog and the second part focuses on the modification made to legacy case histories. This chapter also discusses the excluded cases both from legacy case history bins that were not able to pass the screening criteria. Finally, the overall resulting database is presented along with database statistics and compared with the previous databases in this chapter and Appendix B.

Chapter 5 summarizes a series of site response analysis results to estimate the cyclic stress ratio. The majority of site response analyses were performed for New Zealand case histories. Details of site characterization, idealization, and deconvolution studies along with site response analysis results are presented in this chapter and Appendix A.

Chapter 6 presents the maximum likelihood analysis method that is utilized to develop the seismic soil liquefaction triggering model. The discussion starts with explaining the protocols followed in estimating the uncertainty terms of each parameter and continues how the likelihood function is chosen. The updated probability-based seismic soil liquefaction triggering models are presented. The new model provides new magnitude-correlated duration weighting factors, overburden stress corrections, and fines corrections. The chapter concludes with a comparison of the available triggering relationships and correction terms in the literature.

Chapter 7 presents a summary of the thesis and outlines the main conclusions of the study and recommendations for future studies.

CHAPTER 2

ENGINEERING APPROACHES TO SEISMIC-SOIL LIQUEFACTION

2.1 Introduction

Seismic soil liquefaction caused extensive damage during the 1964 Niigata and 1964 Alaska earthquakes, which accelerated the research studies on understanding the seismic soil liquefaction behavior of soils. Once again, the recent earthquake events (e.g. 2011 Tohoku, 2010 Darfield, etc.) caused widespread liquefaction that results in significant loss of life, and economic overburden and continued to bring out additional lessons to be learned.

This chapter will present the basic definition of the terms involved in the evaluation of the seismic soil liquefaction triggering methodologies. The chapter starts with fundamental definitions of the seismic soil liquefaction phenomenon and the potentially liquefiable soils.

Semi-empirical seismic soil liquefaction triggering relationships have become a viable tool in engineering practice to predict the performance of potentially liquefiable soils. Those relationships were derived in a 2-D demand versus capacity space. The use of in-situ field test results is accepted to be a reliable approach to assessing the resistance against seismic soil liquefaction triggering. Standard Penetration Test (SPT)-based liquefaction triggering methods will be presented within the context of this dissertation. A detailed discussion about the standard penetration test and the corrections applied to SPT blow counts along with the recent advances in the literature will be presented. The simplified procedure, which is used to estimate the cyclic stress ratio, CSR, and the correction terms applied to convert

field CSR values to the ones corresponding to the reference duration, overburden, and static shear stress will be discussed in this chapter. These discussions are followed by a summary of triggering relationships in the literature.

2.2 Definition of Seismic-Soil Liquefaction

The definition and types of soil liquefaction are presented in this section. Soil liquefaction was first addressed by Terzaghi and Peck (1948) as the sudden strength reduction of loose sands. After the major events of the 1964 Niigata and Alaska Earthquakes, the soil liquefaction behavior was studied by many researcher groups (e.g. Seed, 1979, Ishihara, 1993, Robertson and Fear, 1995, etc.). In its more general terms, liquefaction can be defined as the reduction of both shear strength and stiffness of saturated loose sandy soils due to excess pore pressure generation under cyclic loading. Robertson and Fear (1995, 1997) defined types of soil liquefaction and used the undrained monotonic test results of Ishihara (1993) to explain the behavior of loose and dense materials. All soils tend to reach the ultimate state line (USL) under shearing, but the path depends on the stress, density state, and drainage conditions of the soil specimen.

Under “drained” loading conditions, loose soils will contract under increasing strain levels until the USL exhibiting strain hardening behavior this time. On the other hand, dense soils will dilate under increasing strain levels which essentially decreases grain-to-grain contact until the USL hence they exhibit strain-softening behavior under “drained” loading conditions.

Under “undrained” loading conditions, in mean effective stress versus void ratio space, a relatively “loose” specimen (e.g. higher void ratio than the USL) strain softens to reach the USL. On the other hand, a relatively “dense” specimen (e.g. lower void ratio than the USL) strain hardens to reach the USL under undrained loading conditions. Some of the soil specimens may have slightly higher void ratios than the ones corresponding to USL, in this case, they exhibit limited strain-softening

for an undrained loading condition. (Robertson and Wride, 1998). Under undrained loading conditions, a “loose” specimen will generate positive excess pore pressure and this causes effective stress to decrease. On the other hand, dense soils will generate negative excess pore pressures which essentially increases effective stress.

On the basis of strain softening and strain hardening responses of soils, a different suite of liquefaction mechanisms was defined by Robertson and Fear (1995) as flow liquefaction, and cyclic softening (e.g. cyclic liquefaction, and cyclic mobility).

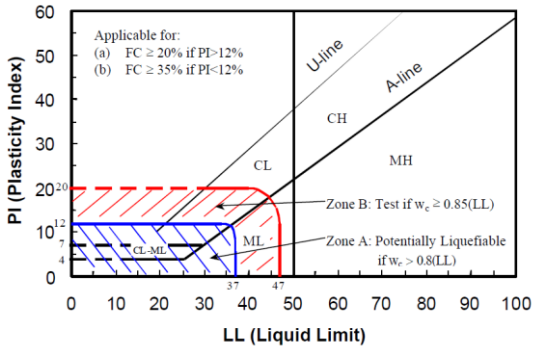
Flow liquefaction is observed when static shear stresses are greater than the ultimate shear strength for the relatively loose sand deposits, which tend to show a strain-softening response. The response may be triggered under “monotonic” or “cyclic” loading conditions. Flow liquefaction can result in high strain disintegrative flow failures (Kayen and Barnhrdt, 2007), the manifestations of which were observed in the 1995 Kobe Earthquake.

Cyclic softening is divided into cyclic liquefaction and cyclic mobility which can be observed due to cyclic undrained loading (e.g. earthquake loading, etc.), and the responses are governed by the magnitude and duration of the cyclic loading. When cyclic stress reversals occur (e.g. during an earthquake shaking, etc.), soils tend to reach the ultimate state due to an increase in excess pore pressure. If the shear reversals are adequate to reach the effective stress to significantly decrease then cyclic liquefaction occurs. As the shear strength is reduced, the stiffness of the soil also decreases, which essentially reaches almost “zero” stiffness (banana loops in shear strain versus shear stress space), which results in large deformations for level or gently sloping grounds. The pore water pressure redistribution may result in flow liquefaction, or deformation may stop after cyclic loading. In the case of cyclic loading not enough for the soil to reach zero effective stress levels (in the case of steep grounds under moderate shaking), cyclic mobility occurs, which results in relatively small deformations. In the case of cyclic mobility stiffness of the soil is also decreased but not essentially reach a value of “zero”, which is the cause of small deformations.

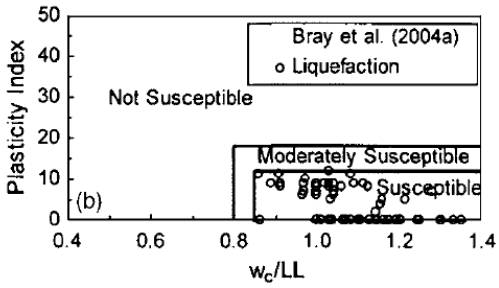
As a result, it is difficult to identify which mechanism caused the observed deformations after an earthquake. The most common mechanism observed in the field is cyclic softening due to earthquake loading. (Robertson and Wride, 1998).

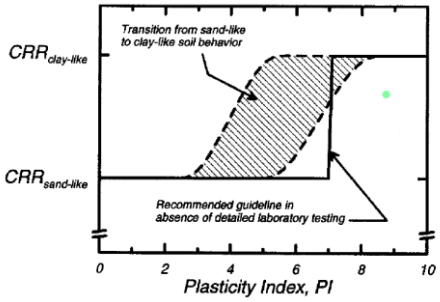
In the analysis of soil liquefaction, the first step is to assess what soil types are potentially liquefiable. Although liquefaction case history data compilations find the vast majority of reported sites to be sands, it is also acknowledged that gravelly, silty, and clayey soil deposits may also liquefy under appropriate conditions. Hence, it is an important step to acquire information regarding potentially liquefiable soils.

Liquefaction triggering is often linked to compositional and environmental factors of the soil (Mitchell and Soga, 2005). These factors are summarized by Green and Ziotopoulou (2015) as mineralogy, geomorphology, geologic age, grain shape, grain size distribution, density, fabric, effective confining stress, and saturation. The first criteria for potentially liquefiable soils were proposed by Wang (1979) known as the Chinese Criteria. The study was a pioneering work on fine-grained materials having liquefaction potential. The study affirms that soils with clay content (grain size smaller than 0.005 mm) lesser than 15% may be potentially liquefiable if the liquid limit (LL) is smaller than 35% and natural water content (w_n) is greater than 90% of the liquid limit. Andrews and Martin (2000) further modified the Chinese criteria indicating that soils with clay content of less than 10% may be potentially liquefiable if the liquid limit (LL) is smaller than 32% independent of natural water content (w_n). Two major earthquake events in 1999, the Kocaeli and Chi-Chi earthquakes, played a key role to assess the soil liquefaction of the sites consisting of fine-grained materials, due to widespread liquefaction observed to occur at those events. Much of the work in this area focused on cyclic laboratory testing on samples collected from Kocaeli and Chi-Chi that were used to determine the susceptibility of materials. Seed et al. (2003), Bray and Sancio (2004), and Boulanger and Idriss (2006) investigated those samples and case histories to provide chart solutions as also shown in Figure 2.1.



(a)





(b) (c)

Figure 2.1. a) Graphical representation of the Seed et al. (2003), b) Bray and Sancio (2006), c) Boulanger and Idriss (2006) criteria.

It is with those studies that not only clean sands but soils with low plastic silt and clay content may also liquefy was emphasized. Although these studies have differences regarding the parameters assessed and proposed to evaluate the liquefaction potential, overall, materials with a moderate level of plasticity index (0-20) were shown to be potentially liquefiable. Bray and Sancio (2006) linked the natural water content-liquid limit ratio to the plasticity index which considers a more comprehensive approach among the other alternatives.

While the discussion about the liquefaction potential of fine-grained soils continues, gravel liquefaction is also another aspect needed to be discussed further for the question of "which soils liquefy?". The topic has gained recent interest in the literature, and the dynamic cone penetration test and DPT-based liquefaction triggering relationship for gravelly soils are studied (e.g. Cao et al., 2013, Rollins et

al., 2021, etc.). However, a comprehensive model including gravelly, sandy, and silty sites with SPT blow counts has not been studied as the previous liquefaction case history database lacks gravelly sites.

Gravelly soils are not very different than sandy (Seed et al., 2003). They are also prone to cyclic pore pressure generation. Some recent events (2008 Wenchuan, 2014 Cephalonia, and 2016 Kaikoura Earthquakes) have provided examples of gravel liquefaction. However, gravels can dissipate pore pressure generation quicker than sands and their mass is greater than sands which favors denser packing in the field. Liquefaction is a soil matrix phenomenon, and soils in nature can be found at different gravel - sand - silt, and clay content levels. If the gravels are surrounded by finer materials they are also observed to liquefy faster, which will later be addressed in this thesis.

In summary, gravelly, sandy, silty, and clayey soils can liquefy. One should be cautious to identify all the aspects of the problem in detail and understand the system response of the soil site. This thesis will present examples of soil sites with different material types that liquefied after earthquake events.

2.3 Seismic Soil Liquefaction Triggering

Seismic soil liquefaction triggering relationships are assessed based on several in-situ field tests. Widely used in-situ field tests for this purpose are the standard penetration test (SPT), cone penetration test (CPT), and shear-wave velocity test (V_s). Less commonly used methods for gravelly soil are the Becker hammer test (BHT), and the dynamic cone penetration test (DPT). All in-situ field tests have inherent advantages and drawbacks. SPT and CPT are large strain tests and the data obtained (SPT-N and tip resistance, q_t) from these tests are strongly correlated to relative density, which controls the cyclic behavior of sands (Kayen et al., 2013, Idriss and Boulanger, 2008). SPT provides soil samples contrary to other field tests. On the other hand, the discrete nature of SPT measurement prevents continuous

characterization of soil layers, while CPT provides a better characterization of thin soil layers, as the test enables continuous data acquisition. In gravelly site conditions, which are observed to be vulnerable to soil liquefaction (e.g. 2010 Darfield Earthquake), CPT fails to penetrate, whereas DPT and V_s are more feasible alternatives. The shear-wave velocity test is the only test that measures a fundamental property of the soil: stiffness (Kayen et al., 2013) although it is a small strain test that lacks soil classification capabilities. The V_s test results are proven to be successful in the determination of liquefaction triggering boundaries. (e.g. Andrus and Stokoe, 2000, Kayen et al., 2013, etc.). Within the confines of this thesis, SPT-based liquefaction triggering relationships will be discussed due to the fact that SPT is still one of the most widely used in-situ field test alternatives worldwide.

Previous attempts by Junfei (1980) had been made to introduce some statistical results on liquefaction potential which can be considered one of the pioneering studies in the field of liquefaction engineering. Seed and Idriss (1971) first introduced the concept to assess seismic soil liquefaction and Seed et al. (1985) offered the first seismic soil liquefaction triggering boundary in the literature which presents the SPT-based liquefaction triggering database and methodology, that inspired many other research teams (e.g. Cetin, 2000, Cetin et al., 2004, 2018a, Idriss and Boulanger, 2010, Boulanger and Idriss, 2014, etc.), which have also proposed deterministic and probabilistic-based liquefaction triggering relationships. The liquefaction performance field case history database was compiled from different areas in the world and assessed on the capacity (equipment and procedure corrected SPT blow counts, $N_{1,60}$) versus demand (cyclic stress ratio, CSR) domain. The standard penetration test procedure, terms, and parameters involved in the calculation of SPT-N and CSR will be discussed next which is then followed by a discussion of correction factors applied to both terms.

2.3.1 Standard Penetration Test (SPT)

Standard Penetration Test (SPT) is performed with a split-spoon sampler attached to a drilling rod, penetrating repeatedly due to dropping off a 63.5-kg hammer from a height of 76 cm as stated by ASTM D-1586. Figure 2.2 provides an illustrative figure prepared after Kovacs et al. (1981). The number of blow counts is measured and recorded at each 15 cm interval, and standard penetration resistance, N is calculated as the sum of blow counts of the last two intervals.

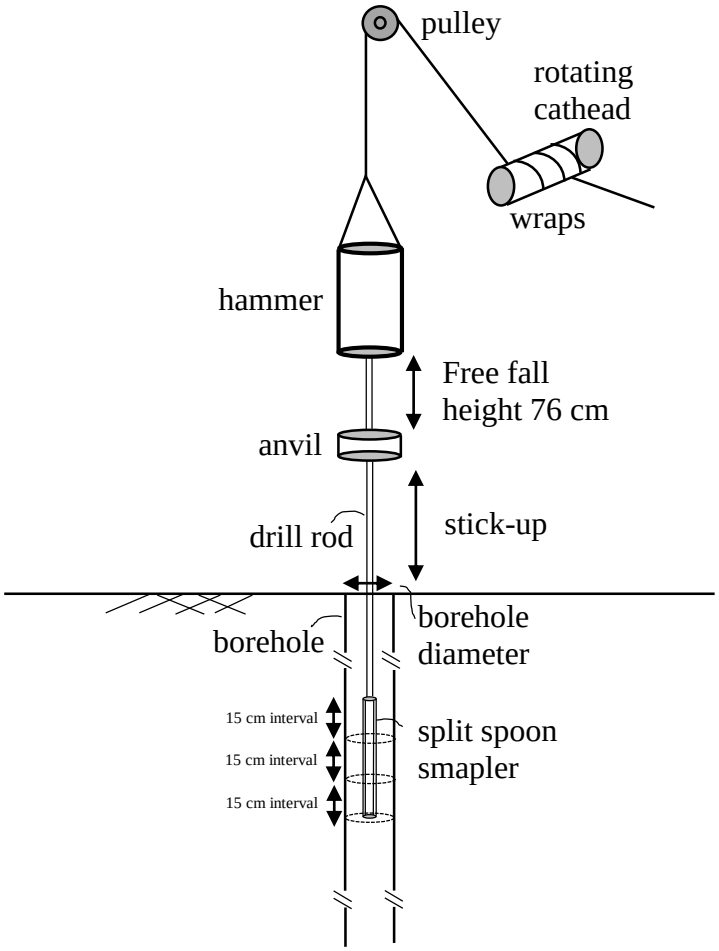


Figure 2.2. Standard Penetration Test (SPT) setup.

SPT procedure and equipment vary significantly in different parts of the world hence a series of corrections are applied in order to standardize the field SPT blow counts

(N). NCEER (1997) workshop recommended the field SPT-N blow counts to be corrected for variables in hammer energy ratio, C_E, borehole diameter, C_B, rod length, C_R, sampling method, C_S. Overburden correction, C_N, is also applied to eliminate the differences in confining stresses. These corrections are applied to field SPT-N values, and the resulting term is denoted by $N_{1,60}$ as given in Equation 2.1.

$$N_{1,60} = N \cdot C_N \cdot C_E \cdot C_B \cdot C_R \cdot C_S \quad (2.1)$$

NCEER (1997) recommendations for SPT corrections are widely accepted in the literature and engineering practice. These factors recommended by NCEER (1997) are summarized in Table 2.1. Cetin et al. (2004, 2018) implemented the same set of SPT corrections as recommended by NCEER (1997) except for short rod length correction as given in Table 2.2. Similarly, Idriss and Boulanger (2010) adopted a similar correction schema except for overburden correction, which will be discussed in Section 2.4.1.1.

Table 2.1. Recommended SPT correction for use in liquefaction correlations (NCEER 1997)

Factor	*Term*	*Equipment Variable*	*Correction*
Overburden Pressure	C_N	-	$C_N = \left(\frac{P_a}{\sigma'_v}\right)^{0.5}$ $C_N \leq 2.0$ P_a=1 tsf or 101 kPa
Energy Ratio	C_E	Safety Hammer	0.60-1.17
		Donut Hammer	0.45-1.00
Borehole Diameter	C_B	65-115 mm	1.00
		150 mm	1.05
		200 mm	1.15
Rod Length	C_R	3-4 m	0.75
		4-6 m	0.85
		6-10 m	0.95
		10-30 m	1.0
		> 30 m	< 1.0
Sampling Method	C_S	Standard Sampler	1.0
		Sampler without liners	1.15-1.30

Table 2.2. Recommended C_R correction proposed by Cetin et al. (2004, 2018)

Term	*Equation*
C_R	$C_R = 0.48 + 0.225 \cdot \ln(d)$; d ≤ 10 m $C_R = 1.0$; 10 m < d < 30 m where d = rod length (or "stick-up") from the top of the SPT sampler to the anvil.

Among the above-mentioned SPT correction factors, a more detailed discussion will be presented for overburden, hammer energy, and short rod corrections due to recent developments, newly available information, and ongoing discussions in the literature related to those correction terms. These discussions will be followed by fines content correction that is applied to SPT blow counts for the seismic soil liquefaction triggering relationships to bring different fines content levels to a reference level.

2.3.1.1 Overburden Correction, C_N

SPT is performed at different depths throughout a boring log. At each depth confining stress and the relative density of soils are different. In order to bring all the measured SPT-N blow counts to a reference stress state, SPT-N blow counts are corrected for overburden stress correction. The reference stress level is chosen as 1 atm. Overburden correction as suggested by Liao and Whitman (1986) and NCEER (2001) is given in Equation 2.2.

$$C_N = \frac{N_1}{N} = \left(\frac{P_a}{\sigma_v'}\right)^m ; \quad m = 0.5 \tag{2.2}$$

Where P_a atmospheric pressure (1 atm), σ_v' is the effective stress, and m is the stress exponent.

Due to the heterogeneous nature of the soil deposits, the assessment of overburden stress correction requires careful assessment of the stratigraphy, soil density, mineralogy, and water table (Deger, 2014). Laboratory experiments were conducted

to investigate the overburden corrections (e.g. Gibbs and Holtz, 1957, Marcuson and Bieganousky, 1977, Deger, 2014, etc.) by using chamber tests. Samples are prepared homogeneously, which enabled researchers to understand the overburden stress effects on in-situ resistance terms regardless of the changes in mineralogy and fabric. Those experiments were mostly performed with laboratory chamber tests. Specimens are prepared in large chambers to avoid boundary interference under different confining stress levels at certain relative density levels. SPT or mini cone (CPT) is performed on those specimens. The ease of application of the mini cone and continuous data acquisition of CPT leads to the common usage of the mini cones in laboratory experiments to assess the overburden stress corrections. On the other hand, some researchers performed SPT in the laboratory on homogenous samples to assess the overburden corrections. The chamber test results are presented as correlated relative density with SPT N or cone tip resistance values for different confining stress levels. The result of the chamber tests revealed that SPT-N blow counts or cone tip resistances at any relative density level depend on effective overburden pressure. An example chamber test result based on SPT data is shown in Figure 2.3by Marcuson and Bieganousky (1977). The stress exponent, m is defined by the expression $C_N = (P_a/\sigma_v')^m$ is regressed based on the chamber test results.

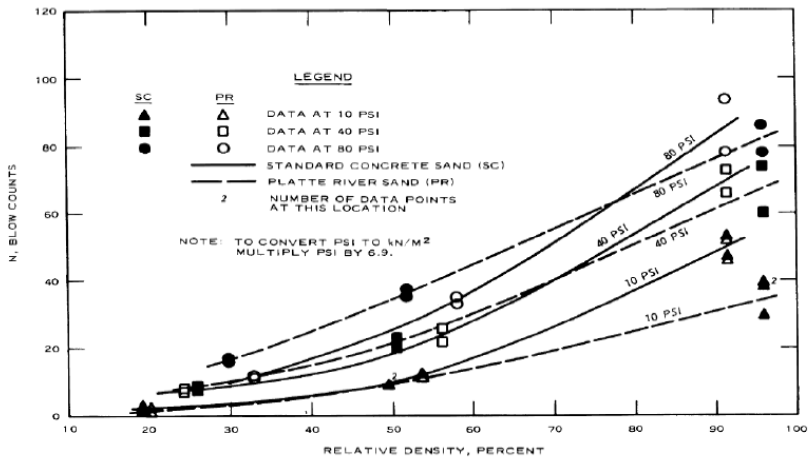


Figure 2.3. Chamber test results by Marcuson and Bieganousky (1977) for two coarse sand specimens.

Another alternative to estimate the stress normalization exponent, m is to evaluate CPT or SPT data obtained from field measurements (e.g. Zolkov and Wiseman, 1965, Bazaraa, 1967, Cetin and Isık, 2007, Deger, 2014, etc.). An example study which assesses field CPT data to derive stress exponent is given in Figure 2.4 by Cetin and Isık (2007). CPT data were collected and the tip resistance values were drawn for vertical stress levels for the uniform soil layers by Cetin and Isık (2007). Stress exponents for different soil layers were regressed. Similar exercises were also performed based on SPT data to derive the stress exponent term by various researchers (e.g., Bazaraa, 1967, Pillai and Stewart, 1994, Wehling and Rennie, 2008, Deger, 2014, etc.). As it is very hard to find homogenous deposits in nature, researchers tend to focus on dam sites that are constructed with the same material homogenously to assess the stress exponent based on field data.

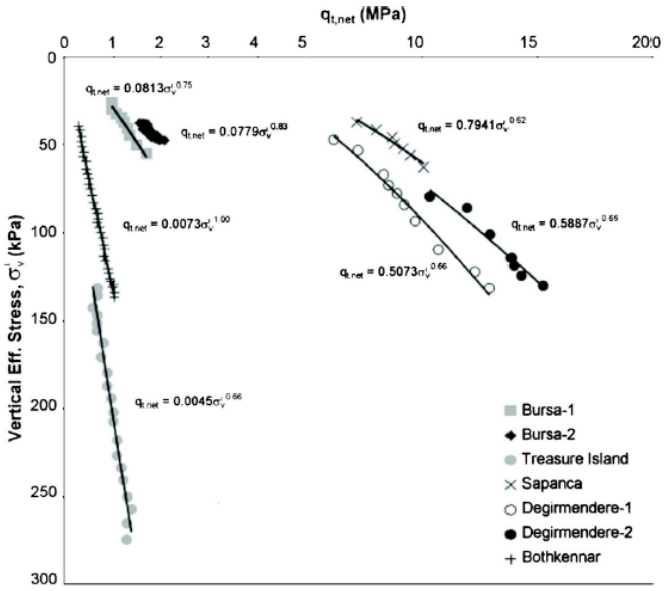


Figure 2.4. Stress normalization exponent estimations by Cetin and Isık (2007) based on field data.

Similar attempts described above were performed by various research groups who provided closed-form overburden correction and stress exponent based on laboratory and/or field data by assessing SPT data (e.g. Teng, 1962, Zolkov and Wiseman,

1965, Bazaraa, 1967, Peck et al., 1974, Seed, 1976, Marcuson and Bieganousky, 1977, Bieganousky, 1977, Seed, 1979, Tokimatsu and Yoshimi, 1981, Liao and Whitman, 1986, Skempton, 1986, Kayen et al., 1992, Castro, 1995, Boulanger, 2003a, Deger, 2014, etc.) A summary of closed-form stress exponent, m, and overburden stress corrections to be used for SPT is given in Table 2.3.

Table 2.3. Recommended SPT overburden corrections

Reference	*C_N Relationships*
Teng (1962)	$C_N = \frac{50}{10 + \sigma'_v}$ *units in* lbs/in^2
Bazaraa (1967)	$C_N = \frac{4}{1 + 2\sigma'_v}$ $for\ \sigma'_v < 1.5$ *units in* $kips/ft^2$ $C_N = \frac{4}{3.25 + 0.5\sigma'_v}$ $for\ \sigma'_v > 1.5$ *units in* $kips/ft^2$
Peck et al. (1974)	$C_N = 0.77 \log\left(\frac{20}{\sigma'_v}\right)$ *units in* $tons/ft^2$
Seed (1976)	$C_N = 1 - 1.25 \log(\sigma'_{vo})$ *units in* $tons/ft^2$
Tokimatsu and Yoshimi (1981)	$C_N = \frac{1.7}{0.7 + \sigma'_{vn}}$ *units in* kg/cm^2
Liao and Whitman (1986)	$C_N = \left(\frac{P_a}{\sigma'_v}\right)^{0.5}$; Pa = 100 kPa (1 atm)
Skempton (1986)	$C_N = \frac{2}{1 + \sigma'_v}$ $for\ fine\ sand$ *and units in* kg/cm^2 $C_N = \frac{3}{2 + \sigma'_v}$ $for\ coarse\ sand$ *and units in* kg/cm^2
Kayen et al. (1992)	$C_N = \left(\frac{2.2}{\frac{1.2 + \sigma'_v}{P_a}}\right)$; Pa = 100 kPa (1 atm)
Idriss and Boulanger (2008)	$C_N = \left(\frac{P_a}{\sigma'_v}\right)^m$ and $m = 0.784 - 0.0768\sqrt{N_{1,60}}$ Pa = 100 kPa (1 atm)

Table 2.3. (cont'd)

Deger (2014)	$C_N = \left(\frac{P_a}{\sigma'_{vo}}\right)^m$; Pa = 100 kPa (1 atm) $m = 0.31 + 0.57e^{-0.078N_{1,60}}$ *for clean sands* $m = 0.27 + 0.23e^{-0.040N_{1,60}}$ *for silty soils*

Figure 2.5 provides a comparison of the overburden correction proposed for SPT by the researchers listed in Table 2.3.

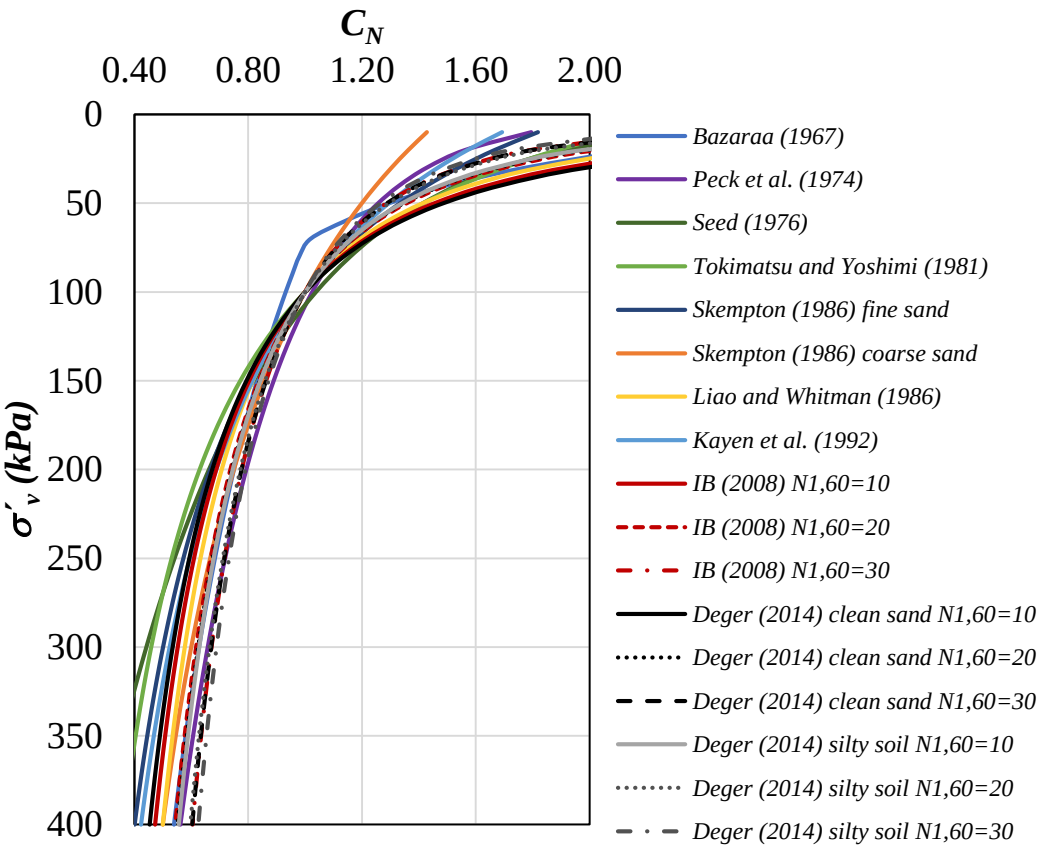


Figure 2.5. Comparison of overburden corrections proposed for SPT.

Overburden correction and stress exponent were assessed to be applied to CPT tip resistance values (e.g. Olson (1994), Olson and Malone (1988), Olson and Koester (1995), Olsen and Mitchell (1995), Salgado et al. (1997), Robertson and Wride (1997), Cetin and Isık (2007), Wroth (1984), Robertson and Campanella (1985),

Suzuki et al. (1995), Olsen and Mitchell (1995), Salgado et al. (1997 a, b), Boulanger (2003a), Idriss and Boulanger (2006), Moss et al. (2006), Robertson (2009), Mayen et al. (2009), Robertson and Cabal (2015), Sadrekarimi (2017), Mayne (2017)). Most of the prementioned studies offered chart solutions hence they did not provide a closed-form solution as the proposed stress exponent is a function of friction ratio, RF (%), and cone tip resistance (q_{t1}). The stress exponent provided by these studies is supportive of the derivation of SPT overburden corrections.

The previous seismic soil liquefaction triggering relationships by NCEER (1997), Seed et. al. (1985), Cetin et al. (2004, 2018) utilized the overburden correction proposed by Liao and Whitman (1986) where the stress exponent is 0.5. Idriss and Boulanger (2010) study applied the overburden correction provided in Idriss and Boulanger (2008). Chapter 6 presents an empirically derived new overburden correction factor developed as part of this dissertation, which is regressed within the model development effort based on field case history data compiled for this thesis.

2.3.1.2 Hammer Energy Ratio Correction, C_E

The SPT energy delivered to the rods can be theoretically calculated as the hammer mass multiplied by the drop height (e.g. potential energy). However, it was shown that the theoretical value of the energy could not be fully transferred to the drill rods (e.g. Schmertmann and Palacios, 1979, Kovacs et al., 1979, Davidson et al., 1999, Howie et al., 2003, Biringen and Davie, 2008, etc.). The factors that affect the efficiency of SPT hammers include hammer type (e.g. donut, safety), hammer release mechanism (e.g. automatic or manual), the number of the rope turns around the cathead, operator experience, and drill rig type, soil type, and rod length. Kovacs et al. (1983) state that:

"The hammer to rod transfer of energy (ETR) is ***important, variable, and unpredictable****. Therefore, the energy in the drill rods, ER_i cannot be predicted from hammer kinetic energy* ***but needs to be measured directly in the rods****.*

The variability of the energy passing through the drill rod as delivered by present U.S. equipment and procedures is too great to be eliminated by a modification of procedures alone. Equipment, as well as procedures, would have to be modified to achieve satisfactory results.

More than one drill rig- SPT system (which includes the operator in the rope-cathead method) at a site can produce N-value variability due to ER_i variability among the drill rigs. ***N-value varies approximately inversely with ER_i****. Correcting blow counts with known average energy ratios to a specified common energy ratio provides a more consistent profile of N values with depth."*

Direct measurements of the actual energy delivered to the rod can be performed with load cells and accelerometers placed on the rod. Work energy theorem is used to estimate the transferred energy within the SPT rod. As shown in Equation 2.3., energy can be calculated by integrating the product of force and velocity (F-V method) as given by Sy and Campanella (1991) over a given time also described by ASTM D4633-05 (ASTM 2005).

$$E(t) = \int F(t) \cdot V(t) dt \tag{2.3}$$

Lack of accelerometer capacity for measuring high frequencies, Schmertmann and Palacios (1979) developed an alternative method to calculate the energy within the system. Velocity term is replaced with Equation 2.4.

$$V(t) = \frac{c}{EA} * F(t) \tag{2.4}$$

so that the energy can be calculated as a function of force, which is called as F^2 method as shown in Equation 2.5.

$$E(t) = c \cdot E \cdot A \cdot \int F(t)^2 dt \tag{25}$$

where F(t) is the force measured as a function of time, V(t) is particle velocity measured as a function of time, Δt is the sampling interval, E is the modulus of

elasticity of the drilling rod, A is the cross-sectional area of the drilling rod, and c is stress wave propagation velocity which is equal to 5120 m/s for steel.

Accelerometer technology advanced in the early 90s and become capable of measuring high frequencies. With this development, energy measurements were made based on acceleration values which are integrated to calculate the velocity term in the energy equation. Sy and Campanella (1991) recorded the acceleration values due to the impact of the hammer on the steel rod during SPT.

The collected data is used to assess the hammer efficiency delivered to the drilling rod. The maximum energy value (EMX) is defined as the maximum value of the measured energy transfer over time which can be calculated with the F-V or F^2 method as given by Equation 2.2. and 2.4. The energy transfer ratio (ETR) is defined as the ratio of EMX to the maximum theoretical potential energy ($E_{theoretical}$) which is hammer mass multiplied by drop height (350 lb−ft or 475 J) for a dropping 63.5-kg hammer from a height of 76 cm (Kovacs 1979, Skempton 1986, ASTM 2005) as shown in Equation 2.6.

$$\mathrm{ETR} = \frac{\mathrm{EMX}}{\mathrm{E_{theoretical}}} \qquad \mathrm{E_{theoretical}} = 350\ \mathrm{lb-ft\ or\ 475\ J} \tag{2.6}$$

Energy transfer ratios (ETR) are calculated at different depths during SPT. It is observed that ETR increases with rod length which is the distance between the top of the rod (stick-up) and the bottom of the split spoon sampler (Deger 2014) until ETR reaches an asymptotic value. This is typically achieved around 35 to 40 feet. This asymptotic value is defined as the hammer efficiency or energy ratio (ER) which is then normalized to 60 % to calculate the hammer energy ratio correction, C_E. Reduction of hammer energy transfer at shallower depth is accounted for by a separated correction which is defined as short rod correction C_R which is the discussion in section 2.4.1.3. As shown in Equation 2.7, C_E and C_R are related to ETR.

$$\mathrm{ETR} = C_R * C_E * 60 \tag{2.7}$$

Schmertmann and Palacios (1979) and Kovacs et al. (1983) stated that SPT –N values are inversely proportional to the delivered energy. As a result, SPT blow counts were corrected for 60 % of energy as shown in Equation 28. by Seed et al (1985), Skempton (1986), and Youd et al. (2001). The 60 % value was selected to be the reference value as it is the efficiency of a safety hammer of a rope and cathead system commonly used in US practice (Kovacs et al., 1979).

$$N_{60} = C_E * N = \frac{ETR_{asymptote}\ or\ ER}{60} * N \tag{2.8}$$

The main reason for different energy transfer from hammer to drilling rod is due to the use of different types of hammers and methods for raising and dropping the weight (Cetin 2000). There are various types of hammers as shown in Figure 2.6. Automatic SPT hammers are more efficient in transferring energy than manual hammers. Davidson et al. (1999) measured the energy in extensive field testing using 44 safety hammers and 14 automatic hammers for different rod lengths. Their work revealed that energy delivered to rods is higher for automatic hammers than for safety hammers, and energy delivery is dependent heavily on the operator for the manually operated safety hammers. Recently, Cevik (2022) compiled a database to assess the energy ratio values for safety and automatic hammers and the study reveals that the hammer energy efficiency values are higher than what had been postulated previously by NCEER (2001).

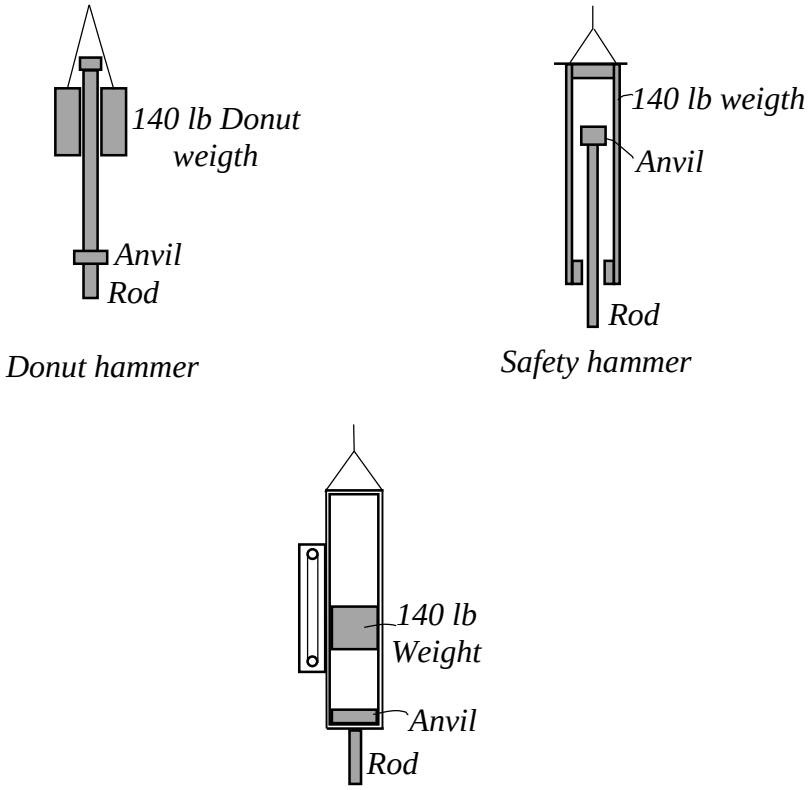


Figure 2.6. Hammer Types.

Tables 2.4, 2.5, and 2.6 summarize energy ratios for the manual, donut, and automatic trip hammers. The scatter in the hammer efficiency values emphasizes the need for hammer efficiency to be measured directly in the rods during SPT driving.

Table 2.4. Donut

Reference	*Energy ratio (ER, %)*
Johnsen et al. (2001)	31-53
Seed et al. (1985)	45-78
Skempton (1986)	45-78
NCEER (1997)	27-60
Seed et al. (2003)	30-60
Kim et al. (2004)	40

Table 2.5. Safety Hammers

Reference	*Energy ratio (ER, %)*
Schmertmann et al. (1978)	45-70
Goble and Ruchti (1981)	76-96
Kovacs et al. (1981)	34-83
Riggs et al. (1984)	80
Seed et al. (1985)	63-72
Riggs (1986)	65-90
Skempton (1986)	55
Gonzalez, 2002,	55-60
Batchelor et al. (1995)	51
Lamb (1997)	67
NCEER (1997)	36-72
Sjoblom et al. (2002)	50-67
Valiquette et al. 2010)	64.4
Davidson et al. (1999)	66±10.7
Seed et al. (2003)	40-75
Sancio and Bray (2005)	55-66
Kelley and Lens (2010)	48-66
Batilas et al. (2017)	46 ± 3.8%

Table 2.6. Automatic trip

Reference	*Energy ratio (ER, %)*
Riggs et al. (1984)	88
Seed et al. (1985)	76-90
Clayton (1990)	60-73
Batchelor et al. (1995)	69-81
Lamb (1997)	75-80
NCEER (1997)	45-78

Table 2.6. (cont'd)

Davidson et al. (1999)	80±7.9
Johnsen et al. (2001)	63-77
Sjoblom et al. (2002)	46-95
Seed et al. (2003)	50-80
Kim et al. (2004)	63
Biringen and Davie (2008)	76
Kelley and Lens (2010)	80-90
Valiquette et al. 2010)	80.8
Yee et al. (2013)	84-94
Değer (2014)	66-92
Honeycutt et al. (2014)	83
Batilas et al. (2017)	77 ± 4.6%

Cetin (2000), Cetin et al. (2004, 2018), Idriss and Boulanger (2010) adopted the hammer energy efficiency recommendations of NCEER (2001) which is based on the F^2 Method. The new specification (ASTM) now requires the use of the F-V Method for hammer energy measurements which suggests higher hammer efficiency values for automatic hammers. Section 3.2.17.4 will present the adopted hammer efficiency values used in this study.

2.3.1.3 Short Rod Correction, C_R

Short rod correction factors (C_R) are introduced by Schmertamnn and Palacious (1979) to account for the lost energy due to rod length at shallow depths (e.g. depths smaller than 30-40 ft). The energy delivered to the anvil propagates down to the rod for sample penetration. However, energy is lost within the system in the form of work done for sample penetration, energy dissipated by the soil (soil damping), energy reflected backward as tension or compression depending on the soil stiffness, and energy lost in couplings of rods and sampler, energy lost due to different cross-

sectional areas of the rods (rod connections). Energy measurements revealed that the actual hammer energy delivered to the rod is reduced when the rod length is short. The short rod length is defined in the range of 0-40 ft based on the energy measurements by different researcher groups.

The pioneering study of Schmertamnn and Palacious (1979) was the first research group that introduced the C_R correction term. The researchers developed a system to measure the compressive and tensile force waves in the rod during field testing. load gauges were placed on the rod beneath the anvil and monitored compression and tension waves. Schmertamnn and Palacious concluded that the energy delivery depends on rod length as a result they provide a correction term for rod lengths.

Schmertmann and Palacios (1979), illustrated the basic wave propagation mechanism due to the first hammer impact. The compressional wave travels down the road and when they reach the base of the rod they trigger the sampler penetration, then the wave is refracted back to the hammer causing a re-tap of hammer and anvil which creates compressional forces downward again. Work energy theorem is used to understand the energy transfer system within the SPT rod.

Schmertmann and Palacios (1979) developed an alternative method to calculate the energy within the system due to the lack of accelerometer capacity for measuring high frequencies (discussed in 2.4.1.2), which is called as F^2 method.

Palacios (1977) used two force recordings located on the upper and lower portions of the rod for different rod lengths (short and long). Their work reveals that short rods provide a faster refracted tensile wave back to the anvil which limits the energy transferred by the first impact of the hammer for full sampler penetration whereas this was not observed in longer rods. However, their methods have limitations since they were not able to record high-frequency data.

Schmertmann and Palacios (1979) work is followed by many engineers including Kovacs and Salomone (1982) who provided energy measurement data based on the F^2 method. Based on these efforts, short rod correction factors are proposed by Seed

et al. (1984), Skempton (1986), Robertson and Wride (1997), Bowles (1996), Youd et al. (2001), Cetin et al. (2004, 2018, 2022).

With the developments in accelerometer technology, energy measurements were made based on acceleration values, which were then integrated to calculate the velocity term in the energy equation. The pioneering study for short rod corrections based on the F-V Method was provided by Sy and Campanella (1991), Morgano and Liang (1992), Davidson et al. (1999) and Butler (1997), Howie et al. (2003), Biringen and Davie (2008).

Sancio and Bray (2005) performed 2000 direct measurements of the energy transmission by a safety hammer with a rope, cathead, and pulley system in Turkey. They concluded that the force-velocity method should be used to calculate the energy transferred, and the use of the force-squared method may lead to overprediction of the energy ratio. Additionally, they stated that the rod length has a small influence on the energy transmitted to the rod string and sampler and the energy delivered depends on the actual resistance to penetration of the test interval (i.e., N-value).

Youd et al. (2008) conducted field measurement for the Wildlife Liquefaction Array (WLA) and provide energy measurement by implementing the F-V method. Their work concluded that the short rod correction by Youd et al. (2001) which implements the F^2 method gives comparable values with the current measurements.

Valiquette et al. (2010) measured the energy, force, and velocity data of 28 SPT hammers (automatic hammers and manual hammers). The study proposed a short rod correction for automatic hammers. Lee et al. (2014) used a high-speed digital line-scan camera to understand the energy transfer by the hammer impact on sampler penetration. They performed SPT to assess the energy transfer ratio by using the F-V method and monitored real-time hammer motion and sampler penetration. It was concluded that energy transfer depends on rod length and N values of the soil at the base.

ASTM revised the specification and states that the short rod effects may be less significant than had earlier been postulated based on early energy measurements developed using the F^2 Method. The new specification now requires the use of the F-V Method for hammer energy measurements. This has generated significant controversy, and it is this controversy that will be addressed by this study.

Another view in the literature is that short rod corrections are not needed. This view claims that secondary energy pulses (reflected and refracted pulses, plus secondary hammer re-strikes) produce energy that is completely transferred to sample penetration. Daniel et al. (2005) used an electric current to observe when the hammer and the anvil are in contact or separated. They used the F-V Method noting that they are now able to measure the duration of the contact. Their work is supported by Decourt (2006) and by Danziger, Danziger, and Cavalcante (2006). The data provided by these researchers are derived from manual hammers.

Batilas et al. (2017) performed SPT at five locations in Greece using manual or automatic hammers. Based on the results of 900 measurements of energy ratio, the following conclusion was made: i) automatic hammers have ER twice that of the manual hammers, ii) ER is not a function of depth noting that manual hammer ER is decreased when the depth is less than 5 m especially when SPT values are less than 8–10, iii) the soil type (cohesive vs. cohesionless) does not affect appreciably the value of ER.

Data were collected by Deger (2014) from a total of 24 SPT borings from dam and levee sites. For each automatic hammer, the SPT driving energies were measured within the calibration borehole over a range of depths. The energy transfer ratios based on the F-V method were obtained for a total of 8879 hammer blows, from 300 SPT performed within 24 different boreholes. The grey dots in the Figure 2.7 represent the rod length correction factors obtained for all 300 SPT from the twenty-four boreholes, and the solid line represents the rod length correction relationship by Deger (2014) developed by regression analysis. As shown in Figure 2.7, C_R decrease at shallow depths with decreasing rod length.

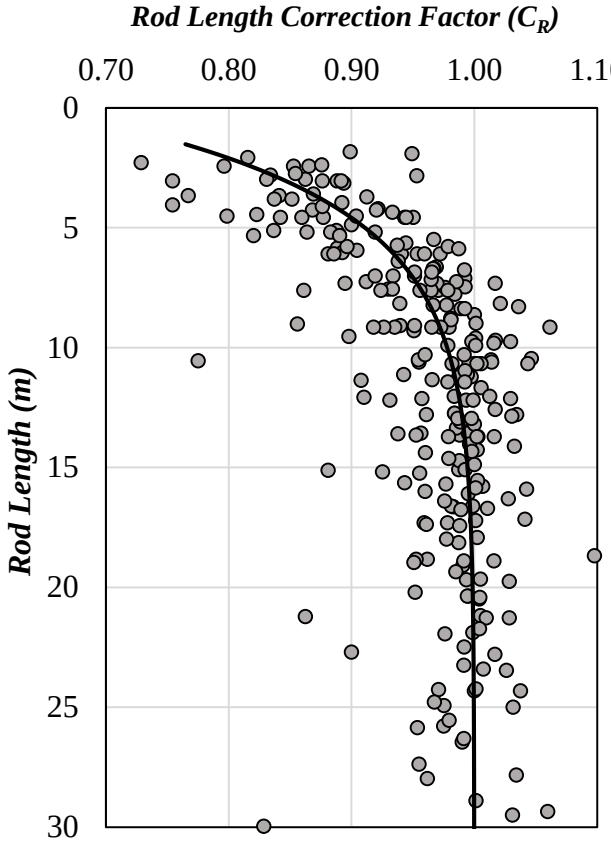


Figure 2.7. Short rod correction database and developed C_R model by Deger (2014)

Based on the data, Deger (2014) proposed Equation 2.9 as the short rod length correction relationship for automatic hammers.

$$C_R = 1 - 0.36 \cdot e^{-0.085 \cdot L} \quad (2.9)$$

where L is the rod length (borehole depth and stick up). Effects of soil type and character were also considered by Deger (2014) however the final functional form was not presented as a function of SPT-N values. C_R values obtained were grouped into four different bins based on the N_{60} values measured for each SPT, and curves were developed for each bin and shown graphically by Deger (2014).

Recently an extensive database is compiled by Cevik (2022) and a new set of short rod corrections is under development (personal communication with Prof. Kemal Onder Cetin).

Figure 2.8 compares the short rod correction proposed by Seed et al. (1984), Skempton (1986), Robertson and Wride (1997), Bowles (1996), Youd et al. (2001), and Cetin et al. (2004) based on F^2 method and Morgano and Liang (1992), Valiquetta et al. (2010), Deger (2014) based on F-V method. It can be concluded that early short rod corrections based on the F^2 method overestimated the short rod effects.

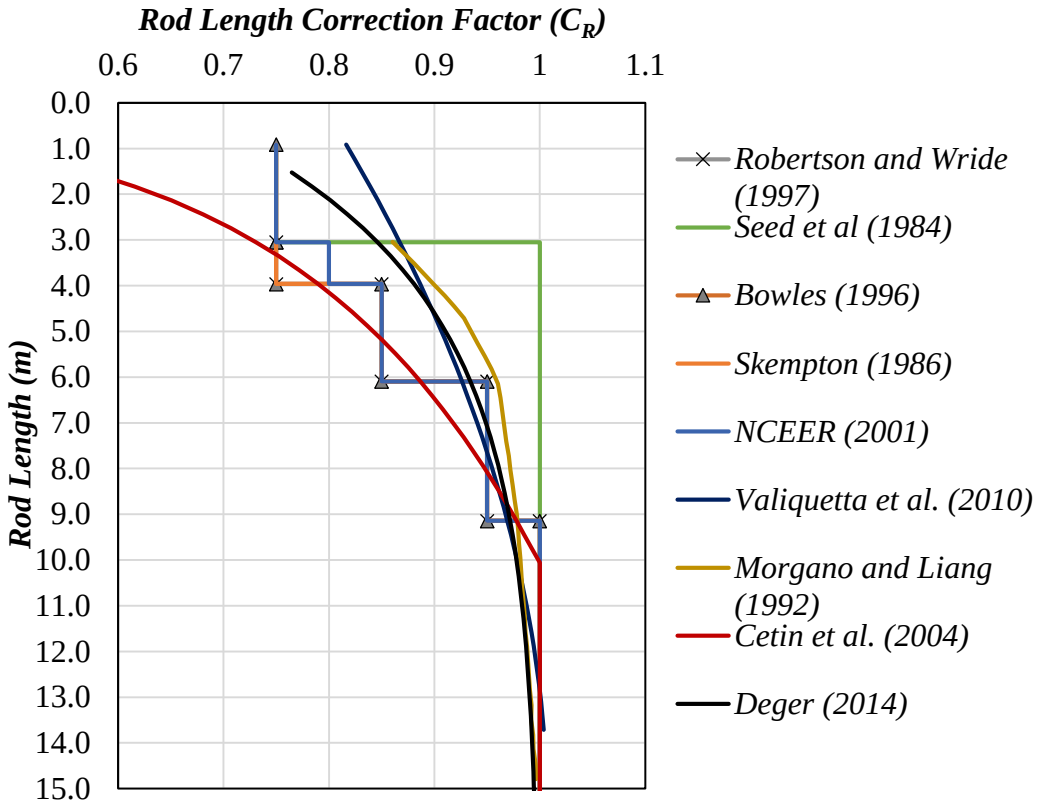


Figure 2.8. Comparison of short rod corrections based on F^2 and F-V methods.

Section 3.2.17.3 will present the adopted short rod corrections within the confines of this study.

2.3.1.4 Fines Content Correction

Fines content correction is the least understand parameter in liquefaction triggering assessment and still the modeling of the fines content effect on liquefaction resistance boundaries includes great uncertainty as a result of how the liquefaction potential is affected by increasing fines content is still under discussion. Fines content within a sand layer affects the minimum and maximum void ratio and relative density. Cubrinovski (2019) states that *'...material and state characterization for fines-containing soils or any liquefiable soil distinctly different from clean sand are not of the same quality and accuracy as that of clean sand.'*

In general, as the fines content (FC) of soil increases, compressibility also increases enhancing the potential for liquefaction, and permeability decreases which restrains the excess pore water pressure dissipation hence the pore pressure increases which reduces shear strength (Lade et al. 1998). However, as the fine material fills the voids between sand particles, fines govern the response, and in general shear strength decrease. This very complex effect of fine content on strength, stiffness, compressibility and permeability characteristics makes it hard to evaluate the FC effect on liquefaction resistance of the soil. The fines content appears to affect the liquefaction potential however its influence on both CSR and $N_{1,60}$ is not yet well defined.

The liquefaction potential of sands is evaluated based on their relative density. When the relative density of the soil deposit is low (e.g. loose deposits) the liquefaction potential increases (Seed, 1979, Seed et al., 1983, Lade et al., 1998). Studies in the literature showing the effect of fine content on the minimum and maximum void ratio (Lade et al (1998), Yamamuro and Lade (1997), Lade and Yamamuro (1997), Cubrinovski and Ishihara (2002) helped researchers to understand fines content effects on liquefaction resistance. These studies revealed that when the fines content is smaller than about a level of 20%, the characteristics of the sandy deposits are controlled by the sand matrix on the other hand when the fines content increases, the matrix is controlled by the silts as also shown by Figure 2.9.

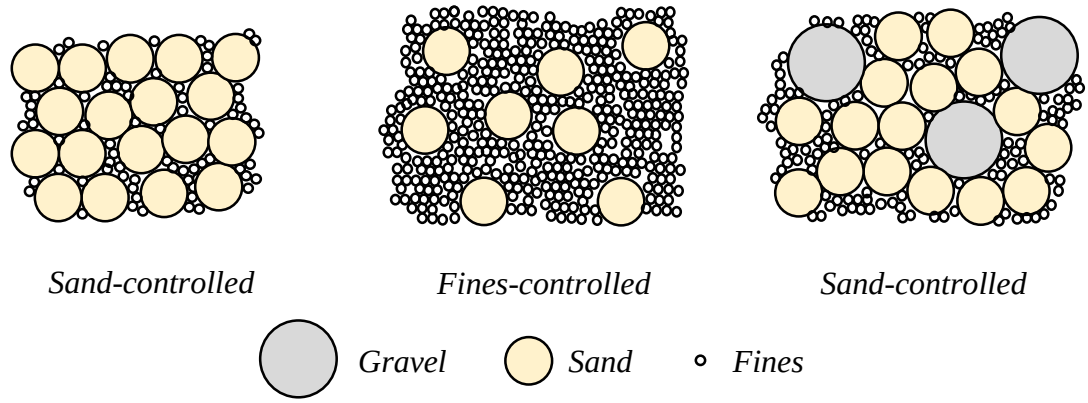


Figure 2.9. Comparative illustration of fines correction

The transition from sand-controlled to fines-controlled behavior occurs over a narrow range of fines content and this range is referred to as threshold (limiting) fine content (Figure 2.10). Cubrinovski and Ishihara (2002) and Lade et al. (1998) compiled void ratio along with fines content data and their work shows that threshold fines content is around 30 - 40%. Cubrinovski (2019) presented Figure 2.11 to show the influence of fines content on index void ratios for Cambria sand – Nevada silt mixtures of sand-silt mixtures.

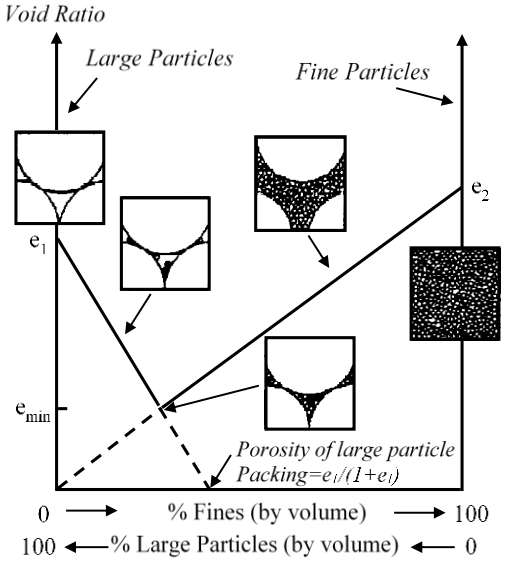


Figure 2.10. Schematic diagram of the theoretical variation of minimum void ratio in binary packings with % fines. (After Lade et al., 1998)

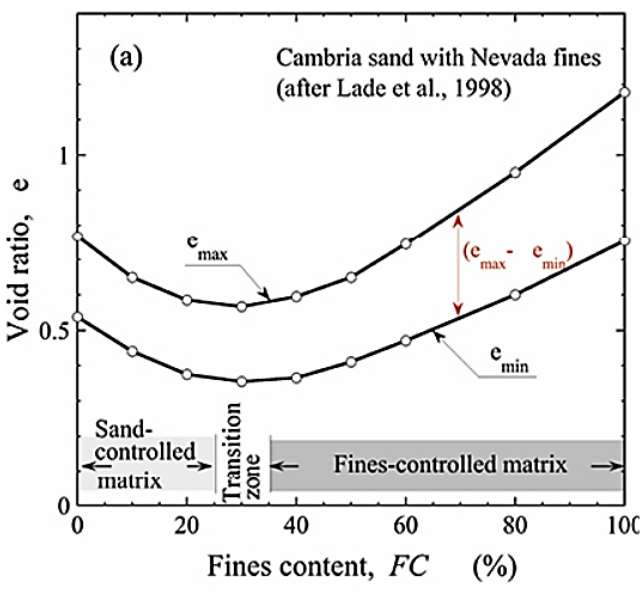


Figure 2.11. Influence of fines content on the packing of sand-silt mixtures variation of index void ratios with fines content for Cambria sand – Nevada silt mixtures (Cubrinovski, 2019)

Seed et al. (1985) provided seismic soil liquefaction triggering relationships for clean sands. Their database has case history data from silty soils as well. In order to encounter fines content effects, they provided liquefaction triggering boundaries for 3 different fines content levels 5%, 15%, and 35%. Following this approach, SPT-N blow counts were corrected by fines content to provide clean sand SPT values to bring all the case histories to a comparable level. Cetin et al. (2004, 2018) have regressed fines corrections within their Bayesian analysis and provided fines content correction derived from field case history data empirically. The overall average fines corrections were dependent on $N_{1,60}$. The fines content correction proposed by various research studies is summarized in Table 2.7.

Table 2.7. Fines Content Correction Terms

Reference	*Fines Content Correction*
Tokimatsu and Yoshimi (1983)	$N_{1,cs} = N_1 + \Delta N$ $\Delta N = 0;\ FC = 0 - 5\%$ $\Delta N = interpolate;\ FC = 5 - 10\%$ $\Delta N = 0.1 \cdot FC + 4;\ FC > 10\%$ $FC_{upper\ limit} \sim 60\%$
Seed et al. (1983)	$N_{1,60,cs} = N_{1,60} + 7.5$
Kayen and Mitchell (1997)	$N_{1,60,cs} = N_{1,60} + \Delta N$ $\Delta N = 0;\ FC = 0 - 5\%$ $\Delta N = (FC - 5)\frac{7}{30};\ FC = 5 - 35\%$ $\Delta N = 7;\ FC > 35\%$
Youd et al. (2001)	$N_{1,60,cs} = \alpha + \beta \cdot N_1$ $\alpha = 0, \beta = 1; FC < 5\%$ $\alpha = e^{1.76 - \frac{190}{FC^2}}, \beta = 0.99 + \frac{FC^{1.5}}{1000};$ $FC <$ 5-35% $\alpha = 5, \beta = 1.2; FC > 35\%$
Cetin et al. (2004)	$N_{1,60,cs} = C_{fines} \cdot N_{1,60}$ $C_{fines} = 1 + 0.04 \cdot FC + 0.05 \cdot (FC/N_{1,60}); FC = 5 - 35\%$
Cetin et al. (2018a,)	$N_{1,60,cs} = C_{fines} \cdot N_{1,60}$ $C_{fines} = 1 + 0.00167 \cdot FC + 0.089 \cdot (FC/N_{1,60}); FC = 5 - 35\%$
Idrissand Boulanger (2004)	$N_{1,60,cs} = N_{1,60} + \Delta N$ $\Delta N = 0; FC < 5\%$ $\Delta N = \mathrm{e}^{1.63 + \left(\frac{9.7}{\mathrm{FC}}\right) - \left(\frac{15.7}{\mathrm{FC}}\right)^2}; FC > 5\%$

Figure 2.12 provides a comparison of fines content corrections graphically by Seed et al (1985), Cetin et al (2004), Cetin et al (2018a), and Idriss and Boulanger (2010). When Table 2.7and Figure 2.12 were examined, it can be seen that the fines content correction increase with increasing fines content (FC) until it reaches to plateau around FC=35%.

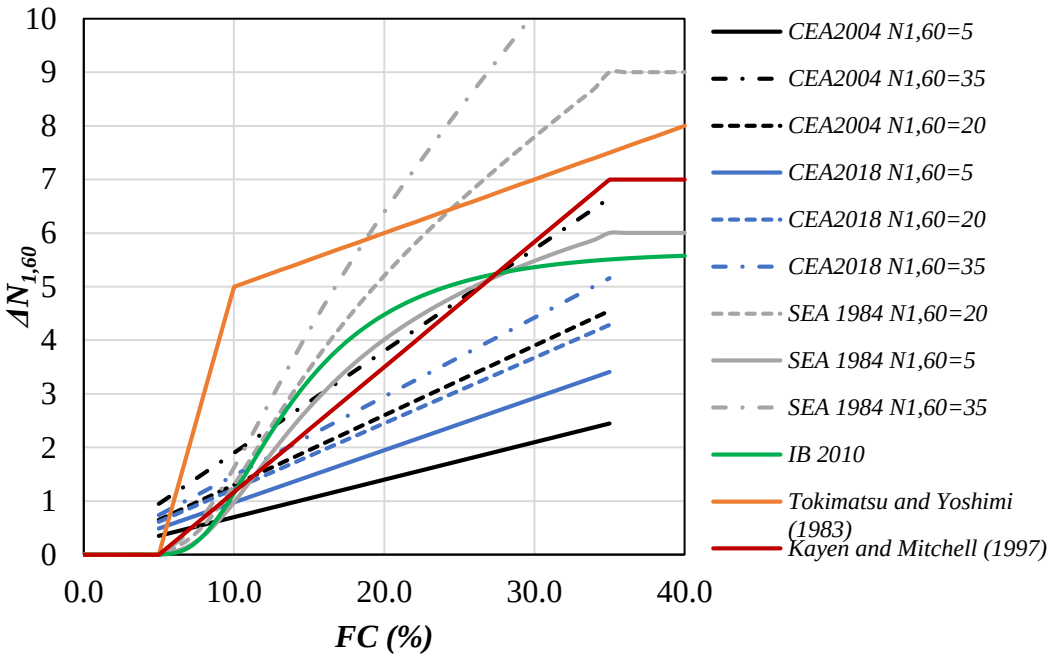


Figure 2.12. Comparative illustration of fines correction

The current fines content correction significantly adjusts the liquefaction triggering relationships. The liquefaction triggering relationships shifts upward and left when FC increases as shown by Seed et al. (1985) in Figure 2.13.

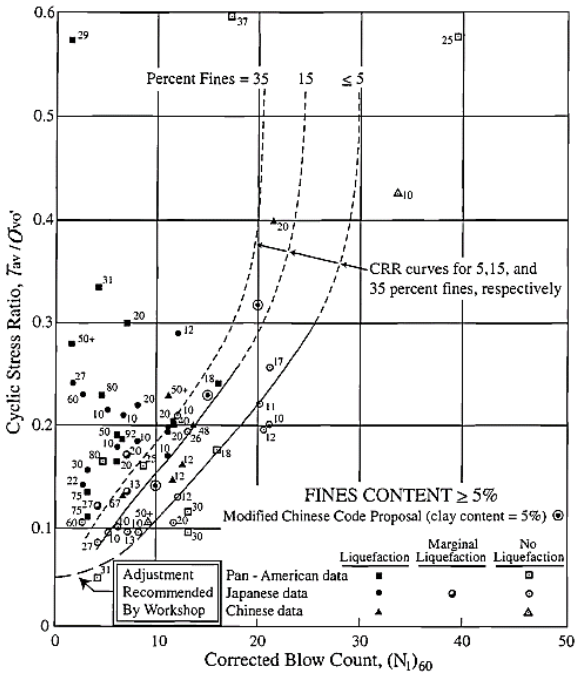


Figure 2.13. CRR boundary curves by Seed et al (1985) for different fines content values.

In summary, fines content has a significant effect on the liquefaction potential of soils but these effects need further research. As previously discussed, the influence of FC on both CSR and $N_{1,60}$ is not yet well defined but a functional form that separates sand-controlled and silt-controlled behavior may reflect FC effect on SPT-N resistance better. This study presents an updated FC correction regressed within the Maximum likelihood analysis in Chapter 6.

The previous liquefaction triggering database efforts focused on sandy and silty deposits, as a result, fines content was the main parameter under discussion related to grain-size composition characteristics. However, the current database investigates the gravelly soil layers as well. As stated by Cubrinovski (2019) *"an increase in gravel content or increase in the grain size of soil causes an increase in penetration resistance. These effects of the grain-size composition of soils on the penetration resistance are significant."* and it is important to address the strength, stiffness,

compressibility, and permeability characteristics of the liquefiable soils with different gravel contents.

2.3.2 Cyclic Stress Ratio, CSR

Seed et al. (1985) presented seismic soil liquefaction database on CSR versus $N_{1,60}$ domain. The seismic demand term CSR is estimated by the simplified procedure as defined by Seed and Idriss (1971). The following section will present the terms and corrections related to CSR.

Shear stresses at the base of rigid soil block are expressed by Seed and Idriss (1971) as given in Equation 2.10. Soil blocks behave as deformable-body, hence a factor is applied to encounter the flexible behavior. This factor defined as mass participation ratio (or stress reduction factor) is applied to $\tau(t)_{rigid}$ to estimate $\tau(t)_{deformable}$ as shown in Equation 2.2.

$$\tau(t)_{rigid} = \gamma \cdot h \cdot \frac{a(t)}{g} \tag{2.10}$$

$$\tau(t)_{deformable} = \gamma \cdot h \cdot \frac{a(t)}{g} \cdot r_d \tag{2.11}$$

where a(t) is the ground surface acceleration at time t, g is the acceleration of gravity, γ is unit weight, h is the soil block height, r_d is mass participation ratio.

Seed and Idriss (1971) judged that 65% of the maximum shear stress (τ_{max}) is well representing an average shear stress $\tau_{average}$. CSR is defined by the simplified procedure as a normalized term of average shear stress to vertical effective stress. Equation 2.3 presents the well-known CSR term as proposed by Seed and Idriss (1971).

$$CSR = \left(\frac{\tau_{av}}{\sigma'_{vo}}\right) = 0.65 \cdot \left(\frac{a_{max}}{g}\right) \cdot \left(\frac{\sigma_{vo}}{\sigma'_{vo}}\right) \cdot r_d \tag{2.12}$$

where a_{max} is horizontal peak ground acceleration, σ_{vo}' is vertical effective stress, σ_{vo} is vertical total stress.

The mass participation ratio is first proposed by Seed and Idriss (1971). The parameter is broadly studied by various research groups (e.g. Imai et al. (1981), Golesorkhi (1989), Idriss (1999), Cetin and Seed (2004), Lasley et al (2016), etc.) based on 1-D site response analysis. Some of the early efforts to develop r_d correlations involved a limited number of site profiles which were analyzed with limited ground motion. Imai et al. (1981) performed 143 one-dimensional site response analyses by using 5 different input motions with actual stratigraphy. Cetin (2000) and Cetin and Seed (2004) advanced the analysis by performing 2153 site response analyses by using 42 ground motions applied to 50 real soil stratigraphy. NAP (2016) indicated that "the median values of r_d predicted by the Cetin and Seed (2004) relationship are considered more representative of the induced cyclic shear stress at liquefaction sites than are other r_d relationships." Lasley et al. (2016) also performed an equivalent linear site response analysis by using the same set of soil profiles as Cetin (2000) by using 195 pairs of horizontal rock motions recorded during 47 earthquakes.

An alternative and a more direct way of calculating CSR is to assess the site response with direct site-specific seismic site response analyses. 1-D site response analysis software that can perform equivalent linear and nonlinear site response analysis (e.g. Shake, Deepsoil, EduShake, etc.) is utilized to perform site-specific seismic site response analyses in which pore pressure generations are not modeled. A representative rock outcrop motion is used in these analyses and the soil layers are modeled as 1-D soil columns. An upward propagation of the surface waves helps to estimate both a_{max} and shear stress hence CSR values. Another alternative to estimate the site and event-specific CSR values is to perform soil-structure-interaction analyses in which the pore water pressure generation is modeled. However, the latter analysis is more sophisticated and needs more complex parameters. Hence 1-D site response analysis is widely used in determining the CSR values of liquefaction case histories.

Once the CSR is calculated a series of correction terms is applied. These corrections are K_σ, K_α, and K_{Mw} which are used to convert overburden and static shear stresses, and duration (magnitude) to the references states of σ_{vo}' =1atm, α=0, and M_w=7.5, as given in Equation 2.4.

$$\mathrm{CSR}_{\sigma_v'=1\ \mathrm{atm},\alpha=0,M_w=7.5} = \mathrm{CSR}_{\sigma_v',\alpha,M_w} \cdot \frac{1}{K_\sigma} \cdot \frac{1}{K_{M_w}} \cdot \frac{1}{K_\alpha} \tag{2.13}$$

The following section discusses the correction terms applied to CSR.

2.3.2.1 Overburden Stress Correction, K_σ

The monotonic and cyclic undrained shear strength of saturated soils increases as the confining stress increases. CSR is a normalized term referring to cyclic shear stresses divided by effective confining stress, which in turn, tends to decrease as the confining stress increases. This is well-explained by Seed and Harder (1990) as follows *"At higher effective overburden stresses, a given CSR and number of loading cycles will be more damaging. This is because while soils generally develop higher cyclic load resistance with increasing confinement, the normalized resistance as expressed in terms of cyclic stress ratio usually decreases with increasing confinement."* Several authors attempted to investigate CSR (or CRR) under different confining stress levels which is also known as overburden stress correction, K_σ. Lee and Seed (1967a, b), Seed and Peacock (1971), Castro and Poulos (1977), Seed and Idriss (1982) conceptually worked on the confining stress effects on CSR (or CRR) (concept of K_σ) however their studies were limited to understand the effects of confining stress on liquefaction resistance and no K_σ corrections were offered at that time. Seed et al. (1983) proposed the first K_σ corrections in the literature as given by Equation 2.5.

$$\mathrm{CSR}_{\sigma_v'} = \mathrm{CSR}_{\sigma_v'=100\mathrm{kPa}} \cdot K_\sigma \tag{2.14}$$

Although the study was a milestone in assessing the overburden effects on CSR (or CRR), the K_σ correction was not implemented by the seismic soil liquefaction

triggering relationships of Seed et al. (1984). Research efforts later tended to focus on applying K_σ corrections to CSR (or CRR) in deriving liquefaction triggering relationships, which turn out to be one of the most important corrections due to the need for the application of these charts at high-stress levels (e.g. dams, etc). This need for the extrapolation of overburden stress corrections outside the liquefaction case history dataset is one of the main reasons for the ongoing research motivation in this field.

The overburden stress corrections were investigated mainly based on laboratory testing. There are also empirical and numerical studies in the literature but the main focus was given to cyclic laboratory testing and recently large-scale centrifuge testing. Undrained cyclic laboratory tests specifically simple shear or triaxial tests were performed by Seed (1983), Olsen (1984), Harder (1988), Seed and Harder (1990), Pillai and Byrne (1994), Vaid and Thomas (1995), Vaid and Thomas (1995), Vaid and Sivathayalan (1996), Vaid and Sivathayalan (1996), Harder and Boulanger (1997), Hynes and Olsen (1999), Youd et al. (2001), Vaid et al. (2001), Wu et al. (2003), Boulanger (2003a), Boulanger and Idriss (2004), Idriss and Boulanger (2006, 2008), Manmatharajan and Sivathayalan (2011), Montgomery et al. (2012, 2014), and Dobry and Abdoun (2015), etc. to understand the overburden stress effects on cyclic strength. Centrifuge testing (Steedman et al., 2000, Gonzalez, 2002, Abdoun et al., 2020, Ni et al., 2020, 2021, etc.) is a more recently used, alternative tool in assessing those corrections.

Another approach was followed by Cetin (2000), Cetin et al. (2004, 2018), and Moss et al. (2006). Liquefaction case histories were compiled and the K_σ correction was obtained within the regression analysis of liquefaction triggering relationships empirically. The resulting K_σ corrections based on field case history data give a reasonably good fit to laboratory test data and it is particularly important that this relationship is based on actual field data. Cetin and Bilge (2013) studied a combined correction term that included both K_σ and K_α (and K_{SRR}) effects and they proposed a collective and strain-dependent unified framework based on the collected and

performed laboratory test data. Lastly, some researchers performed numerical analyses to model varying overburden stress levels and the corresponding cyclic strength of soils. For example, El-Sekelly et al. (2020) have performed numerical simulations of centrifuge tests at high effective overburden stresses and investigated the pore pressure generation and liquefaction response of a sand layer.

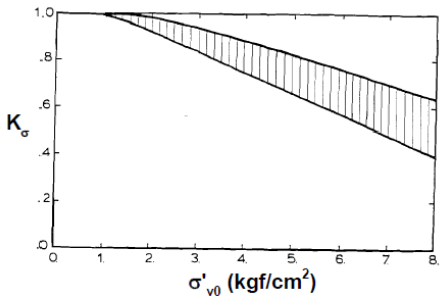
Inspired by Bolton (1986) and Konrad (1988) critical state line and state parameter studies, Pillai and Muhunthan (2001) and Stamatopoulos (2010) link the effects of D_R and σ'_c to CRR of sands with state parameter (ξ) and similarly, Boulanger (2003a) and Idriss and Boulanger (2008) related K_σ to relative state parameter (ξ_R). Boulanger (2003a) proposed a closed-form function of K_σ correction for sands to be used in liquefaction triggering analysis. The study is important in terms of the emphasis on K_σ corrections' dependency on D_R and encouraging the use of D_R-dependent K_σ corrections in liquefaction analysis.

These studies revealed K_σ correction to be dependent on D_R, σ'_c, overconsolidation ratio (OCR), FC, soil deposition method, aging, stress history, cementation, and fabric. Many of the early efforts to estimate K_σ corrections are proposed for clean sands as the relative density concept is valid for clean sands. As a result, the application of these overburden corrections for silty soils is ambiguous.

Some attempts were made to understand the overburden correction for silty sands (e.g. Jafarian et al., 2013, Montgomery et al., 2014, etc.). Jafarian et al (2013) presented K_σ correction based on the results of the cyclic triaxial tests on reconstituted samples on sands and non-plastic silty sands (FC 0-50%). Montgomery et al. (2014) shared cyclic laboratory test results on samples having fines content up to 35% and concludes that the overburden corrections provided by Boulanger (2003a) and Idriss and Boulanger (2008) offer a good fit for clean sands, and are slightly unconservative for sands with FC of 7 -35% which reveals that the current stress corrections are mostly applicable to clean sands. The overburden stress corrections of soils with high fines content (e.g. FC>50%) still need further

investigation. Some of the studies that proposed K_σ relationships are presented in Table 2.8.

Table 2.8. Overburden Stress Correction

Reference	*Overburden Stress Correction, K_σ*
Seed (1983)	
Hynes and Olsen (1999)	$K_\sigma = \left(\frac{\sigma'_{v,0}}{P_a}\right)^{f-1}$
Youd et al. (2001)	$K_\sigma = \left(\frac{\sigma'_{v,0}}{P_a}\right)^{f-1}$ $f = 0.6, 0.7, 0.8\ for\ dense, medium - dense, loose\ sands$
Boulanger (2003a)	$K_\sigma = 1 - C_\sigma \cdot \ln\left(\frac{\sigma'_v}{P_a}\right)$ $C_\sigma = \frac{1}{18.9 - 17.3 \cdot D_R} \leq 0.3$
Cetin et al. (2004)	$K_\sigma = \exp\left(-0.278 \cdot ln\left(\frac{\sigma'_v}{P_a}\right)\right)$
Cetin et al. (2018)	$K_\sigma = \exp\left(-0.336 \cdot ln\left(\frac{\sigma'_v}{P_a}\right)\right)$
Bilge and Cetin (2011)	$ln(K_\sigma) = \ln\left(\left(\frac{\sigma'_v}{P_a}\right)^{-0.0047 \cdot D_R}\right) \mp 0.044$

K_σ corrections by Idriss and Boulanger (2010) and Cetin et al. (2004, 2018a) were plotted comparatively in Figure 2.14 along with laboratory data of Montgomery et al. (2014) and Cetin and Bilge (2012). At shallow depths, the scatter among those

relationships is great and it is the main reason for the discussions of the current literature. It should be noted that most of the liquefaction case history database consist of sites where the potentially liquefiable layer is located close to the surface where a great difference exists among researchers.

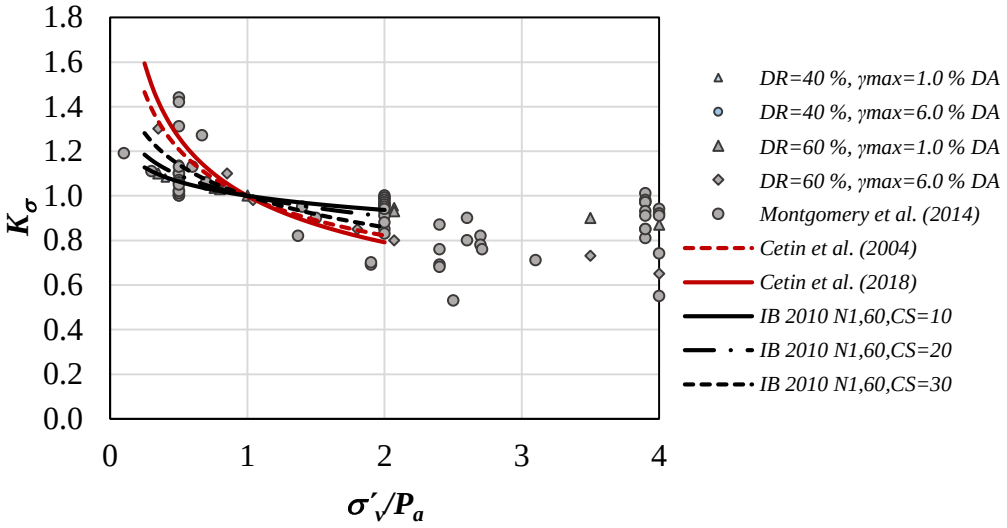


Figure 2.14. The recommended K_σ relationship of Idriss and Boulanger (2010) and Cetin et al. (2004, 2018) along with laboratory data of Montgomery et al. (2014) and Cetin and Bilge (2012)

2.3.2.2 Duration (Magnitude) Correction, K_{Mw}

The effect of magnitude (duration) of cyclic loading on liquefaction triggering relationships is conceptually defined by Seed and Lee (1966). Seed et al. (1984) proposed liquefaction triggering curves on overburden-corrected SPT blow counts, $N_{1,60}$ versus CSR space for M_w=7.5 event as the dataset consists of earthquakes with magnitudes close to M_w=7.5. The earthquake events with different moment magnitude values were adjusted to a magnitude of 7.5 by applying magnitude (duration) scaling factors. As stated by Seed et al. (1983) *"from liquefaction point of view, the main difference between different magnitude events is in the number of cycles of stress which they induce."* Magnitude scaling factors are actually an

earthquake "duration" factor which is used to adjust the various events to a reference state of M_w=7.5 (number of cycles=15 is selected by Seed et al., 1983) which depends on the imposed loading and the soil's loading response, as it is the case of any type of fatigue problem (Boulanger and Idriss, 2014). The correction term is usually shown as MSF in the literature and will be referred to as K_{Mw} in this study.

The need for correcting CSR for various moment magnitude events required linking "CSR-number of cycle (N)-moment magnitude (M)". Seed et al. (1975) proposed stress weighting factor (m) to convert an irregular cyclic loading history to the equivalent number of uniform loading cycles (e.g. linking N to CSR). The weighting factor has formed the basis of the subsequent studies (e.g. Idriss, 1999, Liu et al., 2001, Green and Terri, 2005, Boulanger and Idriss, 2007, Cetin and Bilge, 2012, etc.). When the number of cycles (N) required to cause liquefaction is plotted against CSR (or CRR) as shown by Seed et al. (1985) in Figure 2.15a, the relationship can be expressed with a power function as shown in Equation 2.15 where a and m are fitting parameters.

$$\mathrm{CSR} = \mathrm{a} \cdot \mathrm{N}^{-\mathrm{m}} \tag{2.15}$$

Seed et al. (1975) presented correlations as provided in Figure 2.15b to convert earthquake magnitude to the number of cycles, N adopting an approximate m value of 0.25 (e.g. linking N to M).

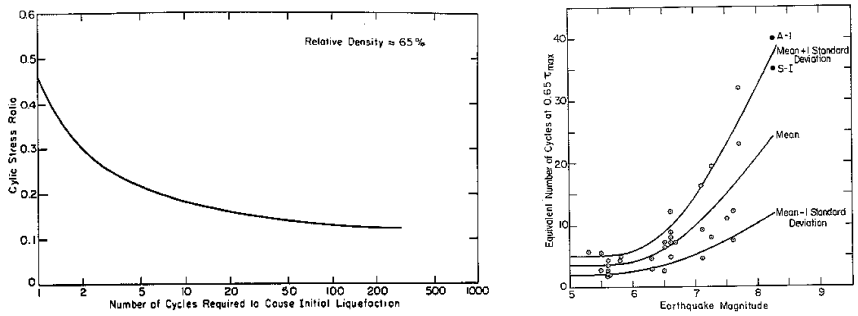


Figure 2.15. a) Representative curve for the relationship between cyclic stress ratio and number of cycles to liquefaction (Seed et al., 1975), b) Equivalent numbers of uniform stress cycles based on strongest components of ground motion (Seed et al., 1975)

Establishing the basis of "CSR-N-M" correlations, Equation 2.6 is used to convert some specific number of cycles to a reference level of M_w=7.5. Subsequently, as firstly offered by Seed et al. (1983) which is later adopted by Seed et al. (1984) liquefaction triggering relationships the duration (magnitude) correction, K_{Mw} to be applied on CSR (or CRR) can be expressed as given by Equation 2.7 and its application on CSR (or CRR) is given in Equation 2.8 to be used in the application of liquefaction triggering relationships.

$$K_{M_w} = \left(\frac{CSR_M}{CSR_{M=7.5}}\right) = \left(\frac{N_{M=7.5}}{N_M}\right)^m \tag{2.16}$$

$$K_{M_w} = \frac{CSR_{M_w} \cdot FS_{liq}}{CRR_{M_w=7.5}} \tag{2.17}$$

As will be discussed in detail later, there exists a significant amount of research on the duration (magnitude) corrections and a large variability among the correction terms in the literature, especially in the low magnitude region. Many researchers focused on CRR and the number of cycle relationships based on cyclic laboratory test results or based on case history field performance data or both in deriving magnitude correction factors. The exponent m (weighting factor) depends on several parameters including D_R, fabric, age, stress history, site-source distance and test device, soil type, and soil property. The following section is a summary of the efforts in the literature.

De Alba et al. (1976) performed large-scale simple shear tests on Monterey Sand samples at 54-90 % relative density. The results of the test indicate that the CRR increases with increasing D_R. Similar laboratory tests were performed on reconstituted or undisturbed sand samples by Yoshimi et al. (1984), Pillia and Stewart (1994), Okamura et al. (2003), Toki et al. (1986), Silver et al. (1976), Boulanger and Seed (1995), Tasuoka et al. (1986). Additional cyclic laboratory tests were performed on silty soils having low plastic fines (e.g. Carraro et al., 2003, Rees, 2010, Towhata et al., 2013, Dahl et al., 2014) and clayey sands with low-plasticity fines (e.g. Kokusho et al., 2012, Park and Kim, 2013, Park and Kim, 2013, Dahl, 2011, etc). Boulanger and Idriss (2007) assessed the cyclic softening behavior of

clays and silt with sufficient plasticity. The results of these tests exhibited similar behavior. The weighting exponent "m" ranges from 0.08-0.54 at different relative density levels for various fines content levels. Various factors (e.g. D_R, fabric, age, stress history, site-source distance and test device, soil type, and soil property) affecting the slope of N-CSR relationships were examined by the above-mentioned studies based on cyclic laboratory tests.

Magnitude (duration) correction factors, K_{Mw} were also studied based on CRR-N relationships determined by cyclic laboratory test results (e.g. Seed and Idriss, 1982, Idriss, 1990, 1999, etc.).

As mentioned above another approach to studying K_{Mw} corrections is examining case history field performance data (e.g. Andrus and Stokoe, 1997, Youd and Noble, 1997, Youd et al., 2001, Cetin et al., 2004, 2018a, Moss et al., 2006, Kayen et al., 2013, etc.). For example, Cetin et al. (2004, 2018a,b) compiled an extensive database of liquefaction field case histories and assessed the data probabilistically to propose a new methodology for SPT-based liquefaction triggering. In their study, K_{Mw} was regressed as a model parameter as a function of M_w, and the proposed correction is empirically derived based on field case history data.

Liu et al. (2001) combined cyclic laboratory testing and case-history liquefaction performance approaches and revealed that N values depend on not only moment magnitude but also fault rupture distance parameters. Previously, Ambraseys (1988) reviewed the work of Seed and Idriss (1982) and Seed et al. (1984) and stated that some consideration of the distance of the site from the seismic source should be included in linking moment magnitude with the number of cycles and he used the field liquefaction data and performed the statistical analysis and provided a series of magnitude duration factor.

Another approach was followed by Arango (1996) whose K_{Mw} relationship was based on the energy concept. Considering the duration factors are similar to any fatigue problem, Green and Terri (2005) and Lee (2009) proposed another approach and implemented the Palmgren-Miner cumulative damage hypothesis, and examined

energy dissipated in the soil when subjected to earthquake. A series of nonlinear site-response analyses were performed and the parametric study showed that N values depend on M_w, site to source distance, and depth in a soil profile. Recently, Lasley et al. (2017) followed the same approach as Green and Terri (2005) and Lee (2009) by implementing different ground-motion databases and soil profiles. Their correlation depends on a_{max}, M_w, and R and the result of the study indicates a negative correlation between a_{max} and N which implies that motions with high amplitudes have short durations. Green et al. (2019) worked on a similar approach and the results of their parametric study revealed that N values depend on earthquake magnitude, site-to-source distance, and depth in a soil profile.

K_{Mw} relationships in the literature are developed mostly for clean sands and do not consider soil properties but only the moment magnitude of the event. Cetin and Bilge (2012) introduced K_{Mw} corrections assessing excess pore water pressure and shear strain accumulation. It is concluded that K_{Mw} is not only a function of the number of equivalent loading cycles but the correction term increase with increasing excess pore water pressure ratio (r_u) or maximum shear strain (γ_{max}) thresholds and decreasing dilational response (i.e., decreasing relative density and/or increasing effective stress states) of soil layers. The study was a benchmark in adding the soil properties effect in duration correction.

Kishida and Tsai (2014) presented K_{Mw} relationships as a function of PGA, the ratio of spectral acceleration (S_1), M_w, period of soil layer (T_s), and weighting factor (b) based on deconvolution analysis performed with the earthquake data collected from PEER database.

Cetin et al. (2021) benefitted from the findings of both case history- and laboratory-based research that requires the conversion of earthquake-induced transient shear stresses to equivalent uniform (harmonic) stress cycles.

Figure 2.16 compares the most widely used K_{Mw} corrections in the literature and reveals that the range between the proposed factors is great, especially in the region of low magnitude events. There exist additional research studies on that topic that

are not discussed herein due to page limitations. (e.g. Biondi et al., 2004, Karamitros, 2010, Ziotopoulou and Boulanger, 2012, Jafarian et al., 2013, Park and Kim, 2013, Costa, 2013, Carter et al., 2016, Izawa and Ueda, 2016, Castiglia and Magistri, 2018, etc.).

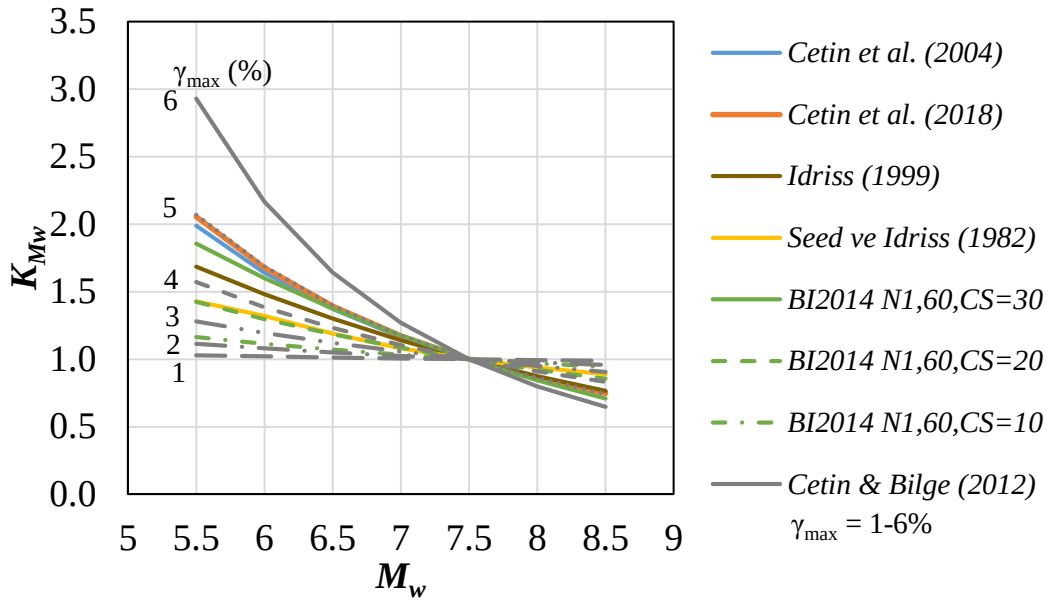


Figure 2.16. Comparison of magnitude (duration) scaling factors

2.3.2.3 Static Shear Stresses Correction, K_α

The effect of the presence of initial static shear stresses (τ_{st}) on liquefaction resistance is one of the least studied topics of liquefaction engineering. Seed (1983) proposed a correction for static shear stresses, K_α, to adjust CSR (or CRR) for level or almost level sites. A normalized static stress ratio term α was proposed as given by Equation 2.9.

$$\alpha = \frac{\tau_{st}}{\sigma'_v} \tag{2.18}$$

Based on laboratory cyclic test data, various research teams studied the effect of initial static shear stresses on cyclic resistance and pore pressure generation responses of saturated cohesionless soils. (e.g. Vaid and Finn, 1979, Vaid and Chern,

1983, Vaid et al., 1985, Seed and Harder, 1990, Boulanger et al., 1991, Youd et al., 2001, Harder and Boulanger, 1997, Vaid et al., 2001, Wu et al., 2003, Boulanger, 2003b, Sivathayalan and Ha, 2011, Cetin and Bilge, 2013, Park et al., 2020, etc.)

The available studies in the literature revealed that cyclic loading resistance depends on relative density, initial static shear stress, and cyclic shear strain level. There exists agreement on the need of applying K_α corrections in the literature. However, there is still no agreement on how initial static shear stresses influence the cyclic response of saturated cohesionless soils (Cetin and Bilge, 2013).

2.3.3 SPT-Based Seismic Soil Liquefaction Triggering Relationships

A case history is defined as a real soil site where the liquefaction performance was reported immediately after an earthquake by the reconnaissance teams. Not only the field performance but also in-situ field data is investigated along with parameters that are needed to assess CSR and $N_{1,60}$ terms. Seed et al. (1984; 1985) introduced 125 case history data mostly from USA and Japan sites. The liquefied sites where evidence of liquefaction was observed (e.g. ground cracks, sand boils or lateral deformations, etc) were drawn as solid points, on the other hand, open circles were drawn for non-liquefied sites where no observation related to the surface manifestation of liquefaction was observed and for marginally liquefied cases, it is decided to denote the sites with semi dots. This database is then used to propose cyclic resistance boundaries also knowns as liquefaction triggering boundaries for different FC levels. The first case history database and liquefaction boundary were developed deterministically by Seed et al. (1984), and the work established the basis of the liquefaction triggering analysis. The boundaries of Seed et al. (1985) were only offered graphically and a closed-form solution was not provided at that time. NCEER (1997) proposed a modified CRR curve of Seed et. al. (1985). The curve proposed by Seed et. al. (1985) goes through origin (CSR=0, $N_{1,60}$=0) however, NCEER (1997) recommended that the CRR curve should have an abscissa of 0.05. Thomas F. Blake (Fugro-West, Inc. Ventura, Calif.) has fitted a mathematical form

to this modified Seed et. al. (1985) curve, which is given in Equation 2.10 which was also graphically presented in Figure 2.15a.

$$CRR_{7.5} = \frac{a+cx+ex^2+gx^3}{1+bx+dx^2+fx^3+hx^4} \quad (2.19)$$

where x = $N_{1,60}$, (3(Robertson and Wride) <$N_{1,60}$<30), a=0.048, b =-0.1248, c=-0.004721, d = 0.009578, e = 0.0006136, f = -0.0003285, g = -1.673E-05, h = 3.714E-06

NCEER (2001) released another closed-form solution of the updated Seed et. al. (1985) curve as proposed by A.F. Rauch at the University of Texas. Equation 2.11 presents this mathematical expression. Both Equation 2.19 and Equation 2.20 are applicable for $(N_1)_{60}$<30.

$$CRR_{7.5} = \frac{1}{34-(N_1)_{60}} + \frac{(N_1)_{60}}{135} + \frac{50}{(10(N_1)_{60}+45)^2} - \frac{1}{200} \quad (2.20)$$

Following the work of Seed et al. (1985), various other research groups developed deterministic and probabilistic boundaries (Liao et al., 1988, Youd and Noble, 1997, Toprak et al., 1999, Juang et al., 2002, etc.). Particular attention will be given to the Cetin et al. (2004, 2018) and Idriss and Boulanger (2010) studies.

Probabilistic analyses were performed by Cetin (2000) and later published by Cetin et. al. (2004). The liquefaction case history database of Cetin (2000) studied the 125 case histories from Seed et al. (1985) and 90 case histories passed the screening criteria of Cetin (2000) and the case histories were re-assessed probabilistically along with updated SPT correction schemes and site-specific estimated CSR. Cetin (2000) and Cetin et al. (2004) added 111 new case histories and published 201 case histories among which 158 are liquefied, 41 non-liquefied, and 2 marginal sites. This study analyzed the mean and standard deviation of each parameter that was assessed in the analysis. The bayesian-based statistical framework was used to develop the liquefaction triggering boundary curves probabilistically. Cetin et. al. (2004) proposed the probability of liquefaction and probabilistically based empirical

correlations of CRR as given in Equation 2.12 and Equation 2.13. The boundary curves of Cetin et. al. (2004) were also presented before in Figure 2.15b.

$$P_L\left(N_{1,60}, CSR_{eq}, M_w, \sigma'_v, FC\right) = \phi\left(-\frac{\begin{pmatrix} N_{1,60}\cdot(1+0.004\cdot FC)-13.32\cdot\ln\left(CSR_{eq}\right)-29.53. \\ \ln(M_w)-3.70\cdot\ln\left(\frac{\sigma'_v}{P_a}\right)+0.05\cdot FC+16.85 \end{pmatrix}}{2.70}\right) \quad (2.21)$$

$$CRR\left(N_{1,60}, CSR_{eq}, M_w, \sigma'_v, FC, P_L\right) = \exp\left(\frac{\begin{pmatrix} N_{1,60}(1+0.004FC)-29.53\ln(M_w)-3.70 \\ \ln\left(\frac{\sigma'_v}{P_a}\right)+0.05FC+16.85 \end{pmatrix}+2.70\phi^{-1}(P_L)}{13.32}\right) \quad (2.22)$$

where $N_{1,60}$ is normalized SPT-N values for σ'_v=1 atm and SPT hammer energy efficiency of 60%, FC is fines content, CSR is cyclic stress ratio, M_w is moment magnitude, σ'_v is effective stress, P_a=1 atm, P_L is the probability of liquefaction in decimals (i.e., P_L=40% is represented as 0.40), Φ=Standard cumulative normal distribution, $\Phi^{-1}(P_L)$ = Inverse of the standard cumulative normal distribution (i.e., mean=0, and standard deviation=1).

Idriss and Boulanger (2010) database consists of 230 case histories, 115 of which are liquefied, 112 non-liquefied, and 3 marginal case history sites. Boulanger and Idriss (2014) database excluded 2 case histories (1979 Imperial Valley earthquake, Wildlife B site and 1987 Superstition Hills earthquake, McKim Ranch A), and additional 24 cases from the 1999 Kocaeli and 1999 Chi-Chi earthquakes were added. The updated database (264 case histories) was not used to develop an updated model but to test the performance of Idriss and Boulanger (2010) triggering relationship which was developed based on 230 case histories. The liquefaction triggering model by Idriss and Boulanger (2010) and Boulanger and Idriss (2014) is given in Equation 2.14 and Equation 2.15, and the boundary curves are shown in Figure 2.15c.

$$P_L\left((N_1)_{60CS}, CSR_{M=7.5,\sigma'_v=1\ atm}\right) = \frac{(N_1)_{60cs}}{14.1} + \left(\frac{(N_1)_{60cs}}{126}\right)^2 - \left(\frac{(N_1)_{60cs}}{23.6}\right)^3 + \left(\frac{(N_1)_{60cs}}{25.4}\right)^4 \quad (2.23)$$

$$\mathrm{CRR}_{\mathrm{M=7.5},\sigma'_{\mathrm{v}}=1\ \mathrm{atm}} = \exp\left\{\begin{matrix}\frac{(\mathrm{N}_1)_{60\mathrm{cs}}}{14.1} + \left(\frac{(\mathrm{N}_1)_{60\mathrm{cs}}}{126}\right)^2 - \left(\frac{(\mathrm{N}_1)_{60\mathrm{cs}}}{23.6}\right)^3 + \left(\frac{(\mathrm{N}_1)_{60\mathrm{cs}}}{25.4}\right)^4 \\ -2.67 + \sigma_{\ln(\mathrm{R})} \cdot \phi^{-1}(\mathrm{P_L})\end{matrix}\right\} \quad (2.24)$$

Ilgac (2015) updated the Cetin et al. (2004) database by excluding 2 case histories (1975 Haicheng Ms=7.3 Shung Tai Zi R and 1994 Northridge M_w=6.7 Malden Street Unit D) and included 13 new cases from 1983 Nihonkai-Chubu M=7.7 and Loma Prieta 1989 Mw=6.93 Earthquakes. The total number of cases reached a value of 211. Cetin et al. (2018a) published an updated relationship with this dataset excluding 1 data point so the resultant number was 210 case histories:113 liquefied, 95 non-liquefied, and 2 marginal data. A similar Bayesian-based statistical framework was used to develop the liquefaction triggering boundary curves probabilistically the resultant empirical correlations of CRR is given in Equation 2.16 and Equation 2.17. The boundary curves of Cetin et. al. (2018) are shown in Figure 2.15d.

$$\mathrm{P_L}\left(\mathrm{N}_{1,60}, \mathrm{CSR_{eq}}, \mathrm{M_w}, \sigma'_{\mathrm{v}}, \mathrm{FC}\right) = \phi\left(-\frac{\begin{pmatrix}\mathrm{N}_{1,60}\cdot(1+0.00167\cdot\mathrm{FC}) - 11.771\cdot\ln\left(\mathrm{CSR_{eq}}\right) - 27.352 \\ \ln(\mathrm{M_w}) - 3.958\cdot\ln\left(\frac{\sigma'_{\mathrm{v}}}{\mathrm{P_a}}\right) + 0.089\cdot\mathrm{FC} + 16.084\end{pmatrix}}{2.95}\right) \quad (2.25)$$

$$\mathrm{CRR}\left(\mathrm{N}_{1,60}, \mathrm{CSR_{eq}}, \mathrm{M_w}, \sigma'_{\mathrm{v}}, \mathrm{FC}, \mathrm{P_L}\right) = \exp\left(\frac{\begin{pmatrix}\mathrm{N}_{1,60}(1+0.00167\mathrm{FC}) - 27.352\ln(\mathrm{M_w}) - 3.958 \\ \ln\left(\frac{\sigma'_{\mathrm{v}}}{\mathrm{P_a}}\right) + 0.089\mathrm{FC} + 16.084\end{pmatrix} + 2.95\phi^{-1}(\mathrm{P_L})}{11.771}\right) \quad (2.26)$$

Figure 2.17 a-d shows the seismic soil liquefaction database and seismic soil liquefaction triggering boundaries of Seed et al. (1985), Cetin et al. (2004, 2018a), and Boulanger and Idriss (2012).

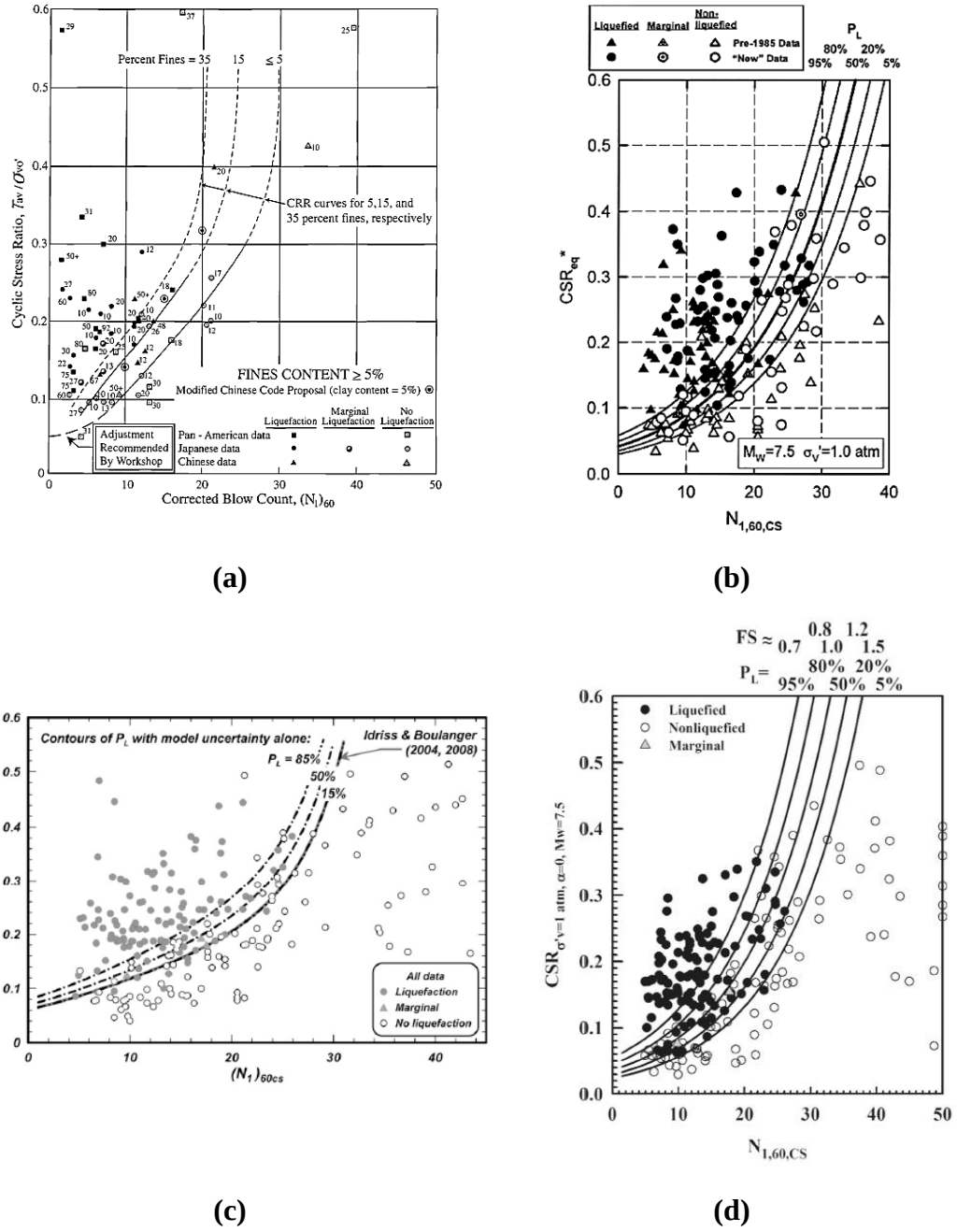


Figure 2.17. Liquefaction triggering database and boundaries of a) Seed et al. (1985), b) Cetin et al. (2004), c) Boulanger and Idriss (2012), and d) Cetin et al. (2018a).

Figure 2.18 presents a comparison graphically among the most widely used seismic soil liquefaction relationships of Seed et al. (1985), Cetin et al. (2004, 2018a), and Idriss and Boulanger (2010) for the probability of liquefaction of 15 % and 50%. As

revealed by Figure 2.18, in the low $N_{1,60}$ region ($N_{1,60}$<20) there is significant controversy among different researchers which triggered the recent studies and raised the need to update the liquefaction case history database and relationships based on the current knowledge that is achieved today.

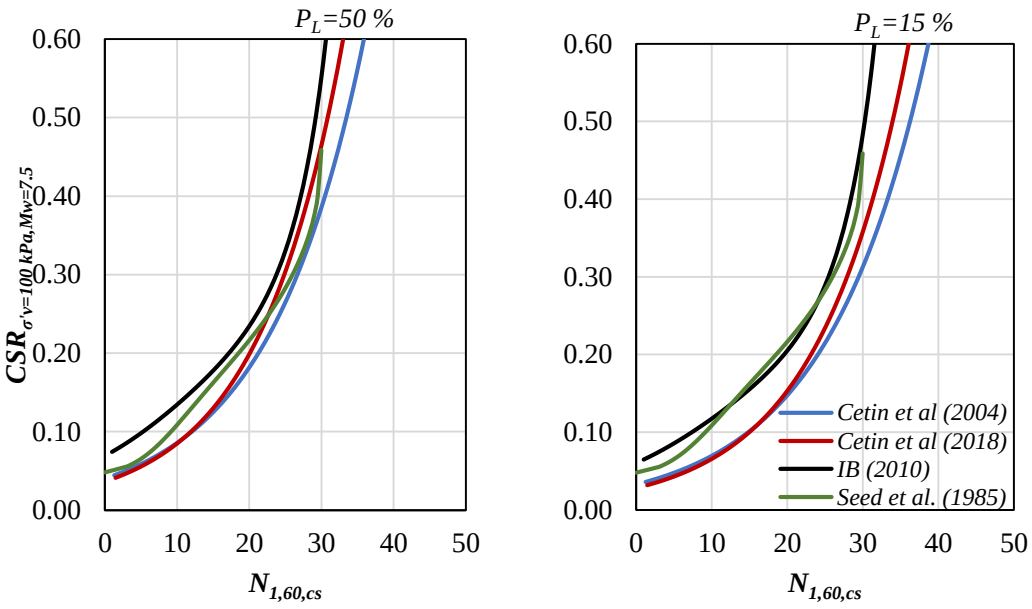


Figure 2.18. Curves of $CRR_{M=7.5,\sigma'v=1\ atm}$ versus $N_{1,60,CS}$ for probabilities of liquefaction of 15 and 50 proposed by Seed et al. (1985), Cetin et al. (2004, 2018a) and Idriss and Boulanger (2010).

CHAPTER 3

DATABASE PROTOCOL & SELECTION OF INPUT PARAMETERS

3.1 Introduction

Ongoing discussions in the literature regarding the effects of database size and quality on the position of the liquefaction triggering boundary curves have initiated the need to update the case history databases. The previous databases (Seed et al., 1985, Cetin, 2000, Cetin et al., 2004, 2018a,c, Idriss and Boulanger 2010, 2012, Boulanger and Idriss, 2014, etc.) do not include the case history data documented in the last two decades, more specifically from relatively low and high magnitude events and PGA levels, gravelly and silty liquefiable layers, different event mechanisms. They also do not reflect the developments regarding overburden, energy, and rod length corrections (e.g. C_R, C_E, C_N, etc.) the effects of geological conditions, and the advances in the correction terms applied to CSR (e.g. K_σ, K_{Mw}, etc.).

Inspired by the previous seismic soil liquefaction triggering databases, the purpose of the current study is to enhance these database efforts with an updated perspective by considering the recent advancements in the field of liquefaction engineering. The development of the updated seismic soil liquefaction triggering boundary requires a good quality case history database that is assessed with the current state of knowledge. Accordingly, a database protocol is established to achieve a high-standard data processing scheme and process the case histories in a relatively unbiased manner. This chapter presents the discussion of the implemented probabilistic case history processing methodology, which is a standardized protocol consisting of screening criteria set to achieve a high-quality dataset.

3.2 Case History Database Protocol and Selection of Input Parameters

The updated database consists of 334 case history sites, which are represented by 80 input parameters (e.g. a_{max}, d_{crt}., etc.). Each parameter involved in the analysis for the probabilistic assessments of liquefaction triggering is represented by the mean and standard deviation, and if applicable, the correlation of coefficient values. This section summarizes how these input parameters were estimated along with the discussion of key decision-making protocols to compile a high-quality database.

3.2.1 Selection of Case History Data

The first step involved in populating with new case history data is to locate a site with documented field performance immediately after the earthquake event along with well-documented SPT procedures (e.g. hammer type, etc.) and soil stratigraphy including soil classification. The next step involves determining the ground motion characteristics (e.g. M_w, event type, epicenter, fault solution, etc.) with the help of local strong ground motion station data. The case history data meeting these three criteria are the first candidates to be included in the database. Each case history is studied in detail, and every input parameter, which will be discussed next is investigated. However, case history data not meeting the initial requirements are excluded from further consideration. These are set as the first screening criteria.

3.2.2 General Information Related to Case History Data

General information regarding earthquake events and case histories are compiled and summarized in a cover page for each case history presented in Appendix B. An example case history (1999 Chi-chi Earthquake, Wufeng Site C) cover page is shown in Figure 3.1. On this cover page, case history number and name, references used in the development of the case history data, nature of failure, GPS latitude, and longitude of the site, potentially liquefiable layer properties, geological unit, details

regarding site response analysis, general comments about the site, available nearby tests (CPT and V_s), event parameters (e.g. fault type, dip angle, R_{rup}, etc.), a summary of input data (e.g. data class, $d_{crtc.}$ range, GWT, etc.), comparison of those parameters with Seed et. al. (1984), Cetin et al. (2004), Idriss and Boulanger (2010), Cetin et al. (2018a, b), and acceleration time history data if available are presented.

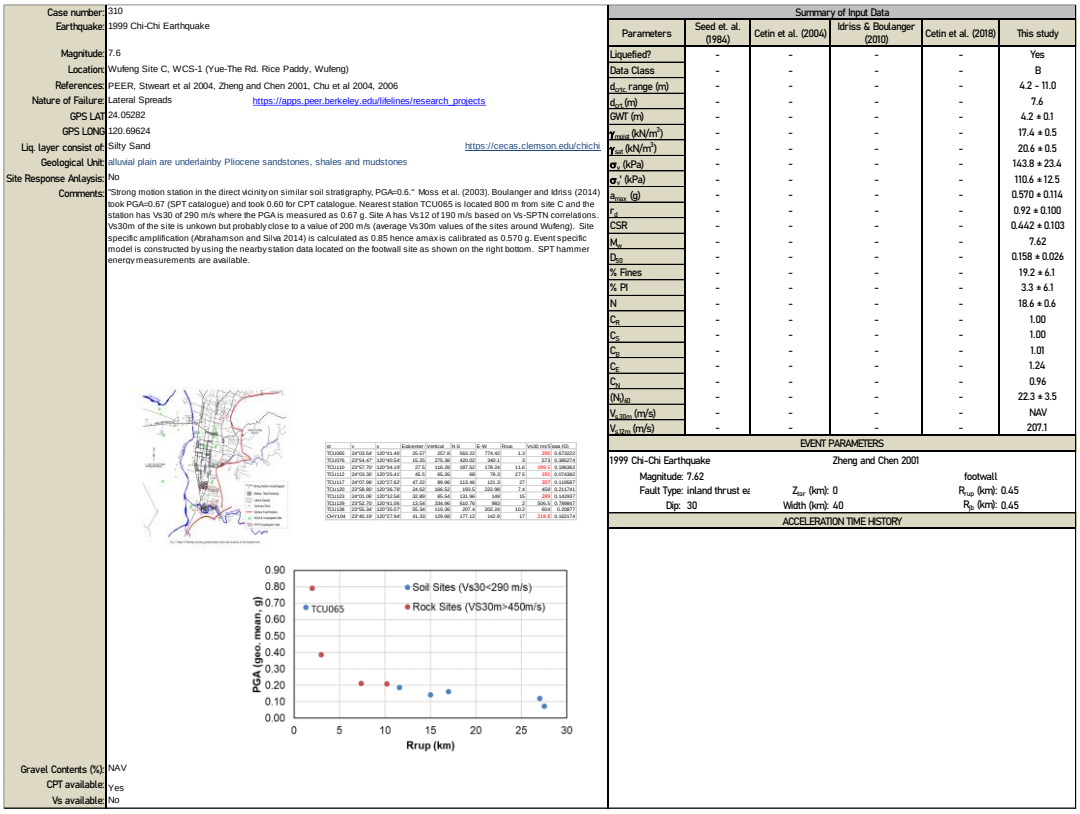


Figure 3.1. An illustrative example of the cover page for Wufeng Site C, WCS-1 (Yue-The Rd. Rice Paddy, Wufeng)

3.2.3 Field Performance

The field performance is adapted from the source documents or based on satellite images based on the presence or lack of surface manifestations. The case histories are classified as liquefied (surface manifestation is observed in the form of the sand boil, ground cracks, settlement, or lateral spread), non-liquefied (no surface manifestation is observed), marginal (located in the boundary of the liquefied and

non-liquefied zone), Yes/No (liquefied based on the interpretation of ground motion data or piezometers accompanied with no surface manifestation due to various reasons (e.g. presence of a crust layer, a deep layer is liquefied which did not create any manifestations, etc.). Also, the "No/Yes" classification was reserved for the case which falls within the boundary of liquefied and non-liquefied zones in the field. Flags are used to separate different field performance data in the form of (x/y). Here "x" denotes the occurrence of liquefaction based on ground motions at the site and "y" denotes liquefaction induced by the surface manifestation. "NAP", "NAV", "1", and "0" indicate not applicable, not available, yes, and no, respectively. For example interpretation of ground motion data suggests liquefaction triggering but no surface manifestation was observed at the site then the flag (1/0) is used, or "no ground motion recording available at the site but liquefaction triggered surface manifestations " then (NAP/1) flag is used.

3.2.4 GNSS (GPS) Coordinates

The previous SPT catalogs did not present latitude and longitude coordinates. The World Geodetic System 1984 (WGS84) coordinates of the legacy case history are approximately compiled based on available maps provided by the source documents, and subsequent field testing at many of the sites by Kayen et al. (2013). When maps were used, the map images are transferred onto Google Earth and the coordinates are determined. The coordinates of the new case history data are collected directly from the source documents. If they are not available then the same procedure adapted for the legacy data is followed. Any older coordinates are converted to the WGS84 coordinate system. These coordinates are then used to determine the geological conditions of the site and rupture distances to a seismic source. Any case history data with an unknown location is excluded. The location of the case history data, the epicenter of the earthquake events, strong ground motion stations, and the faults are integrated into Google Earth and a digital dataset is formed as illustrated in Figure 3.2 for the 2012 Emilia Romagna event.

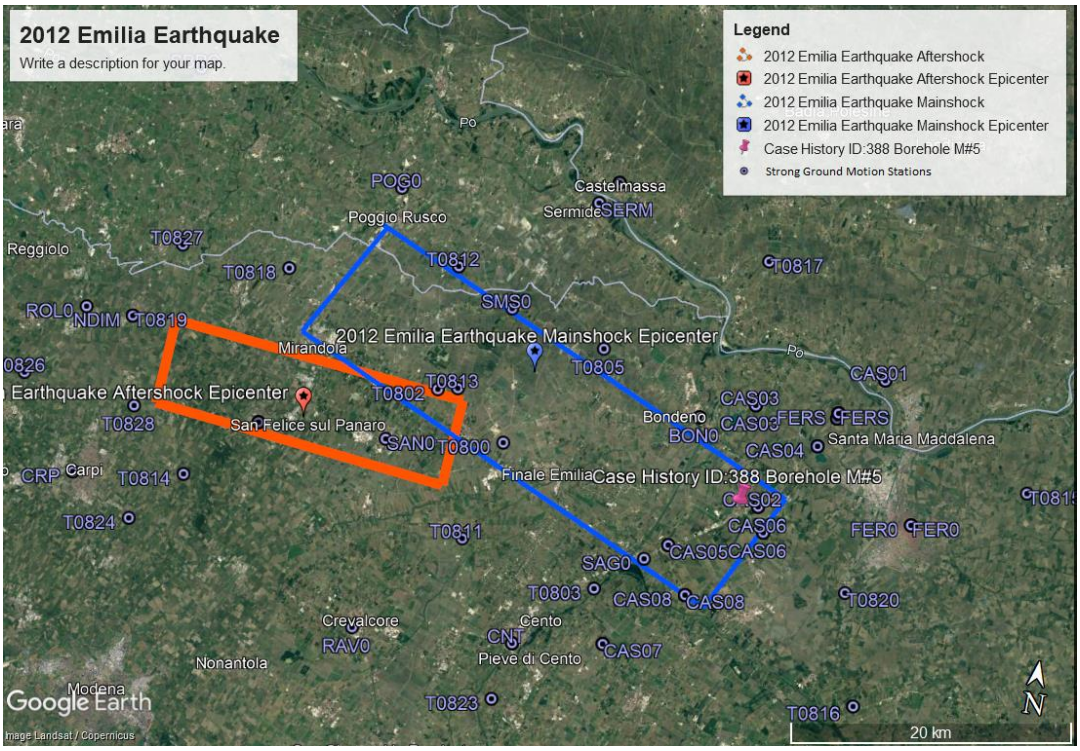


Figure 3.2. The map of the new database on Google Earth.

3.2.5 Geological Unit

The details of the Quarternary geology for each case history data were determined from soil boring logs, geologic maps, and other site descriptors, and this information is a new descriptive parameter of the updated database. The first geologic division is to separate the sites that are located on artificial fill from natural deposits. The second division is related to the age of the natural deposit which is collected based on regional geology maps (e.g. Quaternary, etc.). The case history database is later assessed considering the geological conditions of the sites to observe the different behavior of artificial fills and natural deposits on liquefaction triggering.

3.2.6 Event Parameters

Parameters related to the earthquake event are determined which is a new feature of the database. As there exist various fault plane solutions for each earthquake event, the most representative one is selected as the reference solution and the fault plane is integrated into Google Earth. An example is shown in Figure 3.3 for the 1999 Chi-chi earthquake.

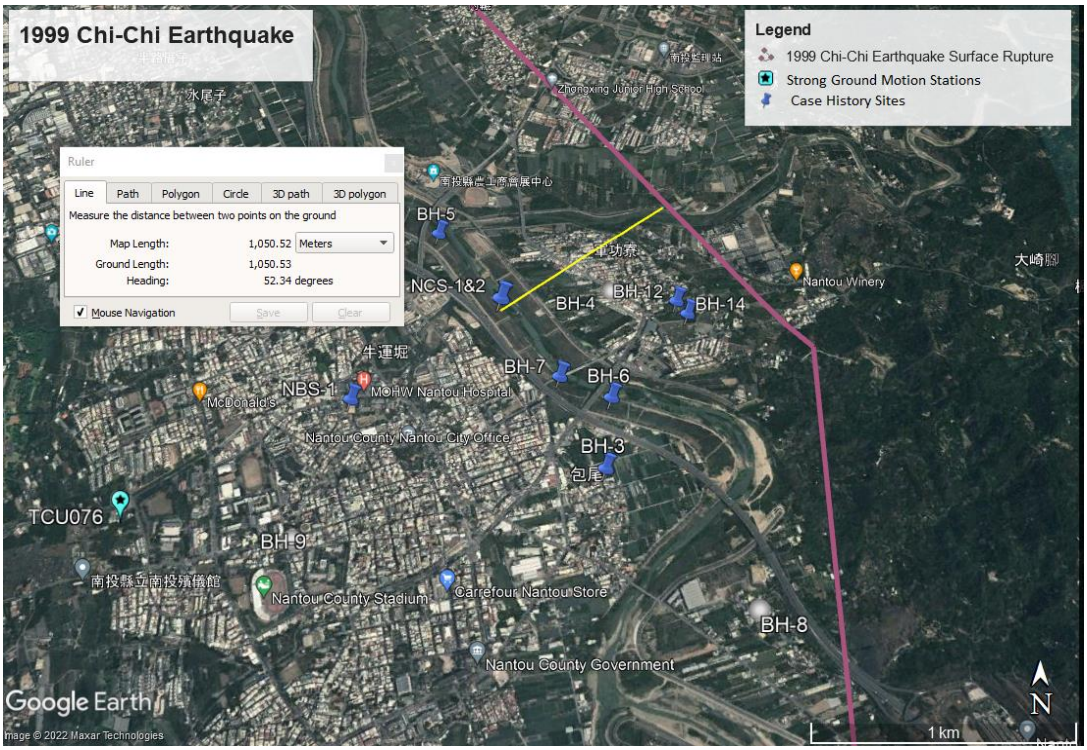


Figure 3.3. Fault plane of 1999 Chi-Chi Earthquake and the case history data on Google Earth and an example calculation of R_{jb}.

For all the events included in the database, event parameters are estimated. These parameters are estimated based on the definitions given in the NGA project. They can be listed as follows along with their definitions:

- M_w: moment magnitude of the event
- R_{rup}: closest distance to coseismic rupture
- R_{jb}: closest distance to surface projection of coseismic rupture

- The fault type
- Dip: average dip of the rupture plane
- Z_{tor}: depth to coseismic rupture
- W: fault rupture width

A summary table is prepared for each case history data and presented on the cover page, as given in Table 3.1 for the event parameters.

Table 3.1. An illustrative example of the summary of the event parameters listed in each case history data

Event Parameters					
1999 Chi-Chi Earthquake		Reference: Wang and Chen 2001			
M_w:	7.60	Located on the footwall site			
Fault Type:	inland thrust earthquake	Z_{tor} (km):	0	R_{rup} (km):	10.6
Dip (°):	30	W (km):	40	R_{jb} (km):	10.6

3.2.7 Critical Layer Selection and Associated Uncertainty

Critical depth is selected by identifying the potentially liquefiable soil layer (e.g. fully saturated low plastic most vulnerable layer). When there exist fine but low plasticity materials, liquefaction susceptibility chart solutions are used to determine the potentially liquefiable layers. If atterberg limits are not available, and if nearby CPT data are available, friction ratio is used to assess potentially liquefiable layers. Although it can be said that each layer is evaluated independently, the response and effects of other layers within the soil profile are also investigated. For example, the presence of a more dilative layer reduces pore water pressure build-up. The selection is made considering the entire soil profile. The engineering judgment in selecting the liquefiable layer plays a significant role.

After having determined the potentially liquefiable layer, the upper and lower bound of its depth is determined by digitizing the selected soil layer depth. The updated database presents fully digitized borehole information, which is a new addition. The

standard deviation of the critical depth is calculated by dividing the thickness of the liquefied layer by 6 so that the layer boundaries stay within the median $\mp$ 3σ bounds as suggested by Cetin (2000).

3.2.8 Ground Water Table and Associated Uncertainty

The groundwater level is determined by using one of the following approaches:

- directly from the related borehole data if available,
- seasonal information available at the time of the earthquake event,
- collocated CPT data pore pressure measurements,
- V_s/V_p ratios shift,
- if more than one tool is available, a median value is adapted along with an overall assessment

For some of the sites, it was observed that the critical layers are only partially saturated despite being located below the groundwater table. The presence of gas produced by the decomposition of organics prevented full saturation, which is evidenced by high V_s/V_p ratios. If critical layers appear to be only partially saturated, the sites are excluded.

Consistent with Ilgac (2015), the standard deviation of groundwater level (σ_{GWT}) is calculated as the average of all available GWT information. If there is only one GWT measurement available, then the standard deviation is assigned as follows

- If there are multiple borings available showing a consistent depth to ground water: σ_{GWT}=0.10 ft (gravel), σ_{GWT}=0.15 ft (sand), σ_{GWT} =0.20 ft (silt), σ_{GWT}=0.25 ft (clay).
- If there is a single borehole with GWT measurement: σ_{GWT}=0.25 ft (gravel), σ_{GWT}=0.30 ft (sand), σ_{GWT} =0.35 ft (silt), σ_{GWT}=0.40 ft (clay)

- If there are multiple borings available showing different GWT measurements, the mean value and standard deviation are calculated directly by using available data.
- If GWT is at the ground surface, σ_{GWT}=0.30 ft

3.2.9 Unit Weight and Associated Uncertainty

A database from the field case histories where the laboratory test is available consisting of N_{60} and unit weight values for different types of materials are compiled. Based on this dataset, a new unit weight schema as a function of N_{60} values, and the soil type is constructed inspired by Ilgac (2015) and Cetin et al. (2016). Table 3.2 presents the updated unit weight schema. For each case history, unit weight values above and below GWT are selected consistently as shown in Table 3.2 unless case-specific information is stated otherwise. The standard deviation of the unit weight $\sigma_{\gamma_{wet}}$ and $\sigma_{\gamma_{sat}}$ values are assigned as 0.471 kN/m^3 if unit weight is assigned from Table 3.2. If laboratory tests are available the median and standard deviation of the unit weight values are calculated specifically to the case history.

Table 3.2. Unit weights

SPT-N_{60} *(blows / ft)*	*γ_{wet}* *(kN/m^3)*	*γ_{sat}* *(kN/m^3)*
For coarse-grained soil layers		
0 – 4	15.7	17.3
5 – 10	17.3	18.9
11 – 30	18.9	20.5
31 – 50	19.9	21.5
For fine-grained soil layers		
0 – 4	15.7	17.3
5 – 8	17.4	19.0
9 – 16	18.1	19.6

3.2.10 Total and Effective Overburden Stress and Associated Uncertainty

As developed by Cetin et al. (2004), the median total and effective overburden stresses, associated uncertainties, and coefficient of correlations are calculated by Equation 3.1-3.6, implementing the first-order approximations of the mean and variance.

$$\sigma_v = d_{GWT} \cdot \gamma_{wet} + (d_{crt} - d_{GWT}) \cdot \gamma_{sat} \tag{3.1}$$

$$\sigma_{\sigma_v} = \sqrt{\begin{matrix}\left(d_{GWT} \cdot \sigma_{\gamma_{wet}}\right)^2 + \left((d_{crt} - d_{GWT}) \cdot \sigma_{\gamma_{sat}}\right)^2 \\ +\left(\gamma_{sat} \cdot \sigma_{d_{crt}}\right)^2 + \left((\gamma_{wet} - \gamma_{sat}) \cdot \sigma_{GWT}\right)^2\end{matrix}} \tag{3.2}$$

$$\sigma'_v = d_{GWT} \cdot \gamma_{wet} + (d_{crt} - d_{GWT}) \cdot (\gamma_{sat} - \gamma_w) \tag{3.3}$$

$$\sigma_{\sigma'_v} = \sqrt{\begin{matrix}\left(d_{GWT} \cdot \sigma_{\gamma_{wet}}\right)^2 + \left((d_{crt} - d_{GWT}) \cdot \sigma_{\gamma_{sat}}\right)^2 \\ +\left((\gamma_{sat} - \gamma_w) \cdot \sigma_{d_{crt}}\right)^2 + \left((\gamma_{wet} - \gamma_{sat} + \gamma_w) \cdot \sigma_{GWT}\right)^2\end{matrix}} \tag{3.4}$$

$$\rho_{\sigma_{vo}\sigma'_{vo}} \cong \frac{\mathrm{cov}(\sigma_{vo}, \sigma'_{vo})}{\sigma^2_{\sigma_v} \cdot \sigma^2_{\sigma'_v}} \tag{3.5}$$

$$\mathrm{cov}(\sigma_{vo}, \sigma'_{vo}) \cong \left(d^2_{GWT} \cdot \sigma^2_{\gamma_{wet}}\right) + (\gamma_{wet} - \gamma_{sat}) \cdot (\gamma_{wet} + \gamma_w - \gamma_{sat}) \cdot \sigma^2_{GWT} + (d_{crt} - d_{GWT})^2 \cdot \sigma_{\gamma^2_{sat}} + \gamma_{sat} \cdot (\gamma_{sat} - \gamma_w) \cdot \sigma^2_{d_{crt}} \tag{3.6}$$

where $\sigma_v, \sigma_{\sigma_v}$: median and standard deviation of total overburden stress, d_{GWT}: median and standard deviation of groundwater table, $\gamma_{wet}, \sigma_{\gamma_{wet}}$: mean and standard deviation of unit weight above GWT, $\gamma_{sat}, \sigma_{\gamma_{sat}}$: mean and standard deviation of unit weight below GWT, $d_{crt}, \sigma_{d_{crt}}$: mean and standard deviation of critical layer depth, $\sigma'_v, \sigma_{\sigma'_v}$: mean and standard deviation of effective overburden stress, $\rho_{\sigma_{vo}\sigma'_{vo}}$: correlation coefficient between total and effective overburden stress, $\mathrm{cov}(\sigma_{vo}, \sigma'_{vo})$: covariance between total and effective overburden stress.

3.2.11 Mass participation Ratio and Associated Uncertainty

The mass participation ratio is calculated with the correlation proposed by Cetin and Seed (2004) which is presented in Equation 3.7. The attributed standard deviation is also calculated by the same research study as shown by Equation 3.8. If site response analysis is performed the standard deviation is taken as 50% of the values given by Equation 3.8.

d<20 m (3.7)

$$r_d = \frac{\left[1+\frac{-23.013-2.949\cdot a_{max}+0.999\cdot M_w+0.0525\cdot V^*_{s,12\ m}}{16.258+0.201\cdot e^{0.341\cdot(-d+0.0785\cdot V^*_{s,12\ m}+7.586)}}\right]}{\left[1+\frac{-23.013-2.949\cdot a_{max}+0.999\cdot M_w+0.0525\cdot V^*_{s,12\ m}}{16.258+0.201\cdot e^{0.341\cdot(0.0785\cdot V^*_{s,12\ m}+7.586)}}\right]} \mp \sigma_{\varepsilon_{r_d}}$$

d≥20 m

$$r_d = \frac{\left[1+\frac{-23.013-2.949\cdot a_{max}+0.999\cdot M_w+0.0525\cdot V^*_{s,12\ m}}{16.258+0.201\cdot e^{0.341\cdot(-d+0.0785\cdot V^*_{s,12\ m}+7.586)}}\right]}{\left[1+\frac{-23.013-2.949\cdot a_{max}+0.999\cdot M_w+0.0525\cdot V^*_{s,12\ m}}{16.258+0.201\cdot e^{0.341\cdot(0.0785\cdot V^*_{s,12\ m}+7.586)}}\right]} - 0.0046(d-20) \mp \sigma_{\varepsilon_{r_d}}$$

$$d < 12\ m\ (\sim 40\ ft) \rightarrow \sigma_{\varepsilon_{r_d}}(d) = d^{0.8500}\cdot 0.0198 \quad (3.8)$$

$$d \geq 12\ m\ (\sim 40\ ft) \rightarrow \sigma_{\varepsilon_{r_d}}(d) = 12^{0.8500}\cdot 0.0198$$

3.2.12 Maximum ground acceleration and Associated Uncertainty

Maximum ground acceleration (PGA, a_{max}) is obtained from recording stations if available, and/or by performing site response analysis along with locally calibrated event or site-specific ground motion prediction models. a_{max} for a site is selected as the geometric mean of the two components of the available acceleration values, and the standard deviation, $\sigma_{\ln(a_{max})}$ is calculated as shown in Equation 3.9 by considering the coefficient of variation, $\mathrm{cov}(a_{max})$ which is assigned accordingly given as follows:

$$\sigma_{\ln(a_{max})} = a_{max}\cdot \mathrm{cov}(a_{max}) \quad (3.9)$$

- If a recording station exists at the site, then the coefficient of variation is taken as $\mathrm{cov} = 0.05$ (Free field), $\mathrm{cov} = 0.10$ (If there exists a low story structure)
- If site response is performed then the coefficient of variation is taken as $\mathrm{cov} = 0.15$
- If a site and event-specific GMPE is available or constructed then the coefficient of variation is taken as $\mathrm{cov} = 0.20$
- If globally available ground motion prediction equations are used then the coefficient of variation is taken as $\mathrm{cov} = 0.30$
- For the 1995 Kobe, 2010 Darfield, and 2011 Christchurch earthquakes coefficient of variation is taken as $\mathrm{cov} = 0.20$

3.2.13 Cyclic Stress Ratio and Associated Uncertainty

Cyclic stress ratio (CSR) is calculated either by the simplified procedure as proposed by Seed and Idriss (1971) as shown in Equation 3.10 or by site-specific 1-D equivalent linear site response analysis. Variance (coefficient of variation), δ^2_{CSR} is calculated by taking the first-order derivative and the correlation of coefficient is calculated as described in Cetin (2000). It is shown in Equation 3.11.

Because the total and effective stress are not independent variables, the second-order moment about the mean is calculated as $2\rho_{\sigma'_{\mathrm{vo}}\sigma_{\mathrm{vo}}}.\delta_{\sigma_{\mathrm{vo}}}.\delta_{\sigma'_{\mathrm{vo}}}$ and subtracted from the first order COV

$$\mathrm{CSR} = \left(\frac{\tau_{\mathrm{av}}}{\sigma'_{\mathrm{vo}}}\right) = 0.65\left(\frac{a_{\mathrm{max}}}{g}\right)\left(\frac{\sigma_{\mathrm{vo}}}{\sigma'_{\mathrm{vo}}}\right) r_{\mathrm{d}} \tag{3.10}$$

$$\delta^2_{\mathrm{CSR}} \cong \delta^2_{a_{\mathrm{max}}} + \delta^2_{r_{\mathrm{d}}} + \delta^2_{\sigma_{\mathrm{vo}}} + \delta^2_{\sigma'_{\mathrm{vo}}} - 2\rho_{\sigma'_{\mathrm{vo}}\sigma_{\mathrm{vo}}}.\delta_{\sigma_{\mathrm{vo}}}.\delta_{\sigma'_{\mathrm{vo}}} \tag{3.11}$$

It is important to note that compiling case histories from similar sites with similar ground motion characteristics is against statistically independent assumptions and may result in correlated input parameters; hence those cases are tried to be avoided in the case history processing.

Within the confines of this thesis, a series of site response analyses was performed to estimate the CSR, which is presented in detail in Chapter 5.

3.2.14 Moment Magnitude, M_w, & Associated Uncertainty

Among other magnitude alternatives (M_L, M_b, and M_s), moment magnitude M_w is widely accepted in the literature and hence used in the database. Necessary conversions were performed to convert different magnitudes scales to their moment magnitude (M_w) equivalent. Although there are some other local and international catalogs available, a more widely used catalog of the U.S. Geological Survey (USGS) earthquake catalog is utilized for the determination of M_w.

The moment magnitude of the earthquake was previously assumed to be deterministic and no uncertainty was assigned. The updated database incorporates the uncertainty of the moment magnitude by using Equation 3.12. This correlation is digitized from Moss and Der Kiureghian (2003) study from the linear fit of the standard deviation of moment magnitude versus moment magnitude reported in the NGA dataset.

$$\sigma_{M_w} = 0.38 - 0.37 \log(M_w) \tag{3.12}$$

3.2.15 Shear Wave Velocity, ($V_{s,30m}$ and $V_{s,12m}$)

Shear wave velocity-related parameters (averaged V_s for the upper 30m and 12 m, respectively, $V_{s,30m}$ and $V_{s,12m}$) are evaluated based on the available shear wave velocity profiles or by using the SPTN-V_s correlations as shown in Equations 3.13 and 3.14 (Japan Road Association Design Specifications for Highway Bridges; 2002.). If the V_s profiles are available $V_{s,30m}$ and $V_{s,12m}$ are estimated directly as given by Equations 3.15 and 3.16.

$$V_{s,12m} = 80 * N_{60}^{1/3} \quad m/s \quad \text{(for sand)} \tag{3.13}$$

$$V_{s,12m} = 100 * N_{60}^{1/3} \quad m/s \quad \text{(for clay)} \tag{3.14}$$

$$V_{s,12m} = \frac{12}{\Sigma\left(\frac{V_{s,i}}{t_i}\right)} \quad (3.15)$$

$$V_{s,30m} = \frac{30}{\Sigma\left(\frac{V_{s,i}}{t_i}\right)} \quad (3.16)$$

3.2.16 Liquefiable Soil Layer Type and Properties

The new dataset provides information regarding the type of soil for the liquefiable layer (e.g. silty sand with gravel content, SP, etc.) which will help to distinguish sand, silt, and gravel liquefaction case histories and observe the different responses and correction terms.

From available borelogs descriptions, or grain size distribution curves, fines content (FC), silt content (SC) and clay contents (CC), and gravel content (GC) values are documented for the critical soil layer. When United Soil Classification System, USCS soil class, or borelog descriptions are available but not grain size distributions, then they are used to assign a range for the grain size parameters (e.g. for a liquefiable layer classified as SP, FC is assigned as <5%, etc.). If more than one fines content, silt, clay, and gravel content data exist, mean and standard deviation values are calculated, statistically. However, if a single value exists, the standard deviation is assigned as σ_{FC}=8.6, σ_{SC}=8.3, σ_{CC}=2.3, σ_{GC}=5.9 % which are determined as the average of the standard deviation values of the available grain size distribution in the database.

D_{50} values are compiled for the critical soil layer from the grain size distribution curves. If more than one D_{50} data exist, mean value and standard deviation values are calculated. If a single value exists, the standard deviation is assigned as σ_{D50}=0.05 mm.

If available, the Plasticity Index (PI) and Liquid Limit (LL) values are documented for the critical soil layer. If more than one data exists, mean and standard deviation values are calculated. If the atterberg limits were not available, but USCS classification or visual descriptions were available, PI values are assigned by taking

into account the literature data that offers atterberg limits for the regions (e.g. for poorly graded sands (SP), PI is assigned as "0" as FC<5% or for the New Zealand sites, PI is taken as 0-7 and 0-4 for ML and SM layers, respectively, etc.).

3.2.17 Standard Penetration Test Blow Counts and Associated Uncertainty

Not only the critical layer but the entire borehole data along with the raw SPT-N values are fully digitized. If more than one SPT-N data exist within the critical layer, the mean value and standard deviation are calculated, and if a single value exists, the standard deviation of $N_{1,60}$ is assigned as $\sigma_{N1,60}$=2. If the standard deviation of the SPT-N value is given in the source document, the reported value is used. $N_{1,60}$ values are corrected for overburden stress (C_N), energy efficiency (C_E), borehole diameter (C_B), and sampler type (C_S) as shown in Equation 3.17.

$$N_{1,60} \cong N \cdot C_N \cdot C_E \cdot C_B \cdot C_S \tag{3.17}$$

The square of the coefficient of variation (c.o.v.) of $N_{1,60}$ can be expressed as the sum of the squared c.o.v. of the individual variables as shown in Equation 3.18.

$$\delta^2_{(N_1)_{60}} \cong \delta^2_N + \delta^2_{C_N} + \delta^2_{C_E} + \delta^2_{C_B} + \delta^2_{C_R} + \delta^2_{C_S} \tag{3.18}$$

Assuming the uncertainties involved in the correction terms are relatively small, it is accepted that the c.o.v. of $N_{1,60}$ is approximately equal to the c.o.v. of N ($\delta_{N_{1,60}} \cong \delta_N$).

3.2.17.1 Sampler Correction

Sampler correction is applied accordingly with the recommendation of NCEER (1997) as shown in Table 3.3.

Table 3.3. Recommended SPT sampler correction for use in liquefaction correlations (NCEER 1997)

Factor	*Term*	*Equipment Variable*	*Correction*
Sampling Method	C_S	Standard Sampler	1.0
		Sampler without liners	1.15-1.30

3.2.17.2 Borehole Diameter Correction

Borehole diameter correction is applied accordingly with the recommendation of NCEER (1997) as shown in Table 3.4.

Table 3.4. Recommended SPT borehole diameter correction for use in liquefaction correlations (NCEER 1997)

Factor	*Term*	*Equipment Variable*	*Correction*
Borehole Diameter	C_B	65-115 mm	1.00
		150 mm	1.05
		200 mm	1.15

3.2.17.3 Short Rod Correction

Short rod corrections were discussed in Section 2.4.1.3, which reveals that early short rod corrections based on mostly F^2 method-based measurements overestimated the short rod effects. ASTM revised the specification and states that F-V method-based measurements should be used. A new short rod correction is utilized in this study. For this purpose, hammer energy efficiency measurements collected by Değer (2014) are studied. The database is used to regress a new short rod correction as given in Equation 3.19 which is very similar to the proposed short rod correction by Deger (2014). A new short rod correction is currently under development including a larger number of hammer efficiency values by Prof. Kemal Onder Cetin and his students (personal communication with Prof. Cetin). Figure 3.4 presents the new model graphically which is implemented in the new database.

$$C_R = 1 - 0.274 \cdot e^{-0.063 \cdot L} \pm 0.059 \qquad \text{(L in feet)} \tag{3.19}$$

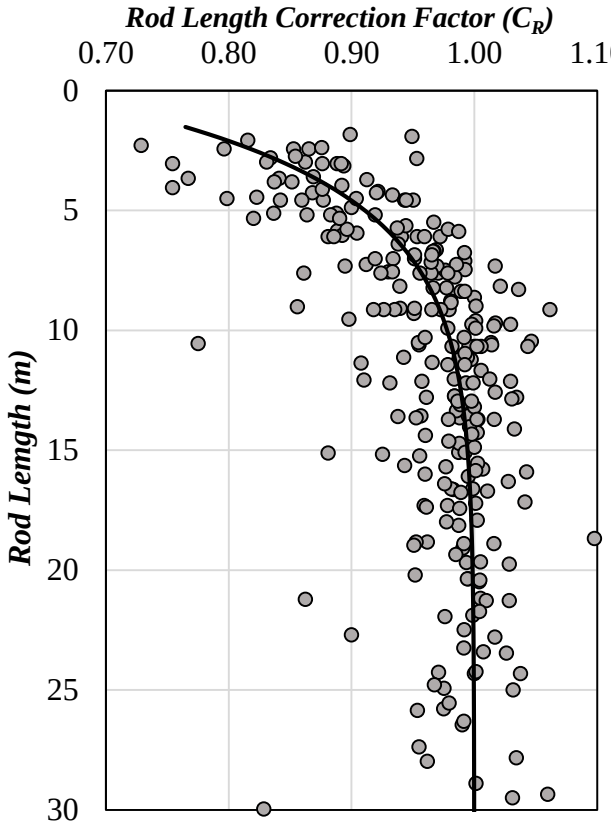


Figure 3.4. Short rod correction data given by Deger (2014) and developed C_R model.

The final discussion related to short rod corrections is to emphasize that the short rod correction is a function of rod length. Inspired by Cetin (2000), and Cetin et al. (2004, 2018a), stick-up is added to the SPT-N depth and the corresponding short rod correction (C_R) is estimated. For USGS boreholes 1.2 m and Japanese and Chinese boreholes, 2.1 m, and for other sites 1.5 m stick-up is added to the SPT-N depth if rod length measurements were not provided.

3.2.17.4 Energy Correction

Cetin (2000), Cetin et al. (2004, 2018a), and Idriss and Boulanger (2010) adopted the hammer energy efficiency recommendations of NCEER (2001), which are based

on the F^2 method-based measurements. The new specification (ASTM) now requires the use of the F-V Method for hammer energy measurements, which suggests higher hammer efficiency values for automatic hammers.

Cevik (2022) and personal communication with Prof. Cetin suggested that the database that they collected gives mean hammer efficiency values of 65.8, 81.7, and 48.9% with a standard deviation of 10.7, 7.3, 10.4% for safety, automatic, and donut hammers respectively which are used in the development of the new database. The hammer energy efficiency values for the new case histories as well as the legacy case histories are updated accordingly, which results in a systematic increase in $N_{1,60}$ values. If direct energy measurements were available for a case history throughout depth, no short rod correction is applied. (e.g. some of the case history data from 1999 Chi-chi, 2010 Darfield, 2011 Christchurch Earthquakes, etc.).

Hammer energy correction, C_E is calculated based on the updated hammer energy efficiency values as given by Equation 3.20. 60% reference energy level was kept unchanged as originally suggested by Seed et al. (1985) although it was selected as an average efficiency value for safety hammers during that time.

$$C_E = \frac{ER}{60\%} \tag{3.20}$$

3.2.17.5 Overburden Correction

Overburden correction, C_N is calculated as given in Equation 3.21 proposed by Liao and Whitman (1986) and NCEER (2001).

$$C_N = \left(\frac{P_a}{\sigma'_{vo}}\right)^m ;\ m = 0.5;\ P_a = \ 1\ \text{atm} \tag{3.21}$$

The stress exponent term (m) is regressed as a function of D_R within the likelihood analysis which will be discussed in Chapter 6.

3.2.18 Reasons for Excluding Case Histories

The case history database is processed individually, and the engineering judgment in this assessment plays a key role. Some of the case history sites were processed and based on initial assessment results they were excluded due to the reasons, which will be explained next. The following reasons are the most common reasons for the exclusions:

- One of the main reasons for the exclusion of the legacy case history data (e.g. 1948 Fukui, the 1944 Tohnankai earthquake, etc.) is the lack of well-monitored seismic shaking intensity data. The current database protocols restrict the PGA estimations to be made based on available ground motion recordings. Hence the intensity-based estimation of PGA was not allowed, as a result, these sites were excluded.
- Some of the sites have very soft (N=0-1 blows/30 cm) clay layers, which disabled to claim that the induced manifestations are due to cyclical mobility or flow liquefaction of cohesionless layers. Hence those sites are also excluded to prevent any ambiguity in the mechanism behind the observed field performance. Additionally, for the sites with very soft layers (N=0-1), it was hard to estimate the r_d and a_{max}, with simplified procedures, occasionally even with site-specific response analyses. Hence those case histories were also excluded.
- The current database presents information regarding the presence of organics and partial saturation problems. (e.g. Christchurch area, etc.). If a specific soil layer contains organic material, the layer may not be fully saturated. V_s/V_p measurements were also studied, which may help to judge the level of saturation. If below groundwater table organic bearing critical layers and V_s/V_p ratio suggests the lack of full saturation, those case histories were excluded, as it is hard to assess the occurrence of liquefaction or non-liquefaction in partially saturated soil layers.

- If there are multiple suspect layers, the site is excluded since it is not easy to decide which layer is responsible for the surface manifestation. Hence these cases are also excluded.
- The updated database jointly and collectively evaluates the nearby CPT and V_s data. As SPT data fails to provide continuous data, the advantage of available CPT data is used. If both SPT and CPT data exist but are not in conformance, the case history is also excluded.
- When Atterberg limits were not available and there is an ambiguity in identifying the critical layer those case histories were also excluded.
- For case history sites where free field conditions were not fulfilled, they were excluded. K_α (correction for sloping sites) needs to be applied for CSR estimations of these sites located on sloping areas (e.g. $\alpha > 3$ %, etc.), or nearby structures or quay walls. The great uncertainty involved in the estimation of static shear stress correction factors prevents the inclusion of these sites in the database.

3.2.19 Data Class

Inspired by Cetin (2000), a data classification scheme is adopted. The mean covariance of CSR is calculated for the entire database as 0.20. The following data class is used to distinguish different quality data within the database.

When equipment and procedural details of SPT data are well documented. Ground motion recoding stations are available and seismicity and site effects are well defined. Good site performance documentation, original borehole information, and other important data are accessible, then case histories are classified according to cov_{CSR} levels as follows:

Class A: $cov_{CSR} \leq 0.20$

Class B: $0.2 < cov_{CSR} \leq 0.35$

Class C: $0.35 < cov_{CSR} \leq 0.5$.

When equipment and procedural details of SPT data are not well documented. Seismicity, and/or site effects not well defined ($cov_{CSR} > 0.5$), poor site performance documentation, original borehole information or other important data not directly accessible, etc. If any of the reasons for excluding case history which is discussed in Section 3.2.19 is valid, then the case histories are classified as **Class D** and excluded.

CHAPTER 4

DEVELOPMENT OF FIELD CASE HISTORY DATABASE

4.1 Introduction

This chapter focuses on the development of a field case history database that includes the existing catalogs of Cetin et al. (2004, 2018), and a large number of new case histories. Several major earthquakes (e.g. 1999 Chi-Chi, 2001 Nisqually, 2003 Bachu, 2008 Achaia-Ilia, 2010 El-Mayor (Baja), 2011 Tohoku, 2010-2011 New Zealand-Canterbury earthquakes, etc.) occurred that produce a large number of new case histories that effectively double the global catalogs. Additionally, new data were also compiled from events (e.g. 1976 Tangshan Earthquake, etc.) that were already covered by the previous database where the newly available information enabled the development of new case history data. Lastly, the currently available liquefaction case history database of Cetin et al. (2004, 2018a, b) was re-visited and -processed to be included in the development of the new database.

The new database has some new processing details to better compute the model parameters. The current digital information enables the determination of the exact GPS coordinates of the site location and field performance confirmation with the satellite images. The nearby acceleration recordings were collected and examined to determine the intensity and duration parameters. Some of the other advantages of the new database can be listed as follows. The database is characterized by the following:

i) a collection of a larger suite of case histories consisting of 334 sites.
ii) It studied new earthquake events that occurred between 1996 and 2022 (e.g. 2001 Nisqually, 2010-2011 New Zealand Earthquake sequence, 2011

Tohoku, 2018 Hualien, 2022 Fukushima earthquakes) and re-investigated legacy case histories (e.g. 1976 Tangshan, 1989 Loma Prieta, etc.).

iii) The database covers normal, reverse, and subduction zone earthquake events which have a wider range of moment magnitude (M_w=4.6-9.1) along with the event parameter terms (R_{rup}, R_{jb}, z_{tor}, etc.).

iv) The case histories have gravelly and silty critical layers.

v) The catalog incorporates digitized full borehole information and comparatively assesses and applies screening criteria with the nearby CPT and V_s data,

vi) The catalog introduces a series of site response analyses in conjunction with deconvolution analysis for the strong ground motion sites,

vii) New parameters are included related to ground motion, site information (e.g. N_{cycle}, V_{s30m}, etc.), and geological conditions. The database is processed with improved knowledge and understanding of standard penetration test data which provides new stress (C_N), energy (C_E), and rod length (C_R) correction terms.

This chapter presents an updated liquefaction performance case history database consisting of revisited and updated Cetin et al. (2004, 2018a, b) database and new field case history data mostly from the events that occurred after 1995. This chapter also discusses the excluded legacy case history data and new case histories that were not able to pass the screening criteria along with the reasons for the exclusion. The resulting database is used for the development of updated probability-based liquefaction triggering relationships, the discussion of which will be presented in Chapter 6.

4.2 History of Compilation of Field Case History Data

Seismic soil liquefaction triggering case histories were first compiled from the 1964 Niigata and 1964 Alaska Earthquake events that caused widespread liquefaction. Seed et al. (1985) compiled a database consisting of 51 non-liquefied, 7 marginal,

and 67 liquefied case histories. Cetin (2000) and Cetin et al. (2004) adopted a probabilistic data processing scheme and processed additional case history data and re-visited the 125 case histories from Seed et al (1985). 90 case histories from Seed et al. (1985) passed the screening criteria of Cetin (2000) and the case histories were re-assessed probabilistically along with updated SPT correction schemes and site-specific estimated CSR. Cetin (2000) and Cetin et al. (2004) added 111 new case histories and published 201 case histories consisting of 158 liquefied, 41 non-liquefied, and 2 marginal sites. Idriss and Boulanger (2010) database include 230 case histories, 115 of which are liquefied, 112 non-liquefied, and 3 marginal case history sites. Boulanger and Idriss (2014) database excluded 2 case histories (1979 Imperial Valley earthquake, Wildlife B site and 1987 Superstition Hills earthquake, McKim Ranch A), and additional 24 cases from the 1999 Kocaeli and 1999 Chi-Chi earthquakes were added. The updated database (264 case histories) was not used to develop an updated model but to test the performance of Idriss and Boulanger (2010) triggering relationship from the original 230 case histories. Ilgac (2015) updated Cetin et al. (2004) database by excluding 2 case histories (1975 Haicheng M_s=7.3 Shung Tai Zi R and 1994 Northridge M_w=6.7 Malden Street Unit D) and including 13 new cases from 1983 Nihonkai-Chubu M=7.7 and Loma Prieta 1989 M_w=6.93 Earthquakes. The total number of cases reached a value of 211. Cetin et al. (2018a) published an updated relationship with this dataset excluding 1 case history and the final number reaches 210 case histories:113 liquefied, 95 non-liquefied, and 2 marginal data.

The updated database presented in this thesis has reached 334, including 179 liquefied, 154 non-liquefied, and 1 marginal case history data. The database sizes of existing databases are presented in Table 4.1.

Table 4.1. The summary of the current SPT-based liquefaction triggering database.

Database	*Liquefied*	*Non-Liquefied*	*Marginal*
Seed et al. (1985)	67	51	7
Cetin et al. (2004)	109	88	3
Cetin et al. (2018a,b)	113	95	2
Idriss and Boulanger (2010)	115	112	3
Boulanger and Idriss (2014)	134	117	3
This Study	179	154	1

4.3 Compilation of New Case History Database

The new SPT-based liquefaction triggering database investigates the case histories from recent earthquake events that occurred in the last 25 years and legacy events if there exist new in-situ field test data. Within the confines of this dissertation, approximately 72 earthquake events that are reported to produce surface manifestation due to liquefaction in the literature are studied. Among numerous earthquake events that triggered liquefaction in the world, after careful review, the resultant number of events that are used to compile case histories is reduced to 45 earthquakes as they did not pass the screening criteria described in Chapter 3. In-situ field data and liquefaction performance along with ground motion parameters were studied for these events. In this catalog, 334 new case histories from 41 different events were populated and processed and the final screening criteria resulted in the exclusion of 180 case histories. Some of the reasons for the exclusion of some events can be listed as a lack of strong ground motion recordings which enable the accurate estimation of intensity parameters (e.g. a_{max}, etc.), or the lack of information regarding SPT procedure which prevents the proper correction of SPT-N values to calculate $N_{1,60}$.

The locations of the new events that are recently added to the database are shown in Figure 4.1. The numbers in the first brackets are M_w values of the events, and the number of case histories populated from those events is shown in the second bracket.

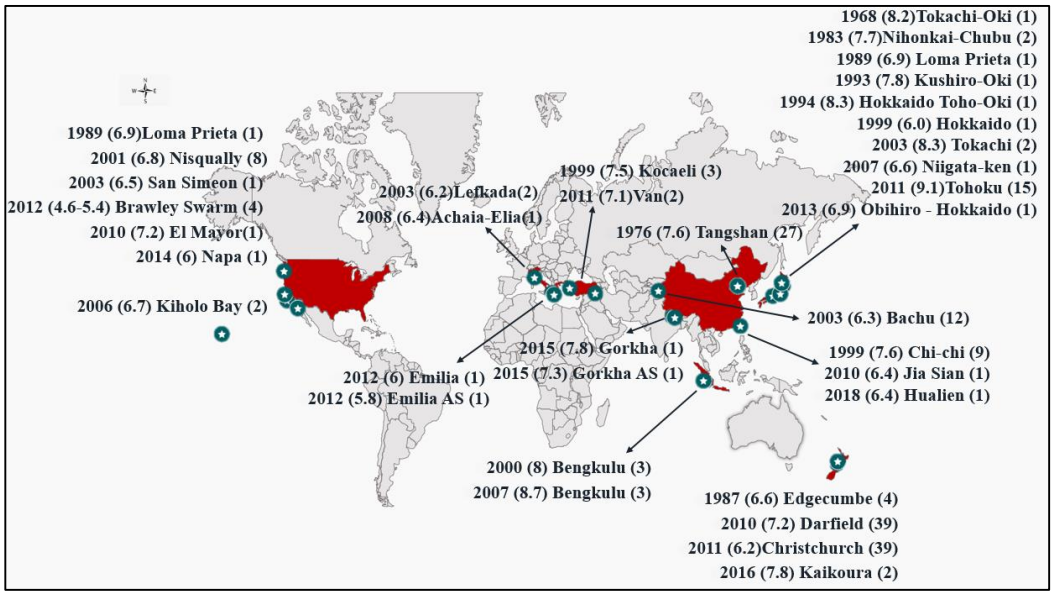


Figure 4.1. The location of the new earthquake events.

The new data are compiled from the following events:

1. 1976 Tangshan Earthquake, China (M_w=7.5)

2. 1978 Miyagiken-Oki Earthquake, Japan (M_w=7.7)

3. 1978 Miyagiken-Oki Earthquake, Japan (M_w=6.5)

4. 1987 Edgecumbe Earthquake, New Zealand (M_w=6.5)

5. 1989 Loma Prieta Earthquake, USA (M_w=6.93)

6. 1993 Kushiro-Oki Earthquake, Japan (M_w=7.8)

7. 1999 Chi-chi Earthquake, Taiwan (M_w=7.62)

8. 1999 Hokkaido Earthquake, Japan (M_w=6.2)

9. 1999 Kocaeli Earthquake, Turkey (M_w=7.51)

10. 2001 Nisqually Earthquake, Seattle, USA (M_w=6.8)

11. 2003 Lefkada Earthquake, Greece (M_w=6.2)

12. 2003 San Simeon Earthquake, Oceana, USA (M_w=6.5)

13. 2003 Tokachi-oki Earthquake, Japan (M_w=8.3)

14. 2006 Kiholo Bay Earthquake, Hawaii, USA (M_w=6.7)

15. 2007 Niigata Chuetsu-oki Earthquake, Japan (M_w=6.6)

16. 2008 Achaia-Elia Earthquake, Greece (M_w=6.4)

17. 2010 Darfield Earthquake, New Zealand (M_w=7.1)

18. 2010 Jia Shan Earthquake, Taiwan (M_w=6.3)

19. 2010 El Mayor-Cucapah (Baja) Earthquake, Mexico (the earthquake has affected the Salton basin area in California, USA), (M_w=7.2)

20. 2010 Maule Earthquake, Chile (M_w=7.2)

21. 2011 Christchurch Earthquake, New Zealand (M_w=6.2)

22. 2011 Tohoku Earthquake, Japan (M_w=9.1)

23. 2011 Van Earthquake, Turkey (M_w=7.1)

24. 2012 Brawley Earthquake Sequence, California, USA (M_w=4.6)

25. 2012 Brawley Earthquake Sequence, California, USA (M_w=5.41)

26. 2012 Brawley Earthquake Sequence, California, USA (M_w=4.4)

27. 2012 Brawley Earthquake Sequence, California, USA (M_w=5.0)

28. 2012 Emilia Earthquake mainshock, Italy (M_w=6.0)

29. 2012 Emilia Earthquake aftershock, Italy (M_w=5.8)

30. 2013 Obihiro - Hokkaido Earthquake, Japan (M_w=6.9)

31. 2014 Napa Earthquake, California, USA (M_w=6.0)

32. 2015 Gorkha Earthquake, Nepal (M_w=7.8)

33. 2015 Gorkha Earthquake Aftershock, Nepal (M_w=7.3)

34. 2016 Kaikoura Earthquake, New Zealand (M_w=7.8)

35. 2018 Hualien Earthquake, Taiwan (M_w=6.4)

Case histories are processed from the following events but not used in the final database.

1. 1975 Haicheng Earthquake, China (M_w=7.0)

2. 1994 Hokkaido Toho-oki (Kuril Islands) Earthquake, Japan (M_w=8.3)

3. 1999 Chi chi Earthquake, Taiwan (M_w=7.62)

4. 1999 Kocaeli Earthquake, Turkey (M_w=7.51)

5. 2000 Bengkulu Earthquake, Indonesia (M_w=8.0)

6. 2000 Western Tottori Earthquake, Japan (M_w=6.6)

7. 2001 Nisqually Earthquake, USA (M_w=6.8)

8. 2003 Bachu Earthquake, China (M_w=6.3)

9. 2003 San Simeon Earthquake, USA (M_w=6.5)

10. 2007 Bengkulu Earthquake, Indonesia (M_w=8.7)

11. 2008 Achaia-Elia Earthquake, Greece (M_w=6.4)

12. 2010 Darfield Earthquake, New Zealand (M_w=7.1)

13. 2010 Maule Earthquake, Chile (M_w=7.1)

14. 2011 Tohoku Earthquake, Japan (M_w=9.1)

15. 2011 Christchurch Earthquake, New Zealand (M_w=6.2)

16. 2012 Emilia Earthquake mainshock, Italy (M_w=6.0)

17. 2012 Emilia Earthquake aftershock, Italy (M_w=5.8)

18. 2014 Cephalonia Earthquake, Greece (M_w=6.0)

19. 2015 Illapel (Chile) Earthquake, Chile (M_w=8.3)

20. 2020 Elazig Earthquake, Turkey (M_w=6.8)

21. 2020 Samos Island Aegean Sea Earthquake, Turkey-Greece (M_w=7.0)

22. 2022 Fukushima Earthquake, Japan (M_w=7.3)

4.3.1 An Illustrative Example of Case History Processing

An illustrative case history processing example is presented in this section. 2011 Christchurch earthquake caused liquefaction in Christchurch, New Zealand. McLaughlin (2017) and New Zealand Geotechnical Database (NZGD) were used to compile information regarding the case history data. Case history Avondale Playground will be presented as an example site. Figure 4.2 shows the location of the site (-43.508503, 172.686906) where liquefaction is observed in the form of sand boils on the surface of the street, backyards, and playground park after the 2011 Christchurch earthquake along with the in-situ field test investigation locations (SPT, CPT, and V_s) as given by McLaughlin (2017).



Figure 4.2. Plan view of the Avondale Playground park along with the in-situ test locations and field performance after the 2011 Christchurch earthquake (McLaughlin, 2017).

Borehole data and SCPT results were downloaded from NZGD as shown in Figure 4.3 The test results include SPT, CPT, and V_s data. Groundwater table, GWT is located at 0.9 m depth based on the information given from borehole 57217. The summary of the in-situ test results is shown in Figure 4.4, Figure 4.5, and Figure 4.6 for SPT, CPT, and V_s, respectively.

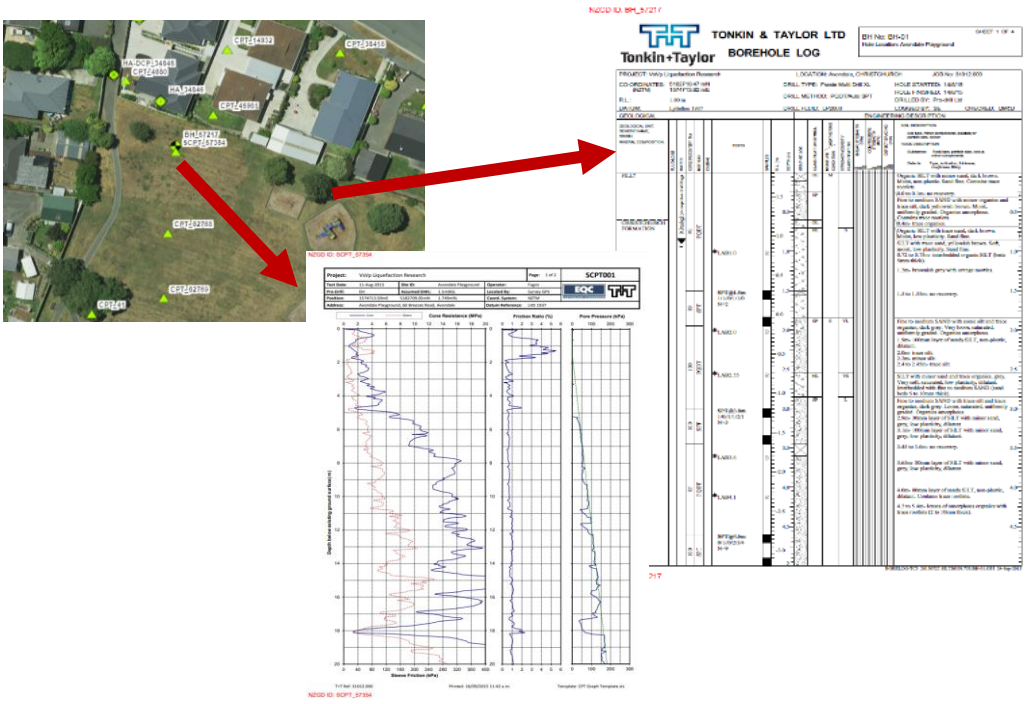


Figure 4.3. Plan view of the Avondale Playground along with the in-situ test locations and test results of SCPT57354 and SPT57217 (Map on the left and data on the right are retrieved from NZGD).

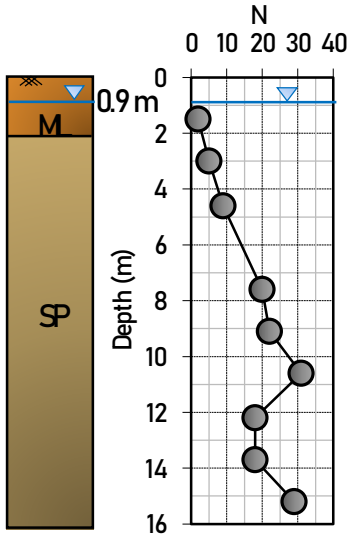


Figure 4.4. Summary of the SPT results (NZGD ID: BH 57217)

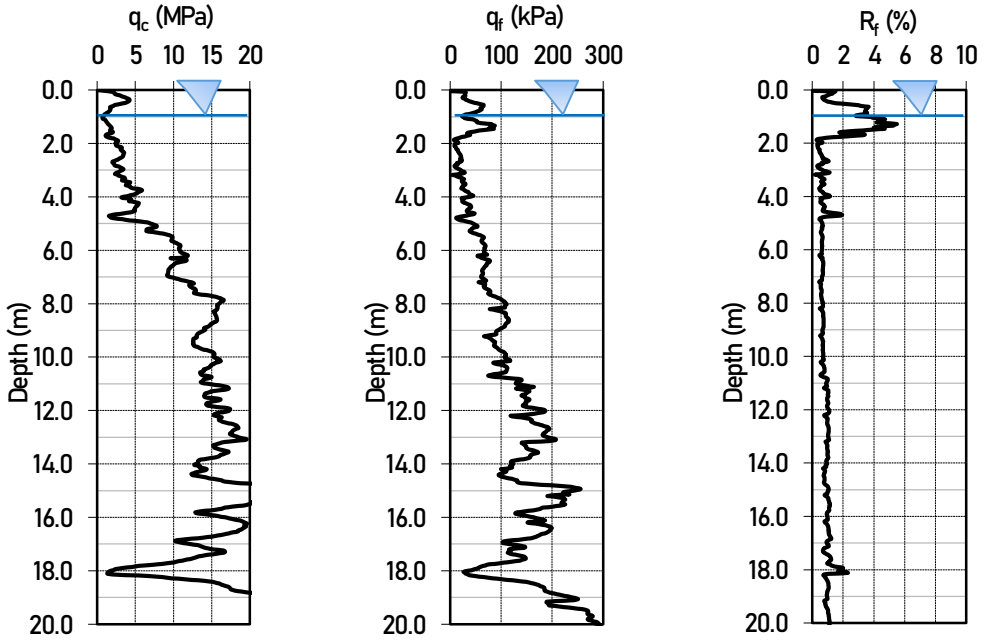


Figure 4.5. Summary of the CPT results. (NZGD ID: CPT 57534)

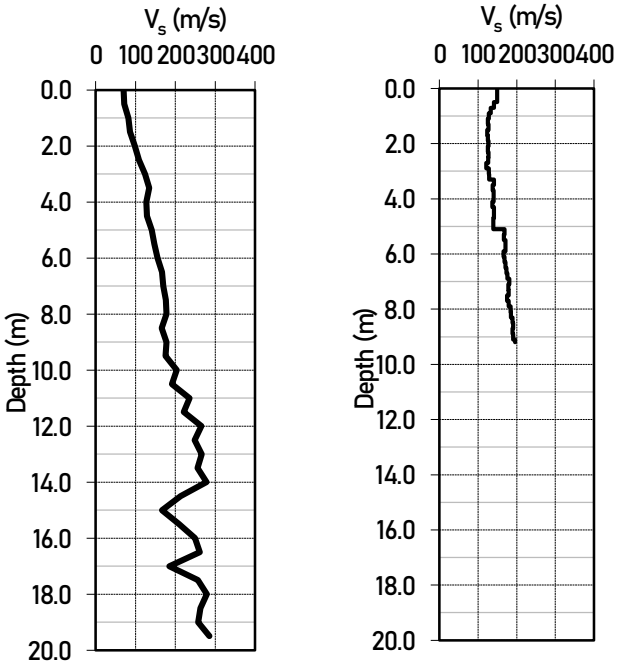


Figure 4.6. Summary of the V_s profile obtained from SCPT data given by a) NZGD (NZGD ID: CPT 57534) and b) McLaughlin (2017).

Critical depth is selected by identifying the potentially liquefiable soil layer (e.g. fully saturated low plastic most vulnerable layer). The critical layer of the Avondale Playground is selected as the sand layer (SP) which is located at 2.4-6.0 m by considering and comparing the individual SPT and CPT results collectively. The mean total and effective stress at the mid-depth of the critical layer is calculated as 76 and 43 kPa, respectively. No information regarding hammer efficiency was provided hence the hammer efficiency of the PQDT/Auto hammer is taken as 82% which is an average value for the automatic hammers in the world. The mean $N_{1,60}$ of the critical layer is calculated as 13.6 blows/30 cm with a standard deviation of 4.2 for the sand (SP) layer. Table 4.2 presents a summary of the measured raw SPT-N, C_R, C_N, and $N_{1,60}$ values and soil type along with depth.

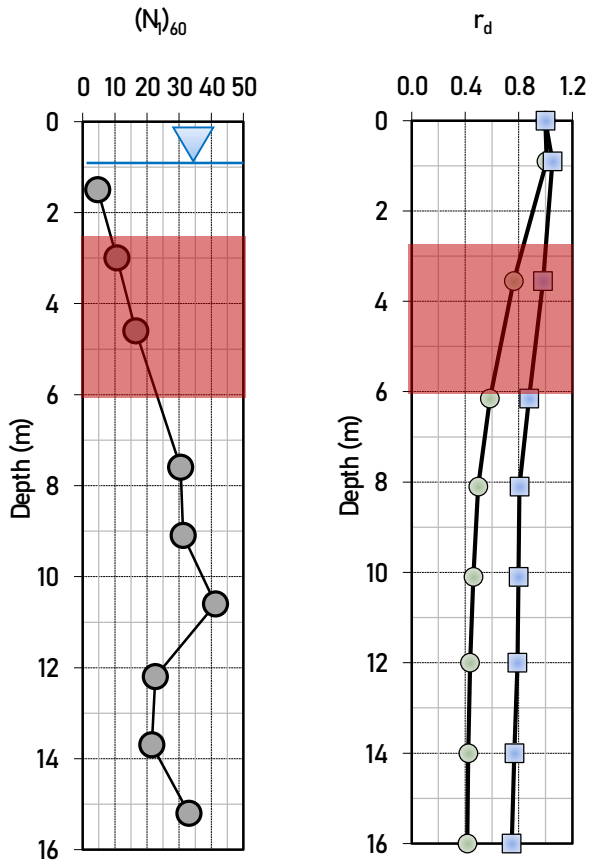
Table 4.2. The summary of the calculation of $N_{1,60}$ for Avondale Playground (NZGD BH-ID 57217).

USCS	*Depth (m)*	*N*	C_N	C_R	$(N_1)_{60}$
ML	1.5	2	2.00	0.85	4.7
SP	***3***	***5***	***1.75***	***0.89***	***10.7***
SP	***4.6***	***9***	***1.46***	***0.92***	***16.5***
SP	7.6	20	1.16	0.96	30.5
SP	9.1	22	1.07	0.97	31.2
SP	10.6	31	1.00	0.98	41.3
SP	12.2	18	0.93	0.98	22.6
SP	13.7	18	0.88	0.99	21.5
SP	15.2	29	0.84	0.99	33.0
				Mean:	13.6
				St. Dev.	4.2

The mass-participation parameter r_d is estimated by the equation developed by Cetin and Seed (2004) as 0.89. Location-specific site response analyses were performed using the field data at Avondale Park and r_d is estimated to be 0.72 and 0.96 for the two horizontal components and the geometric mean of which is 0.83. A PGA is calculated as 0.36 g by the site response analysis as the geometric mean of the two horizontal components. The details regarding the site response analyses will be

discussed in Chapter 5. McLaughlin (2017) estimated PGA as 0.40 g based on the conditional distributions described by Green et al. (2014) and Bradley (2014). It was concluded that the PGA and r_d are for this event to be 0.40 g and 0.83, respectively. For some of the case history sites, the site response analysis PGA values are not informants with the event and site-specific GMPE predictions. A possible reason for this is that beyond strain levels of 1 % site response predictions are not reliable. For those case histories, PGA is directly estimated based on site- and event-specific GMPE models developed coupled with site response-based r_d values estimation of CSR. CSR is estimated as 0.374 with a standard deviation of 0.056 at the mid-depth of the critical layer.

The computed $N_{1,60}$ and r_d plots for the two horizontal components are presented for the Avondale Playground site as shown in Figure 4.7 a and b. The critical layer is shaded with red color, and a summary of the input parameters is presented in Figure 4.7 c.



Parameters	This study
Liquefied?	Yes
Data Class	B
$d_{crtc.}$ range (m)	2.4 - 6.0
$d_{crt.}$ (m)	4.2
GWT (m)	0.9 ± 0.7
γ_{moist} (kN/m^3)	15.7
γ_{sat} (kN/m^3)	18.9
σ_v (kPa)	76.1 ± 11.8
σ_v' (kPa)	43.9 ± 7.4
a_{max} (g)	0.400 ± 0.020
r_d	0.83 ± 0.030
CSR	0.374 ± 0.056
M_w	6.20
D_{50}	NAV
% Fines	<5 ± 8.6
% PI	0
N	7.2 ± 2.2
C_R	0.92
C_S	1.00
C_B	1.00
C_E	1.37
C_N	1.52
$(N_1)_{60}$	13.6 ± 4.2
$V_{s,30m}$ (m/s)	NAV
$V_{s,12m}$ (m/s)	158.7

Figure 4.7. a) Corrected $N_{1,60}$ profile, b) r_d plot with respect to depth, and c) summary of the input parameters for Avondale Playground case history.

2011 Christchurch earthquake occurred on a reverse blind fault and the moment magnitude of the event is M_w=6.2, where the depth to the top of rupture, Z_{TOR} was 0.5 km. The dip angle and the width of the fault are 64º and 6.5 km. The site locations and fault ruptures were integrated into Google Earth, and rupture distances were measured. The rupture distance (R_{rup} and R_{jb}) of the site is estimated as 3.83 and 3.80 km.

Figure 4.8, Figure 4.9, and Figure 4.10 present the summary of the site response analyses and summary pages prepared for the Avondale Playground site.

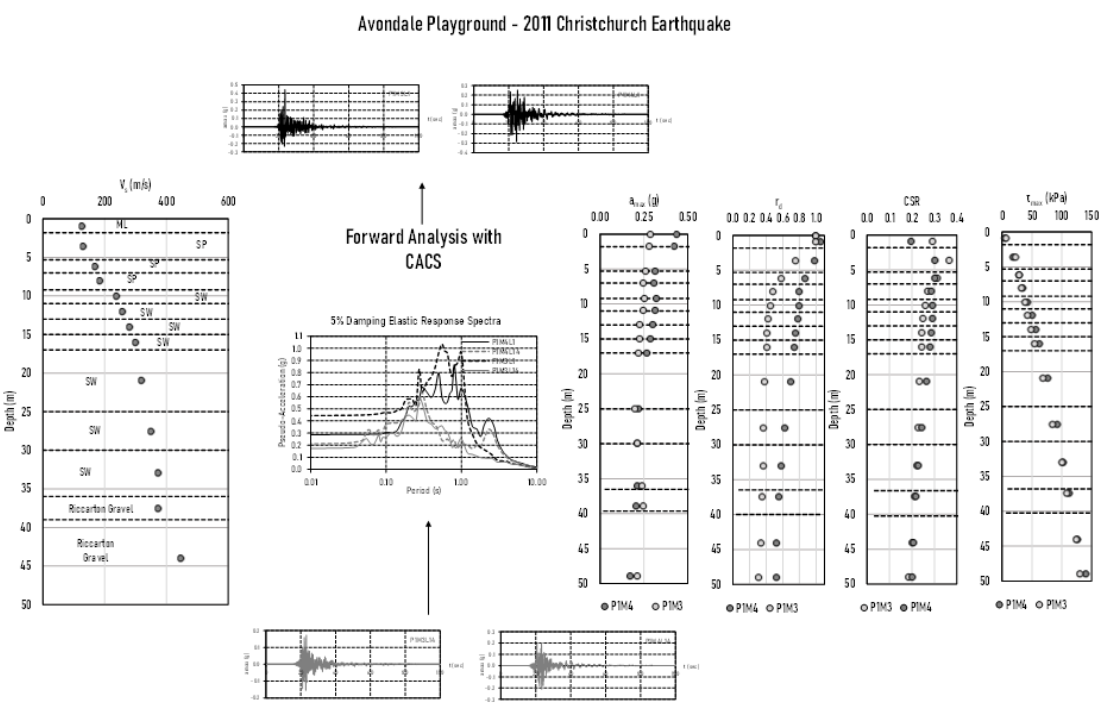


Figure 4.8. The summary page of the site response analyses results for Avondale Playground case history.

Case number:	219
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Avondale Playground
References:	McLaughlin (2017), NZGD
Nature of Failure:	Moderate-Severe. Sand boils were observed
GPS LAT	-43.508503
GPS LONG	172.686906
Liq. layer consist of:	Sand (SP)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.40 g by McLaughlin (2017) abased on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD. Hammer energy is assigned as 82% for PQDT/Auto SPT by Tonkin and Taylor. Vs,12m is calculated based on the mesaured Vs values. GWT is estimated based on SPT FC is assigned based on the SP classification from USCS. Lab data is asked to Tonkin and Taylor.



After McLaughlin (2017)

Gravel Content (%)	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

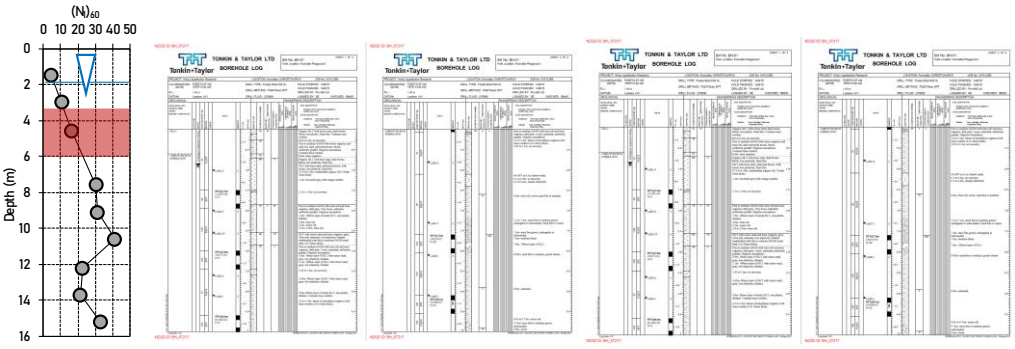
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crust} range (m)	-	-	-	-	2.4 - 6.0
d_{crust} (m)	-	-	-	-	4.2
GWT (m)	-	-	-	-	0.9 ± 0.7
γ_{moist} (kN/m^3)	-	-	-	-	15.7
γ_{sat} (kN/m^3)	-	-	-	-	18.9
σ_v (kPa)	-	-	-	-	76.1 ± 11.8
σ_v' (kPa)	-	-	-	-	43.9 ± 7.4
a_{max} (g)	-	-	-	-	0.400 ± 0.020
r_d	-	-	-	-	0.83 ± 0.030
CSR	-	-	-	-	0.374 ± 0.056
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	7.2 ± 2.2
C_B	-	-	-	-	0.92
C_S	-	-	-	-	1.00
C_R	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.52
$(N_1)_{60}$	-	-	-	-	13.6 ± 4.2
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	158.7

EVENT PARAMETERS

2011 Christchurch Earthquake
Magnitude: 6.20
Fault Type: Reverse Fault — Z_{tor} (km): 0.5 — R_{rup} (km): 3.83
Dip: 64 — Width (km): 6.5 — R_{jb} (km): 3.80

ACCELERATION TIME HISTORY

Figure 4.9. Summary page for Avondale Playground case history.



	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
ML	1.5	4.9		2	2.00	0.85	4.7
SP	*3*	*9.8*		*5*	*1.75*	*0.89*	*10.7*
SP	*4.6*	*15.1*		*9*	*1.46*	*0.92*	*16.5*
SP	7.6	24.9	Site	20	1.16	0.96	30.5
SP	9.1	29.9	Response	22	1.07	0.97	31.2
SP	10.6	34.8	Analysis	31	1.00	0.98	41.3
SP	12.2	40.0		18	0.93	0.98	22.6
SP	13.7	44.9		18	0.88	0.99	21.5
SP	15.2	49.9		29	0.84	0.99	33.0
						Mean:	13.6
						St. Dev.	4.2

GWT	
by Vs	2.05 m
by Vs	2.14 m
SPT	0.9 m

Figure 4.10. The second page of the summary for Avondale Playground case history.

4.3.2 An Overview of the New Case Histories

This section presents the new case history data, which consists of 163 new liquefaction field case history data (e.g. legacy case histories were not included in this section) which are compiled from the literature.

Table 4.3 summarizes the mean and mean of the standard deviation, minimum and maximum values of some of the input parameters $d_{crt.}$, GWT, γ_{moist}, γ_{wet}, σ_v, σ'_v, SC, GC, CC, FC, C_N, C_R, C_E, $N_{1,60}$, a_{max}, M_w, $V_{s,12m}$, r_d $CSR_{\sigma'v,Mw}$, $N_{1,60,CS}$, K_{Mw}, K_σ, $CSR_{\sigma'v=1atm,Mw=7.5}$, V_{s30m}, R_{jb} for the new 163 case history data. histories.

Table 4.3. Statistics of input parameters for the new case histories (163 data)

Parameters	***Mean***	***St. Dev.***	***Min.***	***Max.***
$d_{crt.}$ *(m)*	6.5	0.82	2.0	22.6
GWT (m)	1.8	0.3	0.1	6.4
γ_{wet} *(kN/m^3)*	17.8	0.48	13.3	21.3
γ_{sat} *(kN/m^3)*	19.9	0.48	17.0	22.8
σ_v *(kPa)*	126.7	16.82	36.6	405.3
σ'_v *(kPa)*	80.9	9.44	28.0	228.8
r_d	0.834	0.066	0.477	1.029
a_{max} *(g)*	0.312	0.048	0.078	0.784
M_w	7.1	0.07	4.6	9.1
CSR	0.258	0.051	0.045	0.656
GC (%)	1.6	6.5	0.0	50.0
SC (%)	26.2	8.7	8.0	57.8
CC (%)	2.1	2.3	0.0	6.1
FC (%)	17.2	8.8	1.0	75.0
D_{50} *(mm)*	0.390	0.099	0.055	4.500
C_R	0.94	-	0.8	1.0
C_B	1.00	-	1.0	1.0
C_E	1.25	-	0.8	1.7
C_N	1.22	-	0.7	1.9
$(N_1)_{60}$	17.2	3.73	3.3	43.2
$V_{s,12m}$ *(m/s)*	178.9	-	109.7	496.1
$V_{s,30m}$ *(m/s)*	215.4	-	131.2	344.6
K_σ	1.060	-	0.876	1.233
K_{Mw}	1.052	-	0.875	1.398
$CSR_{Mw=7.5,\sigma'v=100kPA}$	0.232	-	0.043	0.614
$N_{1,60,CS}$	19.6	-	5.1	43.3

Figure 4.11 a-x presents the distribution of input parameters (e.g. $d_{crt.}$, γ_{moist}, γ_{wet}, GWT, σ_v, σ'_v, FC, a_{max}, M_w, $V_{s,12m}$, r_d, $CSR_{\sigma'v,Mw}$, C_N, C_R, C_E, $N_{1,60}$, $N_{1,60,CS}$, K_σ, K_{Mw}, $CSR_{\sigma'v=1atm,Mw=7.5}$,) for the new case histories (163 case history). Some of the descriptive parameters are presented in Figure 4.11 according to new database case history ID numbers (#1-334). The grey circles represent liquefied sites, open circles

and grey triangles represent non-liquefied and marginal sites, respectively. The mean and standard deviation values of the database for the selected parameters are shown on the same figures with red solid and red dashed lines, respectively. Several additional parameters exist, but due to page limitations, they will not be presented herein.

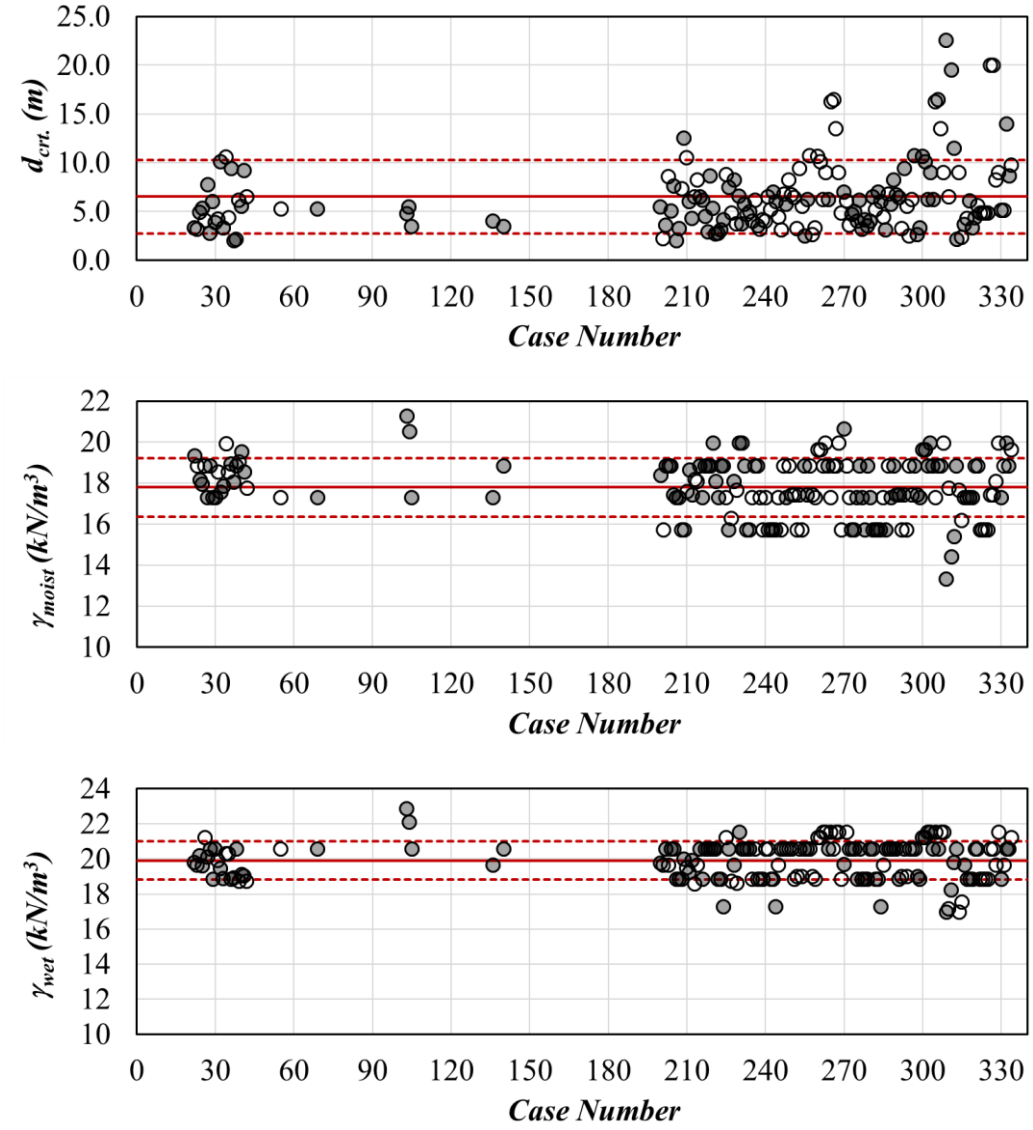


Figure 4.11. Comparison of input parameters a) $d_{crt.}$, b) γ_{moist}, c) γ_{wet}, d) GWT, e) σ_v, f) σ'_v, g) FC, h) a_{max}, i) M_w, j) $V_{s,12m}$, k) r_d, l) $CSR_{\sigma'v,Mw}$, m) C_N, n) C_R, o) C_E, p) $N_{1,60}$, r) $N_{1,60,CS}$, s) K_σ, t) K_{Mw}, u) $CSR_{\sigma'v=1atm,Mw=7.}$

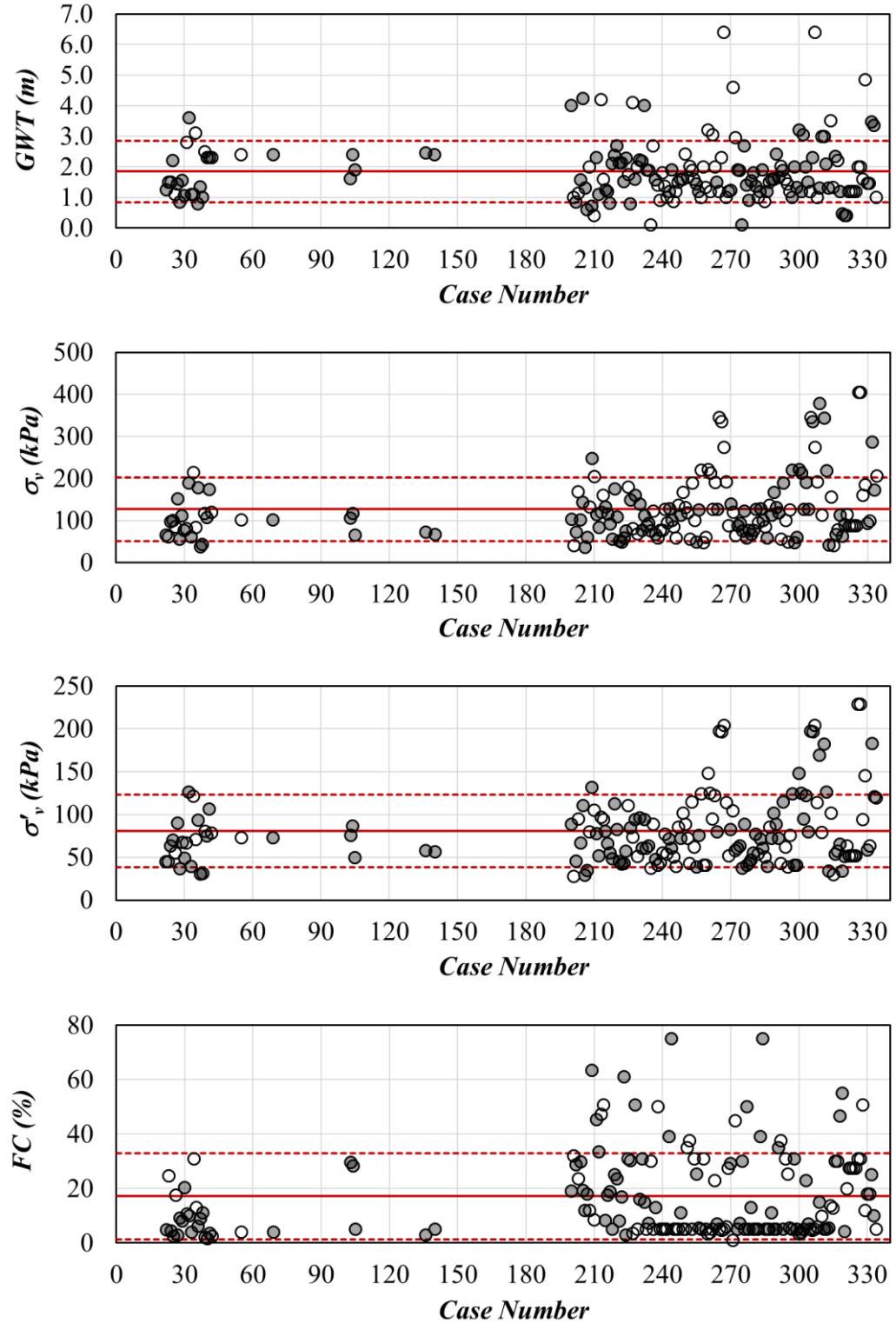


Figure 4.11. (cont'd)

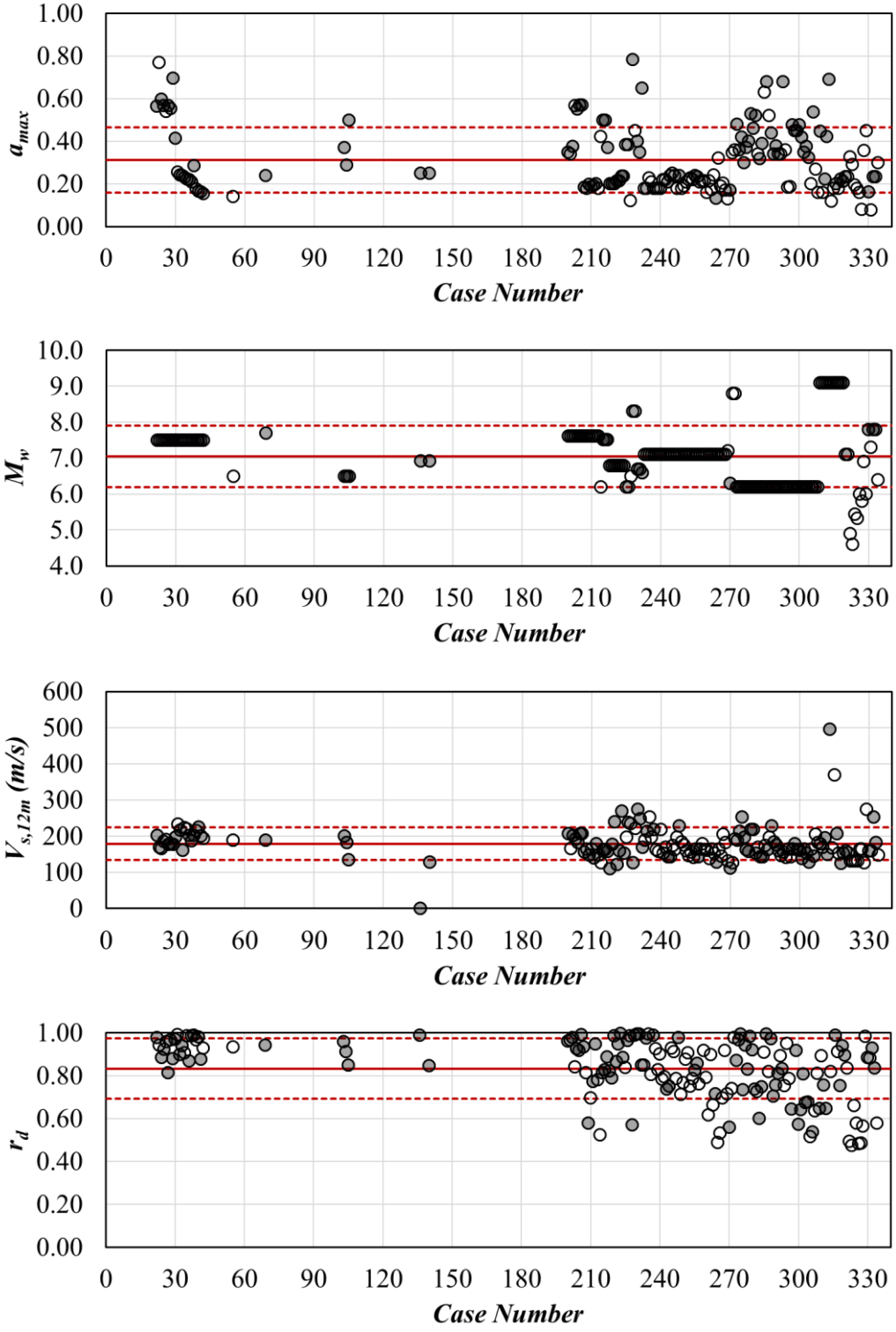


Figure 4.11. (cont'd)

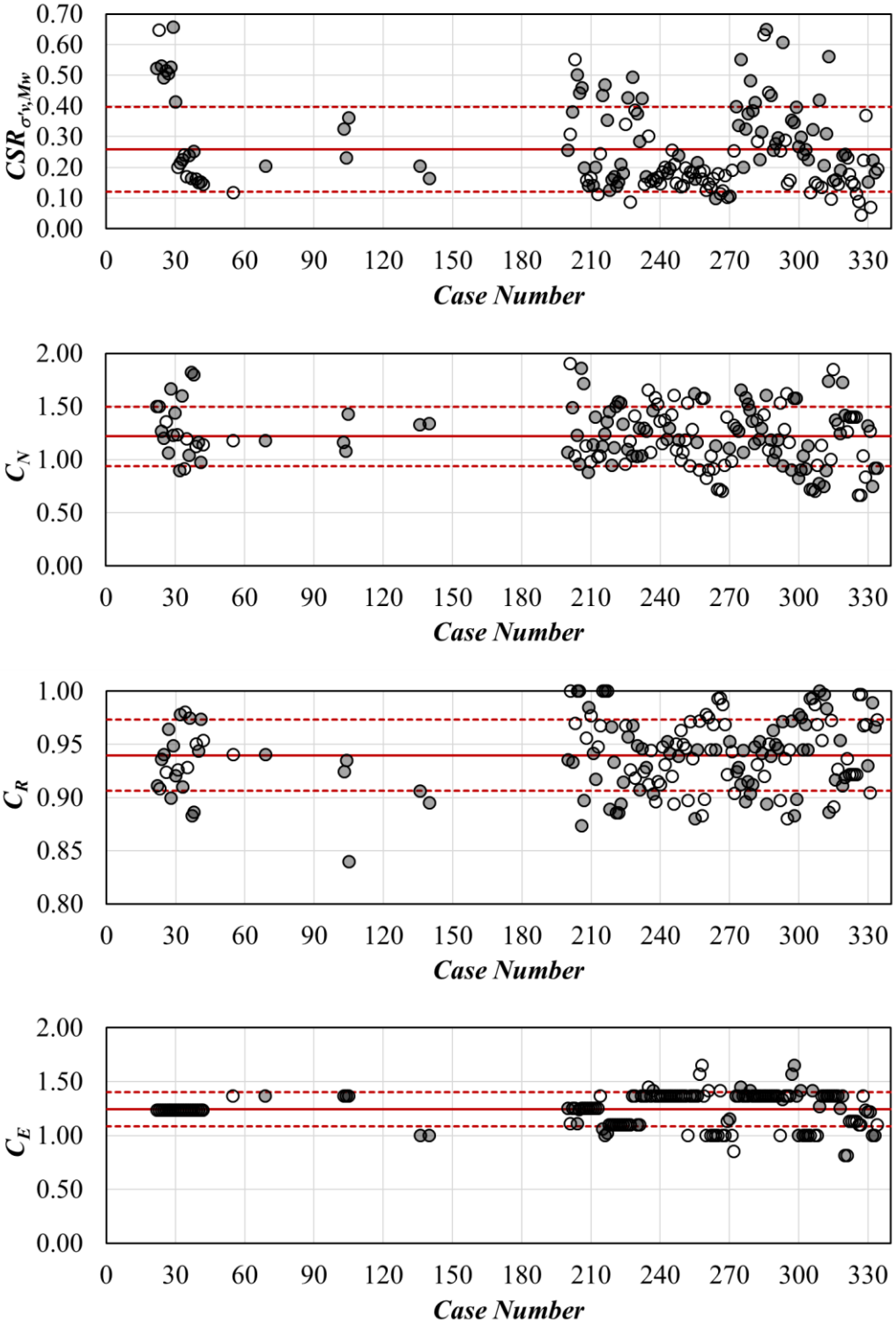


Figure 4.11. (cont'd)

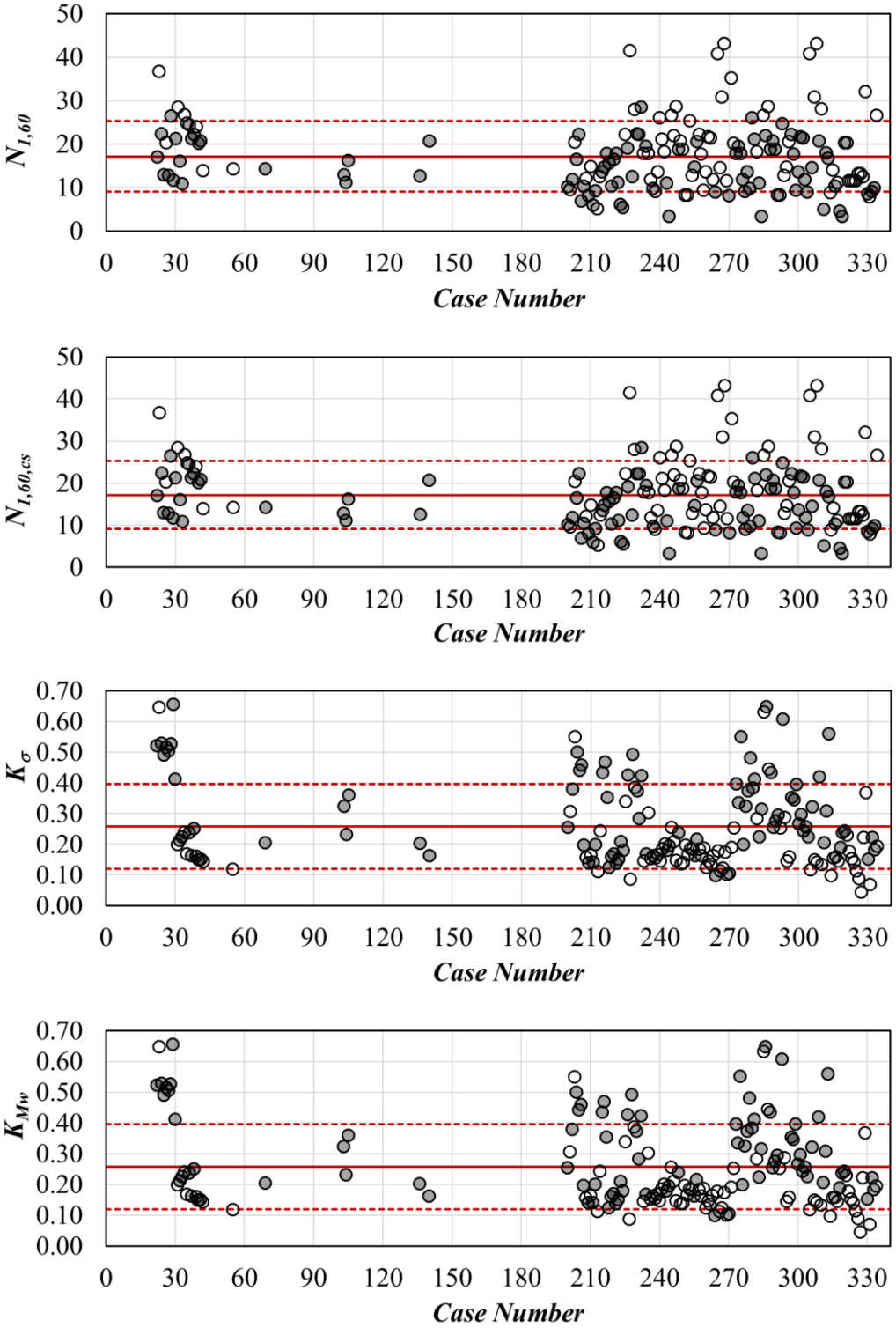


Figure 4.11. (cont'd)

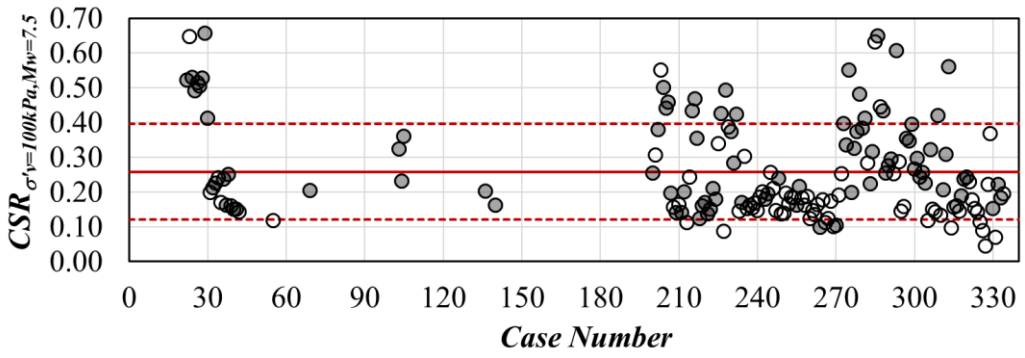


Figure 4.11. (cont'd)

Figure 4.12 presents the mean values of the corrected $N_{1,60}$ versus $CSR_{\sigma'v,Mw}$ (not normalized for K_σ, K_{Mw}, K_α effects) case history data for the new catalog (163 case histories).

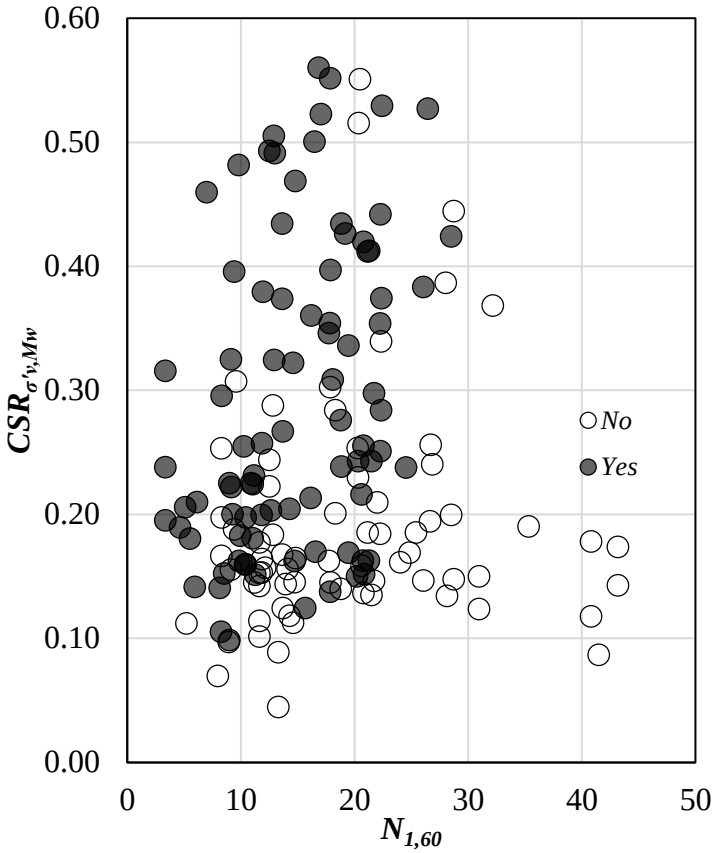


Figure 4.12. New case histories (163) on corrected $N_{1,60}$ versus $CSR_{\sigma'v,Mw}$

4.4 Re-evaluation of Legacy Case History Database of Cetin et al. (2004, 2018a, b)

The legacy case history database of Cetin (2000), and Cetin et al. (2004, 2018a, b) are re-investigated and re-processed. The database of Cetin et al. (2018a, b) has 210 case histories. 37 case histories are excluded mainly to achieve higher data standards and to produce better predictive models. Exclusion reasons are due to poor ground motion characterization (e.g. PGA levels were estimated based on intensity measures, global ground-motion equations, etc.), the violation of the statistically independent assumption of case histories (e.g. two liquefied case histories from the same unit, etc.) and presence of very soft layers (e.g. SPT-N values are 0-1 blows/30 cm for 2 m thick layer, etc.) which disables accurate estimation of r_d and a_{max}. 1989 Loma Prieta case histories Marine Laboratory UC-B1 and Marine Laboratory UC-B2 are merged as Marine Laboratory UC-B1&B2. Hence the total number of case histories that are re-investigated and included in the new database from Cetin et al. (2018a, b) database is 171 case histories. These case histories were re-processed to meet the current screening criteria, which were discussed extensively in Chapter 3. A new set of parameters are collected for those sites and the input parameters are reviewed and updated if necessary.

4.4.1 Modification of Cetin et. al. (2018a, b) Database

Cetin et. al. (2018a, b) database consists of 210 case history data. 37 case history data were excluded and 2 case histories were merged and represented as single case history data. In this section, the modifications and changes applied to 171 case histories from the Cetin et. al. (2018a, b) database are summarized briefly. Changes made to the Cetin et. al. (2018a, b) database include the followings:

1. For a more accurate estimation of $V_{s,12m}$ values, if V_s measurements are available, the data is collected and digitized. $V_{s,12m}$ values are re-calculated based on the V_s profiles. Additionally, if V_s measurements are not available

and V_s-SPTN correlation is used considering the digitized SPT-N for the upper 12 m as discussed in Chapter 3. This update produced a 9.1 % increase in $V_{s,12m}$ values, in the overall average for the legacy case history data.

2. An updated unit weight protocol is established and unit weights for each case history site are updated consistently with the information summarized in Chapter 3. This update produced a 2.0 % and 3.1 % increase in γ_{wet} and γ_{sat} values, in the overall average for the legacy case history data.
3. As presented in Chapter 3, an updated short rod correction, C_R, was implemented for the legacy sites of Cetin et al. (2018a, b). The effect of the updated C_R values is hard to distinguish as some of the critical layer selections are also updated. Considering the changes in critical layer selection are minor, the change in C_R can be attributed to the new short rod corrections applied in this study. Overall, updated C_R values are 3% higher than Cetin et al. (2018a, b).
4. As presented in Chapter 3, an updated hammer efficiency scheme are implemented for safety, automatic, and donut hammer which cause a 12.3 % increase in the overall average values of C_E.
5. Due to the changes in some of the critical layers and updated unit weight and effective stress levels, overburden correction decreased by 2%.
6. For the sites where site-specific site response analyses were performed by Cetin (2000), the uncertainty of r_d is calculated as half of the uncertainty term which was given by Cetin and Seed (2004) to consider the reduced uncertainty. This produces a 6 % decrease in the overall average standard deviation for r_d values.
7. For all case history sites of Cetin et al. (2018a, b), new parameters were added. The liquefiable layer properties include atterberg limits, fines content, soil type, and USCS description, grain size parameters, gravel, sand, silt, and clay contents (if available in the source document), digitized soil layer depth, geological units, nearby available CPT and V_s data, event type, rupture distance (R_{rup}, R_{jb}), dip angle, z_{tor}, V_{s30m}, GPS coordinates are determined.

8. The entire borehole information is digitized which produced minor changes in depth and SPT-N values. The soil classification or descriptions are also collected for each SPT-N value throughout the soil profile. This results in minor changes in the depth hence critical layer selections, $d_{crtc.}$ was reviewed which produced a 0.2 % decrease.

The above-mentioned corrections were common to every case history in the Cetin et al. (2018a, b) database. The following modifications are implemented specifically to each case history:

1. The new database included all the cases of Cetin et. al. (2018a, b) except 37 case histories, which are excluded from the database. The reasons for the exclusion of those case histories will be discussed in Section 4.3.2. in detail.
2. Some of the earthquake magnitudes were updated based on the recent developments in strong ground motion seismology, which resulted in a 0.5% decrease in M_w values.
3. The standard deviation for each parameter is also re-visited accordingly with the protocols presented in Chapter 3.
4. For some case history data, groundwater table, a_{max}, average fines content as well as average critical depth, and average SPT-N values, were re-visited and updated based on the newly available information.
5. Updates on critical depth, M_w, $V_{s12,m}$, and a_{max} resulted in a 1.8 % increase in r_d values.
6. Updates on critical depth, GWT, and unit weight resulted in a 2.7 % and 4.1 % increase in σ_v and σ'_v values.

4.4.2 Excluded Case History Data from Cetin et al. (2004, 2018a)

Cetin et. al. (2018a, b) database consists of 210 case history data. 37 case history data are excluded and 2 of them were merged. Table 4.4 presents the reasons for the exclusion of the case histories from Cetin et al. (2018a, b).

Table 4.4. The excluded case histories from the Cetin et al. (2018a, b) database.

Earthquake	*Site*	*Reason of exclusion*
1944 Tohnankai Earthquake	#1_Ienaga	No recording station is available for that event hence the sites are excluded. The new database does not include case histories with intensity-based acceleration estimations.
	#2_Komei	
	#3_Meiko	The site is excluded due to 1) multiple suspect layers which is the silty upper layer whose SPT ranges from 1-3 and very soft silty clay layer SPT=0-1 both of which may cause settlements observed on the ground surface, 2) the presence of 5 m thick very soft fine-grained layer SPT=0-1 r_d and a_{max} is hard to estimate. No recording station is available for that event hence the site is excluded. The new database does not use intensity-based acceleration estimations.
1948 Fukui Earthquake	#4_Shonenji Temple	No recording station is available for that event hence the site is excluded.
	#5_Takaya 45	The site is excluded due to multiple suspect medium sand layers SPT-N=21.4 with FC=3% versus silty fine sand layer SPT-N=6.6 with FC=49.7 %. Additionally, the same reason with the above site.
1964 Niigata Earthquake	#15_Showa Br. 2	Due to organic material in the upper coarse sand layer and medium sand layer, the site is excluded. Additionally, the presence of the Showa bridge makes the case history an example of soil-structure interaction site. Lastly, Hamada and O'Rourke's (1992) map indicates that the site is sloping where lateral spread occurred. This confirms that the sites are not free field sites and hence excluded from the database.
	#16_Showa Br. 4	

Table 4.4. (cont'd)

1975 Haicheng Earthquake	#24_Panjin Ch. F. P.	No recording station is available for that event hence the sites are excluded.
	#25_Ying Kou G. F. P.	
	#26_Ying Kou P. P.	
1971 San Fernando Earthquake	#22_Juvenile Hall	The sites have a slope of 1-3%. It was also indicated by the original reference as the site has a slope of 1.5%. Bennett (1989) "Maximum displacement was 1.5 m on an average slope of 1.5%". Hence the sites are not free field. The sites are excluded but they can be included if K_α is applied.
	#23_Van Norman	
1976 Guatemala Earthquake	#27_Amatitlan B-1	No recording station is available for that event hence the sites are excluded. The new database does not use intensity-based acceleration estimations.
	#28_Amatitlan B-2	
	#29_Amatitlan B-3&4	
1978 Miyagiken-Oki M_w=6.5 Earthquake	#44_Ishinomaki-2	There exist another suspicious layer at 12-17 m. The presence of multiple suspect layers prevents the selection of the critical layer which produced liquefaction/non-liquefaction performance. As a result, the case history is excluded to eliminate the ambiguity.
	#50_Shiomi 6	There exist another suspect layer at 11-17 m. The presence of multiple suspect layers prevents the selection of the critical layer which produced liquefaction/non-liquefaction performance. As a result, the case history is excluded to eliminate the ambiguity.

Table 4.4. (cont'd)

1978 Miyagiken-Oki M_w=6.5 Earthquake	#54_Yuriagekami-1	There exist another suspicious layer at 6-7.5 m. The presence of multiple suspect layers prevents the selection of the critical layer As a result, the case history is excluded to eliminate the ambiguity. Additionally, between 3-3.4 m of organic materials were observed which intervenes in the saturation of the layers. The case history is excluded to prevent ambiguity.
1978 Miyagiken-Oki Mw=7.7 Earthquake	#59_Ishinomaki-2	There exist another suspicious layer at 12-17 m. The presence of multiple suspect layers makes the selection of the critical layer a difficult task. As a result, the case history is excluded to eliminate the ambiguity.
	#60_Ishinomaki-4	The presence of an oil tank at the site does not only affect the vertical stresses but the horizontal stresses as well. Additionally, there exists another suspect layer at 12-17 m. The presence of multiple suspect layers prevents the selection of the critical layer which produced liquefaction/non-liquefaction performance. As a result, the case history is excluded to eliminate ambiguity.
	#63_Nakajima 2	Nakajima 18 and 2 use the same borehole hence they are the same case histories. As a result, Nakajima 2 is excluded.
	#68_Shiomi 6	There exist another suspicious layer at 11-17 m. The presence of multiple suspect layers prevents the selection of the critical layer which produced liquefaction/non-liquefaction performance. As a result, the case history is excluded to eliminate ambiguity.

Table 4.4. (cont'd)

1978 Miyagiken-Oki Mw=7.7 Earthquake	#73_Yuriagekami-1	There exist another suspicious layer at 6-7.5 m. The presence of multiple suspect layers prevents the selection of the critical layer which produced liquefaction/non-liquefaction performance. Additionally, between 3-3.4 m of organic materials were observed which cause partial saturation of the layer as a result CSR can not be accurately calculated. The case history is excluded to prevent ambiguity.
1979 Imperial Valley Earthquake	#83_RiverPark A	The critical layer consists of SM, ML, CL and is located at a very shallow depth (1.5 m depth) which is hard to correct for overburden stress (C_N>2.0). Hence the site is excluded.
1980 Mid-Chiba Earthquake	#85_Owi-2	#84_Owi-1 and #85_Owi-2 were two non-liquefied case histories from the same borehole in Cetin et al. (2004, 2018a, b) which is against the statistically dependent assumption. Hence #85 was excluded.
1981 Westmorland Earthquake	#89_RiverPark A	The critical layer consists of SM, ML, CL and is located at a very shallow depth (1.5 m depth) which is hard to correct for overburden stress (C_N>2.0). Hence the site is excluded.
1983 Nihonkai-Chubu M=6.7 Earthquake	#94_Arayamotomachi Coarse Sand	#93_Arayamotomachi and #94_Arayamotamachi coarse sand were two non-liquefied case histories from the same borehole in Cetin et al. (2004, 2018a, b) which is against statistically independency assumption. Hence #94 was excluded.
	#95_Takeda El. Sch.	The critical layer is sandwiched between two very soft silt layers (N=0-1) which makes it very difficult to estimate r_d and a_{max} hence the site is excluded.

Table 4.4. (cont'd)

	#100_Gaiko Wharf	#100_Gaiko Wharf and #99_Gaiko 1&2 are merged as the sites were the same. Repetitive case histories hence #100 excluded.
1983 Nihonkai-Chubu M=7.4 Earthquake	#101_Hakodate	There is an ambiguity if the site is free field or not in the vicinity of the Pacific Ocean. In addition, the location of the site may not be correctly located from the map given in the source document since the scale is very small and the coordinates of the borehole are not available. No soil classification information is available hence the site is excluded.
	#110_Takeda El. Sch.	The critical layer is sandwiched between two very soft silt layers (N=0-1) which makes it very difficult to estimate r_d and a_{max} hence the site is excluded.
1987 Superstition Hills Earthquake	#120_RiverPark A	The critical layer consists of SM, ML, CL and is located at a very shallow depth (1.5 m depth) which is hard to correct for overburden stress (C_N>2.0). Hence the site is excluded.
1989 Loma Prieta Earthquake	#143_MarineLab_B-2	Marine Laboratory B-1 & B-2 were two separate case histories. However, they are merged in this study as they are 100 ft apart and the critical layer is the same beach sand. Those case histories are statistically dependent. As a result, they are merged.
1990 Luzon Earthquake	#148_Perez Blv. B-11 #147_Cereenan St. B-12	No recording station is available for that event hence the sites are excluded. The new database does not use intensity-based acceleration estimations.

Table 4.4. (cont'd)

1995 Hyogoken-Nambu Earthquake	#156_Ashiyama A (Marine Sand)	Case histories #156_Ashiyama A (Marine Sand) and #157_Mountain Sand were two non-liquefied case histories in Cetin (2000). This is against statistically independent assumption hence case 156 is excluded.
	#157_Ashiyama C&D&E (Mountain Sand 2)	Case histories #157_ Ashiyama C&D&E (Marine Sand 2) and #158_Mountain Sand were two liquefied case histories in Cetin (2000). This is against statistically independent assumption hence case 158 is excluded.
	#210_Torishima Dike	The site is excluded due to the presence of a very soft layer SPT=0-0-0 which makes r_d and a_{max} hard to estimate. As a result, the site is excluded.

4.4.3 An Overview of the Updated Case Histories from Cetin et al. (2004, 2018a, b)

Previous discussions frame the modifications implemented on the Cetin et al. (2018a, b) database. It should be noted that the Cetin et al. (2018a, b) database includes 210 data on the other hand the new database compiled for this study used 171 of these data. This section presents an overview of the updated case histories from Cetin et al. databases graphically and statistically. However, considering the data size (210 case history data) of Cetin et al. (2018a, b) and the case histories included in the new database (171 case history data), the comparison could only be made based on the same sample of data (common 171 case histories). It should be noted that some of the sites were merged, so the comparison was made based on 171 data.

Figure 4.13 a-m presents a graphical comparison of the effects of changes implemented on the Cetin et al. (2018a, b) database. In these figures, the grey symbols represent the values from the Cetin et. al. (2018a, b) database, and the transparent blue symbols represent the updated (2022) database. Case numbers of Cetin et al. (2018a, b) are used here (#1-210).

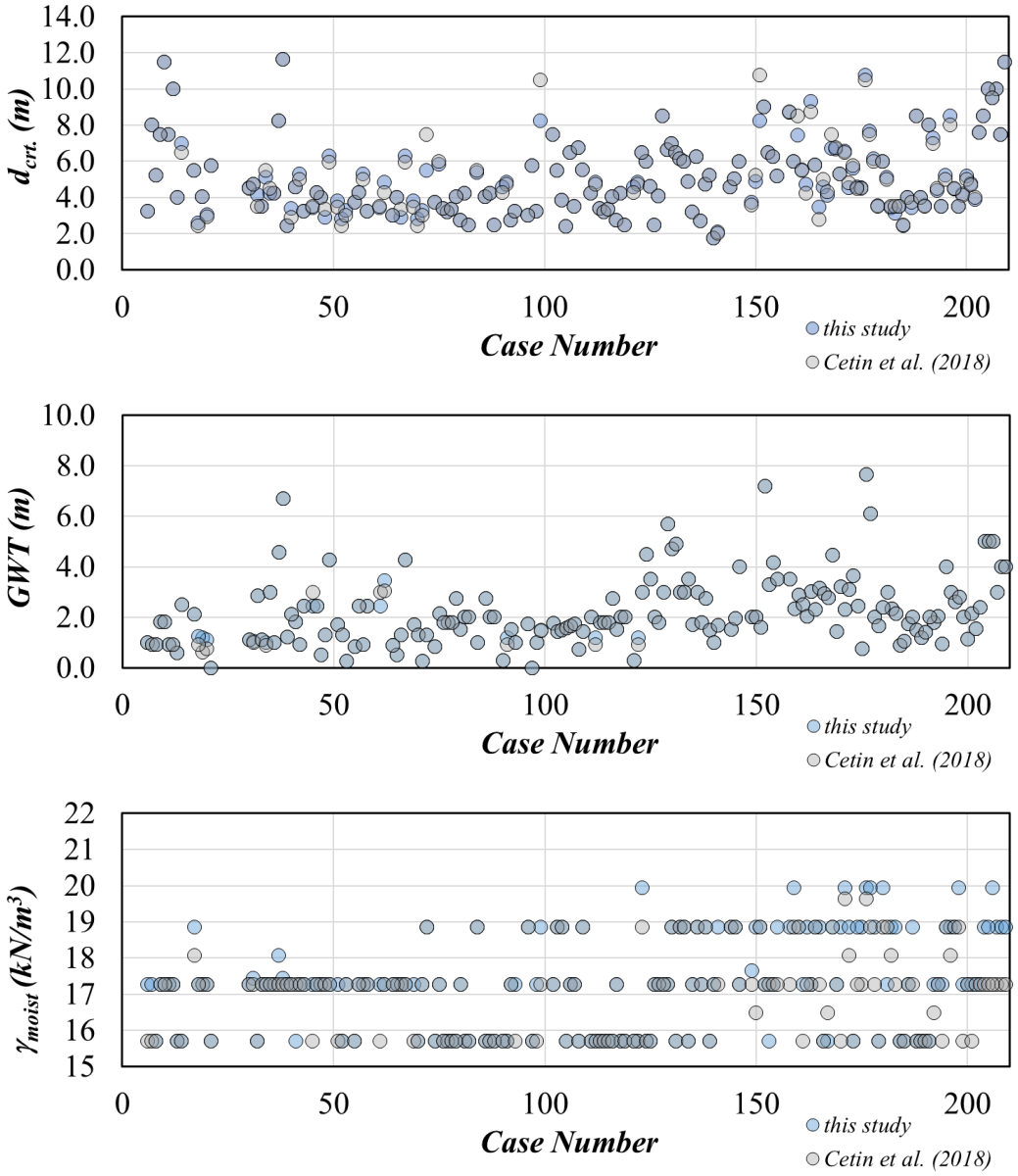


Figure 4.13. Comparison of input parameters according to case history numbers.

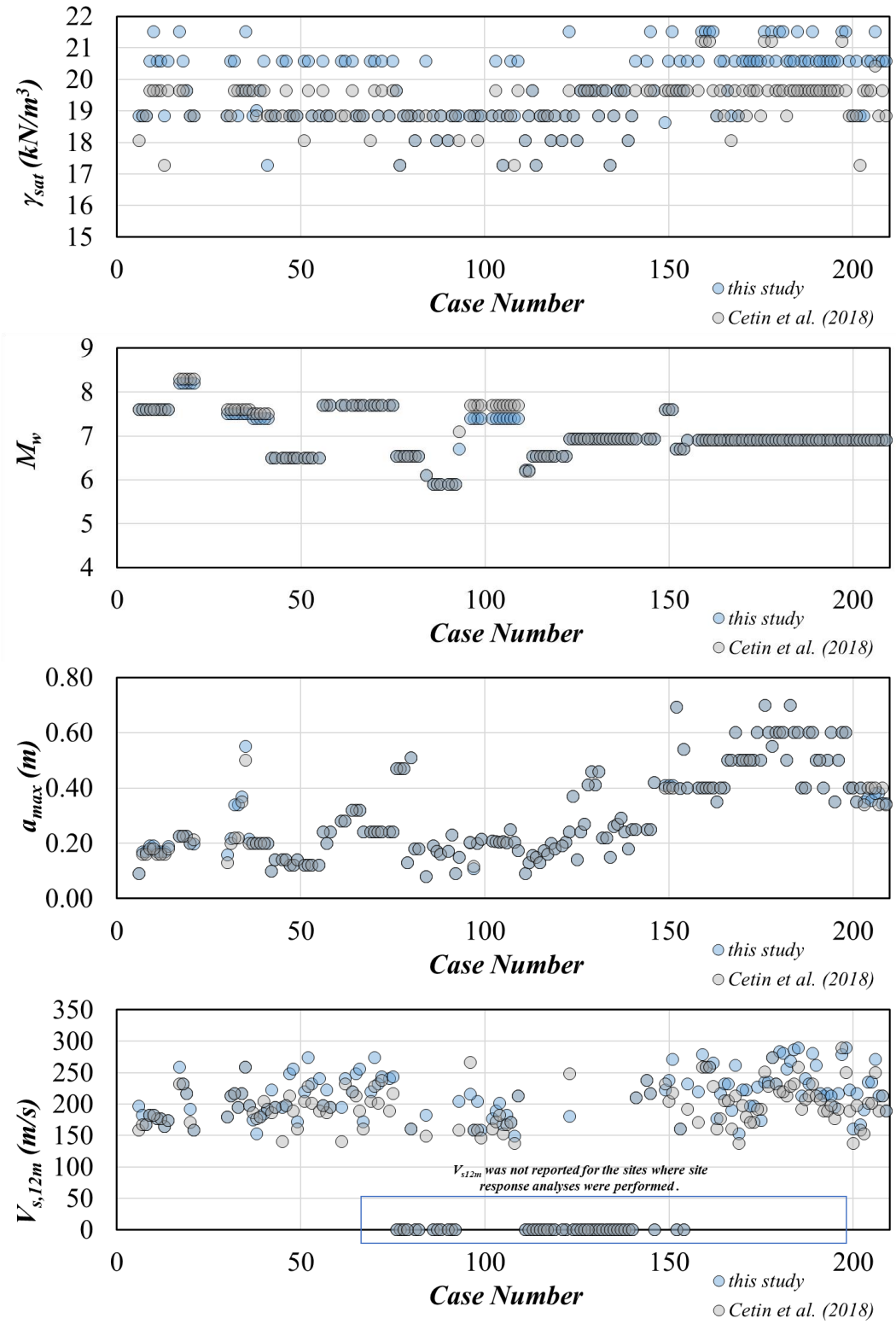


Figure 4.13. (cont'd)

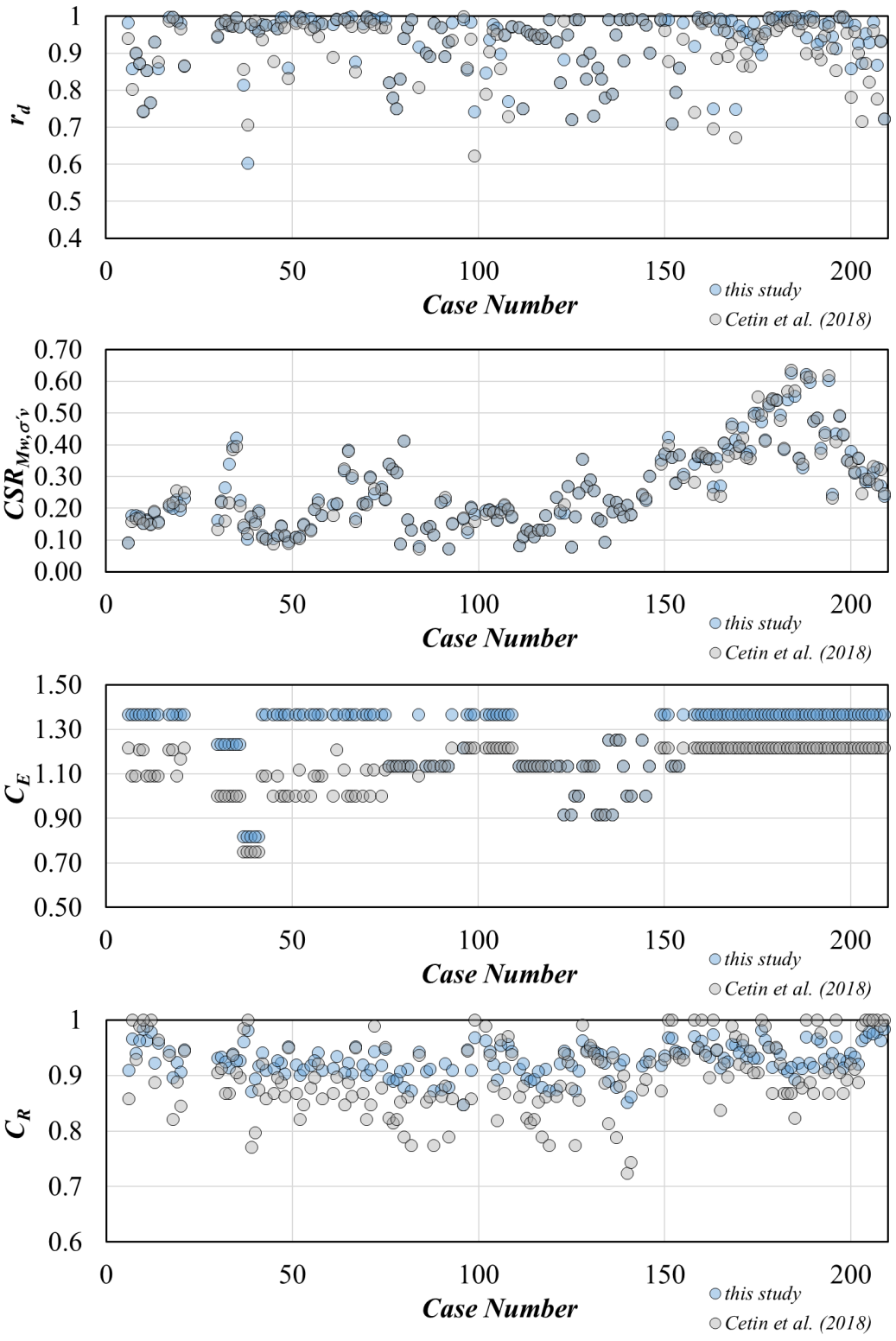


Figure 4.13. (cont'd)

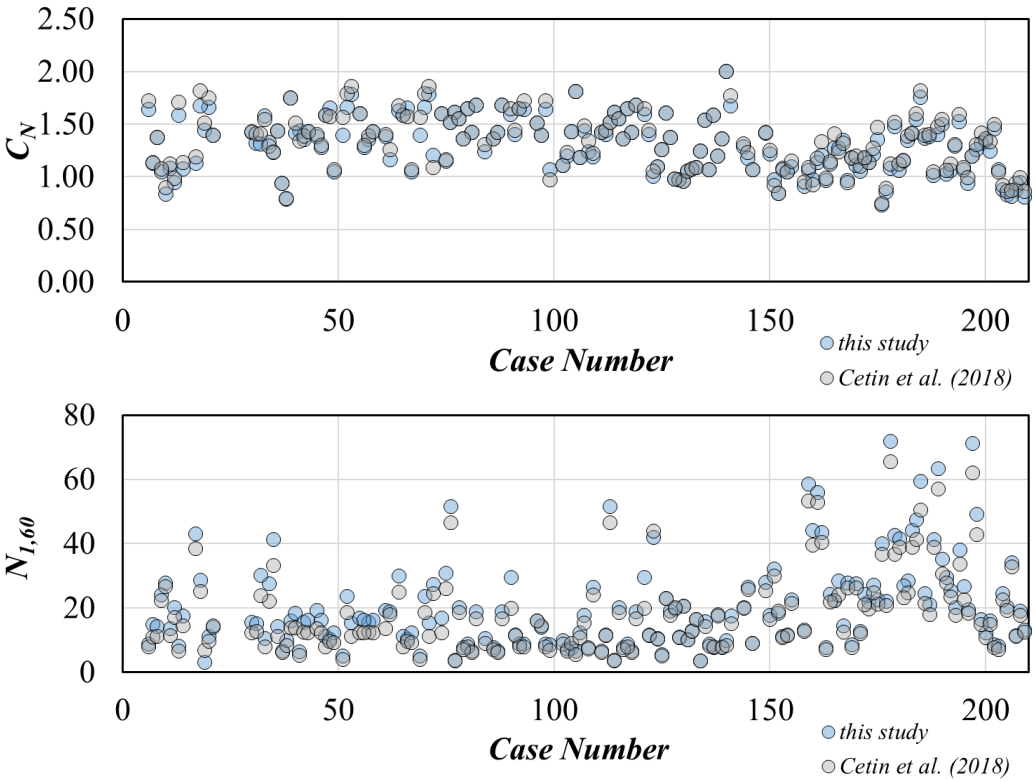


Figure 4.13. (cont'd)

Figure 4.14 a-m presents a graphical comparison of the effects of changes implemented on the Cetin et al. (2018a, b) database.

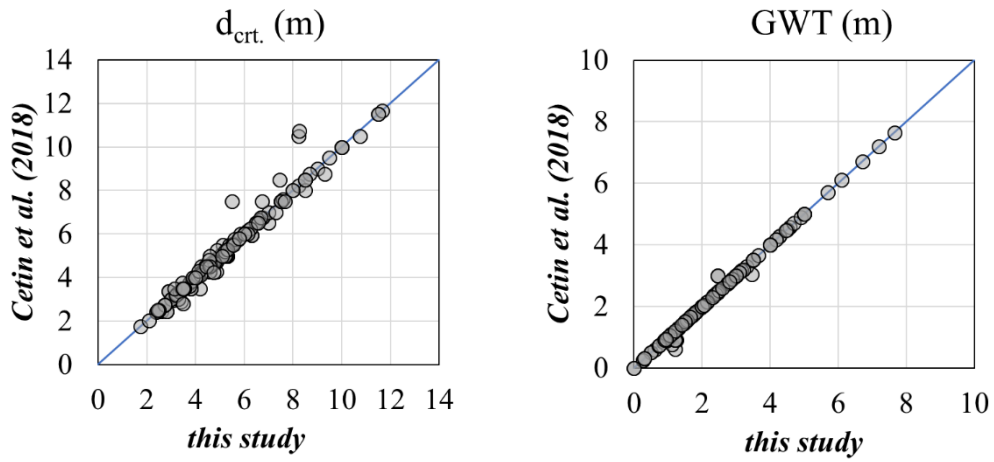


Figure 4.14. Comparison of input parameters on this study versus Cetin et al. (2018a, b) plot.

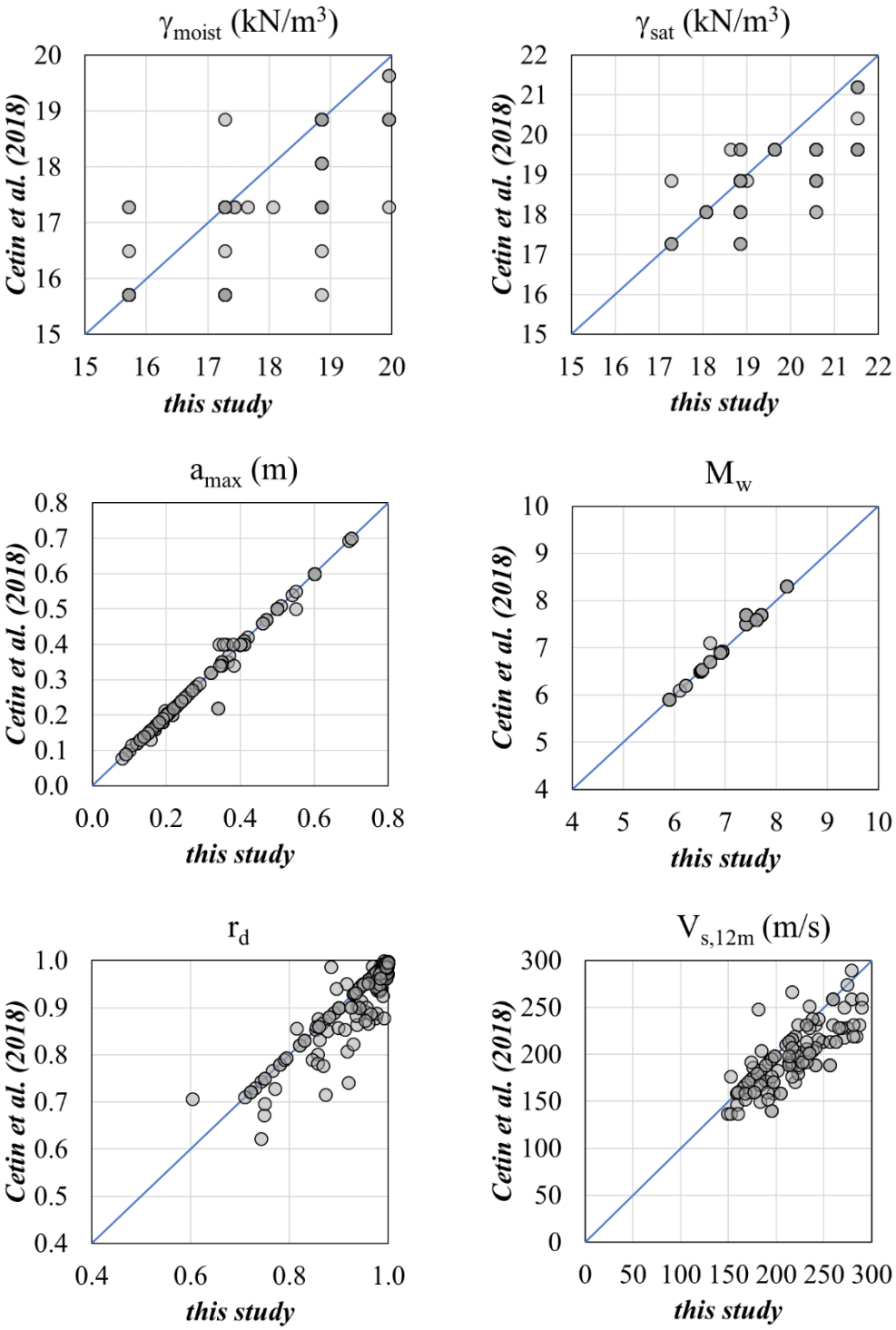


Figure 4.14. (cont'd)

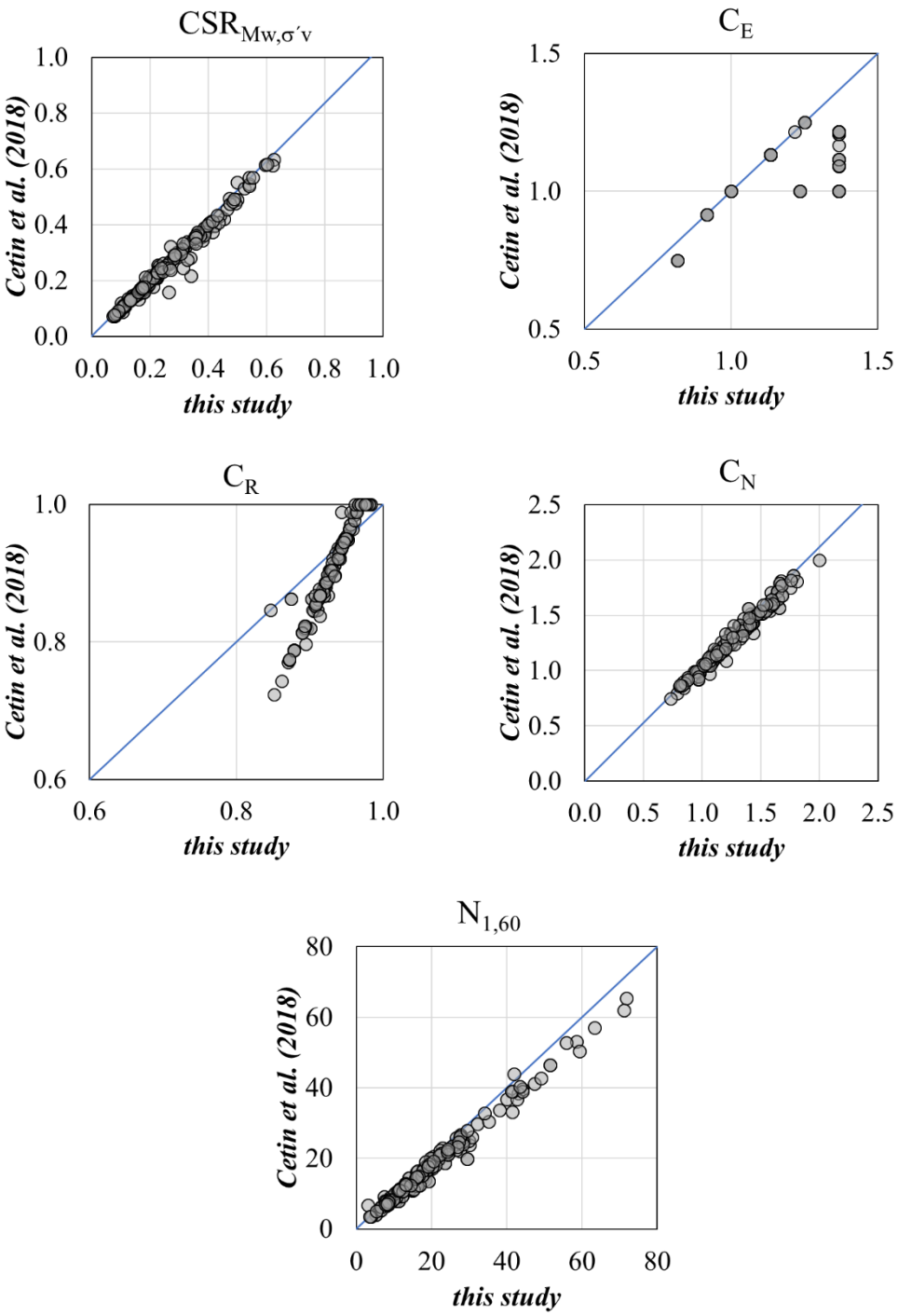


Figure 4.14. (cont'd)

Table 4.5 summarizes a list of the effects of all of these changes. As it can be inferred from this table, the updates are minor. Some important observations regarding the

modifications implemented on the Cetin et al. (2018a, b) database are summarized as follows:

1. $N_{1,60}$ values increased by 12.4% which is mostly due to the increased hammer energy efficiency and less pronounced short rod corrections.
2. CSR values increased by 1.4 % which is mainly due to increased unit weights.

Table 4.5. A summary of the average input parameters (171 case history)

Parameters	*Mean*		*Mean of the St. Dev.*		*Min.*		*Max.*	
	CEA 2018	***this study***	***CEA 2018***	***this study***	***CEA 2018***	***this study***	***CEA 2018***	***this study***
$d_{crt.}$ *(m)*	5.1	5.1	0.5	0.6	1.8	1.8	11.7	11.7
GWT (m)	2.2	2.2	0.1	0.1	0.0	0.0	7.7	7.7
γ_{wet} *(kN/m^3)*	17.0	17.3	0.5	0.5	15.7	15.7	19.6	20.0
γ_{sat} *(kN/m^3)*	19.2	19.8	0.5	0.5	17.3	17.3	21.2	21.5
σ_v *(kPa)*	94.0	96.5	10.5	11.7	31.5	31.5	222.1	240.3
σ'_v *(kPa)*	65.4	68.1	5.6	6.3	24.1	24.1	183.2	189.4
r_d	0.915	0.931	0.059	0.063	0.622	0.603	0.999	0.999
a_{max} *(g)*	0.310	0.312	0.063	0.058	0.079	0.080	0.700	0.700
M_w	7.1	7.0	-	0.067	5.9	5.9	8.3	8.2
CSR	0.262	0.265	0.059	0.055	0.072	0.072	0.634	0.626
FC (%)	12.5	12.2	3.8	8.2	0.0	0.0	83.0	83.0
D_{50} *(mm)*	0.293	0.280	0.045	0.104	0.045	0.045	1.600	1.540
C_R	0.90	0.93	-	-	0.72	0.85	1.00	0.98
C_B	1.00	1.00	-	-	1.00	1.00	1.15	1.15
C_E	1.13	1.27	-	-	0.75	0.82	1.25	1.37
C_N	1.33	1.30	-	-	0.74	0.73	2.00	2.00
$(N_1)_{60}$	18.0	20.3	3.4	3.8	3.5	3.1	65.5	71.7
$V_{s,12m}$ *(m/s)*	197.6	215.5	-	-	137.2	149.4	289.6	289.6
K_σ	1.21	1.09	-	-	0.82	0.90	1.62	1.26
K_{Mw}	1.18	1.05	-	-	0.79	0.94	1.75	1.18
$CSR_{Mw=7.5,\sigma'v=1atm}$	0.195	0.236	-	-	0.029	0.052	0.496	0.585
$N_{1,60,CS}$	19.4	21.9	-	-	5.0	3.1	66.5	71.7

**Cetin et al. (2018a, b) denoted as CEA 2018.*

Table 4.5 and Figure 4.15 present the mean values of the corrected $N_{1,60}$ versus $CSR_{\sigma'v,\,Mw}$ (not normalized for K_σ, K_{Mw}, K_α effects) data points compiled from the Cetin et al. (2018a, b) database, as they were updated and re-processed.

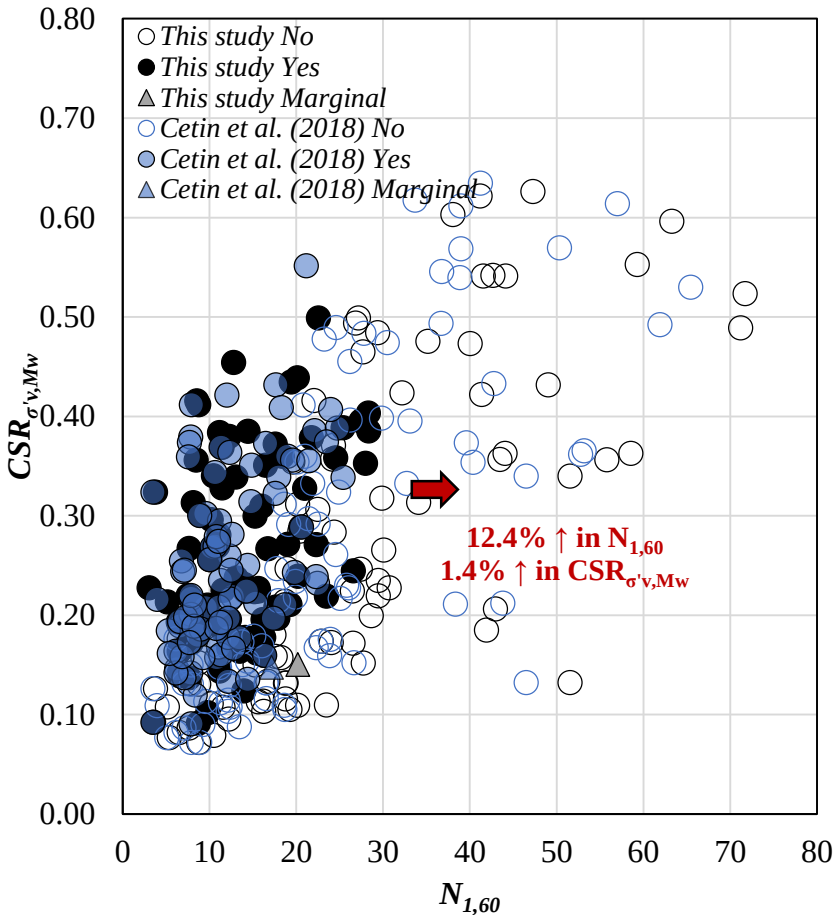


Figure 4.15. Comparison of updated Cetin et al. (2018a, b) and the re-processed case histories within this thesis (171) on corrected $N_{1,60}$ versus $CSR_{\sigma'v,\,Mw}$.

4.5 An Overview of the Case History Database

The new database which includes the new data and updated legacy case histories consists of 178 liquefied, 154 non-liquefied, and 1 marginal case history in total. This section presents the new case history database catalog which consists of 334 liquefaction field case history data. Table 4.6 presents the summary sheets of the compiled database.

Table 4.6. Summary of the SPT-based case history database. (334 case histories)

ID #	Earthquake & Site	GMIndicates Liq. (No=0/Yes=1)	Surface Manif. (No=0/Yes=1)	Liq.?	d_{crt} (m)	GWT (m)	γ_1 (kN/m^3)	γ_2 (kN/m^3)	σ_v (kPa)	σ_v' (kPa)	$V^*_{s,12m}$ (m/s)	r_d	a_{max}	M_w	CSR	D_{50} (mm)	FC %	C_S	C_R	C_B	C_E	C_N	$(N_1)_{60}$	K_σ	K_{Mw}	$CSR_{Mw=7.5,\sigma'v=1 atm}$	$N_{1,60,CS}$
	1964 Niigata Earthquake																										
1	*Arayamotomachi*	*NAP*	*1*	*Yes*	*3.3 ± 0.8*	*1.0 ± 0.1*	*17.3*	*18.9*	*59.7 ± 14.2*	*37.6 ± 6.9*	*197*	*0.98 ± 0.05*	*0.09 ± 0.01*	*7.6 ± 0.1*	*0.09 ± 0.02*	*0.15 ± 0.05*	*5.0 ± 8.6*	*1.00*	*0.91*	*1.00*	*1.37*	*1.64*	*8.8 ± 3.8*	*1.18*	*0.99*	*0.08*	*8.77*
2	*Cc17-1*	*NAP*	*1*	*Yes*	*8.0 ± 1.0*	*0.9 ± 0.1*	*17.3*	*18.9*	*149.4 ± 19.1*	*79.9 ± 9.7*	*183*	*0.86 ± 0.12*	*0.17 ± 0.03*	*7.6 ± 0.1*	*0.18 ± 0.04*	*0.20 ± 0.05*	*2.0 ± 8.6*	*1.00*	*0.97*	*1.00*	*1.37*	*1.13*	*14.9 ± 4.1*	*1.04*	*0.99*	*0.17*	*14.87*
3	*Cc17-2*	*NAP*	*1*	*Yes*	*5.3 ± 0.6*	*0.9 ± 0.1*	*15.7*	*18.9*	*96.1 ± 11.2*	*53.6 ± 5.7*	*168*	*0.90 ± 0.08*	*0.17 ± 0.03*	*7.6 ± 0.1*	*0.18 ± 0.03*	*0.20 ± 0.05*	*2.0 ± 8.6*	*1.00*	*0.94*	*1.00*	*1.37*	*1.38*	*14.1 ± 2.3*	*1.11*	*0.99*	*0.16*	*14.13*
4	*Old Town -1*	*NAP*	*0*	*No*	*7.5 ± 0.8*	*1.8 ± 0.1*	*17.3*	*20.6*	*148.3 ± 17.4*	*92.7 ± 9.4*	*183*	*0.87 ± 0.11*	*0.19 ± 0.03*	*7.6 ± 0.1*	*0.17 ± 0.03*	*0.20 ± 0.05*	*2.0 ± 8.6*	*1.00*	*0.96*	*1.00*	*1.37*	*1.05*	*24.1 ± 0.3*	*1.01*	*0.99*	*0.17*	*24.06*
5	*Old Town -2*	*NAP*	*0*	*No*	*11.5 ± 0.5*	*1.8 ± 0.1*	*17.3*	*21.5*	*239.7 ± 11.7*	*144.9 ± 7.5*	*183*	*0.74 ± 0.16*	*0.19 ± 0.03*	*7.6 ± 0.1*	*0.15 ± 0.04*	*0.20 ± 0.05*	*2.0 ± 8.6*	*1.00*	*0.98*	*1.00*	*1.37*	*0.84*	*27.8 ± 3.4*	*0.94*	*0.99*	*0.16*	*27.76*
6	*Rail Road-2*	*NAP*	*0.5*	*No/Yes*	*10.0 ± 0.3*	*0.9 ± 0.3*	*17.3*	*20.6*	*202.8 ± 8.2*	*113.7 ± 5.9*	*177*	*0.77 ± 0.14*	*0.17 ± 0.03*	*7.6 ± 0.1*	*0.15 ± 0.04*	*0.20 ± 0.05*	*2.0 ± 8.6*	*1.00*	*0.98*	*1.00*	*1.37*	*0.94*	*20.2 ± 2.0*	*0.98*	*0.99*	*0.15*	*20.18*
7	*Rail Road-1*	*NAP*	*1*	*Yes*	*7.5 ± 0.8*	*0.9 ± 0.1*	*17.3*	*20.6*	*151.3 ± 17.4*	*86.8 ± 9.5*	*177*	*0.85 ± 0.11*	*0.17 ± 0.03*	*7.6 ± 0.1*	*0.16 ± 0.03*	*0.20 ± 0.05*	*2.0 ± 8.6*	*1.00*	*0.96*	*1.00*	*1.37*	*1.08*	*13.5 ± 1.3*	*1.03*	*0.99*	*0.16*	*13.50*
8	*River Site*	*NAP*	*1*	*Yes*	*4.0 ± 0.7*	*0.6 ± 0.1*	*15.7*	*18.9*	*73.5 ± 12.7*	*40.2 ± 6.3*	*165*	*0.93 ± 0.06*	*0.17 ± 0.03*	*7.6 ± 0.1*	*0.19 ± 0.03*	*0.40 ± 0.05*	*0.0 ± 8.6*	*1.00*	*0.92*	*1.00*	*1.37*	*1.59*	*8.1 ± 2.1*	*1.16*	*0.99*	*0.16*	*8.10*
9	*Road Site*	*NAP*	*0*	*No*	*7.0 ± 1.0*	*2.5 ± 0.1*	*15.7*	*20.6*	*131.9 ± 20.7*	*87.8 ± 11.1*	*174*	*0.86 ± 0.10*	*0.19 ± 0.03*	*7.6 ± 0.1*	*0.16 ± 0.03*	*0.36 ± 0.13*	*0.0 ± 8.6*	*1.00*	*0.96*	*1.00*	*1.37*	*1.07*	*17.6 ± 4.7*	*1.02*	*0.99*	*0.16*	*17.59*
	1968 Tokachi-oki Earthquake																										
10	*Hachinohe - 2*	*NAP*	*0*	*No*	*5.5 ± 0.8*	*2.1 ± 0.1*	*18.9*	*21.5*	*112.4 ± 17.6*	*79.5 ± 9.7*	*259*	*1.00 ± 0.08*	*0.23 ± 0.07*	*8.2 ± 0.0*	*0.21 ± 0.06*	*0.25 ± 0.05*	*5.0 ± 8.6*	*1.00*	*0.94*	*1.00*	*1.37*	*1.13*	*43.0 ± 8.4*	*1.04*	*0.94*	*0.21*	*42.98*
11	*Hachinohe - 4*	*NAP*	*0*	*No*	*2.6 ± 0.5*	*1.3 ± 0.1*	*17.3*	*20.6*	*49.5 ± 9.3*	*36.2 ± 5.0*	*232*	*1.00 ± 0.04*	*0.23 ± 0.07*	*8.2 ± 0.0*	*0.20 ± 0.06*	*0.25 ± 0.05*	*5.0 ± 8.6*	*1.00*	*0.90*	*1.00*	*1.37*	*1.67*	*28.7 ± 1.8*	*1.18*	*0.94*	*0.18*	*28.68*
12	*Hachinohe - 6*	*NAP*	*1*	*Yes*	*4.1 ± 0.7*	*1.2 ± 0.1*	*17.3*	*19.6*	*76.8 ± 13.4*	*48.8 ± 6.9*	*216*	*0.99 ± 0.06*	*0.23 ± 0.07*	*8.2 ± 0.0*	*0.23 ± 0.07*	*0.25 ± 0.05*	*5.0 ± 8.6*	*1.00*	*0.92*	*1.00*	*1.37*	*1.44*	*3.1 ± 1.9*	*1.13*	*0.94*	*0.21*	*3.09*
13	*Nanaehama 1-2-3*	*NAP*	*1*	*Yes*	*3.1 ± 0.7*	*1.1 ± 0.2*	*17.3*	*18.9*	*55.8 ± 12.3*	*36.7 ± 6.1*	*192*	*0.98 ± 0.05*	*0.20 ± 0.06*	*8.2 ± 0.0*	*0.19 ± 0.06*	*0.12 ± 0.03*	*21.7 ± 4.8*	*1.00*	*0.91*	*1.00*	*1.37*	*1.66*	*11.2 ± 1.8*	*1.18*	*0.94*	*0.17*	*15.87*
14	*Aomori Railway Station*	*NAP*	*1*	*Yes*	*5.8 ± 0.6*	*0.0 ± 0.1*	*15.7*	*18.9*	*108.4 ± 11.3*	*52.0 ± 6.0*	*158*	*0.87 ± 0.09*	*0.20 ± 0.01*	*8.2 ± 0.0*	*0.23 ± 0.03*	*0.25 ± 0.05*	*5.0 ± 8.6*	*1.00*	*0.95*	*1.00*	*1.37*	*1.40*	*14.0 ± 2.6*	*1.11*	*0.94*	*0.22*	*13.98*
	1976 Tangshan Earthquake																										
15	*Coastal Region*	*NAP*	*1*	*Yes*	*4.6 ± 0.7*	*1.1 ± 0.1*	*17.3*	*18.9*	*84.0 ± 12.4*	*50.2 ± 6.2*	*180*	*0.94 ± 0.06*	*0.16 ± 0.03*	*7.5 ± 0.1*	*0.16 ± 0.03*	*0.14 ± 0.05*	*12.0 ± 8.6*	*1.00*	*0.93*	*1.00*	*1.23*	*1.42*	*15.5 ± 3.4*	*1.12*	*1.00*	*0.14*	*17.39*
16	*Le Ting*	*NAP*	*1*	*Yes*	*4.8 ± 0.4*	*1.1 ± 0.2*	*17.4*	*20.6*	*94.4 ± 8.8*	*58.2 ± 5.0*	*213*	*0.98 ± 0.07*	*0.22 ± 0.04*	*7.5 ± 0.1*	*0.22 ± 0.05*	*0.19 ± 0.04*	*12.0 ± 8.6*	*1.00*	*0.93*	*1.00*	*1.23*	*1.32*	*15.2 ± 3.0*	*1.09*	*1.00*	*0.20*	*17.10*
17	*Luan Nan-L1*	*NAP*	*0*	*No*	*4.2 ± 0.4*	*2.9 ± 0.1*	*15.7*	*20.6*	*72.0 ± 9.2*	*59.0 ± 5.0*	*216*	*0.98 ± 0.06*	*0.34 ± 0.07*	*7.5 ± 0.1*	*0.27 ± 0.06*	*0.17 ± 0.05*	*5.0 ± 8.6*	*1.00*	*0.92*	*1.00*	*1.23*	*1.31*	*30.1 ± 3.8*	*1.09*	*1.00*	*0.24*	*30.11*
18	*Luan Nan-L2*	*NAP*	*1*	*Yes*	*3.5 ± 0.7*	*1.1 ± 0.1*	*17.3*	*18.9*	*64.2 ± 12.6*	*40.7 ± 6.2*	*195*	*0.97 ± 0.05*	*0.34 ± 0.07*	*7.5 ± 0.1*	*0.34 ± 0.07*	*0.17 ± 0.05*	*3.0 ± 8.6*	*1.00*	*0.91*	*1.00*	*1.23*	*1.58*	*10.5 ± 1.0*	*1.16*	*1.00*	*0.29*	*10.49*
19	*Qing Jia Ying*	*NAP*	*1*	*Yes*	*5.1 ± 0.5*	*1.0 ± 0.1*	*17.3*	*19.6*	*98.3 ± 9.2*	*57.8 ± 5.0*	*216*	*0.98 ± 0.07*	*0.37 ± 0.07*	*7.5 ± 0.1*	*0.40 ± 0.08*	*0.14 ± 0.05*	*20.0 ± 8.6*	*1.00*	*0.94*	*1.00*	*1.23*	*1.32*	*27.5 ± 2.9*	*1.10*	*1.00*	*0.36*	*31.81*
20	*Tangshan City*	*NAP*	*0*	*No*	*4.3 ± 0.4*	*3.0 ± 0.1*	*17.3*	*21.5*	*78.7 ± 9.1*	*66.5 ± 5.1*	*259*	*1.00 ± 0.06*	*0.55 ± 0.11*	*7.5 ± 0.1*	*0.42 ± 0.09*	*0.20 ± 0.05*	*10.0 ± 8.6*	*1.00*	*0.93*	*1.00*	*1.23*	*1.23*	*41.4 ± 9.0*	*1.07*	*1.00*	*0.39*	*42.65*
21	*Yao Yuan Village*	*NAP*	*1*	*Yes*	*4.3 ± 0.3*	*1.0 ± 0.1*	*17.3*	*19.6*	*81.1 ± 5.2*	*49.2 ± 3.0*	*198*	*0.97 ± 0.06*	*0.22 ± 0.04*	*7.5 ± 0.1*	*0.22 ± 0.05*	*0.15 ± 0.05*	*20.0 ± 8.6*	*1.00*	*0.93*	*1.00*	*1.23*	*1.43*	*14.2 ± 6.5*	*1.12*	*1.00*	*0.20*	*18.49*
22	*Tangshan_Wali*	*NAP*	*1*	*Yes*	*3.4 ± 0.4*	*1.3 ± 0.1*	*19.3*	*19.8*	*65.8 ± 7.0*	*45.2 ± 3.8*	*202*	*0.98 ± 0.05*	*0.56 ± 0.11*	*7.5 ± 0.1*	*0.52 ± 0.11*	*0.28 ± 0.11*	*4.9 ± 6.5*	*1.00*	*0.91*	*1.00*	*1.23*	*1.50*	*17.0 ± 1.1*	*1.14*	*1.00*	*0.46*	*17.00*
23	*Fengnan_Xugezhuang*	*NAP*	*0*	*No*	*3.2 ± 0.5*	*1.5 ± 0.1*	*18.9*	*19.6*	*61.7 ± 9.2*	*45.0 ± 4.8*	*170*	*0.94 ± 0.05*	*0.77 ± 0.15*	*7.5 ± 0.1*	*0.65 ± 0.14*	*0.16 ± 0.08*	*24.7 ± 19.4*	*1.00*	*0.91*	*1.00*	*1.23*	*1.50*	*36.7 ± 10.0*	*1.14*	*1.00*	*0.57*	*41.87*
24	*Tangshan_Xidafutuo*	*NAP*	*1*	*Yes*	*5.0 ± 0.2*	*1.5 ± 0.1*	*18.1*	*20.2*	*96.9 ± 4.1*	*63.1 ± 2.7*	*166*	*0.89 ± 0.07*	*0.60 ± 0.12*	*7.5 ± 0.1*	*0.53 ± 0.11*	*0.30 ± 0.05*	*4.4 ± 8.6*	*1.00*	*0.94*	*1.00*	*1.23*	*1.27*	*22.4 ± 2.0*	*1.08*	*1.00*	*0.49*	*22.38*
25	*Tangshan_Laobianzhuang*	*NAP*	*1*	*Yes*	*5.3 ± 0.5*	*2.2 ± 0.1*	*17.9*	*19.6*	*100.8 ± 9.2*	*70.1 ± 4.9*	*186*	*0.93 ± 0.07*	*0.57 ± 0.11*	*7.5 ± 0.1*	*0.49 ± 0.11*	*0.47 ± 0.12*	*2.4 ± 1.5*	*1.00*	*0.94*	*1.00*	*1.23*	*1.20*	*13.0 ± 1.9*	*1.06*	*1.00*	*0.46*	*12.96*
26	*Fengnan_Rice field*	*NAP*	*0*	*No*	*4.1 ± 0.4*	*1.1 ± 0.1*	*18.9*	*21.2*	*84.4 ± 8.6*	*54.9 ± 4.9*	*190*	*0.96 ± 0.06*	*0.54 ± 0.11*	*7.5 ± 0.1*	*0.52 ± 0.11*	*0.15 ± 0.05*	*17.5 ± 8.9*	*1.00*	*0.92*	*1.00*	*1.23*	*1.36*	*20.3 ± 2.0*	*1.10*	*1.00*	*0.47*	*24.01*
27	*Fengnan_Jingzhuang*	*NAP*	*1*	*Yes*	*7.8 ± 0.6*	*1.5 ± 0.1*	*17.3*	*20.1*	*151.7 ± 12.1*	*90.0 ± 6.8*	*177*	*0.81 ± 0.10*	*0.57 ± 0.11*	*7.5 ± 0.1*	*0.51 ± 0.12*	*0.29 ± 0.03*	*3.0 ± 0.9*	*1.00*	*0.96*	*1.00*	*1.23*	*1.06*	*12.9 ± 2.1*	*1.02*	*1.00*	*0.50*	*12.87*
28	*Fengnan_Fanzhuang*	*NAP*	*1*	*Yes*	*2.8 ± 0.3*	*0.9 ± 0.1*	*18.9*	*20.6*	*55.1 ± 5.2*	*36.5 ± 3.0*	*179*	*0.97 ± 0.04*	*0.55 ± 0.11*	*7.5 ± 0.1*	*0.53 ± 0.11*	*0.16 ± 0.02*	*9.2 ± 0.8*	*1.00*	*0.90*	*1.00*	*1.23*	*1.67*	*26.4 ± 1.9*	*1.18*	*1.00*	*0.45*	*27.45*
29	*Fengnan_Xuanzhuang*	*NAP*	*1*	*Yes*	*6.0 ± 1.4*	*1.6 ± 0.1*	*17.3*	*18.9*	*110.7 ± 26.5*	*67.0 ± 12.9*	*178*	*0.88 ± 0.08*	*0.70 ± 0.14*	*7.5 ± 0.1*	*0.66 ± 0.15*	*0.18 ± 0.04*	*8.0 ± 5.1*	*1.00*	*0.95*	*1.00*	*1.23*	*1.23*	*11.7 ± 3.4*	*1.07*	*1.00*	*0.61*	*12.41*
30	*Fengnan_Caogezhuang*	*NAP*	*1*	*Yes*	*3.9 ± 0.6*	*1.1 ± 0.1*	*17.3*	*20.6*	*76.8 ± 13.1*	*48.9 ± 7.0*	*198*	*0.97 ± 0.06*	*0.42 ± 0.08*	*7.5 ± 0.1*	*0.41 ± 0.09*	*0.16 ± 0.04*	*20.3 ± 7.3*	*1.00*	*0.92*	*1.00*	*1.23*	*1.44*	*21.3 ± 7.3*	*1.13*	*1.00*	*0.37*	*25.63*
31	*Luannan_Zhuanglizhuang*	*NAP*	*0*	*No*	*4.3 ± 0.5*	*2.8 ± 0.1*	*18.5*	*19.9*	*80.8 ± 9.7*	*66.6 ± 5.2*	*234*	*0.99 ± 0.06*	*0.26 ± 0.05*	*7.5 ± 0.1*	*0.20 ± 0.04*	*0.20 ± 0.05*	*10.7 ± 2.1*	*1.00*	*0.93*	*1.00*	*1.23*	*1.23*	*28.5 ± 3.9*	*1.07*	*1.00*	*0.19*	*29.94*
32	*Luannan_Wangguanzhai*	*NAP*	*1*	*Yes*	*10.1 ± 0.1*	*3.6 ± 0.1*	*17.6*	*19.5*	*189.7 ± 4.4*	*126.0 ± 3.8*	*217*	*0.90 ± 0.13*	*0.24 ± 0.05*	*7.5 ± 0.1*	*0.21 ± 0.05*	*0.20 ± 0.05*	*10.0 ± 8.6*	*1.00*	*0.98*	*1.00*	*1.23*	*0.90*	*16.1 ± 2.0*	*0.97*	*1.00*	*0.22*	*17.38*
33	*Luannan_Jiangpao*	*NAP*	*1*	*Yes*	*3.3 ± 0.7*	*1.1 ± 0.1*	*17.8*	*18.9*	*61.2 ± 13.9*	*39.6 ± 6.8*	*162*	*0.94 ± 0.05*	*0.24 ± 0.05*	*7.5 ± 0.1*	*0.23 ± 0.05*	*0.23 ± 0.06*	*3.9 ± 6.3*	*1.00*	*0.91*	*1.00*	*1.23*	*1.60*	*10.9 ± 1.4*	*1.17*	*1.00*	*0.19*	*10.86*
34	*Luannan_Gaocaozhuang*	*NAP*	*0*	*No*	*10.6 ± 0.6*	*1.1 ± 0.1*	*19.9*	*20.3*	*214.8 ± 13.6*	*121.6 ± 8.1*	*224*	*0.91 ± 0.13*	*0.23 ± 0.05*	*7.5 ± 0.1*	*0.24 ± 0.06*	*NAV + NAV*	*31.0 ± 10.0*	*1.00*	*0.98*	*1.00*	*1.23*	*0.91*	*26.8 ± 2.3*	*0.97*	*1.00*	*0.25*	*32.45*
35	*Luannan_Crematory*	*NAP*	*0*	*No*	*4.4 ± 0.4*	*3.1 ± 0.1*	*18.5*	*20.3*	*83.8 ± 8.9*	*71.1 ± 4.9*	*221*	*0.99 ± 0.06*	*0.22 ± 0.04*	*7.5 ± 0.1*	*0.17 ± 0.04*	*0.23 ± 0.08*	*13.0 ± 11.8*	*1.00*	*0.93*	*1.00*	*1.23*	*1.19*	*24.8 ± 3.7*	*1.06*	*1.00*	*0.16*	*27.04*
36	*Luannan_Xinzhuangzi*	*NAP*	*1*	*Yes*	*9.5 ± 0.6*	*0.8 ± 0.1*	*18.9*	*18.8*	*178.0 ± 11.7*	*93.2 ± 6.7*	*202*	*0.87 ± 0.12*	*0.22 ± 0.04*	*7.5 ± 0.1*	*0.24 ± 0.06*	*0.21 ± 0.06*	*6.1 ± 4.1*	*1.00*	*0.97*	*1.00*	*1.23*	*1.04*	*24.5 ± 3.6*	*1.01*	*1.00*	*0.23*	*24.74*
37	*Luannan_Weigezhuang*	*NAP*	*1*	*Yes*	*2.0 ± 0.2*	*1.4 ± 0.1*	*18.0*	*18.9*	*37.1 ± 4.3*	*30.5 ± 2.3*	*188*	*0.99 ± 0.03*	*0.21 ± 0.04*	*7.5 ± 0.1*	*0.16 ± 0.03*	*0.15 ± 0.05*	*9.0 ± 2.1*	*1.00*	*0.88*	*1.00*	*1.23*	*1.82*	*21.2 ± 0.1*	*1.22*	*1.00*	*0.13*	*22.19*
38	*Baigezhuang_Farm6*	*NAP*	*1*	*Yes*	*2.2 ± 0.4*	*1.0 ± 0.1*	*18.9*	*20.6*	*42.5 ± 7.9*	*31.2 ± 4.3*	*202*	*0.99 ± 0.03*	*0.29 ± 0.06*	*7.5 ± 0.1*	*0.25 ± 0.05*	*0.17 ± 0.05*	*11.0 ± 8.9*	*1.00*	*0.89*	*1.00*	*1.23*	*1.80*	*22.2 ± 11.2*	*1.21*	*1.00*	*0.21*	*23.82*
39	*Leting_Magezhuang*	*NAP*	*0*	*No*	*6.2 ± 0.5*	*2.5 ± 0.1*	*19.0*	*18.7*	*116.9 ± 9.6*	*80.6 ± 5.0*	*216*	*0.97 ± 0.08*	*0.18 ± 0.04*	*7.5 ± 0.1*	*0.16 ± 0.04*	*0.27 ± 0.06*	*2.0 ± 0.8*	*1.00*	*0.95*	*1.00*	*1.23*	*1.12*	*24.0 ± 2.1*	*1.04*	*1.00*	*0.16*	*23.99*
40	*Leting_Caigezhuang*	*NAP*	*1*	*Yes*	*5.6 ± 1.0*	*2.3 ± 0.1*	*19.5*	*19.1*	*107.0 ± 18.9*	*75.2 ± 9.4*	*226*	*0.98 ± 0.08*	*0.17 ± 0.03*	*7.5 ± 0.1*	*0.15 ± 0.03*	*0.32 ± 0.14*	*1.6 ± 0.5*	*1.00*	*0.94*	*1.00*	*1.23*	*1.16*	*20.2 ± 5.0*	*1.05*	*1.00*	*0.14*	*20.20*
41	*Leting_Liubianzhuang*	*NAP*	*1*	*Yes*	*9.2 ± 1.5*	*2.3 ± 0.1*	*18.5*	*19.0*	*173.9 ± 28.7*	*106.3 ± 14.3*	*201*	*0.88 ± 0.12*	*0.16 ± 0.03*	*7.5 ± 0.1*	*0.15 ± 0.04*	*0.31 ± 0.03*	*3.6 ± 2.1*	*1.00*	*0.97*	*1.00*	*1.23*	*0.98*	*20.8 ± 2.9*	*0.99*	*1.00*	*0.15*	*20.81*
42	*Leting_Maozhuang*	*NAP*	*0*	*No*	*6.5 ± 0.3*	*2.3 ± 0.1*	*17.8*	*18.7*	*119.5 ± 6.6*	*78.3 ± 3.8*	*195*	*0.93 ± 0.09*	*0.16 ± 0.03*	*7.5 ± 0.1*	*0.14 ± 0.03*	*0.23 ± 0.02*	*2.5 ± 0.5*	*1.00*	*0.95*	*1.00*	*1.23*	*1.14*	*13.9 ± 1.4*	*1.04*	*1.00*	*0.14*	*13.91*
	1977 Argentina Earthquake																										
43	*San Juan B-1*	*NAP*	*1*	*Yes*	*8.2 ± 0.1*	*4.6 ± 0.1*	*18.1*	*18.9*	*151.5 ± 3.4*	*115.7 ± 3.1*	*175*	*0.81 ± 0.11*	*0.20 ± 0.04*	*7.4 ± 0.1*	*0.14 ± 0.03*	*0.14 ± 0.05*	*20.0 ± 8.6*	*1.00*	*0.96*	*1.00*	*0.82*	*0.94*	*6.6 ± 2.0*	*0.98*	*1.01*	*0.14*	*10.93*
44	*San Juan B-3*	*NAP*	*1*	*Yes*	*11.7 ± 0.5*	*6.7 ± 0.1*	*17.4*	*19.0*	*210.9 ± 10.0*	*162.4 ± 6.0*	*152*	*0.60 ± 0.14*	*0.20 ± 0.04*	*7.4 ± 0.1*	*0.10 ± 0.03*	*0.14 ± 0.05*	*5.0 ± 8.6*	*1.00*	*0.98*	*1.00*	*0.82*	*0.79*	*9.8 ± 2.1*	*0.93*	*1.01*	*0.11*	*9.80*
45	*San Juan B-4*	*NAP*	*0*	*No*	*2.4 ± 0.4*	*1.2 ± 0.1*	*17.3*	*19.6*	*45.0 ± 8.0*	*33.1 ± 4.1*	*180*	*0.98 ± 0.04*	*0.20 ± 0.04*	*7.4 ± 0.1*	*0.17 ± 0.04*	*0.29 ± 0.05*	*4.0 ± 8.6*	*1.00*	*0.87*	*1.00*	*0.82*	*1.75*	*16.0 ± 3.0*	*1.20*	*1.01*	*0.14*	*16.00*
46	*San Juan B-5*	*NAP*	*0*	*No*	*3.4 ± 0.4*	*2.1 ± 0.1*	*17.3*	*20.6*	*63.3 ± 8.9*	*50.7 ± 4.8*	*184*	*0.97 ± 0.05*	*0.20 ± 0.04*	*7.4 ± 0.1*	*0.16 ± 0.03*	*0.24 ± 0.05*	*17.0 ± 5.0*	*1.00*	*0.89*	*1.00*	*0.82*	*1.41*	*18.3 ± 0.8*	*1.12*	*1.01*	*0.14*	*21.80*
47	*San Juan B-6*	*NAP*	*1*	*Yes*	*4.6 ± 0.3*	*1.8 ± 0.1*	*15.7*	*17.3*	*76.1 ± 5.5*	*49.2 ± 2.9*	*192*	*0.96 ± 0.06*	*0.20 ± 0.04*	*7.4 ± 0.1*	*0.19 ± 0.04*	*0.10 ± 0.05*	*50.0 ± 8.6*	*1.00*	*0.92*	*1.00*	*0.82*	*1.43*	*6.4 ± 0.2*	*1.12*	*1.01*	*0.17*	*12.22*

Table 4.6. (cont'd)

ID #	Earthquake & Site	GMIndicates Liq. (No=0/Yes=1)	Surface Manif. (No=0/Yes=1)	Liq.?	d_{crt} (m)	GWT (m)	γ_1 (kN/m^3)	γ_2 (kN/m^3)	σ_v (kPa)	σ_v' (kPa)	$V^*_{s,12m}$ (m/s)	r_d	a_{max}	M_w	CSR	D_{50} (mm)	FC %	C_S	C_R	C_B	C_E	C_N	$(N_1)_{60}$	K_σ	K_{Mw}	$CSR_{Mw=7.5,\sigma'v=1 atm}$	$N_{1,60,CS}$
	1978 Miyagiken-Oki Mw=6.5 Earthquake																										
48	*Arahama*	*NAP*	*0*	*No*	*5.3 ± 1.1*	*0.9 ± 0.1*	*17.3*	*18.9*	*98.5 ± 20.8*	*55.5 ± 10.2*	*223*	*0.98 ± 0.07*	*0.10 ± 0.02*	*6.5 ± 0.1*	*0.11 ± 0.02*	*0.45 ± 0.05*	*0.0 ± 8.6*	*1.00*	*0.94*	*1.00*	*1.37*	*1.35*	*15.6 ± 3.8*	*1.10*	*1.10*	*0.09*	*15.63*
49	*Hiyori-18*	*NAP*	*0*	*No*	*3.3 ± 0.3*	*2.4 ± 0.1*	*17.3*	*18.9*	*57.4 ± 4.9*	*49.5 ± 2.7*	*195*	*0.98 ± 0.05*	*0.14 ± 0.03*	*6.5 ± 0.1*	*0.10 ± 0.02*	*0.15 ± 0.05*	*20.0 ± 8.6*	*1.00*	*0.91*	*1.00*	*1.37*	*1.43*	*16.3 ± 2.0*	*1.12*	*1.10*	*0.08*	*20.59*
50	*Kitawabuchi-2*	*NAP*	*0*	*No*	*3.5 ± 0.2*	*2.5 ± 0.1*	*17.3*	*20.6*	*62.9 ± 4.6*	*53.1 ± 2.7*	*195*	*0.97 ± 0.05*	*0.14 ± 0.03*	*6.5 ± 0.1*	*0.10 ± 0.02*	*0.53 ± 0.05*	*5.0 ± 8.6*	*1.00*	*0.91*	*1.00*	*1.37*	*1.38*	*19.3 ± 2.0*	*1.11*	*1.10*	*0.09*	*19.30*
51	*Nakajima-18*	*NAP*	*0*	*No*	*4.3 ± 0.6*	*2.4 ± 0.1*	*17.3*	*20.6*	*79.8 ± 12.6*	*61.8 ± 6.8*	*198*	*0.97 ± 0.06*	*0.14 ± 0.03*	*6.5 ± 0.1*	*0.11 ± 0.02*	*0.35 ± 0.05*	*3.0 ± 8.6*	*1.00*	*0.93*	*1.00*	*1.37*	*1.28*	*16.2 ± 6.9*	*1.08*	*1.10*	*0.09*	*16.21*
52	*Nakamura 4*	*NAP*	*1*	*Yes*	*4.0 ± 0.3*	*0.5 ± 0.1*	*17.3*	*18.9*	*74.6 ± 6.5*	*40.3 ± 3.5*	*248*	*1.00 ± 0.06*	*0.12 ± 0.02*	*6.5 ± 0.1*	*0.14 ± 0.03*	*0.54 ± 0.18*	*5.0 ± 8.6*	*1.00*	*0.92*	*1.00*	*1.37*	*1.59*	*11.2 ± 0.7*	*1.16*	*1.10*	*0.11*	*11.19*
53	*Nakamura 5*	*NAP*	*0*	*No*	*2.9 ± 0.4*	*1.3 ± 0.1*	*17.3*	*18.9*	*52.6 ± 7.0*	*36.9 ± 3.5*	*256*	*1.00 ± 0.04*	*0.12 ± 0.02*	*6.5 ± 0.1*	*0.11 ± 0.02*	*0.28 ± 0.05*	*4.0 ± 8.6*	*1.00*	*0.90*	*1.00*	*1.37*	*1.66*	*10.2 ± 5.1*	*1.18*	*1.10*	*0.09*	*10.21*
54	*Oiiri-1*	*NAP*	*0*	*No*	*6.3 ± 0.2*	*4.3 ± 0.1*	*17.3*	*18.9*	*112.1 ± 3.9*	*92.1 ± 2.8*	*172*	*0.86 ± 0.09*	*0.14 ± 0.03*	*6.5 ± 0.1*	*0.10 ± 0.02*	*0.34 ± 0.05*	*5.0 ± 8.6*	*1.00*	*0.95*	*1.00*	*1.37*	*1.05*	*12.3 ± 2.0*	*1.02*	*1.10*	*0.08*	*12.27*
55	*Oiiri-2*	*NAP*	*0*	*No*	*5.3 ± 0.5*	*2.4 ± 0.1*	*17.3*	*20.6*	*101.1 ± 10.4*	*72.7 ± 5.7*	*189*	*0.93 ± 0.07*	*0.14 ± 0.03*	*6.5 ± 0.1*	*0.12 ± 0.03*	*0.34 ± 0.05*	*4.0 ± 8.6*	*1.00*	*0.94*	*1.00*	*1.37*	*1.18*	*14.3 ± 3.2*	*1.06*	*1.10*	*0.10*	*14.26*
56	*Yuriage Br-1*	*NAP*	*0*	*No*	*3.8 ± 0.3*	*1.7 ± 0.1*	*17.3*	*20.6*	*72.6 ± 7.0*	*52.0 ± 3.9*	*219*	*0.99 ± 0.06*	*0.12 ± 0.02*	*6.5 ± 0.1*	*0.11 ± 0.02*	*0.28 ± 0.18*	*10.0 ± 8.6*	*1.00*	*0.92*	*1.00*	*1.37*	*1.40*	*5.2 ± 2.2*	*1.11*	*1.10*	*0.09*	*6.44*
57	*Yuriage Br-2*	*NAP*	*0*	*No*	*2.8 ± 0.3*	*1.3 ± 0.1*	*15.7*	*20.6*	*51.6 ± 6.8*	*36.7 ± 3.7*	*274*	*1.00 ± 0.04*	*0.12 ± 0.02*	*6.5 ± 0.1*	*0.11 ± 0.02*	*0.34 ± 0.37*	*7.0 ± 8.6*	*1.00*	*0.90*	*1.00*	*1.37*	*1.66*	*23.5 ± 2.3*	*1.18*	*1.10*	*0.08*	*23.95*
58	*Yuriage Br-3*	*NAP*	*0*	*No*	*3.3 ± 0.4*	*0.3 ± 0.1*	*17.3*	*18.9*	*61.8 ± 8.3*	*32.0 ± 4.2*	*232*	*0.99 ± 0.05*	*0.12 ± 0.02*	*6.5 ± 0.1*	*0.15 ± 0.03*	*1.03 ± 0.38*	*12.0 ± 8.6*	*1.00*	*0.91*	*1.00*	*1.37*	*1.78*	*15.3 ± 2.8*	*1.21*	*1.10*	*0.11*	*17.18*
59	*Yuriagekami-2*	*NAP*	*0*	*No*	*3.8 ± 0.6*	*0.9 ± 0.1*	*15.7*	*18.9*	*68.0 ± 11.1*	*39.6 ± 5.5*	*241*	*0.99 ± 0.05*	*0.12 ± 0.02*	*6.5 ± 0.1*	*0.13 ± 0.03*	*0.48 ± 0.09*	*0.0 ± 8.6*	*1.00*	*0.92*	*1.00*	*1.37*	*1.60*	*16.8 ± 6.2*	*1.17*	*1.10*	*0.10*	*16.76*
	1978 Miyagiken-Oki Mw=7.7 Earthquake																										
60	*Nakajima-18*	*NAP*	*1*	*Yes*	*4.3 ± 0.6*	*2.4 ± 0.1*	*17.3*	*20.6*	*79.8 ± 12.6*	*61.8 ± 6.8*	*198*	*0.97 ± 0.06*	*0.24 ± 0.05*	*7.7 ± 0.1*	*0.20 ± 0.04*	*0.35 ± 0.05*	*3.0 ± 8.6*	*1.00*	*0.93*	*1.00*	*1.37*	*1.28*	*16.2 ± 6.9*	*1.08*	*0.98*	*0.18*	*16.21*
61	*Arahama*	*NAP*	*1*	*Yes*	*5.3 ± 1.1*	*0.9 ± 0.1*	*17.3*	*18.9*	*98.5 ± 20.8*	*55.5 ± 10.2*	*223*	*0.98 ± 0.07*	*0.20 ± 0.04*	*7.7 ± 0.1*	*0.23 ± 0.05*	*0.45 ± 0.05*	*0.0 ± 8.6*	*1.00*	*0.94*	*1.00*	*1.37*	*1.35*	*15.6 ± 3.8*	*1.10*	*0.98*	*0.21*	*15.63*
62	*Hiyori-18*	*NAP*	*1*	*Yes*	*3.3 ± 0.3*	*2.4 ± 0.1*	*17.3*	*18.9*	*57.4 ± 4.9*	*49.5 ± 2.7*	*195*	*0.98 ± 0.05*	*0.24 ± 0.05*	*7.7 ± 0.1*	*0.18 ± 0.04*	*0.15 ± 0.05*	*20.0 ± 8.6*	*1.00*	*0.91*	*1.00*	*1.37*	*1.43*	*16.3 ± 2.0*	*1.12*	*0.98*	*0.16*	*20.59*
63	*Kitawabuchi-2*	*NAP*	*1*	*Yes*	*3.5 ± 0.2*	*2.5 ± 0.1*	*17.3*	*20.6*	*62.9 ± 4.6*	*53.1 ± 2.7*	*195*	*0.98 ± 0.05*	*0.28 ± 0.06*	*7.7 ± 0.1*	*0.21 ± 0.04*	*0.53 ± 0.05*	*5.0 ± 8.6*	*1.00*	*0.91*	*1.00*	*1.37*	*1.38*	*19.3 ± 2.0*	*1.11*	*0.98*	*0.19*	*19.30*
64	*Kitawabuchi-3*	*NAP*	*0*	*No*	*4.9 ± 0.3*	*3.5 ± 0.9*	*17.3*	*20.6*	*88.4 ± 7.4*	*74.7 ± 7.1*	*241*	*0.99 ± 0.07*	*0.28 ± 0.06*	*7.7 ± 0.1*	*0.21 ± 0.05*	*0.41 ± 0.05*	*0.0 ± 8.6*	*1.00*	*0.93*	*1.00*	*1.37*	*1.16*	*18.7 ± 0.3*	*1.05*	*0.98*	*0.21*	*18.75*
65	*Nakamura 1*	*NAP*	*0*	*No*	*3.0 ± 0.3*	*0.9 ± 0.1*	*17.3*	*20.6*	*58.8 ± 6.9*	*38.2 ± 3.8*	*219*	*0.99 ± 0.05*	*0.32 ± 0.06*	*7.7 ± 0.1*	*0.32 ± 0.07*	*0.28 ± 0.05*	*4.0 ± 8.6*	*1.00*	*0.90*	*1.00*	*1.37*	*1.63*	*29.9 ± 7.6*	*1.17*	*0.98*	*0.28*	*29.90*
66	*Nakamura 4*	*NAP*	*1*	*Yes*	*4.0 ± 0.3*	*0.5 ± 0.1*	*17.3*	*18.9*	*74.6 ± 6.5*	*40.3 ± 3.5*	*248*	*1.00 ± 0.06*	*0.32 ± 0.06*	*7.7 ± 0.1*	*0.38 ± 0.08*	*0.54 ± 0.18*	*5.0 ± 8.6*	*1.00*	*0.92*	*1.00*	*1.37*	*1.59*	*11.2 ± 0.7*	*1.16*	*0.98*	*0.34*	*11.19*
67	*Nakamura 5*	*NAP*	*1*	*Yes*	*2.9 ± 0.4*	*1.3 ± 0.1*	*17.3*	*18.9*	*52.6 ± 7.0*	*36.9 ± 3.5*	*256*	*1.00 ± 0.04*	*0.32 ± 0.06*	*7.7 ± 0.1*	*0.30 ± 0.06*	*0.28 ± 0.05*	*4.0 ± 8.6*	*1.00*	*0.90*	*1.00*	*1.37*	*1.66*	*10.2 ± 5.1*	*1.18*	*0.98*	*0.26*	*10.21*
68	*Oiiri-1*	*NAP*	*1*	*Yes*	*6.3 ± 0.2*	*4.3 ± 0.1*	*17.3*	*18.9*	*112.1 ± 3.9*	*92.1 ± 2.8*	*172*	*0.88 ± 0.09*	*0.24 ± 0.05*	*7.7 ± 0.1*	*0.17 ± 0.04*	*0.34 ± 0.05*	*5.0 ± 8.6*	*1.00*	*0.95*	*1.00*	*1.37*	*1.05*	*12.3 ± 2.0*	*1.02*	*0.98*	*0.17*	*12.27*
69	*Oiiri-2*	*NAP*	*1*	*Yes*	*5.3 ± 0.5*	*2.4 ± 0.1*	*17.3*	*20.6*	*101.1 ± 10.4*	*72.7 ± 5.7*	*189*	*0.94 ± 0.07*	*0.24 ± 0.05*	*7.7 ± 0.1*	*0.20 ± 0.04*	*0.34 ± 0.05*	*4.0 ± 8.6*	*1.00*	*0.94*	*1.00*	*1.37*	*1.18*	*14.3 ± 3.2*	*1.06*	*0.98*	*0.20*	*14.26*
70	*Yuriage Br-1*	*NAP*	*1*	*Yes*	*3.8 ± 0.3*	*1.7 ± 0.1*	*17.3*	*20.6*	*72.6 ± 7.0*	*52.0 ± 3.9*	*219*	*0.98 ± 0.06*	*0.24 ± 0.05*	*7.7 ± 0.1*	*0.21 ± 0.04*	*0.28 ± 0.18*	*10.0 ± 8.6*	*1.00*	*0.92*	*1.00*	*1.37*	*1.40*	*5.2 ± 2.2*	*1.11*	*0.98*	*0.19*	*6.44*
71	*Yuriage Br-2*	*NAP*	*1*	*Yes*	*2.8 ± 0.3*	*1.3 ± 0.1*	*15.7*	*20.6*	*51.6 ± 6.8*	*36.7 ± 3.7*	*274*	*1.00 ± 0.04*	*0.24 ± 0.05*	*7.7 ± 0.1*	*0.22 ± 0.05*	*0.34 ± 0.37*	*7.0 ± 8.6*	*1.00*	*0.90*	*1.00*	*1.37*	*1.66*	*23.5 ± 2.3*	*1.18*	*0.98*	*0.19*	*23.95*
72	*Yuriage Br-3*	*NAP*	*1*	*Yes*	*3.3 ± 0.4*	*0.3 ± 0.1*	*17.3*	*18.9*	*61.8 ± 8.3*	*32.0 ± 4.2*	*232*	*0.99 ± 0.05*	*0.24 ± 0.05*	*7.7 ± 0.1*	*0.30 ± 0.06*	*1.03 ± 0.38*	*12.0 ± 8.6*	*1.00*	*0.91*	*1.00*	*1.37*	*1.78*	*15.3 ± 2.8*	*1.21*	*0.98*	*0.25*	*17.18*
73	*Yuriage Br-5*	*NAP*	*0*	*No*	*5.5 ± 0.8*	*1.3 ± 0.2*	*18.9*	*20.6*	*110.9 ± 17.3*	*69.8 ± 9.3*	*244*	*0.99 ± 0.08*	*0.24 ± 0.05*	*7.7 ± 0.1*	*0.25 ± 0.05*	*0.5-5 ± 0.05*	*17.0 ± 8.6*	*1.00*	*0.94*	*1.00*	*1.37*	*1.21*	*27.4 ± 3.6*	*1.06*	*0.98*	*0.24*	*30.93*
74	*Yuriagekami-2*	*NAP*	*1*	*Yes*	*3.8 ± 0.6*	*0.9 ± 0.1*	*15.7*	*18.9*	*68.0 ± 11.1*	*39.6 ± 5.5*	*241*	*1.00 ± 0.05*	*0.24 ± 0.05*	*7.7 ± 0.1*	*0.27 ± 0.06*	*0.48 ± 0.09*	*0.0 ± 8.6*	*1.00*	*0.92*	*1.00*	*1.37*	*1.60*	*16.8 ± 6.2*	*1.17*	*0.98*	*0.23*	*16.76*
75	*Yuriagekami-3*	*NAP*	*0*	*No*	*5.9 ± 0.7*	*2.2 ± 0.1*	*17.3*	*20.6*	*113.3 ± 14.2*	*77.0 ± 7.7*	*244*	*0.99 ± 0.08*	*0.24 ± 0.05*	*7.7 ± 0.1*	*0.23 ± 0.05*	*0.64 ± 0.14*	*0.0 ± 8.6*	*1.00*	*0.95*	*1.00*	*1.37*	*1.15*	*30.7 ± 3.0*	*1.05*	*0.98*	*0.22*	*30.72*
	1979 Imperial Valley Earthquake																										
76	*Heber Road A1*	*NAP*	*0*	*No*	*3.4 ± 0.5*	*1.8 ± 0.1*	*15.7*	*19.6*	*59.7 ± 10.5*	*44.0 ± 5.4*	*	*0.82 ± 0.03*	*0.47 ± 0.07*	*6.5 ± 0.1*	*0.34 ± 0.06*	*0.11 ± 0.01*	*13.0 ± 3.9*	*1.00*	*0.89*	*1.00*	*1.13*	*1.52*	*51.6 ± 3.2*	*1.15*	*1.10*	*0.27*	*53.81*
77	*Heber Road A2*	*NAP*	*1*	*Yes*	*3.2 ± 0.5*	*1.8 ± 0.1*	*15.7*	*17.3*	*52.8 ± 8.0*	*38.9 ± 3.7*	*	*0.78 ± 0.02*	*0.47 ± 0.07*	*6.5 ± 0.1*	*0.32 ± 0.05*	*0.12 ± 0.01*	*20.9 ± 5.0*	*1.00*	*0.89*	*1.00*	*1.13*	*1.61*	*3.8 ± 2.3*	*1.17*	*1.10*	*0.25*	*8.33*
78	*Heber Road A3*	*NAP*	*0*	*No*	*3.4 ± 0.5*	*1.8 ± 0.1*	*15.7*	*18.9*	*57.5 ± 9.8*	*42.3 ± 4.8*	*	*0.75 ± 0.02*	*0.47 ± 0.07*	*6.5 ± 0.1*	*0.31 ± 0.05*	*0.09 ± 0.00*	*25.3 ± 5.2*	*1.00*	*0.89*	*1.00*	*1.13*	*1.55*	*20.2 ± 6.3*	*1.15*	*1.10*	*0.25*	*25.41*
79	*Kornbloom B*	*NAP*	*0*	*No*	*4.0 ± 0.4*	*2.7 ± 0.1*	*15.7*	*18.9*	*67.5 ± 8.3*	*54.8 ± 4.2*	*	*0.83 ± 0.03*	*0.13 ± 0.02*	*6.5 ± 0.1*	*0.09 ± 0.01*	*0.04 ± 0.01*	*83.0 ± 9.6*	*1.00*	*0.91*	*1.00*	*1.13*	*1.36*	*7.7 ± 4.3*	*1.11*	*1.10*	*0.07*	*13.46*
80	*McKim Ranch A*	*NAP*	*1*	*Yes*	*2.7 ± 0.4*	*1.5 ± 0.1*	*17.3*	*18.9*	*49.3 ± 7.7*	*37.4 ± 3.9*	*160*	*0.94 ± 0.04*	*0.51 ± 0.15*	*6.5 ± 0.1*	*0.41 ± 0.13*	*0.11 ± 0.00*	*19.8 ± 3.5*	*1.00*	*0.88*	*1.00*	*1.13*	*1.65*	*8.8 ± 4.2*	*1.18*	*1.10*	*0.32*	*13.03*
81	*Radio Tower B1*	*NAP*	*1*	*Yes*	*4.3 ± 0.4*	*2.0 ± 0.1*	*15.7*	*18.1*	*72.1 ± 7.7*	*50.0 ± 3.8*	*	*0.97 ± 0.03*	*0.18 ± 0.03*	*6.5 ± 0.1*	*0.16 ± 0.03*	*0.07 ± 0.04*	*43.5 ± 29.0*	*1.00*	*0.91*	*1.00*	*1.13*	*1.42*	*6.5 ± 4.7*	*1.12*	*1.10*	*0.13*	*12.32*
82	*Radio Tower B2*	*NAP*	*0*	*No*	*2.5 ± 0.2*	*2.0 ± 0.1*	*15.7*	*18.9*	*40.8 ± 3.2*	*35.9 ± 1.9*	*	*0.99 ± 0.02*	*0.18 ± 0.03*	*6.5 ± 0.1*	*0.13 ± 0.02*	*0.10 ± 0.05*	*18.0 ± 8.6*	*1.00*	*0.87*	*1.00*	*1.13*	*1.68*	*18.8 ± 2.0*	*1.18*	*1.10*	*0.10*	*22.65*
	1980 Mid-Chiba Earthquake																										
83	*Owi-1*	*0*	*0*	*No*	*5.4 ± 0.6*	*1.0 ± 0.1*	*18.9*	*20.6*	*109.4 ± 12.5*	*66.3 ± 6.8*	*183*	*0.92 ± 0.07*	*0.08 ± 0.00*	*6.1 ± 0.1*	*0.08 ± 0.01*	*0.12 ± 0.03*	*41.3 ± 16.5*	*1.00*	*0.94*	*1.15*	*1.37*	*1.24*	*10.5 ± 4.3*	*1.07*	*1.15*	*0.06*	*16.30*
	1981 Westmorland Earthquake																										
84	*Kornbloom B*	*NAP*	*1*	*Yes*	*4.0 ± 0.4*	*2.7 ± 0.1*	*15.7*	*18.9*	*67.5 ± 8.3*	*54.8 ± 4.2*	*	*0.90 ± 0.03*	*0.19 ± 0.03*	*5.9 ± 0.1*	*0.14 ± 0.02*	*0.04 ± 0.01*	*83.0 ± 9.6*	*1.00*	*0.91*	*1.00*	*1.13*	*1.36*	*7.7 ± 4.3*	*1.11*	*1.18*	*0.10*	*13.46*
85	*Radio Tower B1*	*NAP*	*1*	*Yes*	*4.3 ± 0.4*	*2.0 ± 0.1*	*15.7*	*18.1*	*72.1 ± 7.7*	*50.0 ± 3.8*	*	*0.89 ± 0.03*	*0.17 ± 0.03*	*5.9 ± 0.1*	*0.14 ± 0.02*	*0.07 ± 0.04*	*43.5 ± 29.0*	*1.00*	*0.91*	*1.00*	*1.13*	*1.42*	*6.5 ± 4.7*	*1.12*	*1.18*	*0.11*	*12.32*
86	*Radio Tower B2*	*NAP*	*0*	*No*	*2.5 ± 0.2*	*2.0 ± 0.1*	*15.7*	*18.9*	*40.7 ± 3.3*	*35.9 ± 1.9*	*	*0.98 ± 0.02*	*0.16 ± 0.02*	*5.9 ± 0.1*	*0.12 ± 0.02*	*0.10 ± 0.05*	*18.0 ± 8.6*	*1.00*	*0.87*	*1.00*	*1.13*	*1.68*	*18.8 ± 2.0*	*1.18*	*1.18*	*0.08*	*22.58*
87	*River Park C*	*NAP*	*0*	*No*	*4.6 ± 0.2*	*0.3 ± 0.1*	*15.7*	*18.1*	*82.0 ± 4.2*	*40.1 ± 2.7*	*	*0.97 ± 0.03*	*0.17 ± 0.03*	*5.9 ± 0.1*	*0.22 ± 0.03*	*0.14 ± 0.02*	*13.2 ± 4.4*	*1.00*	*0.87*	*1.00*	*1.13*	*1.59*	*29.5 ± 6.5*	*1.16*	*1.18*	*0.16*	*31.76*
88	*Wildlife B*	*NAV*	*1*	*Yes*	*4.9 ± 0.7*	*1.2 ± 0.1*	*15.7*	*18.9*	*87.7 ± 13.6*	*51.9 ± 6.8*	*	*0.89 ± 0.03*	*0.23 ± 0.01*	*5.9 ± 0.1*	*0.22 ± 0.02*	*0.09 ± 0.01*	*27.4 ± 9.0*	*1.00*	*0.92*	*1.00*	*1.13*	*1.40*	*11.6 ± 5.1*	*1.12*	*1.18*	*0.17*	*17.02*
89	*McKim Ranch A*	*NAP*	*0*	*No*	*2.7 ± 0.4*	*1.5 ± 0.1*	*17.3*	*18.9*	*49.3 ± 7.7*	*37.4 ± 3.9*	*	*0.93 ± 0.02*	*0.09 ± 0.01*	*5.9 ± 0.1*	*0.07 ± 0.01*	*0.11 ± 0.00*	*19.8 ± 3.5*	*1.00*	*0.88*	*1.00*	*1.13*	*1.65*	*8.8 ± 4.2*	*1.18*	*1.18*	*0.05*	*13.03*
	1983 Nihonkai-Chubu Mw=6.7 Earthquake																										
90	*Arayamotomachi*	*NAP*	*0*	*No*	*3.3 ± 0.8*	*1.0 ± 0.1*	*17.3*	*18.9*	*59.7 ± 14.2*	*37.6 ± 6.9*	*204*	*0.98 ± 0.05*	*0.15 ± 0.05*	*6.7 ± 0.1*	*0.15 ± 0.05*	*0.15 ± 0.05*	*5.0 ± 8.6*	*1.00*	*0.91*	*1.00*	*1.37*	*1.64*	*8.8 ± 3.8*	*1.18*	*1.08*	*0.12*	*8.77*

Table 4.6. (cont'd)

ID #	Earthquake & Site	GMIndicates Liq. (No=0/Yes=1)	Surface Manif. (No=0/Yes=1)	Liq.?	$d_{crt.}$ (m)	GWT (m)	γ_1 (kN/m^3)	γ_2 (kN/m^3)	σ_v (kPa)	σ_v' (kPa)	$V^*_{s,12m}$ (m/s)	r_d	a_{max}	M_w	CSR	D_{50} (mm)	FC %	C_S	C_R	C_B	C_E	C_N	$(N_1)_{60}$	K_σ	K_{Mw}	$CSR_{Mw=7.5,\sigma'v=1 atm}$	$N_{1,60,CS}$
	1983 Nihonkai-Chubu Mw=7.4 Earthquake																										
91	*Akita Station*	*0*	*0*	*No*	*3.0 ± 0.3*	*1.8 ± 0.9*	*18.9*	*18.9*	*56.6 ± 6.4*	*44.3 ± 9.5*	*216*	*0.99 ± 0.05*	*0.20 ± 0.01*	*7.4 ± 0.1*	*0.17 ± 0.04*	*NAV ± NAV*	*2.7 ± 1.5*	*1.00*	*0.85*	*1.00*	*1.22*	*1.51*	*16.0 ± 2.8*	*1.14*	*1.01*	*0.14*	*16.04*
92	*Arayamotomachi*	*NAP*	*1*	*Yes*	*3.3 ± 0.8*	*1.0 ± 0.1*	*17.3*	*18.9*	*59.7 ± 14.2*	*37.6 ± 6.9*	*204*	*0.98 ± 0.05*	*0.20 ± 0.06*	*7.4 ± 0.1*	*0.20 ± 0.06*	*0.15 ± 0.05*	*5.0 ± 8.6*	*1.00*	*0.91*	*1.00*	*1.37*	*1.64*	*8.8 ± 3.8*	*1.18*	*1.01*	*0.17*	*8.77*
93	*Gaiko*	*NAP*	*1*	*Yes*	*8.2 ± 2.3*	*1.5 ± 0.1*	*18.9*	*18.9*	*155.4 ± 42.6*	*89.1 ± 20.7*	*158*	*0.74 ± 0.11*	*0.21 ± 0.03*	*7.4 ± 0.1*	*0.18 ± 0.04*	*NAV ± NAV*	*4.6 ± 5.5*	*1.00*	*0.97*	*1.00*	*1.37*	*1.07*	*8.6 ± 2.9*	*1.02*	*1.01*	*0.17*	*8.60*
94	*Nakajima No. 1 (5)*	*NAP*	*1*	*Yes*	*7.5 ± 1.8*	*1.8 ± 0.1*	*17.3*	*18.9*	*138.6 ± 34.7*	*82.3 ± 16.8*	*177*	*0.85 ± 0.10*	*0.21 ± 0.03*	*7.4 ± 0.1*	*0.19 ± 0.04*	*NAV ± NAV*	*14.6 ± 17.4*	*1.00*	*0.96*	*1.00*	*1.37*	*1.11*	*9.9 ± 3.7*	*1.03*	*1.01*	*0.18*	*12.69*
95	*Nakajima No. 2 (1)*	*NAP*	*1*	*Yes*	*5.5 ± 1.2*	*1.5 ± 0.1*	*18.9*	*20.6*	*110.7 ± 24.1*	*71.0 ± 12.8*	*189*	*0.94 ± 0.08*	*0.21 ± 0.03*	*7.4 ± 0.1*	*0.20 ± 0.03*	*NAV ± NAV*	*2.0 ± 1.0*	*1.00*	*0.94*	*1.00*	*1.37*	*1.19*	*7.3 ± 1.7*	*1.06*	*1.01*	*0.18*	*7.31*
96	*Nakajima No. 2 (2)*	*NAP*	*1*	*Yes*	*3.9 ± 0.6*	*1.5 ± 0.1*	*18.9*	*18.9*	*72.6 ± 11.7*	*49.5 ± 5.8*	*201*	*0.98 ± 0.06*	*0.20 ± 0.03*	*7.4 ± 0.1*	*0.19 ± 0.03*	*- ± -*	*8.0 ± 5.7*	*1.00*	*0.92*	*1.00*	*1.37*	*1.43*	*7.4 ± 4.5*	*1.12*	*1.01*	*0.17*	*8.06*
97	*Nakajima No. 3 (3)*	*NAP*	*1*	*Yes*	*2.4 ± 0.5*	*1.6 ± 0.1*	*15.7*	*17.3*	*39.0 ± 8.1*	*31.0 ± 3.7*	*168*	*0.97 ± 0.04*	*0.21 ± 0.03*	*7.4 ± 0.1*	*0.16 ± 0.03*	*NAV ± NAV*	*3.0 ± 8.6*	*1.00*	*0.89*	*1.00*	*1.37*	*1.81*	*6.6 ± 0.5*	*1.21*	*1.01*	*0.13*	*6.62*
98	*Nakajima No. 3 (4)*	*NAP*	*1*	*Yes*	*6.5 ± 1.6*	*1.7 ± 0.1*	*17.3*	*18.9*	*119.9 ± 29.6*	*72.4 ± 14.4*	*183*	*0.90 ± 0.09*	*0.20 ± 0.03*	*7.4 ± 0.1*	*0.20 ± 0.04*	*NAV ± NAV*	*2.0 ± 1.0*	*1.00*	*0.95*	*1.00*	*1.37*	*1.18*	*12.3 ± 4.5*	*1.06*	*1.01*	*0.18*	*12.33*
99	*Noshiro Section N-7*	*NAP*	*1*	*Yes*	*3.5 ± 0.5*	*1.8 ± 0.1*	*17.3*	*20.6*	*66.3 ± 10.4*	*49.1 ± 5.5*	*171*	*0.95 ± 0.05*	*0.25 ± 0.08*	*7.4 ± 0.1*	*0.21 ± 0.06*	*0.25 ± 0.05*	*1.0 ± 8.6*	*1.00*	*0.91*	*1.00*	*1.37*	*1.44*	*17.7 ± 3.8*	*1.13*	*1.01*	*0.18*	*17.67*
100	*Ohama No. 2 (2)*	*NAP*	*1*	*Yes*	*6.8 ± 1.5*	*0.7 ± 0.1*	*15.7*	*18.9*	*125.0 ± 28.7*	*65.9 ± 14.0*	*149*	*0.77 ± 0.09*	*0.20 ± 0.03*	*7.4 ± 0.1*	*0.19 ± 0.04*	*NAV ± NAV*	*1.1 ± 0.5*	*1.00*	*0.96*	*1.00*	*1.37*	*1.24*	*7.6 ± 4.6*	*1.07*	*1.01*	*0.18*	*7.62*
101	*Ohama No. Rvt. (1)*	*NAP*	*0*	*No*	*5.6 ± 0.7*	*1.5 ± 0.9*	*18.9*	*20.6*	*111.7 ± 14.3*	*71.5 ± 10.6*	*213*	*0.97 ± 0.08*	*0.17 ± 0.03*	*7.4 ± 0.1*	*0.17 ± 0.04*	*NAV ± NAV*	*3.0 ± 1.0*	*1.00*	*0.94*	*1.00*	*1.37*	*1.19*	*26.6 ± 4.3*	*1.06*	*1.01*	*0.16*	*26.55*
102	*Aomori Railway Station*	*NAV*	*1*	*Yes*	*5.8 ± 0.6*	*0.0 ± 0.1*	*15.7*	*18.9*	*108.4 ± 11.3*	*52.0 ± 6.0*	*158*	*0.85 ± 0.09*	*0.11 ± 0.01*	*7.4 ± 0.1*	*0.12 ± 0.01*	*0.25 ± 0.05*	*5.0 ± 8.6*	*1.00*	*0.95*	*1.00*	*1.37*	*1.40*	*14.0 ± 2.6*	*1.11*	*1.01*	*0.11*	*13.98*
	1987 Edgecumbe Earthquake																										
103	*Brady Farm 1*	*NAP*	*1*	*Yes*	*4.8 ± 0.8*	*1.6 ± 0.1*	*21.3*	*22.8*	*106.0 ± 17.2*	*75.3 ± 9.9*	*201*	*0.96 ± 0.07*	*0.37 ± 0.07*	*6.5 ± 0.1*	*0.32 ± 0.07*	*0.38 ± 0.34*	*29.7 ± 16.9*	*1.00*	*0.92*	*1.00*	*1.37*	*1.16*	*12.9 ± 5.9*	*1.05*	*1.10*	*0.28*	*18.47*
104	*Whakatane Pony Club*	*NAP*	*1*	*Yes*	*5.5 ± 0.5*	*2.4 ± 0.9*	*20.5*	*22.1*	*116.7 ± 10.9*	*86.7 ± 9.9*	*183*	*0.91 ± 0.08*	*0.29 ± 0.06*	*6.5 ± 0.1*	*0.23 ± 0.06*	*0.19 ± 0.09*	*28.3 ± 14.6*	*1.00*	*0.93*	*1.00*	*1.37*	*1.08*	*11.1 ± 5.1*	*1.03*	*1.10*	*0.20*	*16.61*
105	*Edgecumbe Substation*	*NAP*	*1*	*Yes*	*3.5 ± 0.5*	*1.9 ± 0.1*	*17.3*	*20.6*	*64.7 ± 10.7*	*49.5 ± 5.7*	*135*	*0.85 ± 0.05*	*0.50 ± 0.10*	*6.5 ± 0.1*	*0.36 ± 0.08*	*- ± -*	*5.0 ± 8.6*	*1.00*	*0.84*	*1.00*	*1.37*	*1.43*	*16.2 ± 0.2*	*1.12*	*1.10*	*0.29*	*16.17*
	1987 Elmore Ranch Earthquake																										
106	*Radio Tower B1*	*NAP*	*0*	*No*	*4.3 ± 0.4*	*2.0 ± 0.1*	*15.7*	*18.1*	*72.1 ± 7.7*	*50.0 ± 3.8*	***	*0.97 ± 0.06*	*0.09 ± 0.01*	*6.2 ± 0.1*	*0.08 ± 0.01*	*0.07 ± 0.04*	*43.5 ± 29.0*	*1.00*	*0.91*	*1.00*	*1.13*	*1.42*	*6.5 ± 4.7*	*1.12*	*1.14*	*0.06*	*12.32*
107	*Wildlife B*	*NAV*	*0*	*No*	*4.9 ± 0.7*	*1.2 ± 0.1*	*15.7*	*18.9*	*87.7 ± 13.6*	*51.9 ± 6.8*	***	*0.75 ± 0.03*	*0.13 ± 0.01*	*6.2 ± 0.1*	*0.11 ± 0.01*	*0.09 ± 0.01*	*27.4 ± 9.0*	*1.00*	*0.92*	*1.00*	*1.13*	*1.40*	*11.6 ± 5.1*	*1.12*	*1.14*	*0.08*	*17.02*
	1987 Superstition Hills Earthquake																										
108	*Heber Road A1*	*NAP*	*0*	*No*	*3.4 ± 0.5*	*1.8 ± 0.1*	*15.7*	*19.6*	*59.7 ± 10.5*	*44.0 ± 5.4*	***	*0.96 ± 0.03*	*0.16 ± 0.02*	*6.5 ± 0.1*	*0.13 ± 0.02*	*0.11 ± 0.01*	*13.0 ± 3.9*	*1.00*	*0.89*	*1.00*	*1.13*	*1.52*	*51.6 ± 3.2*	*1.15*	*1.10*	*0.10*	*53.81*
109	*Heber Road A2*	*NAP*	*0*	*No*	*3.2 ± 0.5*	*1.8 ± 0.1*	*15.7*	*17.3*	*52.8 ± 8.0*	*38.9 ± 3.7*	***	*0.95 ± 0.02*	*0.15 ± 0.02*	*6.5 ± 0.1*	*0.13 ± 0.02*	*0.12 ± 0.01*	*20.9 ± 5.0*	*1.00*	*0.89*	*1.00*	*1.13*	*1.61*	*3.8 ± 2.3*	*1.17*	*1.10*	*0.10*	*8.33*
110	*Heber Road A3*	*NAP*	*0*	*No*	*3.4 ± 0.5*	*1.8 ± 0.1*	*15.7*	*18.9*	*57.5 ± 9.8*	*42.3 ± 4.8*	***	*0.95 ± 0.02*	*0.13 ± 0.02*	*6.5 ± 0.1*	*0.11 ± 0.02*	*0.09 ± 0.00*	*25.3 ± 5.2*	*1.00*	*0.89*	*1.00*	*1.13*	*1.55*	*20.2 ± 6.3*	*1.15*	*1.10*	*0.09*	*25.41*
111	*Kornbloom B*	*NAP*	*0*	*No*	*4.0 ± 0.4*	*2.7 ± 0.1*	*15.7*	*18.9*	*67.5 ± 8.3*	*54.8 ± 4.2*	***	*0.94 ± 0.03*	*0.17 ± 0.03*	*6.5 ± 0.1*	*0.13 ± 0.02*	*0.04 ± 0.01*	*83.0 ± 9.6*	*1.00*	*0.91*	*1.00*	*1.13*	*1.36*	*7.7 ± 4.3*	*1.11*	*1.10*	*0.11*	*13.46*
112	*McKim Ranch A*	*NAP*	*0*	*No*	*2.7 ± 0.4*	*1.5 ± 0.1*	*17.3*	*18.9*	*49.3 ± 7.7*	*37.4 ± 3.9*	***	*0.95 ± 0.02*	*0.16 ± 0.05*	*6.5 ± 0.1*	*0.13 ± 0.04*	*0.11 ± 0.00*	*19.8 ± 3.5*	*1.00*	*0.88*	*1.00*	*1.13*	*1.65*	*8.8 ± 4.2*	*1.18*	*1.10*	*0.10*	*13.03*
113	*Radio Tower B1*	*NAP*	*0*	*No*	*4.3 ± 0.4*	*2.0 ± 0.1*	*15.7*	*18.1*	*72.1 ± 7.7*	*50.0 ± 3.8*	***	*0.94 ± 0.03*	*0.20 ± 0.03*	*6.5 ± 0.1*	*0.18 ± 0.03*	*0.07 ± 0.04*	*43.5 ± 29.0*	*1.00*	*0.91*	*1.00*	*1.13*	*1.42*	*6.5 ± 4.7*	*1.12*	*1.10*	*0.14*	*12.32*
114	*Radio Tower B2*	*NAP*	*0*	*No*	*2.5 ± 0.2*	*2.0 ± 0.1*	*15.7*	*18.9*	*40.7 ± 3.3*	*35.9 ± 1.9*	***	*0.99 ± 0.02*	*0.18 ± 0.03*	*6.5 ± 0.1*	*0.13 ± 0.02*	*0.10 ± 0.05*	*18.0 ± 8.6*	*1.00*	*0.87*	*1.00*	*1.13*	*1.68*	*18.8 ± 2.0*	*1.18*	*1.10*	*0.10*	*22.58*
115	*River Park C*	*NAP*	*0*	*No*	*4.6 ± 0.2*	*0.3 ± 0.1*	*15.7*	*18.1*	*82.0 ± 4.2*	*40.1 ± 2.7*	***	*0.93 ± 0.03*	*0.19 ± 0.03*	*6.5 ± 0.1*	*0.23 ± 0.04*	*0.14 ± 0.02*	*13.2 ± 4.4*	*1.00*	*0.87*	*1.00*	*1.13*	*1.59*	*29.5 ± 6.5*	*1.16*	*1.10*	*0.18*	*31.76*
116	*Wildlife B*	*NAV*	*1*	*Yes*	*4.9 ± 0.7*	*1.2 ± 0.1*	*15.7*	*18.9*	*87.7 ± 13.6*	*51.9 ± 6.8*	***	*0.82 ± 0.03*	*0.20 ± 0.01*	*6.5 ± 0.1*	*0.18 ± 0.01*	*0.09 ± 0.01*	*27.4 ± 9.0*	*1.00*	*0.92*	*1.00*	*1.13*	*1.40*	*11.6 ± 5.1*	*1.12*	*1.10*	*0.15*	*17.02*
	1989 Loma Prieta Earthquake																										
117	*Alameda BF Dike*	*NAP*	*0*	*No*	*6.5 ± 0.2*	*3.0 ± 0.1*	*19.9*	*21.5*	*135.2 ± 4.2*	*100.9 ± 3.0*	*181*	*0.88 ± 0.09*	*0.24 ± 0.04*	*6.9 ± 0.1*	*0.18 ± 0.03*	*0.28 ± 0.05*	*7.0 ± 8.6*	*1.30*	*0.94*	*1.00*	*0.92*	*1.00*	*41.9 ± 2.2*	*1.00*	*1.06*	*0.17*	*42.38*
118	*Farris Farm*	*NAP*	*1*	*Yes*	*6.0 ± 0.3*	*4.5 ± 0.1*	*15.7*	*18.9*	*99.0 ± 6.7*	*84.3 ± 3.8*	***	*0.95 ± 0.04*	*0.37 ± 0.06*	*6.9 ± 0.1*	*0.27 ± 0.04*	*0.11 ± 0.05*	*21.0 ± 8.6*	*1.00*	*0.94*	*1.00*	*1.13*	*1.10*	*10.5 ± 2.0*	*1.03*	*1.06*	*0.25*	*15.02*
119	*Hall Avenue*	*NAP*	*0*	*No*	*4.6 ± 0.4*	*3.5 ± 0.1*	*15.7*	*18.1*	*75.3 ± 7.0*	*64.3 ± 3.6*	***	*0.72 ± 0.03*	*0.14 ± 0.02*	*6.9 ± 0.1*	*0.08 ± 0.01*	*0.09 ± 0.05*	*30.0 ± 8.6*	*1.10*	*0.92*	*1.00*	*0.92*	*1.26*	*5.4 ± 3.8*	*1.08*	*1.06*	*0.07*	*11.00*
120	*MBARI NO:3 EB-1*	*NAP*	*0*	*No*	*2.5 ± 0.2*	*2.0 ± 0.1*	*17.3*	*19.6*	*44.4 ± 3.4*	*39.5 ± 2.0*	***	*0.99 ± 0.02*	*0.24 ± 0.04*	*6.9 ± 0.1*	*0.17 ± 0.03*	*0.60 ± 0.05*	*1.0 ± 8.6*	*1.00*	*0.87*	*1.00*	*1.00*	*1.60*	*22.9 ± 2.0*	*1.17*	*1.06*	*0.14*	*22.92*
121	*MBARI NO:3 EB-5*	*NAP*	*0*	*No*	*4.1 ± 0.8*	*1.8 ± 0.1*	*17.3*	*19.6*	*76.3 ± 15.1*	*53.7 ± 7.7*	***	*0.99 ± 0.03*	*0.27 ± 0.04*	*6.9 ± 0.1*	*0.25 ± 0.04*	*0.60 ± 0.05*	*1.0 ± 8.6*	*1.00*	*0.91*	*1.00*	*1.00*	*1.37*	*19.0 ± 2.8*	*1.11*	*1.06*	*0.21*	*18.96*
122	*Miller Farm CMF10*	*NAP*	*0*	*No*	*8.5 ± 0.5*	*3.0 ± 0.1*	*17.3*	*19.6*	*159.8 ± 10.3*	*105.9 ± 5.8*	***	*0.88 ± 0.05*	*0.41 ± 0.06*	*6.9 ± 0.1*	*0.35 ± 0.06*	*0.13 ± 0.03*	*20.0 ± 8.6*	*1.00*	*0.96*	*1.00*	*1.13*	*0.98*	*19.6 ± 8.9*	*0.99*	*1.06*	*0.34*	*23.96*
123	*Miller Farm CMF3*	*NAP*	*1*	*Yes*	*6.6 ± 0.3*	*5.7 ± 0.1*	*17.3*	*19.6*	*116.7 ± 6.3*	*107.6 ± 4.0*	***	*0.83 ± 0.04*	*0.46 ± 0.07*	*6.9 ± 0.1*	*0.27 ± 0.04*	*0.12 ± 0.03*	*27.3 ± 11.9*	*1.00*	*0.95*	*1.00*	*1.13*	*0.97*	*11.0 ± 3.9*	*0.99*	*1.06*	*0.26*	*16.39*
124	*Miller Farm CMF5*	*NAP*	*1*	*Yes*	*7.0 ± 0.5*	*4.7 ± 0.1*	*18.9*	*19.6*	*133.8 ± 10.1*	*111.2 ± 5.6*	***	*0.90 ± 0.05*	*0.41 ± 0.06*	*6.9 ± 0.1*	*0.29 ± 0.05*	*0.19 ± 0.05*	*13.0 ± 8.6*	*1.00*	*0.95*	*1.00*	*1.13*	*0.95*	*20.5 ± 2.0*	*0.98*	*1.06*	*0.28*	*22.78*
125	*Miller Farm CMF8*	*NAP*	*1*	*Yes*	*6.5 ± 0.5*	*4.9 ± 0.1*	*15.7*	*18.9*	*107.1 ± 9.7*	*91.4 ± 5.2*	***	*0.73 ± 0.04*	*0.46 ± 0.07*	*6.9 ± 0.1*	*0.26 ± 0.04*	*0.20 ± 0.08*	*15.5 ± 2.1*	*1.00*	*0.94*	*1.00*	*1.13*	*1.05*	*10.1 ± 2.0*	*1.02*	*1.06*	*0.24*	*13.14*
126	*POO7-2*	*NAP*	*1*	*Yes*	*6.2 ± 0.2*	*3.0 ± 0.1*	*18.9*	*19.6*	*118.4 ± 4.7*	*87.5 ± 3.1*	***	*0.86 ± 0.04*	*0.22 ± 0.03*	*6.9 ± 0.1*	*0.17 ± 0.03*	*0.30 ± 0.05*	*3.0 ± 8.6*	*1.10*	*0.94*	*1.00*	*0.92*	*1.08*	*13.0 ± 3.1*	*1.02*	*1.06*	*0.15*	*13.00*
127	*POO7-3*	*NAP*	*1*	*Yes*	*6.0 ± 0.3*	*3.0 ± 0.1*	*18.9*	*19.6*	*115.5 ± 6.8*	*86.1 ± 3.9*	***	*0.83 ± 0.04*	*0.22 ± 0.03*	*6.9 ± 0.1*	*0.16 ± 0.03*	*0.32 ± 0.05*	*5.0 ± 6.4*	*1.10*	*0.94*	*1.00*	*0.92*	*1.09*	*16.3 ± 6.4*	*1.03*	*1.06*	*0.15*	*16.32*
128	*POR-2&3&4*	*NAP*	*1*	*Yes*	*4.9 ± 0.3*	*3.5 ± 0.1*	*15.7*	*17.3*	*79.1 ± 5.5*	*65.4 ± 3.0*	***	*0.78 ± 0.03*	*0.15 ± 0.02*	*6.9 ± 0.1*	*0.09 ± 0.01*	*0.09 ± 0.05*	*50.0 ± 8.6*	*1.10*	*0.92*	*1.00*	*0.92*	*1.24*	*3.6 ± 1.1*	*1.07*	*1.06*	*0.08*	*9.36*
129	*Sandholdt UC-B10*	*NAP*	*1*	*Yes*	*3.2 ± 0.3*	*1.7 ± 0.1*	*17.3*	*18.9*	*57.6 ± 4.9*	*43.0 ± 2.6*	***	*0.99 ± 0.02*	*0.26 ± 0.04*	*6.9 ± 0.1*	*0.22 ± 0.04*	*0.80 ± 0.05*	*2.0 ± 8.6*	*1.00*	*0.89*	*1.00*	*1.25*	*1.53*	*15.7 ± 6.7*	*1.15*	*1.06*	*0.18*	*15.70*
130	*SFOBB-1&2*	*NAP*	*1*	*Yes*	*6.3 ± 0.3*	*3.0 ± 0.1*	*18.9*	*19.6*	*120.4 ± 5.3*	*88.5 ± 3.3*	***	*0.79 ± 0.04*	*0.27 ± 0.04*	*6.9 ± 0.1*	*0.19 ± 0.03*	*0.28 ± 0.05*	*8.0 ± 8.6*	*1.20*	*0.94*	*1.00*	*0.92*	*1.07*	*8.8 ± 3.5*	*1.02*	*1.06*	*0.17*	*9.44*
131	*State Beach UC-B1*	*NAP*	*1*	*Yes*	*2.7 ± 0.3*	*1.8 ± 0.1*	*17.3*	*19.6*	*49.3 ± 6.2*	*40.2 ± 3.3*	***	*0.95 ± 0.02*	*0.29 ± 0.04*	*6.9 ± 0.1*	*0.22 ± 0.04*	*0.26 ± 0.05*	*1.7 ± 0.6*	*1.00*	*0.88*	*1.00*	*1.25*	*1.59*	*7.6 ± 2.3*	*1.16*	*1.06*	*0.18*	*7.58*
132	*State Beach UC-B2*	*NAP*	*1*	*Yes*	*4.7 ± 0.7*	*2.7 ± 0.1*	*18.9*	*19.6*	*90.6 ± 13.1*	*71.2 ± 6.7*	***	*0.99 ± 0.03*	*0.24 ± 0.04*	*6.9 ± 0.1*	*0.20 ± 0.03*	*0.40 ± 0.05*	*1.0 ± 8.6*	*1.00*	*0.92*	*1.00*	*1.25*	*1.19*	*17.9 ± 3.0*	*1.06*	*1.06*	*0.18*	*17.89*
133	*Treasure Island*	*NAP*	*1*	*Yes*	*5.3 ± 1.3*	*1.5 ± 0.0*	*15.7*	*18.1*	*91.3 ± 22.7*	*54.5 ± 10.5*	***	*0.88 ± 0.04*	*0.18 ± 0.03*	*6.9 ± 0.1*	*0.17 ± 0.03*	*0.17 ± 0.05*	*21.7 ± 14.1*	*1.10*	*0.93*	*1.00*	*1.13*	*1.36*	*8.0 ± 5.1*	*1.11*	*1.06*	*0.15*	*12.62*
134	*WoodMarine UC-B4*	*NAP*	*1*	*Yes*	*1.8 ± 0.3*	*1.0 ± 0.1*	*17.3*	*18.9*	*31.4 ± 4.8*	*24.1 ± 2.5*	***	*0.99 ± 0.01*	*0.25 ± 0.04*	*6.9 ± 0.1*	*0.21 ± 0.03*	*0.10 ± 0.05*	*35.0 ± 8.6*	*1.00*	*0.85*	*1.00*	*1.00*	*2.00*	*9.8 ± 0.3*	*1.26*	*1.06*	*0.16*	*15.56*
135	*General Fish*	*NAP*	*0*	*No*	*2.1 ± 0.1*	*1.7 ± 0.0*	*18.9*	*20.6*	*40.3 ± 3.1*	*36.1 ± 1.8*	*210*	*0.99 ± 0.01*	*0.25 ± 0.08*	*6.9 ± 0.1*	*0.18 ± 0.05*	*0.55 ± 0.05*	*5.0 ± 8.6*	*1.00*	*0.86*	*1.00*	*1.00*	*1.67*	*17.5 ± 3.6*	*1.18*	*1.06*	*0.14*	*17.45*
136	*Marine Laboratory B-1 & B-2*	*NAP*	*1*	*Yes*	*4.0 ± 0.7*	*2.5 ± 0.1*	*17.3*	*19.6*	*72.8 ± 13.2*	*57.6 ± 6.7*	***	*0.99 ± 0.03*	*0.25 ± 0.04*	*6.9 ± 0.1*	*0.20 ± 0.03*	*0.80 ± 0.05*	*3.0 ± 8.6*	*1.00*	*0.91*	*1.00*	*1.00*	*1.33*	*12.6 ± 1.7*	*1.10*	*1.06*	*0.18*	*12.62*

Table 4.6. (cont'd)

ID #	Earthquake & Site	GMIndicates Liq. (No=0/Yes=1)	Surface Manif. (No=0/Yes=1)	Liq.?	$d_{crt.}$ (m)	GWT (m)	γ_1 (kN/m^3)	γ_2 (kN/m^3)	σ_v (kPa)	σ_v' (kPa)	$V^*_{s,12m}$ (m/s)	r_d	a $_{max}$	M_w	CSR	D_{50} (mm)	FC %	C_S	C_R	C_B	C_E	C_N	$(N_1)_{60}$	K_σ	K_{Mw}	$CSR_{Mw=7.5,\sigma'v=1 atm}$	$N_{1,60,CS}$
137	*Marine Laboratory_F1-F7*	NAP	1	Yes	4.6 ± 0.4	1.5 ± 0.0	18.9	20.6	91.5 ± 7.5	61.6 ± 4.2	238	0.99 ± 0.01	0.25 ± 0.08	6.9 ± 0.1	0.24 ± 0.07	0.43 ± 0.08	3.0 ± 1.4	1.00	0.92	1.00	1.25	1.28	20.2 ± 6.7	1.08	1.06	0.21	20.21
138	*MBARI N0.4-B4B5EB2EB3*	NAP	0	No	5.1 ± 0.9	2.0 ± 0.5	18.9	21.5	103.5 ± 19.1	73.1 ± 11.1	216	0.98 ± 0.04	0.25 ± 0.08	6.9 ± 0.1	0.22 ± 0.07	0.55 ± 0.15	5.0 ± 8.6	1.00	0.92	1.00	1.00	1.18	26.5 ± 5.5	1.05	1.06	0.20	26.50
139	*Miller Farm*	NAP	1	Yes	6.0 ± 0.7	4.0 ± 0.1	17.3	19.6	108.4 ± 13.3	88.8 ± 6.9	*	0.90 ± 0.04	0.42 ± 0.06	6.9 ± 0.1	0.30 ± 0.05	0.16 ± 0.05	22.0 ± 8.6	1.00	0.94	1.00	1.13	1.07	9.0 ± 3.6	1.02	1.06	0.28	13.76
140	*Alameda Strong Motion Station*	1	1	Yes	3.5 ± 0.4	2.4 ± 0.1	18.9	20.6	66.8 ± 7.3	56.6 ± 4.0	129	0.85 ± 0.05	0.25 ± 0.01	6.9 ± 0.1	0.16 ± 0.01	- ± -	5.0 ± 8.6	1.30	0.90	1.00	1.00	1.34	20.7 ± 2.0	1.10	1.06	0.14	20.71
141	*Kushiro Port Site A*	NAP	1	Yes	4.9 ± 0.8	2.0 ± 0.1	18.9	20.6	96.9 ± 16.8	68.7 ± 8.9	238	0.99 ± 0.07	0.41 ± 0.06	7.6 ± 0.1	0.37 ± 0.06	0.34 ± 0.05	2.0 ± 8.6	1.00	0.94	1.00	1.37	1.21	17.6 ± 4.4	1.07	0.99	0.35	17.61
142	*Kushiro Port Site D*	NAP	0	No	8.3 ± 0.7	1.6 ± 0.1	18.9	21.5	173.3 ± 15.1	108.1 ± 8.7	271	0.99 ± 0.11	0.41 ± 0.06	7.6 ± 0.1	0.42 ± 0.08	0.34 ± 0.05	0.0 ± 8.6	1.00	0.97	1.00	1.37	0.97	32.2 ± 4.6	0.99	0.99	0.43	32.20
143	*Kushiro Port*	1	1	Yes	3.8 ± 0.6	2.0 ± 0.1	17.7	18.6	67.9 ± 10.9	50.8 ± 5.4	222	0.99 ± 0.05	0.41 ± 0.02	7.6 ± 0.1	0.35 ± 0.03	0.35 ± 0.05	5.0 ± 8.6	1.00	0.92	1.00	1.37	1.41	28.0 ± 1.9	1.12	0.99	0.32	28.01
144	*Balboa Blv. Unit C*	NAP	1	Yes	9.0 ± 0.3	7.2 ± 0.1	17.3	19.6	159.8 ± 6.0	142.1 ± 4.4	*	0.71 ± 0.06	0.69 ± 0.10	6.7 ± 0.1	0.36 ± 0.06	0.11 ± 0.04	39.8 ± 12.7	1.00	0.97	1.00	1.13	0.84	18.4 ± 4.0	0.95	1.08	0.35	24.18
145	*Potrero Canyon C1*	NAP	1	Yes	6.5 ± 0.2	3.3 ± 0.9	15.7	20.6	117.7 ± 5.9	86.3 ± 5.1	160	0.79 ± 0.09	0.40 ± 0.12	6.7 ± 0.1	0.28 ± 0.09	0.10 ± 0.01	44.5 ± 2.1	1.00	0.94	1.00	1.13	1.08	11.1 ± 0.6	1.03	1.08	0.25	16.90
146	*Wynne Ave. Unit C1*	NAP	1	Yes	6.3 ± 0.2	4.2 ± 0.5	17.3	19.6	112.9 ± 4.1	92.5 ± 4.5	*	0.86 ± 0.04	0.54 ± 0.08	6.7 ± 0.1	0.37 ± 0.06	0.13 ± 0.03	37.3 ± 6.0	1.00	0.94	1.00	1.13	1.05	11.5 ± 1.7	1.01	1.08	0.34	17.27
	1995 Hyogoken-Nanbu (Kobe) Earthquake																										
147	*Ashiyama A (Mountain Sand 1)*	NAP	0	No	5.2 ± 0.6	3.5 ± 0.1	18.9	20.6	101.0 ± 11.8	84.3 ± 6.4	232	0.98 ± 0.07	0.40 ± 0.08	6.9 ± 0.1	0.31 ± 0.07	0.13 ± 0.05	18.0 ± 8.6	1.00	0.94	1.00	1.37	1.10	22.5 ± 5.9	1.03	1.06	0.28	26.33
148	*Ashiyama C-D-E (Marine Sand)*	NAP	1	Yes	8.7 ± 0.4	3.5 ± 0.0	18.9	20.6	173.0 ± 9.4	122.0 ± 5.5	219	0.92 ± 0.11	0.40 ± 0.08	6.9 ± 0.1	0.34 ± 0.08	0.19 ± 0.05	2.0 ± 8.6	1.00	0.97	1.00	1.37	0.91	13.1 ± 3.8	0.97	1.06	0.33	13.05
149	*Kobe No 1*	NAP	0	No	6.0 ± 0.3	2.4 ± 0.1	19.9	21.5	125.4 ± 7.5	89.7 ± 4.5	279	1.00 ± 0.08	0.40 ± 0.08	6.9 ± 0.1	0.36 ± 0.08	- ± -	3.5 ± 4.9	1.00	0.95	1.00	1.37	1.06	58.6 ± 4.3	1.02	1.06	0.34	58.57
150	*Kobe No 2*	NAP	0	No	7.4 ± 1.5	2.9 ± 0.1	18.9	21.5	152.5 ± 32.8	107.9 ± 18.0	259	0.99 ± 0.10	0.40 ± 0.08	6.9 ± 0.1	0.36 ± 0.08	- ± -	14.8 ± 11.5	1.00	0.96	1.00	1.37	0.97	44.1 ± 10.5	0.99	1.06	0.35	46.93
151	*Kobe No 3*	NAP	0	No	5.6 ± 0.7	2.5 ± 0.1	17.3	21.5	108.8 ± 14.8	78.9 ± 8.2	259	0.99 ± 0.08	0.40 ± 0.08	6.9 ± 0.1	0.36 ± 0.08	- ± -	3.3 ± 2.2	1.00	0.94	1.00	1.37	1.13	55.8 ± 8.6	1.04	1.06	0.32	55.80
152	*Kobe No 4*	NAP	0	No	4.8 ± 0.6	2.1 ± 0.1	18.9	21.5	96.7 ± 12.7	70.3 ± 7.1	265	1.00 ± 0.07	0.40 ± 0.08	6.9 ± 0.1	0.36 ± 0.08	- ± -	1.3 ± 2.3	1.00	0.93	1.00	1.37	1.20	43.5 ± 4.0	1.06	1.06	0.32	43.50
153	*Kobe No 5*	NAP	1	Yes	9.3 ± 0.8	3.0 ± 0.1	17.3	18.9	170.6 ± 16.0	109.0 ± 8.3	177	0.75 ± 0.12	0.35 ± 0.07	6.9 ± 0.1	0.27 ± 0.07	- ± -	1.3 ± 2.5	1.00	0.97	1.00	1.37	0.96	7.7 ± 1.8	0.99	1.06	0.26	7.70
154	*Kobe No 6*	NAP	0	No	5.8 ± 0.5	2.3 ± 0.1	18.9	20.6	115.4 ± 10.5	81.1 ± 5.8	216	0.96 ± 0.08	0.40 ± 0.08	6.9 ± 0.1	0.36 ± 0.08	- ± -	24.7 ± 9.2	1.00	0.95	1.00	1.37	1.12	24.2 ± 5.0	1.04	1.06	0.32	29.35
155	*Kobe No 7*	NAP	1	Yes	3.5 ± 0.1	3.2 ± 0.1	18.9	20.6	66.2 ± 2.7	63.0 ± 2.0	232	0.99 ± 0.05	0.40 ± 0.08	6.9 ± 0.1	0.27 ± 0.06	- ± -	0.0 ± 8.6	1.00	0.91	1.00	1.37	1.27	22.3 ± 7.9	1.08	1.06	0.24	22.32
156	*Kobe No 8*	NAP	1	Yes	4.6 ± 0.6	3.0 ± 0.1	15.7	19.6	78.7 ± 10.9	62.6 ± 5.7	232	0.99 ± 0.07	0.50 ± 0.10	6.9 ± 0.1	0.40 ± 0.09	- ± -	0.0 ± 8.6	1.00	0.93	1.00	1.37	1.27	28.3 ± 3.3	1.08	1.06	0.35	28.34
157	*Kobe No 9*	NAP	1	Yes	4.1 ± 0.5	2.8 ± 0.1	15.7	18.9	69.2 ± 8.7	55.9 ± 4.4	191	0.96 ± 0.06	0.50 ± 0.10	6.9 ± 0.1	0.38 ± 0.08	- ± -	2.3 ± 4.0	1.00	0.92	1.00	1.37	1.35	14.5 ± 6.1	1.10	1.06	0.33	14.46
158	*Kobe No 10*	NAP	0	No	6.7 ± 0.8	4.5 ± 0.1	18.9	20.6	130.8 ± 15.7	108.5 ± 8.5	262	0.99 ± 0.09	0.60 ± 0.12	6.9 ± 0.1	0.46 ± 0.10	- ± -	8.8 ± 2.5	1.00	0.96	1.00	1.37	0.97	27.7 ± 4.1	0.99	1.06	0.44	28.60
159	*Kobe No 11*	NAP	1	Yes	6.7 ± 1.1	1.5 ± 0.1	17.3	18.9	123.5 ± 20.7	72.3 ± 10.2	152	0.75 ± 0.09	0.50 ± 0.10	6.9 ± 0.1	0.42 ± 0.10	- ± -	5.0 ± 8.6	1.00	0.96	1.00	1.37	1.18	8.6 ± 2.6	1.06	1.06	0.37	8.58
160	*Kobe No 12*	NAP	0	No	5.3 ± 0.5	3.2 ± 0.1	18.9	20.6	103.5 ± 10.4	83.0 ± 5.7	223	0.97 ± 0.07	0.50 ± 0.10	6.9 ± 0.1	0.40 ± 0.09	- ± -	14.0 ± 14.0	1.00	0.94	1.00	1.37	1.11	27.6 ± 2.2	1.03	1.06	0.36	30.13
161	*Kobe No 13*	NAP	1	Yes	6.6 ± 0.7	2.3 ± 0.1	19.9	20.6	133.9 ± 15.4	92.0 ± 8.4	223	0.96 ± 0.09	0.50 ± 0.10	6.9 ± 0.1	0.45 ± 0.10	- ± -	15.0 ± 10.0	1.00	0.95	1.00	1.37	1.05	12.8 ± 1.7	1.02	1.06	0.42	15.70
162	*Kobe No 14*	NAP	0	No	4.6 ± 0.4	3.1 ± 0.1	18.9	20.6	88.3 ± 8.7	74.1 ± 4.8	197	0.96 ± 0.06	0.50 ± 0.10	6.9 ± 0.1	0.37 ± 0.08	- ± -	18.5 ± 16.3	1.00	0.93	1.00	1.37	1.17	24.3 ± 2.5	1.05	1.06	0.33	28.27
163	*Kobe No 15*	NAP	1	Yes	5.6 ± 0.5	3.7 ± 0.1	15.7	20.6	97.5 ± 11.2	78.4 ± 6.1	197	0.94 ± 0.08	0.50 ± 0.10	6.9 ± 0.1	0.38 ± 0.08	- ± -	4.7 ± 4.5	1.00	0.94	1.00	1.37	1.14	21.8 ± 3.8	1.04	1.06	0.34	21.79
164	*Kobe No 16*	NAP	0	No	4.6 ± 0.3	2.5 ± 0.1	18.9	20.6	89.9 ± 6.5	69.1 ± 3.7	227	0.98 ± 0.06	0.60 ± 0.12	6.9 ± 0.1	0.50 ± 0.11	- ± -	5.0 ± 8.6	1.00	0.93	1.00	1.37	1.21	27.2 ± 2.3	1.06	1.06	0.44	27.19
165	*Kobe No 17*	NAP	1	Yes	4.6 ± 0.7	0.8 ± 0.1	18.9	20.6	92.3 ± 13.5	55.1 ± 7.3	174	0.92 ± 0.06	0.50 ± 0.10	6.9 ± 0.1	0.50 ± 0.11	- ± -	5.0 ± 8.6	1.00	0.93	1.00	1.37	1.36	22.6 ± 7.2	1.10	1.06	0.43	22.59
166	*Kobe No 18*	NAP	0	No	10.8 ± 0.7	7.7 ± 0.1	19.9	21.5	219.3 ± 14.5	188.9 ± 8.6	235	0.90 ± 0.13	0.70 ± 0.14	6.9 ± 0.1	0.47 ± 0.12	- ± -	0.0 ± 8.6	1.00	0.98	1.00	1.37	0.73	40.0 ± 4.2	0.90	1.06	0.49	40.04
167	*Kobe No 19*	NAP	0	No	7.7 ± 0.4	6.1 ± 0.1	19.9	20.6	154.1 ± 8.6	138.7 ± 5.2	235	0.96 ± 0.10	0.60 ± 0.12	6.9 ± 0.1	0.42 ± 0.09	- ± -	10.0 ± 8.6	1.00	0.96	1.00	1.37	0.85	22.1 ± 1.3	0.95	1.06	0.41	23.33
168	*Kobe No 20*	NAP	0	No	6.2 ± 0.9	2.0 ± 0.1	18.9	21.5	127.0 ± 18.4	86.3 ± 10.2	274	0.99 ± 0.08	0.55 ± 0.11	6.9 ± 0.1	0.52 ± 0.11	- ± -	0.0 ± 8.6	1.00	0.95	1.00	1.37	1.08	71.7 ± 6.8	1.03	1.06	0.48	71.74
169	*Kobe No 21*	NAP	0	No	3.6 ± 0.3	1.7 ± 0.1	15.7	20.6	65.0 ± 6.3	46.4 ± 3.5	232	0.99 ± 0.05	0.60 ± 0.12	6.9 ± 0.1	0.54 ± 0.11	- ± -	0.0 ± 8.6	1.00	0.91	1.00	1.37	1.48	42.7 ± 2.3	1.14	1.06	0.45	42.67
170	*Kobe No 22*	NAP	0	No	6.0 ± 0.8	2.4 ± 0.1	19.9	21.5	125.4 ± 18.1	90.1 ± 10.0	283	1.00 ± 0.08	0.60 ± 0.12	6.9 ± 0.1	0.54 ± 0.12	- ± -	6.0 ± 5.5	1.00	0.95	1.00	1.37	1.06	41.6 ± 13.2	1.02	1.06	0.50	41.80
171	*Kobe No 23*	NAP	0	No	5.1 ± 0.4	3.0 ± 0.1	17.3	21.5	97.0 ± 9.5	76.4 ± 5.4	280	1.00 ± 0.07	0.60 ± 0.12	6.9 ± 0.1	0.49 ± 0.11	- ± -	10.0 ± 8.6	1.00	0.94	1.00	1.37	1.15	26.9 ± 2.4	1.05	1.06	0.45	28.13
172	*Kobe No 24*	NAP	1	Yes	3.4 ± 0.4	2.4 ± 0.1	18.9	20.6	66.4 ± 7.5	55.9 ± 4.1	256	1.00 ± 0.05	0.50 ± 0.10	6.9 ± 0.1	0.38 ± 0.08	- ± -	0.0 ± 8.6	1.00	0.91	1.00	1.37	1.35	28.4 ± 0.8	1.10	1.06	0.33	28.38
173	*Kobe No 25*	NAP	0	No	3.2 ± 0.3	2.2 ± 0.1	18.9	20.6	61.1 ± 5.9	51.3 ± 3.3	268	1.00 ± 0.05	0.70 ± 0.14	6.9 ± 0.1	0.54 ± 0.11	- ± -	2.5 ± 3.5	1.00	0.91	1.00	1.37	1.41	44.2 ± 2.5	1.12	1.06	0.46	44.17
174	*Kobe No 26*	NAP	0	No	3.5 ± 0.3	0.9 ± 0.1	15.7	20.6	68.2 ± 5.8	42.4 ± 3.3	287	1.00 ± 0.05	0.60 ± 0.12	6.9 ± 0.1	0.63 ± 0.13	- ± -	0.0 ± 8.6	1.00	0.91	1.00	1.37	1.55	47.3 ± 6.0	1.15	1.06	0.51	47.30
175	*Kobe No 27*	NAP	0	No	2.5 ± 0.2	1.1 ± 0.1	15.7	21.5	46.6 ± 5.1	32.9 ± 2.9	290	1.00 ± 0.04	0.60 ± 0.12	6.9 ± 0.1	0.55 ± 0.11	- ± -	10.0 ± 8.6	1.00	0.89	1.00	1.37	1.75	59.3 ± 10.9	1.20	1.06	0.43	60.58
176	*Kobe No 28*	NAP	1	Yes	4.0 ± 0.5	1.8 ± 0.1	17.3	20.6	76.5 ± 10.4	54.5 ± 5.6	213	0.98 ± 0.06	0.40 ± 0.08	6.9 ± 0.1	0.36 ± 0.08	- ± -	8.0 ± 3.5	1.00	0.92	1.00	1.37	1.36	24.6 ± 6.1	1.11	1.06	0.31	25.27
177	*Kobe No 29*	NAP	1	Yes	3.5 ± 0.5	2.0 ± 0.1	18.9	20.6	67.5 ± 9.3	53.3 ± 5.0	241	0.99 ± 0.05	0.40 ± 0.08	6.9 ± 0.1	0.33 ± 0.07	- ± -	0.0 ± 8.6	1.00	0.91	1.00	1.37	1.38	21.0 ± 3.5	1.11	1.06	0.28	20.98
178	*Kobe No 30*	NAP	0	No	8.5 ± 0.7	1.5 ± 0.1	15.7	20.6	167.6 ± 14.1	99.0 ± 7.9	232	0.94 ± 0.11	0.60 ± 0.12	6.9 ± 0.1	0.62 ± 0.14	- ± -	10.0 ± 8.6	1.00	0.97	1.00	1.37	1.01	41.2 ± 6.0	1.00	1.06	0.58	42.48
179	*Kobe No 31*	NAP	0	No	4.0 ± 0.5	1.2 ± 0.1	15.7	21.5	79.1 ± 10.9	51.7 ± 6.0	280	1.00 ± 0.06	0.60 ± 0.12	6.9 ± 0.1	0.60 ± 0.13	- ± -	0.0 ± 8.6	1.00	0.92	1.00	1.37	1.40	63.3 ± 6.5	1.12	1.06	0.50	63.28
180	*Kobe No 32*	NAP	0	No	3.6 ± 0.7	1.4 ± 0.1	15.7	20.6	66.2 ± 14.8	45.2 ± 7.8	262	1.00 ± 0.05	0.50 ± 0.10	6.9 ± 0.1	0.48 ± 0.10	- ± -	6.3 ± 4.8	1.00	0.91	1.00	1.37	1.50	35.2 ± 5.2	1.14	1.06	0.39	35.46
181	*Kobe No 33*	NAP	0	No	8.0 ± 0.5	2.0 ± 0.1	15.7	20.6	154.9 ± 10.7	96.1 ± 6.2	216	0.92 ± 0.10	0.50 ± 0.10	6.9 ± 0.1	0.48 ± 0.11	- ± -	50.0 ± 8.6	1.00	0.97	1.00	1.37	1.03	29.4 ± 2.1	1.01	1.06	0.45	35.19
182	*Kobe No 34*	NAP	1	Yes	7.3 ± 1.1	1.8 ± 0.1	17.3	20.6	144.3 ± 22.1	90.4 ± 11.8	213	0.94 ± 0.10	0.40 ± 0.08	6.9 ± 0.1	0.39 ± 0.09	- ± -	9.3 ± 1.9	1.00	0.96	1.00	1.37	1.06	25.4 ± 4.8	1.02	1.06	0.36	26.49
183	*Kobe No 35*	NAP	1	Yes	4.4 ± 0.7	2.1 ± 0.1	17.3	20.6	83.8 ± 14.5	60.7 ± 7.7	216	0.98 ± 0.06	0.50 ± 0.10	6.9 ± 0.1	0.44 ± 0.09	- ± -	6.3 ± 4.8	1.00	0.93	1.00	1.37	1.29	20.2 ± 3.6	1.09	1.06	0.38	20.42
184	*Kobe No 36*	NAP	0	No	3.5 ± 0.3	0.9 ± 0.1	17.3	20.6	68.9 ± 7.0	43.8 ± 3.9	213	0.98 ± 0.05	0.60 ± 0.12	6.9 ± 0.1	0.60 ± 0.13	- ± -	2.5 ± 3.5	1.00	0.91	1.00	1.37	1.52	38.1 ± 2.8	1.15	1.06	0.50	38.07
185	*Kobe No 37*	NAP	1	Yes	5.3 ± 0.4	4.0 ± 0.1	18.9	20.6	101.1 ± 8.8	88.9 ± 5.0	195	0.94 ± 0.07	0.35 ± 0.07	6.9 ± 0.1	0.24 ± 0.05	- ± -	0.0 ± 8.6	1.00	0.94	1.00	1.37	1.07	26.6 ± 5.0	1.02	1.06	0.23	26.61
186	*Kobe No 38*	NAP	1	Yes	8.5 ± 0.7	3.0 ± 0.1	18.9	20.6	169.7 ± 14.0	115.8 ± 7.8	216	0.91 ± 0.11	0.50 ± 0.10	6.9 ± 0.1	0.43 ± 0.10	- ± -	5.0 ± 8.6	1.00	0.97	1.00	1.37	0.94	19.5 ± 2.6	0.98	1.06	0.42	19.45

Table 4.6. (cont'd)

ID #	Earthquake & Site	GMIndicates Liq. (No=0/Yes=1)	Surface Manif. (No=0/Yes=1)	Liq.?	$d_{crt.}$ (m)	GWT (m)	γ_1 (kN/m^3)	γ_2 (kN/m^3)	σ_v (kPa)	σ_v' (kPa)	$V^*_{s,12m}$ (m/s)	r_d	a_{max}	M_w	CSR	D_{50} (mm)	FC %	C_S	C_R	C_B	C_E	C_N	$(N_1)_{60}$	K_σ	K_{Mw}	$CSR_{Mw=7.5,\sigma'v=1 atm}$	$N_{1,60,CS}$
187	*Kobe No 39*	*NAP*	*0*	*No*	*4.5 ± 0.3*	*2.6 ± 0.1*	*18.9*	*21.5*	*88.8 ± 7.0*	*70.7 ± 4.1*	*279*	*1.00 ± 0.06*	*0.60 ± 0.12*	*6.9 ± 0.1*	*0.49 ± 0.10*	*- ± -*	*0.0 ± 8.6*	*1.00*	*0.93*	*1.00*	*1.37*	*1.20*	*71.2 ± 3.1*	*1.06*	*1.06*	*0.44*	*71.22*
188	*Kobe No 40*	*NAP*	*0*	*No*	*3.5 ± 0.3*	*2.8 ± 0.1*	*19.9*	*21.5*	*70.9 ± 7.3*	*64.1 ± 4.2*	*290*	*1.00 ± 0.05*	*0.60 ± 0.12*	*6.9 ± 0.1*	*0.43 ± 0.09*	*- ± -*	*0.0 ± 8.6*	*1.00*	*0.91*	*1.00*	*1.37*	*1.26*	*49.1 ± 13.6*	*1.08*	*1.06*	*0.38*	*49.08*
189	*Kobe No 41*	*NAP*	*1*	*Yes*	*4.2 ± 0.8*	*2.0 ± 0.1*	*17.3*	*20.6*	*79.8 ± 15.8*	*58.3 ± 8.4*	*223*	*0.98 ± 0.06*	*0.40 ± 0.08*	*6.9 ± 0.1*	*0.35 ± 0.08*	*- ± -*	*0.0 ± 8.6*	*1.00*	*0.93*	*1.00*	*1.37*	*1.32*	*16.5 ± 3.7*	*1.09*	*1.06*	*0.30*	*16.51*
190	*Kobe No 42*	*NAP*	*1*	*Yes*	*5.2 ± 0.5*	*1.2 ± 0.1*	*17.3*	*18.9*	*96.2 ± 9.0*	*56.5 ± 4.7*	*160*	*0.86 ± 0.07*	*0.40 ± 0.08*	*6.9 ± 0.1*	*0.38 ± 0.08*	*- ± -*	*10.0 ± 8.6*	*1.00*	*0.94*	*1.00*	*1.37*	*1.34*	*12.3 ± 0.9*	*1.10*	*1.06*	*0.33*	*13.56*
191	*Kobe No 43*	*NAP*	*1*	*Yes*	*4.8 ± 0.3*	*2.2 ± 0.1*	*17.3*	*20.6*	*91.2 ± 6.2*	*65.4 ± 3.6*	*216*	*0.98 ± 0.07*	*0.35 ± 0.07*	*6.9 ± 0.1*	*0.31 ± 0.07*	*- ± -*	*20.0 ± 8.6*	*1.00*	*0.93*	*1.00*	*1.37*	*1.24*	*16.0 ± 0.8*	*1.07*	*1.06*	*0.27*	*20.35*
192	*Kobe No 44*	*NAP*	*1*	*Yes*	*3.9 ± 0.4*	*1.6 ± 0.1*	*17.3*	*18.9*	*71.1 ± 8.3*	*48.0 ± 4.2*	*168*	*0.93 ± 0.06*	*0.40 ± 0.08*	*6.9 ± 0.1*	*0.36 ± 0.08*	*- ± -*	*5.0 ± 8.6*	*1.00*	*0.92*	*1.00*	*1.37*	*1.45*	*8.5 ± 2.1*	*1.13*	*1.06*	*0.30*	*8.50*
193	*ort Island Borehole Array Statio*	*1*	*1*	*Yes*	*7.6 ± 1.8*	*2.4 ± 0.1*	*17.3*	*18.9*	*139.5 ± 34.7*	*88.5 ± 16.8*	*191*	*0.87 ± 0.10*	*0.35 ± 0.02*	*6.9 ± 0.1*	*0.31 ± 0.04*	*0.40 ± 0.66*	*9.8 ± 8.3*	*1.00*	*0.96*	*1.00*	*1.37*	*1.07*	*8.2 ± 2.2*	*1.02*	*1.06*	*0.29*	*9.38*
194	*ort Island Improved Site (Ikegay*	*NAP*	*0*	*No*	*8.5 ± 1.2*	*5.0 ± 0.1*	*18.9*	*20.6*	*166.3 ± 24.2*	*132.0 ± 12.9*	*235*	*0.95 ± 0.11*	*0.36 ± 0.07*	*6.9 ± 0.1*	*0.28 ± 0.07*	*0.40 ± 0.66*	*9.8 ± 8.3*	*1.00*	*0.97*	*1.00*	*1.37*	*0.88*	*24.4 ± 5.2*	*0.96*	*1.06*	*0.28*	*25.59*
195	*rt Island Improved Site (Tanahas*	*NAP*	*0*	*No*	*10.0 ± 1.7*	*5.0 ± 0.1*	*18.9*	*20.6*	*197.1 ± 34.5*	*148.1 ± 18.3*	*235*	*0.93 ± 0.13*	*0.35 ± 0.07*	*6.9 ± 0.1*	*0.28 ± 0.07*	*0.40 ± 0.66*	*9.8 ± 8.3*	*1.00*	*0.98*	*1.00*	*1.37*	*0.83*	*20.4 ± 4.0*	*0.94*	*1.06*	*0.29*	*21.66*
196	*rt Island Improved Site (Watanal*	*NAP*	*0*	*No*	*9.5 ± 1.5*	*5.0 ± 0.1*	*19.9*	*21.5*	*196.6 ± 32.4*	*152.5 ± 17.9*	*271*	*0.98 ± 0.12*	*0.38 ± 0.08*	*6.9 ± 0.1*	*0.31 ± 0.08*	*0.40 ± 0.66*	*9.8 ± 8.3*	*1.00*	*0.97*	*1.00*	*1.37*	*0.82*	*34.1 ± 7.4*	*0.94*	*1.06*	*0.32*	*35.32*
197	*Port Island Site I*	*NAP*	*1*	*Yes*	*10.0 ± 1.3*	*3.0 ± 0.1*	*18.9*	*20.6*	*200.6 ± 27.7*	*132.0 ± 14.8*	*213*	*0.87 ± 0.13*	*0.38 ± 0.08*	*6.9 ± 0.1*	*0.33 ± 0.08*	*0.40 ± 0.00*	*9.8 ± 8.3*	*1.00*	*0.98*	*1.00*	*1.37*	*0.88*	*11.5 ± 1.9*	*0.96*	*1.06*	*0.32*	*12.69*
198	*Rokko Island Building D*	*NAP*	*1*	*Yes*	*7.5 ± 1.2*	*4.0 ± 0.1*	*18.9*	*20.6*	*147.4 ± 24.1*	*113.1 ± 12.8*	*213*	*0.93 ± 0.10*	*0.34 ± 0.07*	*6.9 ± 0.1*	*0.27 ± 0.06*	*1.54 ± 1.38*	*12.6 ± 8.1*	*1.00*	*0.96*	*1.00*	*1.37*	*0.95*	*19.0 ± 7.6*	*0.98*	*1.06*	*0.26*	*21.15*
199	*Rokko Island Site G*	*NAP*	*1*	*Yes*	*11.5 ± 2.5*	*4.0 ± 0.1*	*18.9*	*20.6*	*229.7 ± 51.6*	*156.2 ± 27.2*	*189*	*0.72 ± 0.14*	*0.34 ± 0.07*	*6.9 ± 0.1*	*0.24 ± 0.07*	*1.54 ± 1.38*	*12.6 ± 8.1*	*1.00*	*0.98*	*1.00*	*1.37*	*0.81*	*13.1 ± 3.6*	*0.93*	*1.06*	*0.24*	*15.20*
	1999 Chi-chi Earthquake																										
200	*Nantou NCREE BH-3*	*NAP*	*1*	*Yes*	*5.5 ± 0.5*	*4.0 ± 0.1*	*18.4*	*19.8*	*103.1 ± 10.3*	*88.4 ± 5.8*	*208*	*0.96 ± 0.08*	*0.35 ± 0.07*	*7.6 ± 0.1*	*0.25 ± 0.06*	*0.16 ± 0.01*	*19.0 ± 1.4*	*1.00*	*0.94*	*1.01*	*1.25*	*1.07*	*10.2 ± 2.1*	*1.02*	*0.99*	*0.25*	*14.29*
201	*Nantou Site B NBS-1*	*NAP*	*0*	*No*	*2.3 ± 0.4*	*1.0 ± 0.1*	*15.7*	*19.6*	*40.3 ± 8.2*	*28.0 ± 4.2*	*166*	*0.97 ± 0.04*	*0.34 ± 0.07*	*7.6 ± 0.1*	*0.31 ± 0.07*	*0.12 ± 0.05*	*32.0 ± 8.6*	*1.00*	*1.00*	*1.01*	*1.11*	*1.90*	*9.6 ± 2.7*	*1.23*	*0.99*	*0.25*	*15.24*
202	*Nantou Site C NCS-1 & NCS-2*	*NAP*	*1*	*Yes*	*3.6 ± 0.5*	*0.9 ± 0.2*	*18.9*	*20.6*	*72.6 ± 11.1*	*45.7 ± 6.1*	*202*	*0.98 ± 0.05*	*0.38 ± 0.08*	*7.6 ± 0.1*	*0.38 ± 0.08*	*0.11 ± 0.04*	*28.8 ± 13.0*	*1.00*	*0.93*	*1.01*	*1.25*	*1.49*	*11.9 ± 6.0*	*1.14*	*0.99*	*0.34*	*17.42*
203	*Wufeng Site A*	*NAP*	*0*	*No*	*8.6 ± 0.8*	*1.1 ± 0.1*	*18.9*	*19.6*	*168.0 ± 16.1*	*94.9 ± 8.7*	*192*	*0.84 ± 0.11*	*0.57 ± 0.11*	*7.6 ± 0.1*	*0.55 ± 0.13*	*0.12 ± 0.02*	*23.5 ± 6.2*	*1.00*	*0.97*	*1.01*	*1.25*	*1.03*	*20.4 ± 3.7*	*1.01*	*0.99*	*0.55*	*25.42*
204	*Wufeng Site B (WBS1)*	*NAP*	*1*	*Yes*	*5.0 ± 1.2*	*1.6 ± 0.1*	*18.9*	*20.6*	*100.9 ± 23.8*	*67.0 ± 12.6*	*183*	*0.93 ± 0.07*	*0.55 ± 0.11*	*7.6 ± 0.1*	*0.50 ± 0.11*	*0.21 ± 0.24*	*29.8 ± 10.7*	*1.00*	*1.00*	*1.01*	*1.11*	*1.23*	*16.5 ± 6.3*	*1.07*	*0.99*	*0.47*	*22.04*
205	*Wufeng Site C (WCS1)*	*NAP*	*1*	*Yes*	*7.6 ± 1.1*	*4.2 ± 0.1*	*17.4*	*20.6*	*143.5 ± 23.3*	*110.3 ± 12.4*	*207*	*0.92 ± 0.10*	*0.57 ± 0.11*	*7.6 ± 0.1*	*0.44 ± 0.10*	*0.16 ± 0.03*	*19.2 ± 6.1*	*1.00*	*1.00*	*1.01*	*1.24*	*0.96*	*22.3 ± 3.5*	*0.99*	*0.99*	*0.45*	*26.38*
206	*Wufeng Site C (WCS2)*	*NAP*	*1*	*Yes*	*2.1 ± 0.3*	*1.3 ± 0.1*	*17.3*	*18.9*	*36.6 ± 4.8*	*29.2 ± 2.5*	*208*	*0.99 ± 0.03*	*0.57 ± 0.11*	*7.6 ± 0.1*	*0.46 ± 0.10*	*0.16 ± 0.02*	*12.0 ± 1.7*	*1.00*	*0.87*	*1.01*	*1.25*	*1.86*	*7.0 ± 4.6*	*1.22*	*0.99*	*0.38*	*8.87*
207	*Yuanlin BH3*	*NAP*	*1*	*Yes*	*3.3 ± 0.3*	*0.6 ± 0.1*	*17.3*	*18.9*	*60.3 ± 4.9*	*34.3 ± 2.7*	*157*	*0.94 ± 0.05*	*0.19 ± 0.04*	*7.6 ± 0.1*	*0.20 ± 0.04*	*0.21 ± 0.05*	*18.0 ± 8.6*	*1.00*	*0.90*	*1.00*	*1.25*	*1.72*	*10.4 ± 2.0*	*1.19*	*0.99*	*0.17*	*14.21*
208	*Yuanlin BH10*	*NAP*	*0*	*No*	*7.4 ± 0.8*	*2.0 ± 0.1*	*15.7*	*18.9*	*132.3 ± 15.0*	*79.8 ± 7.6*	*165*	*0.81 ± 0.10*	*0.18 ± 0.04*	*7.6 ± 0.1*	*0.16 ± 0.04*	*0.41 ± 0.17*	*12.1 ± 2.0*	*1.00*	*0.96*	*1.00*	*1.25*	*1.13*	*12.1 ± 2.0*	*1.04*	*0.99*	*0.15*	*14.04*
209	*Yuanlin BH21*	*NAP*	*1*	*Yes*	*12.5 ± 0.3*	*0.7 ± 0.1*	*15.7*	*20.0*	*247.0 ± 8.7*	*131.4 ± 6.5*	*148*	*0.58 ± 0.15*	*0.20 ± 0.04*	*7.6 ± 0.1*	*0.14 ± 0.05*	*0.06 ± 0.01*	*63.5 ± 6.4*	*1.00*	*0.98*	*1.00*	*1.25*	*0.88*	*8.1 ± 2.0*	*0.96*	*0.99*	*0.15*	*13.88*
210	*Yuanlin BH27*	*NAP*	*0*	*No*	*10.5 ± 0.8*	*0.4 ± 0.1*	*17.6*	*19.5*	*204.0 ± 18.8*	*105.0 ± 12.5*	*165*	*0.70 ± 0.13*	*0.19 ± 0.04*	*7.6 ± 0.1*	*0.16 ± 0.05*	*0.25 ± 0.13*	*8.6 ± 6.6*	*1.00*	*0.98*	*1.01*	*1.25*	*0.98*	*14.8 ± 1.3*	*0.99*	*0.99*	*0.17*	*15.65*
211	*Yuanlin BH28*	*NAP*	*1*	*Yes*	*6.0 ± 0.7*	*2.3 ± 0.1*	*18.6*	*19.2*	*114.0 ± 13.1*	*77.7 ± 6.8*	*140*	*0.77 ± 0.08*	*0.19 ± 0.04*	*7.6 ± 0.1*	*0.14 ± 0.03*	*0.10 ± 0.03*	*45.3 ± 14.0*	*1.00*	*0.94*	*1.00*	*1.25*	*1.14*	*5.9 ± 0.8*	*1.04*	*0.99*	*0.14*	*11.69*
212	*Yuanlin BH30*	*NAP*	*1*	*Yes*	*4.3 ± 1.1*	*1.1 ± 0.1*	*17.4*	*19.9*	*82.9 ± 21.5*	*51.5 ± 11.3*	*179*	*0.95 ± 0.06*	*0.20 ± 0.04*	*7.6 ± 0.1*	*0.20 ± 0.04*	*0.18 ± 0.13*	*33.4 ± 24.3*	*1.00*	*0.92*	*1.01*	*1.25*	*1.40*	*9.2 ± 0.9*	*1.12*	*0.99*	*0.18*	*14.97*
213	*Yuanlin BH31*	*NAP*	*0*	*No*	*6.5 ± 0.8*	*4.2 ± 0.1*	*18.2*	*18.6*	*119.1 ± 16.2*	*96.6 ± 8.8*	*147*	*0.78 ± 0.09*	*0.18 ± 0.04*	*7.6 ± 0.1*	*0.11 ± 0.03*	*0.10 ± 0.09*	*47.3 ± 28.1*	*1.00*	*0.95*	*1.01*	*1.25*	*1.02*	*5.2 ± 1.5*	*1.01*	*0.99*	*0.11*	*10.97*
	1999 Hokkaido Earthquake																										
214	*HKD086*	*0*	*0*	*No*	*8.3 ± 1.9*	*1.6 ± 0.5*	*18.1*	*19.6*	*159.5 ± 37.8*	*94.3 ± 19.6*	*127*	*0.52 ± 0.11*	*0.42 ± 0.02*	*6.2 ± 0.1*	*0.24 ± 0.05*	*NAV ± NAV*	*50.7 ± 41.6*	*1.00*	*0.97*	*1.00*	*1.37*	*1.04*	*12.5 ± 4.9*	*1.01*	*1.14*	*0.21*	*18.25*
	1999 Kocaeli Earthquake																										
215	*Hotel Sapanca SH-7*	*NAP*	*1*	*Yes*	*6.5 ± 1.5*	*1.3 ± 0.1*	*18.9*	*20.6*	*131.6 ± 31.0*	*80.1 ± 16.4*	*162*	*0.81 ± 0.09*	*0.50 ± 0.10*	*7.5 ± 0.1*	*0.43 ± 0.10*	*2.70 ± 1.11*	*8.3 ± 3.5*	*1.00*	*1.00*	*1.00*	*1.06*	*1.12*	*13.6 ± 4.0*	*1.04*	*1.00*	*0.42*	*14.36*
216	*Hotel Sapanca SH-11*	*NAP*	*1*	*Yes*	*6.2 ± 1.7*	*1.2 ± 0.1*	*17.3*	*18.9*	*115.0 ± 31.5*	*66.0 ± 15.3*	*162*	*0.83 ± 0.08*	*0.50 ± 0.10*	*7.5 ± 0.1*	*0.47 ± 0.11*	*2.29 ± 1.62*	*17.6 ± 18.6*	*1.00*	*1.00*	*1.00*	*1.00*	*1.24*	*14.7 ± 4.3*	*1.07*	*1.00*	*0.44*	*18.43*
217	*Yalova Harbor*	*NAP*	*1*	*Yes*	*4.5 ± 1.2*	*0.8 ± 0.1*	*18.9*	*20.6*	*91.4 ± 25.4*	*55.2 ± 13.4*	*158*	*0.89 ± 0.06*	*0.37 ± 0.07*	*7.5 ± 0.1*	*0.35 ± 0.08*	*0.22 ± 0.07*	*18.9 ± 16.7*	*1.30*	*1.00*	*1.00*	*1.02*	*1.36*	*17.8 ± 4.2*	*1.10*	*1.00*	*0.32*	*21.85*
	2001 Nisqually Earthquake																										
218	*Harbour Island*	*NAP*	*1*	*Yes*	*2.9 ± 0.3*	*2.1 ± 0.1*	*18.9*	*20.6*	*55.7 ± 5.4*	*48.1 ± 3.1*	*110*	*0.82 ± 0.04*	*0.20 ± 0.01*	*6.8 ± 0.1*	*0.12 ± 0.01*	*NAV ± NAV*	*5.0 ± 8.6*	*1.00*	*0.89*	*1.00*	*1.10*	*1.45*	*15.6 ± 0.7*	*1.13*	*1.07*	*0.10*	*15.62*
219	*Terminal 18*	*NAP*	*1*	*Yes*	*8.7 ± 2.1*	*2.4 ± 0.1*	*18.9*	*20.6*	*174.6 ± 43.4*	*112.7 ± 22.9*	*178*	*0.79 ± 0.11*	*0.20 ± 0.04*	*6.8 ± 0.1*	*0.16 ± 0.04*	*0.32 ± 0.12*	*25.0 ± 11.2*	*1.00*	*0.97*	*1.00*	*1.10*	*0.95*	*10.4 ± 6.6*	*0.98*	*1.07*	*0.15*	*15.56*
220	*Terminal 30*	*NAP*	*1*	*Yes*	*5.3 ± 0.9*	*2.7 ± 0.1*	*19.9*	*20.6*	*108.2 ± 18.3*	*82.2 ± 9.7*	*240*	*0.99 ± 0.07*	*0.20 ± 0.04*	*6.8 ± 0.1*	*0.17 ± 0.04*	*NAV ± NAV*	*23.5 ± 1.5*	*1.00*	*0.93*	*1.00*	*1.10*	*1.11*	*16.5 ± 4.5*	*1.03*	*1.07*	*0.15*	*21.50*
221	*Kings airport*	*NAP*	*1*	*Yes*	*2.7 ± 0.2*	*2.1 ± 0.7*	*18.1*	*20.6*	*51.0 ± 4.7*	*45.0 ± 5.6*	*122*	*0.87 ± 0.04*	*0.22 ± 0.04*	*6.8 ± 0.1*	*0.14 ± 0.04*	*0.15 ± 0.05*	*8.0 ± 8.6*	*1.00*	*0.89*	*1.00*	*1.10*	*1.50*	*17.8 ± 4.0*	*1.14*	*1.07*	*0.11*	*18.52*
222	*Kings airport 2*	*NAP*	*1*	*Yes*	*2.7 ± 0.2*	*2.1 ± 0.1*	*17.3*	*18.9*	*48.4 ± 4.0*	*42.4 ± 2.2*	*160*	*0.95 ± 0.04*	*0.22 ± 0.04*	*6.8 ± 0.1*	*0.15 ± 0.03*	*NAV ± NAV*	*17.0 ± 5.0*	*1.00*	*0.89*	*1.00*	*1.10*	*1.55*	*11.2 ± 3.6*	*1.15*	*1.07*	*0.12*	*14.75*
223	*Capitol Lake*	*NAP*	*1*	*Yes*	*3.1 ± 0.2*	*1.5 ± 0.1*	*18.9*	*18.9*	*58.4 ± 3.3*	*43.0 ± 2.0*	*270*	*1.00 ± 0.05*	*0.24 ± 0.05*	*6.8 ± 0.1*	*0.21 ± 0.04*	*NAV ± NAV*	*61.0 ± 8.6*	*1.00*	*0.89*	*1.00*	*1.10*	*1.54*	*6.1 ± 2.0*	*1.15*	*1.07*	*0.17*	*11.89*
224	*Port of Olympia*	*NAP*	*1*	*Yes*	*4.1 ± 0.6*	*2.3 ± 0.1*	*18.9*	*17.3*	*75.2 ± 10.8*	*57.1 ± 4.9*	*153*	*0.89 ± 0.06*	*0.24 ± 0.05*	*6.8 ± 0.1*	*0.18 ± 0.04*	*0.32 ± 0.05*	*3.0 ± 8.6*	*1.00*	*0.91*	*1.00*	*1.10*	*1.33*	*5.5 ± 4.9*	*1.10*	*1.07*	*0.15*	*5.50*
	2003 Lefkada Earthquake																										
225	*Lefkada town GL11-12*	*NAP*	*0*	*No*	*8.8 ± 0.9*	*1.8 ± 0.8*	*17.3*	*21.2*	*179.7 ± 20.3*	*110.6 ± 12.0*	*198*	*0.84 ± 0.11*	*0.38 ± 0.08*	*6.2 ± 0.1*	*0.34 ± 0.08*	*NAV ± NAV*	*31.0 ± 4.3*	*1.00*	*0.97*	*1.00*	*1.10*	*0.96*	*22.3 ± 0.9*	*0.99*	*1.14*	*0.30*	*27.94*
226	*Lefkada town GX5*	*NAP*	*1*	*Yes*	*7.5 ± 1.0*	*0.8 ± 0.1*	*15.7*	*20.6*	*149.4 ± 19.8*	*84.2 ± 10.7*	*238*	*0.97 ± 0.10*	*0.38 ± 0.08*	*6.2 ± 0.1*	*0.43 ± 0.10*	*NAV ± NAV*	*30.3 ± 10.1*	*1.00*	*0.96*	*1.00*	*1.10*	*1.10*	*19.2 ± 3.9*	*1.03*	*1.14*	*0.36*	*24.77*
	2003 San Simeon Earthquake																										
227	*SOC 10*	*NAP*	*0*	*No*	*4.9 ± 0.3*	*4.1 ± 0.0*	*16.3*	*18.7*	*80.8 ± 5.1*	*73.4 ± 3.0*	*234*	*0.99 ± 0.07*	*0.12 ± 0.02*	*6.5 ± 0.1*	*0.09 ± 0.02*	*0.15 ± 0.00*	*3.6 ± 5.0*	*1.00*	*0.93*	*1.00*	*1.10*	*1.17*	*41.5 ± 2.0*	*1.05*	*1.10*	*0.07*	*41.47*
	2003 Tokachi-oki Earthquake																										
228	*HKD086*	*1*	*1*	*Yes*	*8.3 ± 1.9*	*1.6 ± 0.5*	*18.1*	*19.6*	*159.5 ± 37.8*	*94.3 ± 19.6*	*127*	*0.57 ± 0.11*	*0.78 ± 0.04*	*8.3 ± 0.0*	*0.49 ± 0.10*	*NAV ± NAV*	*50.7 ± 41.6*	*1.00*	*0.97*	*1.00*	*1.37*	*1.04*	*12.5 ± 4.9*	*1.01*	*0.93*	*0.52*	*18.25*
229	*Kushiro Port*	*0*	*0*	*No*	*3.8 ± 0.6*	*2.0 ± 0.1*	*17.7*	*18.6*	*67.9 ± 10.9*	*50.8 ± 5.4*	*222*	*0.99 ± 0.05*	*0.45 ± 0.02*	*8.3 ± 0.0*	*0.39 ± 0.04*	*0.35 ± 0.05*	*5.0 ± 8.6*	*1.00*	*0.92*	*1.00*	*1.37*	*1.41*	*28.0 ± 1.9*	*1.12*	*0.93*	*0.37*	*28.01*

Table 4.6. (cont'd)

ID #	Earthquake & Site	GMIndicates Liq. (No=0/Yes=1)	Surface Manif. (No=0/Yes=1)	Liq.?	$d_{crt.}$ (m)	GWT (m)	γ_1 (kN/m^3)	γ_2 (kN/m^3)	σ_v (kPa)	σ_v' (kPa)	$V^*_{s,12m}$ (m/s)	r_d	a_{max}	M_w	CSR	D_{50} (mm)	FC %	C_S	C_R	C_B	C_E	C_N	$(N_1)_{60}$	K_σ	K_{Mw}	$CSR_{Mw=7.5,\sigma v=1 atm}$	$N_{1,60,CS}$
	2006 Kiholo Bay Earthquake																										
230	Kawaihae Harbor_Pier-1	NAP	1	Yes	6.6 ± 1.5	2.2 ± 0.9	19.9	21.5	138.8 ± 31.6	95.8 ± 18.9	274	0.99 ± 0.09	0.40 ± 0.08	6.7 ± 0.1	0.37 ± 0.09	NAV ± NAV	16.0 ± 5.0	1.00	0.95	1.00	1.10	1.03	22.3 ± 9.7	1.01	1.08	0.34	25.54
231	Kawaihae Harbor_Pier-2	NAP	1	Yes	3.8 ± 0.4	2.2 ± 0.5	19.9	20.6	75.8 ± 8.7	60.4 ± 6.5	249	1.00 ± 0.05	0.35 ± 0.07	6.7 ± 0.1	0.28 ± 0.06	NAV ± NAV	31.0 ± 10.0	1.00	0.91	1.00	1.10	1.30	22.3 ± 3.5	1.09	1.08	0.24	27.94
	2007 Niigata Chuetsu-oki Earthquake																										
232	NIG018	1	0	No or Yes	5.8 ± 0.6	4.0 ± 0.1	18.9	20.6	111.4 ± 12.2	94.3 ± 6.7	170	0.85 ± 0.08	0.65 ± 0.03	6.6 ± 0.1	0.42 ± 0.05	NAV ± NAV	15.0 ± 8.6	1.00	0.95	1.00	1.37	1.04	28.5 ± 4.7	1.01	1.09	0.38	31.38
	2010 Darfield Earthquake																										
233	Corhampton Street (VSVP 5719	NAP	0	No	4.7 ± 0.8	1.9 ± 0.5	15.7	20.6	88.0 ± 15.9	60.3 ± 8.7	190	0.85 ± 0.03	0.18 ± 0.03	7.1 ± 0.1	0.15 ± 0.03	NAV ± NAV	5.0 ± 8.6	1.00	0.92	1.00	1.37	1.30	17.8 ± 6.8	1.09	1.04	0.13	17.85
234	EQC-4 - Avondale	NAP	1	Yes	5.0 ± 1.0	1.9 ± 0.3	15.7	20.6	93.7 ± 20.7	63.2 ± 11.0	213	0.97 ± 0.07	0.18 ± 0.04	7.1 ± 0.1	0.17 ± 0.04	0.20 ± 0.05	7.1 ± 6.9	1.00	0.93	1.00	1.37	1.27	19.4 ± 2.5	1.08	1.04	0.15	19.92
235	Site 14-Barrington	NAP	0	No	4.0 ± 0.5	0.1 ± 0.2	17.3	18.9	75.2 ± 9.6	37.0 ± 5.1	253	1.00 ± 0.06	0.23 ± 0.05	7.1 ± 0.1	0.30 ± 0.06	0.10 ± 0.05	30.0 ± 8.6	1.00	0.91	1.00	1.45	1.65	17.8 ± 4.3	1.18	1.04	0.25	23.43
236	rmans Road/Papanui Road (572(	NAP	0	No	6.2 ± 0.6	2.7 ± 0.4	18.9	20.6	123.0 ± 12.5	88.4 ± 7.7	198	0.81 ± 0.04	0.21 ± 0.03	7.1 ± 0.1	0.15 ± 0.03	NAV ± NAV	5.0 ± 8.6	1.00	0.94	1.00	1.37	1.07	11.8 ± 0.3	1.02	1.04	0.14	11.81
237	EQC-6 - Bexley	NAP	1	Yes	3.6 ± 0.5	1.6 ± 0.3	18.9	18.9	66.9 ± 9.2	47.6 ± 5.4	219	0.99 ± 0.05	0.18 ± 0.04	7.1 ± 0.1	0.16 ± 0.04	NAV ± NAV	13.0 ± 8.7	1.00	0.90	1.00	1.42	1.46	9.8 ± 8.8	1.13	1.04	0.14	12.05
238	Avondale Park (VSVP 57187)	NAP	0	No	3.2 ± 0.6	1.4 ± 0.1	17.3	18.9	58.1 ± 11.4	40.5 ± 5.7	163	0.93 ± 0.02	0.18 ± 0.03	7.1 ± 0.1	0.16 ± 0.03	NAV ± NAV	50.0 ± 10.0	1.00	0.90	1.00	1.37	1.58	9.1 ± 5.0	1.16	1.04	0.13	14.88
239	ondale Playground (VSVP 5706.	NAP	0	No	4.2 ± 0.6	0.9 ± 0.7	15.7	18.9	75.9 ± 11.8	43.8 ± 7.4	159	0.83 ± 0.03	0.18 ± 0.03	7.1 ± 0.1	0.17 ± 0.03	NAV ± NAV	5.0 ± 8.6	1.00	0.92	1.00	1.37	1.52	13.6 ± 4.2	1.15	1.04	0.14	13.60
240	Carisbrooke Playground (57193)	NAP	0	No	4.0 ± 0.3	1.8 ± 0.6	17.3	20.6	76.4 ± 7.3	54.8 ± 5.6	218	0.90 ± 0.03	0.18 ± 0.03	7.1 ± 0.1	0.15 ± 0.03	NAV ± NAV	5.0 ± 8.6	1.00	0.91	1.00	1.37	1.36	26.0 ± 2.4	1.11	1.04	0.13	26.01
241	29 Charles Street (VSVP 57196)	NAP	0	No	6.5 ± 1.2	1.4 ± 0.5	15.7	20.6	127.1 ± 24.2	76.8 ± 13.0	152	0.78 ± 0.09	0.22 ± 0.04	7.1 ± 0.1	0.19 ± 0.04	NAV ± NAV	5.0 ± 8.6	1.00	0.95	1.00	1.37	1.15	21.1 ± 4.4	1.05	1.04	0.17	21.12
242	Harrington Park (VSVP 57141)	NAP	0	No	5.2 ± 0.3	1.0 ± 0.4	15.7	18.9	94.9 ± 5.9	53.7 ± 4.4	170	0.80 ± 0.04	0.22 ± 0.03	7.1 ± 0.1	0.20 ± 0.03	NAV ± NAV	5.0 ± 8.6	1.00	0.93	1.00	1.37	1.37	18.3 ± 2.0	1.11	1.04	0.17	18.27
243	n Normal Intermediate School (5	NAP	1	Yes	7.0 ± 0.3	1.2 ± 0.2	15.7	18.9	128.2 ± 6.9	71.3 ± 4.4	143	0.74 ± 0.05	0.21 ± 0.03	7.1 ± 0.1	0.18 ± 0.03	NAV ± NAV	39.0 ± 7.0	1.00	0.95	1.00	1.37	1.19	11.0 ± 2.8	1.06	1.04	0.16	16.79
244	Hillmerton Highschool (57201)	NAP	1	Yes	6.0 ± 0.8	1.9 ± 0.5	15.7	17.3	100.7 ± 14.6	60.5 ± 7.6	144	0.75 ± 0.04	0.24 ± 0.04	7.1 ± 0.1	0.20 ± 0.04	NAV ± NAV	75.0 ± 12.5	1.00	0.94	1.00	1.37	1.29	3.3 ± 0.2	1.09	1.04	0.17	9.11
245	Hillsborough Park (VSVP 57202)	NAP	0	No	4.5 ± 0.2	0.9 ± 0.1	17.3	19.6	85.3 ± 4.0	50.3 ± 2.6	175	0.93 ± 0.06	0.25 ± 0.05	7.1 ± 0.1	0.26 ± 0.05	NAV ± NAV	5.0 ± 8.6	1.00	0.92	1.00	1.37	1.42	26.7 ± 2.0	1.12	1.04	0.22	26.68
246	Palinurus Road (VSVP 57185)	NAP	0	No	3.1 ± 0.6	1.2 ± 0.1	15.7	20.6	57.9 ± 13.1	39.3 ± 6.9	163	0.91 ± 0.02	0.24 ± 0.04	7.1 ± 0.1	0.21 ± 0.03	NAV ± NAV	5.0 ± 8.6	1.00	0.89	1.00	1.37	1.61	22.0 ± 0.2	1.17	1.04	0.17	21.96
247	Rawhiti Domain (VSVP 57188)	NAP	0	No	6.8 ± 1.4	1.5 ± 0.6	18.9	20.6	136.8 ± 29.5	85.2 ± 16.3	198	0.79 ± 0.05	0.18 ± 0.03	7.1 ± 0.1	0.15 ± 0.03	NAV ± NAV	5.0 ± 8.6	1.00	0.95	1.00	1.37	1.09	28.7 ± 5.0	1.03	1.04	0.14	28.69
248	Rydal Reserve (VSVP 57190)	NAP	1	Yes	5.8 ± 1.3	1.6 ± 0.2	17.3	20.6	113.0 ± 25.8	72.4 ± 13.7	229	0.98 ± 0.08	0.24 ± 0.05	7.1 ± 0.1	0.24 ± 0.05	NAV ± NAV	11.0 ± 2.5	1.00	0.94	1.00	1.37	1.18	18.8 ± 5.0	1.06	1.04	0.22	20.40
249	Sabina Playground (VSVP 57192	NAP	0	No	8.3 ± 0.4	1.6 ± 0.3	18.9	20.6	167.0 ± 9.2	101.8 ± 5.9	184	0.71 ± 0.05	0.18 ± 0.03	7.1 ± 0.1	0.14 ± 0.02	NAV ± NAV	5.0 ± 8.6	1.00	0.96	1.00	1.37	1.00	20.8 ± 4.6	1.00	1.04	0.13	20.75
250	ey Intermediate School (VSVP 57	NAP	0	No	6.7 ± 0.9	2.4 ± 0.4	17.4	20.6	130.3 ± 18.7	88.4 ± 10.3	176	0.77 ± 0.04	0.19 ± 0.03	7.1 ± 0.1	0.14 ± 0.02	NAV ± NAV	5.0 ± 8.6	1.00	0.95	1.00	1.37	1.07	18.8 ± 3.9	1.02	1.04	0.13	18.76
251	St. Albans Catholic School	NAP	0	No	6.4 ± 0.7	1.7 ± 0.4	17.4	18.9	118.8 ± 13.0	72.1 ± 7.3	159	0.88 ± 0.04	0.21 ± 0.03	7.1 ± 0.1	0.20 ± 0.03	NAV ± NAV	35.0 ± 7.5	1.00	0.95	1.00	1.37	1.19	8.3 ± 1.3	1.06	1.04	0.18	14.06
252	St. Teresa's School (VSVP 57191)	NAP	0	No	3.3 ± 0.4	2.0 ± 1.6	15.7	19.0	55.3 ± 9.6	43.1 ± 11.2	146	0.91 ± 0.05	0.22 ± 0.04	7.1 ± 0.1	0.17 ± 0.07	NAV ± NAV	37.5 ± 7.5	1.00	0.90	1.00	1.00	1.53	8.3 ± 2.5	1.15	1.04	0.14	14.03
253	Ti Rakau Reserve (VSVP 57186)	NAP	0	No	9.5 ± 2.1	1.9 ± 1.7	17.4	20.6	188.6 ± 43.0	114.3 ± 25.2	156	0.75 ± 0.06	0.23 ± 0.03	7.1 ± 0.1	0.19 ± 0.04	NAV ± NAV	5.0 ± 8.6	1.00	0.97	1.00	1.37	0.94	25.4 ± 3.8	0.98	1.04	0.18	25.37
254	Wharenui School (VSVP 57165)	NAP	0	No	5.6 ± 0.4	1.6 ± 0.4	15.7	19.0	100.7 ± 7.2	61.7 ± 4.8	142	0.79 ± 0.08	0.22 ± 0.04	7.1 ± 0.1	0.18 ± 0.04	NAV ± NAV	31.0 ± 10.0	1.00	0.94	1.00	1.37	1.28	12.8 ± 9.1	1.08	1.04	0.16	18.43
255	SW KAN 09	NAP	1	Yes	2.5 ± 0.3	1.5 ± 0.3	18.9	20.6	48.9 ± 6.9	38.6 ± 4.5	164	0.83 ± 0.02	0.24 ± 0.04	7.1 ± 0.1	0.16 ± 0.03	NAV ± NAV	25.3 ± 9.7	1.00	0.88	1.00	1.37	1.62	14.7 ± 2.8	1.17	1.04	0.13	19.91
256	SW KAN 19	NAP	1	Yes	6.3 ± 1.4	1.2 ± 0.3	17.4	20.6	124.8 ± 29.3	75.3 ± 15.6	143	0.86 ± 0.04	0.23 ± 0.04	7.1 ± 0.1	0.22 ± 0.04	NAV ± NAV	5.5 ± 2.7	1.00	0.94	1.00	1.37	1.16	20.6 ± 7.6	1.05	1.04	0.20	20.68
257	SW Z2-4	NAP	0	No	10.8 ± 1.6	1.0 ± 0.1	18.9	20.6	219.5 ± 32.9	123.9 ± 17.7	164	0.76 ± 0.07	0.21 ± 0.03	7.1 ± 0.1	0.18 ± 0.03	NAV ± NAV	5.0 ± 8.6	1.00	0.97	1.00	1.57	0.90	22.2 ± 3.9	0.97	1.04	0.18	22.23
258	SW Z4-4	NAP	0	No	2.6 ± 0.2	2.0 ± 0.1	17.4	19.0	46.8 ± 4.1	40.6 ± 2.3	179	1.01 ± 0.02	0.22 ± 0.03	7.1 ± 0.1	0.16 ± 0.03	NAV ± NAV	31.0 ± 10.0	1.00	0.88	1.00	1.65	1.58	17.7 ± 2.0	1.16	1.04	0.13	23.36
259	SW Z2-6	NAP	0	No	3.3 ± 0.4	1.3 ± 0.7	17.3	18.9	60.1 ± 8.3	40.9 ± 7.1	163	0.92 ± 0.02	0.21 ± 0.03	7.1 ± 0.1	0.19 ± 0.04	NAV ± NAV	5.0 ± 8.6	1.00	0.90	1.00	1.37	1.57	9.4 ± 0.8	1.16	1.04	0.16	9.38
260	CBGS	0	0	No	10.7 ± 0.6	3.2 ± 0.1	19.6	21.2	221.8 ± 13.3	148.3 ± 7.9	162	0.79 ± 0.07	0.16 ± 0.01	7.1 ± 0.1	0.12 ± 0.01	NAV ± NAV	3.2 ± 2.1	1.00	0.98	1.00	1.00	0.83	13.7 ± 2.0	0.94	1.04	0.13	13.66
261	CCCC	0	0	No	10.1 ± 1.3	1.2 ± 0.1	19.6	21.2	212.3 ± 27.9	125.1 ± 15.4	138	0.62 ± 0.06	0.22 ± 0.01	7.1 ± 0.1	0.15 ± 0.02	NAV ± NAV	3.9 ± 2.2	1.00	0.97	1.00	1.42	0.90	21.7 ± 8.1	0.97	1.04	0.15	21.69
262	CHHC	0	0	No	6.3 ± 0.3	3.1 ± 0.1	18.9	21.5	126.5 ± 5.8	95.1 ± 3.6	164	0.90 ± 0.04	0.17 ± 0.01	7.1 ± 0.1	0.14 ± 0.01	NAV ± NAV	5.0 ± 8.6	1.00	0.94	1.00	1.00	1.03	21.5 ± 3.2	1.01	1.04	0.13	21.46
263	CMHS	0	0	No	9.0 ± 0.7	2.0 ± 0.1	19.9	21.5	190.5 ± 14.8	121.9 ± 8.6	152	0.67 ± 0.06	0.24 ± 0.01	7.1 ± 0.1	0.16 ± 0.02	NAV ± NAV	23.0 ± 5.6	1.00	0.97	1.00	1.00	0.91	11.8 ± 5.6	0.97	1.04	0.16	16.73
264	HPSC	1	1	Yes	6.3 ± 1.6	1.5 ± 0.1	18.9	20.6	126.0 ± 32.7	79.5 ± 17.2	128	0.71 ± 0.04	0.13 ± 0.01	7.1 ± 0.1	0.10 ± 0.01	NAV ± NAV	7.0 ± 8.6	1.00	0.94	1.00	1.00	1.13	9.0 ± 3.8	1.04	1.04	0.09	9.40
265	KPOC	0	0	No	16.3 ± 4.6	1.2 ± 0.1	17.3	21.5	344.6 ± 98.9	197.1 ± 54.2	164	0.49 ± 0.07	0.32 ± 0.02	7.1 ± 0.1	0.18 ± 0.03	NAV ± NAV	5.0 ± 8.6	1.00	0.99	1.00	1.00	0.72	40.8 ± 6.1	0.90	1.04	0.19	40.79
266	NNBS	0	0	No	16.5 ± 0.7	2.3 ± 0.1	18.9	20.6	335.6 ± 15.3	196.4 ± 9.9	145	0.53 ± 0.07	0.19 ± 0.01	7.1 ± 0.1	0.11 ± 0.02	NAV ± NAV	4.5 ± 2.8	1.00	0.99	1.00	1.42	0.72	14.6 ± 4.3	0.90	1.04	0.12	14.56
267	RHSC	0	0	No	13.5 ± 1.2	6.4 ± 0.1	18.9	21.5	273.4 ± 25.5	203.8 ± 14.4	205	0.70 ± 0.07	0.20 ± 0.01	7.1 ± 0.1	0.12 ± 0.01	NAV ± NAV	5.0 ± 8.6	1.00	0.99	1.00	1.00	0.71	30.9 ± 6.5	0.89	1.04	0.13	30.92
268	SMTC	0	0	No	9.0 ± 0.7	1.0 ± 0.1	19.9	21.5	192.1 ± 14.8	113.7 ± 8.7	183	0.92 ± 0.06	0.17 ± 0.03	7.1 ± 0.1	0.17 ± 0.03	NAV ± NAV	5.9 ± 5.8	1.00	0.97	1.00	1.00	0.94	43.2 ± 5.7	0.98	1.04	0.17	43.34
	2010 El Mayor-Cucapah (Baja) Earthquake																										
269	Wildlife B	0	0	No	4.9 ± 0.7	1.2 ± 0.1	15.7	18.9	87.7 ± 13.6	51.9 ± 6.8	131	0.72 ± 0.03	0.13 ± 0.01	7.2 ± 0.1	0.10 ± 0.01	0.09 ± 0.01	27.4 ± 9.0	1.00	0.92	1.00	1.13	1.40	11.6 ± 5.1	1.12	1.03	0.09	17.02
	2010 Jia Shan Earthquake																										
270	Siinhua	NAP	1	Yes	7.0 ± 0.8	1.2 ± 0.2	20.7	19.7	138.9 ± 17.0	82.4 ± 9.6	113	0.56 ± 0.09	0.17 ± 0.03	6.3 ± 0.1	0.11 ± 0.03	0.09 ± 0.05	29.2 ± 10.3	1.00	0.95	1.00	1.15	1.11	8.2 ± 4.2	1.03	1.13	0.09	13.76
	2010 Maule Earthquake																										
271	Constitución ID 15	NAV	0	No	6.1 ± 0.4	4.6 ± 0.1	18.9	21.5	119.3 ± 8.0	104.5 ± 4.8	127	0.74 ± 0.08	0.35 ± 0.07	8.8 ± 0.0	0.19 ± 0.04	0.20 ± 0.05	1.0 ± 8.6	1.00	0.94	1.00	1.00	0.98	35.3 ± 2.8	1.00	0.90	0.21	35.29
272	Concepción Site ID_02	NAV	0	No	3.6 ± 0.2	3.0 ± 0.1	17.3	20.6	64.1 ± 4.6	57.9 ± 2.8	193	0.98 ± 0.05	0.36 ± 0.07	8.8 ± 0.0	0.25 ± 0.05	0.15 ± 0.05	45.0 ± 45.4	1.00	0.90	1.00	0.85	1.32	20.2 ± 3.4	1.10	0.90	0.26	26.01

Table 4.6. (cont'd)

ID #	Earthquake & Site	GMIndicates Liq. (No=0/Yes=1)	Surface Manif. (No=0/Yes=1)	Liq.?	d_{crt} (m)	GWT (m)	γ_1 (kN/m^3)	γ_2 (kN/m^3)	σ_v (kPa)	σ_v' (kPa)	$V^*_{s,12m}$ (m/s)	r_d	a_{max}	M_w	CSR	D_{50} (mm)	FC %	C_S	C_R	C_B	C_E	C_N	$(N_1)_{60}$	K_σ	K_{Mw}	$CSR_{Mw=7.5,\sigma'v=1 atm}$	$N_{1,60,CS}$
	2011 Christchurch Earthquake																										
273	*Corhampton Street (VSVP 5719*	*NAP*	*1*	*Yes*	*4.7 ± 0.8*	*1.9 ± 0.5*	*15.7*	*20.6*	*88.0 ± 15.9*	*60.3 ± 8.7*	*190*	*0.87 ± 0.03*	*0.48 ± 0.07*	*6.2 ± 0.1*	*0.40 ± 0.07*	*NAV ± NAV*	*5.0 ± 8.6*	*1.00*	*0.92*	*1.00*	*1.37*	*1.30*	*17.8 ± 6.8*	*1.09*	*1.14*	*0.32*	*17.85*
274	*EQC-4 - Avondale*	*NAP*	*1*	*Yes*	*5.0 ± 1.0*	*1.9 ± 0.3*	*15.7*	*20.6*	*93.7 ± 20.7*	*63.2 ± 11.0*	*213*	*0.97 ± 0.07*	*0.36 ± 0.07*	*6.2 ± 0.1*	*0.34 ± 0.07*	*0.20 ± 0.05*	*7.1 ± 6.9*	*1.00*	*0.93*	*1.00*	*1.37*	*1.27*	*19.4 ± 2.5*	*1.08*	*1.14*	*0.27*	*19.92*
275	*Site 14-Barrington*	*NAP*	*1*	*Yes*	*4.0 ± 0.5*	*0.1 ± 0.2*	*17.3*	*18.9*	*75.2 ± 9.6*	*37.0 ± 5.1*	*253*	*0.99 ± 0.06*	*0.42 ± 0.08*	*6.2 ± 0.1*	*0.55 ± 0.12*	*0.10 ± 0.05*	*30.0 ± 8.6*	*1.00*	*0.91*	*1.00*	*1.45*	*1.65*	*17.8 ± 4.3*	*1.18*	*1.14*	*0.41*	*23.43*
276	*rmans Road/Papanui Road (572(*	*NAP*	*1*	*Yes*	*6.2 ± 0.6*	*2.7 ± 0.4*	*18.9*	*20.6*	*123.0 ± 12.5*	*88.4 ± 7.7*	*198*	*0.74 ± 0.04*	*0.30 ± 0.05*	*6.2 ± 0.1*	*0.20 ± 0.03*	*NAV ± NAV*	*5.0 ± 8.6*	*1.00*	*0.94*	*1.00*	*1.37*	*1.07*	*11.8 ± 0.3*	*1.02*	*1.14*	*0.17*	*11.81*
277	*Avondale Park (VSVP 57187)*	*NAP*	*1*	*Yes*	*3.2 ± 0.6*	*1.4 ± 0.1*	*17.3*	*18.9*	*58.1 ± 11.4*	*40.5 ± 5.7*	*163*	*0.94 ± 0.02*	*0.37 ± 0.06*	*6.2 ± 0.1*	*0.33 ± 0.05*	*NAV ± NAV*	*50.0 ± 10.0*	*1.00*	*0.90*	*1.00*	*1.37*	*1.58*	*9.1 ± 5.0*	*1.16*	*1.14*	*0.25*	*14.88*
278	*ondale Playground (VSVP 5706.*	*NAP*	*1*	*Yes*	*4.2 ± 0.6*	*0.9 ± 0.7*	*15.7*	*18.9*	*75.9 ± 11.8*	*43.8 ± 7.4*	*159*	*0.83 ± 0.03*	*0.40 ± 0.02*	*6.2 ± 0.1*	*0.37 ± 0.06*	*NAV ± NAV*	*5.0 ± 8.6*	*1.00*	*0.92*	*1.00*	*1.37*	*1.52*	*13.6 ± 4.2*	*1.15*	*1.14*	*0.29*	*13.60*
279	*EQC-6 - Bexley*	*NAP*	*1*	*Yes*	*3.6 ± 0.5*	*1.5 ± 0.3*	*18.9*	*18.9*	*66.9 ± 9.2*	*47.1 ± 5.4*	*219*	*0.98 ± 0.05*	*0.53 ± 0.11*	*6.2 ± 0.1*	*0.48 ± 0.11*	*NAV ± NAV*	*13.0 ± 8.7*	*1.00*	*0.90*	*1.00*	*1.42*	*1.47*	*9.8 ± 8.8*	*1.13*	*1.14*	*0.37*	*12.01*
280	*Carisbrroke Playground (57193)*	*NAP*	*1*	*Yes*	*4.0 ± 0.3*	*1.8 ± 0.6*	*17.3*	*20.6*	*76.4 ± 7.3*	*54.8 ± 5.6*	*218*	*0.92 ± 0.03*	*0.46 ± 0.07*	*6.2 ± 0.1*	*0.38 ± 0.07*	*NAV ± NAV*	*5.0 ± 8.6*	*1.00*	*0.91*	*1.00*	*1.37*	*1.36*	*26.0 ± 2.4*	*1.11*	*1.14*	*0.30*	*26.01*
281	*29 Charles Street (VSVP 57196)*	*NAP*	*1*	*Yes*	*6.5 ± 1.2*	*1.4 ± 0.5*	*15.7*	*20.6*	*127.1 ± 24.2*	*76.8 ± 13.0*	*152*	*0.74 ± 0.09*	*0.52 ± 0.10*	*6.2 ± 0.1*	*0.41 ± 0.10*	*NAV ± NAV*	*5.0 ± 8.6*	*1.00*	*0.95*	*1.00*	*1.37*	*1.15*	*21.1 ± 4.4*	*1.05*	*1.14*	*0.35*	*21.12*
282	*Harrington Park (VSVP 57141)*	*NAP*	*0*	*No*	*5.2 ± 0.3*	*1.0 ± 0.4*	*15.7*	*18.9*	*94.9 ± 5.9*	*53.7 ± 4.4*	*170*	*0.73 ± 0.04*	*0.34 ± 0.05*	*6.2 ± 0.1*	*0.28 ± 0.05*	*NAV ± NAV*	*5.0 ± 8.6*	*1.00*	*0.93*	*1.00*	*1.37*	*1.37*	*18.3 ± 2.0*	*1.11*	*1.14*	*0.22*	*18.27*
283	*n Normal Intermediate School (5*	*NAP*	*1*	*Yes*	*7.0 ± 0.3*	*1.2 ± 0.2*	*15.7*	*18.9*	*128.2 ± 6.9*	*71.3 ± 4.4*	*143*	*0.60 ± 0.05*	*0.32 ± 0.05*	*6.2 ± 0.1*	*0.22 ± 0.04*	*NAV ± NAV*	*39.0 ± 7.0*	*1.00*	*0.95*	*1.00*	*1.37*	*1.19*	*11.0 ± 2.8*	*1.06*	*1.14*	*0.19*	*16.79*
284	*Hillmerton Highschool (57201)*	*NAP*	*1*	*Yes*	*6.0 ± 0.8*	*1.9 ± 0.5*	*15.7*	*17.3*	*100.7 ± 14.6*	*60.5 ± 7.6*	*144*	*0.75 ± 0.04*	*0.39 ± 0.06*	*6.2 ± 0.1*	*0.32 ± 0.06*	*NAV ± NAV*	*75.0 ± 12.5*	*1.00*	*0.94*	*1.00*	*1.37*	*1.29*	*3.3 ± 0.2*	*1.09*	*1.14*	*0.25*	*9.11*
285	*Hillsborough Park (VSVP 57202)*	*NAP*	*0*	*No*	*4.5 ± 0.2*	*0.9 ± 0.1*	*17.3*	*19.6*	*85.3 ± 4.0*	*50.3 ± 2.6*	*175*	*0.91 ± 0.06*	*0.63 ± 0.13*	*6.2 ± 0.1*	*0.63 ± 0.13*	*NAV ± NAV*	*5.0 ± 8.6*	*1.00*	*0.92*	*1.00*	*1.37*	*1.42*	*26.7 ± 2.0*	*1.12*	*1.14*	*0.49*	*26.68*
286	*Palinurus Road (VSVP 57185)*	*NAP*	*1*	*Yes*	*3.1 ± 0.6*	*1.2 ± 0.1*	*15.7*	*20.6*	*57.9 ± 13.1*	*39.3 ± 6.9*	*163*	*1.00 ± 0.02*	*0.68 ± 0.10*	*6.2 ± 0.1*	*0.65 ± 0.10*	*NAV ± NAV*	*5.0 ± 8.6*	*1.00*	*0.89*	*1.00*	*1.37*	*1.61*	*22.0 ± 0.2*	*1.17*	*1.14*	*0.49*	*21.96*
287	*Rawhiti Domain (VSVP 57188)*	*NAP*	*0*	*No*	*6.8 ± 1.4*	*1.5 ± 0.6*	*18.9*	*20.6*	*136.8 ± 29.5*	*85.2 ± 16.3*	*198*	*0.82 ± 0.05*	*0.52 ± 0.08*	*6.2 ± 0.1*	*0.44 ± 0.08*	*NAV ± NAV*	*5.0 ± 8.6*	*1.00*	*0.95*	*1.00*	*1.37*	*1.09*	*28.7 ± 5.0*	*1.03*	*1.14*	*0.38*	*28.69*
288	*Rydal Reserve (VSVP 57190)*	*NAP*	*1*	*Yes*	*5.8 ± 1.3*	*1.6 ± 0.2*	*17.3*	*20.6*	*113.0 ± 25.8*	*72.4 ± 13.7*	*229*	*0.97 ± 0.08*	*0.44 ± 0.09*	*6.2 ± 0.1*	*0.43 ± 0.10*	*NAV ± NAV*	*11.0 ± 2.5*	*1.00*	*0.94*	*1.00*	*1.37*	*1.18*	*18.8 ± 5.0*	*1.06*	*1.14*	*0.36*	*20.40*
289	*abina Playground (VSVP 57192*	*NAP*	*1*	*Yes*	*8.3 ± 0.4*	*1.6 ± 0.3*	*18.9*	*20.6*	*167.0 ± 9.2*	*101.8 ± 5.9*	*184*	*0.70 ± 0.05*	*0.34 ± 0.05*	*6.2 ± 0.1*	*0.26 ± 0.04*	*NAV ± NAV*	*5.0 ± 8.6*	*1.00*	*0.96*	*1.00*	*1.37*	*1.00*	*20.8 ± 4.6*	*1.00*	*1.14*	*0.22*	*20.75*
290	*y Intermediate School (VSVP 57*	*NAP*	*1*	*Yes*	*6.7 ± 0.9*	*2.4 ± 0.4*	*17.4*	*20.6*	*130.3 ± 18.7*	*88.4 ± 10.3*	*176*	*0.76 ± 0.04*	*0.38 ± 0.06*	*6.2 ± 0.1*	*0.28 ± 0.05*	*NAV ± NAV*	*5.0 ± 8.6*	*1.00*	*0.95*	*1.00*	*1.37*	*1.07*	*18.8 ± 3.9*	*1.02*	*1.14*	*0.24*	*18.76*
291	*St. Albans Catholic School*	*NAP*	*1*	*Yes*	*6.4 ± 0.7*	*1.7 ± 0.4*	*17.4*	*18.9*	*118.8 ± 13.0*	*72.1 ± 7.3*	*159*	*0.81 ± 0.04*	*0.34 ± 0.05*	*6.2 ± 0.1*	*0.30 ± 0.05*	*NAV ± NAV*	*35.0 ± 7.5*	*1.00*	*0.95*	*1.00*	*1.37*	*1.19*	*8.3 ± 1.3*	*1.06*	*1.14*	*0.25*	*14.06*
292	*St. Teresa's School (VSVP 57191)*	*NAP*	*0*	*No*	*3.3 ± 0.4*	*2.0 ± 1.6*	*15.7*	*19.0*	*55.3 ± 9.6*	*43.1 ± 11.2*	*146*	*0.89 ± 0.05*	*0.34 ± 0.07*	*6.2 ± 0.1*	*0.25 ± 0.10*	*NAV ± NAV*	*37.5 ± 7.5*	*1.00*	*0.90*	*1.00*	*1.00*	*1.53*	*8.3 ± 2.5*	*1.15*	*1.14*	*0.19*	*14.03*
293	*Ti Rakau Reserve (VSVP 57186)*	*NAP*	*1*	*Yes*	*9.5 ± 2.1*	*1.9 ± 1.7*	*17.4*	*20.6*	*188.6 ± 43.0*	*114.3 ± 25.2*	*156*	*0.83 ± 0.06*	*0.68 ± 0.10*	*6.2 ± 0.1*	*0.61 ± 0.13*	*NAV ± NAV*	*5.0 ± 8.6*	*1.00*	*0.97*	*1.00*	*1.33*	*0.94*	*24.8 ± 3.7*	*0.98*	*1.14*	*0.54*	*24.75*
294	*Wharenui School (VSVP 57165)*	*NAP*	*0*	*No*	*5.6 ± 0.4*	*1.6 ± 0.4*	*15.7*	*19.0*	*100.7 ± 7.2*	*61.7 ± 4.8*	*142*	*0.75 ± 0.08*	*0.36 ± 0.07*	*6.2 ± 0.1*	*0.29 ± 0.07*	*NAV ± NAV*	*31.0 ± 10.0*	*1.00*	*0.94*	*1.00*	*1.37*	*1.28*	*12.8 ± 9.1*	*1.08*	*1.14*	*0.23*	*18.43*
295	*SW KAN 09*	*NAP*	*0*	*No*	*2.5 ± 0.3*	*1.5 ± 0.3*	*18.9*	*20.6*	*48.9 ± 6.9*	*38.6 ± 4.5*	*164*	*0.95 ± 0.02*	*0.19 ± 0.03*	*6.2 ± 0.1*	*0.15 ± 0.03*	*NAV ± NAV*	*25.3 ± 9.7*	*1.00*	*0.88*	*1.00*	*1.37*	*1.62*	*14.7 ± 2.8*	*1.17*	*1.14*	*0.11*	*19.91*
296	*SW KAN 19*	*NAP*	*0*	*No*	*6.3 ± 1.4*	*1.2 ± 0.3*	*17.4*	*20.6*	*124.8 ± 29.3*	*75.3 ± 15.6*	*143*	*0.79 ± 0.04*	*0.19 ± 0.03*	*6.2 ± 0.1*	*0.16 ± 0.03*	*NAV ± NAV*	*5.5 ± 2.7*	*1.00*	*0.94*	*1.00*	*1.37*	*1.16*	*20.6 ± 7.6*	*1.05*	*1.14*	*0.13*	*20.68*
297	*SW Z2-4*	*NAP*	*1*	*Yes*	*10.8 ± 1.6*	*1.0 ± 0.1*	*18.9*	*20.6*	*219.5 ± 32.9*	*123.9 ± 17.7*	*164*	*0.64 ± 0.07*	*0.48 ± 0.07*	*6.2 ± 0.1*	*0.35 ± 0.07*	*NAV ± NAV*	*5.0 ± 8.6*	*1.00*	*0.97*	*1.00*	*1.57*	*0.90*	*22.2 ± 3.9*	*0.97*	*1.14*	*0.32*	*22.23*
298	*SW Z4-4*	*NAP*	*1*	*Yes*	*2.6 ± 0.2*	*2.0 ± 0.1*	*17.4*	*19.0*	*46.8 ± 4.1*	*40.6 ± 2.3*	*179*	*1.03 ± 0.02*	*0.45 ± 0.07*	*6.2 ± 0.1*	*0.35 ± 0.05*	*NAV ± NAV*	*31.0 ± 10.0*	*1.00*	*0.88*	*1.00*	*1.65*	*1.58*	*17.7 ± 2.0*	*1.16*	*1.14*	*0.26*	*23.36*
299	*SW Z2-6*	*NAP*	*1*	*Yes*	*3.3 ± 0.4*	*1.3 ± 0.7*	*17.3*	*18.9*	*60.1 ± 8.3*	*40.9 ± 7.1*	*163*	*0.92 ± 0.02*	*0.45 ± 0.07*	*6.2 ± 0.1*	*0.40 ± 0.09*	*NAV ± NAV*	*5.0 ± 8.6*	*1.00*	*0.90*	*1.00*	*1.37*	*1.57*	*9.4 ± 0.8*	*1.16*	*1.14*	*0.30*	*9.38*
300	*CBGS*	*1*	*0*	*No or Yes*	*10.7 ± 0.6*	*3.2 ± 0.1*	*19.6*	*21.2*	*221.8 ± 13.3*	*148.3 ± 7.9*	*162*	*0.58 ± 0.07*	*0.48 ± 0.02*	*6.2 ± 0.1*	*0.27 ± 0.03*	*NAV ± NAV*	*3.2 ± 2.1*	*1.00*	*0.98*	*1.00*	*1.00*	*0.83*	*13.7 ± 2.0*	*0.94*	*1.14*	*0.25*	*13.66*
301	*CCCC*	*1*	*1*	*Yes*	*10.1 ± 1.3*	*1.2 ± 0.1*	*19.6*	*21.2*	*212.3 ± 27.9*	*125.1 ± 15.4*	*138*	*0.64 ± 0.06*	*0.42 ± 0.02*	*6.2 ± 0.1*	*0.30 ± 0.03*	*NAV ± NAV*	*3.9 ± 2.2*	*1.00*	*0.97*	*1.00*	*1.42*	*0.90*	*21.7 ± 8.1*	*0.97*	*1.14*	*0.27*	*21.69*
302	*CHHC*	*1*	*1*	*Yes*	*6.3 ± 0.3*	*3.1 ± 0.1*	*18.9*	*21.5*	*126.5 ± 5.8*	*95.1 ± 3.6*	*164*	*0.81 ± 0.04*	*0.35 ± 0.02*	*6.2 ± 0.1*	*0.24 ± 0.02*	*NAV ± NAV*	*5.0 ± 8.6*	*1.00*	*0.94*	*1.00*	*1.00*	*1.03*	*21.5 ± 3.2*	*1.01*	*1.14*	*0.21*	*21.46*
303	*CMHS*	*1*	*0*	*No or Yes*	*9.0 ± 0.7*	*2.0 ± 0.1*	*19.9*	*21.5*	*190.5 ± 14.8*	*121.9 ± 8.6*	*152*	*0.68 ± 0.06*	*0.38 ± 0.02*	*6.2 ± 0.1*	*0.26 ± 0.03*	*NAV ± NAV*	*23.0 ± 5.6*	*1.00*	*0.97*	*1.00*	*1.00*	*0.91*	*11.8 ± 5.6*	*0.97*	*1.14*	*0.23*	*16.73*
304	*HPSC*	*1*	*1*	*Yes*	*6.3 ± 1.6*	*1.5 ± 0.1*	*18.9*	*20.6*	*126.0 ± 32.7*	*79.5 ± 17.2*	*128*	*0.68 ± 0.04*	*0.32 ± 0.02*	*6.2 ± 0.1*	*0.23 ± 0.02*	*NAV ± NAV*	*7.0 ± 8.6*	*1.00*	*0.94*	*1.00*	*1.00*	*1.13*	*9.0 ± 3.8*	*1.04*	*1.14*	*0.19*	*9.40*
305	*KPOC*	*0*	*0*	*No*	*16.3 ± 4.6*	*1.2 ± 0.1*	*17.3*	*21.5*	*344.6 ± 98.9*	*197.1 ± 54.2*	*164*	*0.52 ± 0.07*	*0.20 ± 0.01*	*6.2 ± 0.1*	*0.12 ± 0.02*	*NAV ± NAV*	*5.0 ± 8.6*	*1.00*	*0.99*	*1.00*	*1.00*	*0.72*	*40.8 ± 6.1*	*0.90*	*1.14*	*0.12*	*40.79*
306	*NNBS*	*1*	*0*	*No or Yes*	*16.5 ± 0.7*	*2.3 ± 0.1*	*18.9*	*20.6*	*335.6 ± 15.3*	*196.4 ± 9.9*	*145*	*0.54 ± 0.07*	*0.54 ± 0.03*	*6.2 ± 0.1*	*0.32 ± 0.05*	*NAV ± NAV*	*4.5 ± 2.8*	*1.00*	*0.99*	*1.00*	*1.42*	*0.72*	*14.6 ± 4.3*	*0.90*	*1.14*	*0.31*	*14.56*
307	*RHSC*	*0*	*0*	*No*	*13.5 ± 1.2*	*6.4 ± 0.1*	*18.9*	*21.5*	*273.4 ± 25.5*	*203.8 ± 14.4*	*205*	*0.64 ± 0.07*	*0.27 ± 0.01*	*6.2 ± 0.1*	*0.15 ± 0.02*	*NAV ± NAV*	*5.0 ± 8.6*	*1.00*	*0.99*	*1.00*	*1.00*	*0.71*	*30.9 ± 6.5*	*0.89*	*1.14*	*0.15*	*30.92*
308	*SMTC*	*0*	*0*	*No*	*9.0 ± 0.7*	*1.0 ± 0.1*	*19.9*	*21.5*	*192.1 ± 14.8*	*113.7 ± 8.7*	*183*	*0.81 ± 0.06*	*0.16 ± 0.02*	*6.2 ± 0.1*	*0.14 ± 0.02*	*NAV ± NAV*	*5.9 ± 5.8*	*1.00*	*0.97*	*1.00*	*1.00*	*0.94*	*43.2 ± 5.7*	*0.98*	*1.14*	*0.13*	*43.34*
	2011 Tohoku Earthquake																										
309	*IBR014*	*1*	*1*	*Yes*	*22.6 ± 1.8*	*1.3 ± 0.1*	*13.3*	*17.0*	*377.9 ± 32.4*	*169.6 ± 16.4*	*179*	*0.65 ± 0.15*	*0.45 ± 0.02*	*9.1 ± 0.0*	*0.42 ± 0.10*	*NAV ± NAV*	*15.0 ± 8.6*	*1.00*	*1.00*	*1.00*	*1.27*	*0.77*	*20.8 ± 9.0*	*0.92*	*0.88*	*0.52*	*23.66*
310	*CHB009*	*0*	*0*	*No*	*6.5 ± 1.0*	*3.0 ± 0.1*	*17.8*	*17.2*	*113.3 ± 17.3*	*79.0 ± 7.7*	*169*	*0.89 ± 0.09*	*0.16 ± 0.01*	*9.1 ± 0.0*	*0.13 ± 0.02*	*NAV ± NAV*	*9.8 ± 4.3*	*1.00*	*0.95*	*1.00*	*1.37*	*1.13*	*28.1 ± 2.5*	*1.04*	*0.88*	*0.15*	*29.31*
311	*CHB024*	*1*	*1*	*Yes*	*19.5 ± 0.3*	*3.0 ± 0.1*	*14.4*	*18.2*	*344.2 ± 10.0*	*182.5 ± 8.4*	*196*	*0.76 ± 0.15*	*0.22 ± 0.01*	*9.1 ± 0.0*	*0.21 ± 0.04*	*0.13 ± 0.05*	*5.0 ± 8.6*	*1.00*	*1.00*	*1.00*	*1.37*	*0.75*	*5.1 ± 0.1*	*0.91*	*0.88*	*0.26*	*5.08*
312	*MYG010*	*1*	*NAV*	*Yes**	*11.5 ± 1.3*	*2.1 ± 0.1*	*15.4*	*19.8*	*218.5 ± 26.8*	*126.4 ± 14.1*	*150*	*0.65 ± 0.14*	*0.42 ± 0.02*	*9.1 ± 0.0*	*0.31 ± 0.07*	*0.20 ± 0.05*	*5.0 ± 8.6*	*1.00*	*0.98*	*1.00*	*1.37*	*0.90*	*18.1 ± 4.2*	*0.96*	*0.88*	*0.37*	*18.05*
313	*Onahama*	*1*	*NAV*	*Yes**	*2.2 ± 0.3*	*1.3 ± 0.1*	*18.9*	*20.6*	*42.0 ± 5.9*	*33.7 ± 3.2*	*496*	*1.00 ± 0.03*	*0.69 ± 0.03*	*9.1 ± 0.0*	*0.56 ± 0.05*	*NAV ± NAV*	*5.5 ± 8.6*	*1.00*	*0.89*	*1.00*	*1.37*	*1.73*	*16.8 ± 2.0*	*1.20*	*0.88*	*0.53*	*16.91*
314	*Chiba-G, GB*	*0*	*0*	*No*	*9.0 ± 0.5*	*3.5 ± 0.1*	*17.7*	*17.0*	*155.1 ± 9.0*	*101.2 ± 4.8*	*168*	*0.82 ± 0.12*	*0.12 ± 0.01*	*9.1 ± 0.0*	*0.10 ± 0.01*	*NAV ± NAV*	*13.7 ± 3.8*	*1.00*	*0.97*	*1.00*	*1.37*	*1.00*	*8.9 ± 3.6*	*1.00*	*0.88*	*0.11*	*11.37*
315	*CHB005*	*0*	*0*	*No*	*2.4 ± 0.1*	*1.3 ± 0.1*	*16.2*	*17.6*	*39.9 ± 1.8*	*29.6 ± 1.3*	*370*	*1.00 ± 0.04*	*0.18 ± 0.01*	*9.1 ± 0.0*	*0.16 ± 0.01*	*NAV ± NAV*	*12.9 ± 8.6*	*1.00*	*0.89*	*1.00*	*1.37*	*1.85*	*14.1 ± 2.0*	*1.22*	*0.88*	*0.15*	*16.28*
316	*Irifune-3*	*NAP*	*1*	*Yes*	*3.7 ± 0.4*	*2.4 ± 0.1*	*17.3*	*19.6*	*66.6 ± 8.8*	*53.6 ± 4.6*	*207*	*0.99 ± 0.05*	*0.20 ± 0.04*	*9.1 ± 0.0*	*0.16 ± 0.03*	*NAV ± NAV*	*30.0 ± 14.0*	*1.00*	*0.92*	*1.00*	*1.37*	*1.37*	*10.3 ± 1.5*	*1.11*	*0.88*	*0.16*	*15.93*
317	*Nekozane 2*	*NAP*	*0*	*No*	*4.3 ± 0.7*	*2.2 ± 0.1*	*17.3*	*18.9*	*77.4 ± 13.2*	*56.9 ± 6.5*	*152*	*0.91 ± 0.06*	*0.18 ± 0.04*	*9.1 ± 0.0*	*0.15 ± 0.03*	*NAV ± NAV*	*30.0 ± 8.6*	*1.00*	*0.93*	*1.00*	*1.37*	*1.33*	*11.2 ± 3.8*	*1.10*	*0.88*	*0.15*	*16.75*
318	*Isobe-8*	*NAP*	*1*	*Yes*	*6.1 ± 1.6*	*1.2 ± 0.1*	*17.3*	*18.9*	*113.1 ± 30.9*	*65.1 ± 15.0*	*125*	*0.76 ± 0.08*	*0.22 ± 0.04*	*9.1 ± 0.0*	*0.19 ± 0.04*	*NAV ± NAV*	*46.7 ± 18.5*	*1.00*	*0.95*	*1.00*	*1.25*	*1.25*	*4.6 ± 2.6*	*1.07*	*0.88*	*0.20*	*10.39*
319	*Takasu 4-2*	*NAP*	*1*	*Yes*	*3.4 ± 0.8*	*0.5 ± 0.1*	*17.3*	*18.9*	*62.4 ± 14.8*	*34.1 ± 7.3*	*153*	*0.94 ± 0.05*	*0.21 ± 0.04*	*9.1 ± 0.0*	*0.24 ± 0.05*	*NAV ± NAV*	*55.0 ± 10.0*	*1.00*	*0.91*	*1.00*	*1.37*	*1.72*	*3.3 ± 0.8*	*1.19*	*0.88*	*0.23*	*9.10*

Table 4.6. (cont'd)

Earthquake & Site	GMIndicates Liq. (No=0/Yes=1)	Surface Manif. (No=0/Yes=1)	Liq.?	$d_{crt.}$ (m)	GWT (m)	γ_1 (kN/m^3)	γ_2 (kN/m^3)	σ_v (kPa)	σ_v' (kPa)	$V^*_{s,12m}$ (m/s)	r_d	a_{max}	M_w	CSR	D_{50} (mm)	FC %	C_S	C_R	C_B	C_E	C_N	$(N_1)_{60}$	K_σ	K_{Mw}	$CSR_{Mw=7.5,\sigma'v=1 atm}$	$N_{1,60,CS}$
2011 Van Earthquake																										
Karasu River LHB-1	*NAP*	*1*	*Yes*	*4.4 ± 0.7*	*0.4 ± 0.1*	*18.9*	*20.6*	*89.9 ± 14.1*	*50.6 ± 7.5*	*159*	*0.90 ± 0.06*	*0.24 ± 0.05*	*7.1 ± 0.1*	*0.24 ± 0.05*	*0.10 ± 0.05*	*4.2 ± 3.1*	*1.00*	*0.92*	*1.00*	*0.82*	*1.41*	*20.3 ± 3.2*	*1.12*	*1.04*	*0.21*	*20.27*
Karasu River LHB-2	*NAP*	*0*	*No*	*5.6 ± 0.6*	*0.4 ± 0.1*	*18.9*	*20.6*	*114.5 ± 13.3*	*63.6 ± 7.3*	*155*	*0.84 ± 0.08*	*0.24 ± 0.05*	*7.1 ± 0.1*	*0.23 ± 0.05*	*0.10 ± 0.05*	*19.9 ± 16.3*	*1.00*	*0.94*	*1.00*	*0.82*	*1.26*	*20.3 ± 6.0*	*1.08*	*1.04*	*0.21*	*24.56*
Brawley Earthquake Swarm M=4.9																										
Wildlife B	*1*	*NAV*	*No**	*4.9 ± 0.7*	*1.2 ± 0.1*	*15.7*	*18.9*	*87.7 ± 13.6*	*51.9 ± 6.8*	*131*	*0.49 ± 0.03*	*0.33 ± 0.02*	*4.9 ± 0.1*	*0.18 ± 0.02*	*0.09 ± 0.01*	*27.4 ± 9.0*	*1.00*	*0.92*	*1.00*	*1.13*	*1.40*	*11.6 ± 5.1*	*1.12*	*1.34*	*0.12*	*17.02*
Brawley Earthquake Swarm M=4.61																										
Wildlife B	*1*	*NAV*	*No**	*4.9 ± 0.7*	*1.2 ± 0.1*	*15.7*	*18.9*	*87.7 ± 13.6*	*51.9 ± 6.8*	*131*	*0.48 ± 0.03*	*0.29 ± 0.01*	*4.6 ± 0.1*	*0.15 ± 0.01*	*0.09 ± 0.01*	*27.4 ± 9.0*	*1.00*	*0.92*	*1.00*	*1.13*	*1.40*	*11.6 ± 5.1*	*1.12*	*1.40*	*0.10*	*17.02*
Brawley Earthquake Swarm M=5.44																										
Wildlife B	*0*	*NAV*	*No**	*4.9 ± 0.7*	*1.2 ± 0.1*	*15.7*	*18.9*	*87.7 ± 13.6*	*51.9 ± 6.8*	*131*	*0.66 ± 0.03*	*0.20 ± 0.01*	*5.4 ± 0.1*	*0.14 ± 0.01*	*0.09 ± 0.01*	*27.4 ± 9.0*	*1.00*	*0.92*	*1.00*	*1.13*	*1.40*	*11.6 ± 5.1*	*1.12*	*1.25*	*0.10*	*17.02*
Brawley Earthquake Swarm M=5.32																										
Wildlife B	*0*	*NAV*	*No**	*4.9 ± 0.7*	*1.2 ± 0.1*	*15.7*	*18.9*	*87.7 ± 13.6*	*51.9 ± 6.8*	*131*	*0.58 ± 0.03*	*0.18 ± 0.01*	*5.3 ± 0.1*	*0.11 ± 0.01*	*0.09 ± 0.01*	*27.4 ± 9.0*	*1.00*	*0.92*	*1.00*	*1.13*	*1.40*	*11.6 ± 5.1*	*1.12*	*1.27*	*0.08*	*17.02*
2012 Emilia Earthquake																										
M#5	*NAP*	*0*	*No*	*20.0 ± 1.5*	*2.0 ± 0.1*	*17.4*	*20.6*	*405.3 ± 32.0*	*228.8 ± 18.3*	*165*	*0.48 ± 0.15*	*0.16 ± 0.03*	*6.0 ± 0.1*	*0.09 ± 0.03*	*NAV ± NAV*	*31.0 ± 10.0*	*1.00*	*1.00*	*1.00*	*1.10*	*0.67*	*13.3 ± 2.2*	*0.88*	*1.17*	*0.09*	*18.92*
12 Emilia Earthquake Aftershock																										
M#5	*NAP*	*0*	*No*	*20.0 ± 1.5*	*2.0 ± 0.1*	*17.4*	*20.6*	*405.3 ± 32.0*	*228.8 ± 18.3*	*165*	*0.49 ± 0.15*	*0.08 ± 0.02*	*5.8 ± 0.1*	*0.04 ± 0.02*	*NAV ± NAV*	*31.0 ± 10.0*	*1.00*	*1.00*	*1.00*	*1.10*	*0.67*	*13.3 ± 2.2*	*0.88*	*1.19*	*0.04*	*18.92*
'3 Obihiro - Hokkaido Earthquake																										
HKD086	*0*	*0*	*No*	*8.3 ± 1.9*	*1.6 ± 0.5*	*18.1*	*19.6*	*159.5 ± 37.8*	*94.3 ± 19.6*	*127*	*0.57 ± 0.11*	*0.36 ± 0.02*	*6.9 ± 0.1*	*0.22 ± 0.05*	*NAV ± NAV*	*50.7 ± 41.6*	*1.00*	*0.97*	*1.00*	*1.37*	*1.04*	*12.5 ± 4.9*	*1.01*	*1.06*	*0.21*	*18.25*
2014 Napa Earthquake																										
Napa	*NAP*	*0*	*No*	*9.0 ± 1.0*	*4.9 ± 0.2*	*19.9*	*21.5*	*185.6 ± 22.3*	*145.1 ± 12.6*	*274*	*0.98 ± 0.11*	*0.45 ± 0.02*	*6.0 ± 0.1*	*0.37 ± 0.05*	*NAV ± NAV*	*12.0 ± 4.2*	*1.00*	*0.97*	*1.00*	*1.23*	*0.84*	*32.1 ± 7.8*	*0.94*	*1.17*	*0.34*	*34.04*
015 Gorkha (Nepal) Earthquake																										
Duwakot	*NAP*	*1*	*Yes*	*5.1 ± 1.0*	*1.5 ± 0.1*	*17.3*	*18.9*	*93.8 ± 18.3*	*58.2 ± 9.0*	*160*	*0.89 ± 0.07*	*0.16 ± 0.05*	*7.8 ± 0.0*	*0.15 ± 0.05*	*0.20 ± 0.05*	*18.0 ± 8.6*	*1.00*	*0.93*	*1.00*	*1.22*	*1.32*	*8.5 ± 0.8*	*1.09*	*0.97*	*0.14*	*12.32*
'orkha (Nepal) Earthquake Aftershock																										
Duwakot	*NAP*	*0*	*No*	*5.1 ± 1.0*	*1.5 ± 0.1*	*18.9*	*19.6*	*99.0 ± 19.1*	*63.3 ± 9.7*	*160*	*0.88 ± 0.07*	*0.08 ± 0.02*	*7.3 ± 0.1*	*0.07 ± 0.02*	*0.20 ± 0.05*	*18.0 ± 2.0*	*1.00*	*0.90*	*1.00*	*1.22*	*1.27*	*7.9 ± 0.7*	*1.08*	*1.02*	*0.06*	*11.75*
2016 Kaikoura Earthquake																										
King's Wharf	*NAP*	*1*	*Yes*	*14.0 ± 0.8*	*3.5 ± 0.9*	*19.9*	*20.6*	*285.9 ± 17.9*	*182.8 ± 13.4*	*253*	*0.93 ± 0.15*	*0.24 ± 0.05*	*7.8 ± 0.0*	*0.22 ± 0.06*	*0.4-0.6 ± 0.05*	*25.0 ± 7.0*	*1.00*	*0.99*	*1.00*	*1.00*	*0.74*	*9.1 ± 4.8*	*0.91*	*0.97*	*0.25*	*14.31*
Thorndon's Wharf	*NAP*	*1*	*Yes*	*8.7 ± 1.8*	*3.4 ± 0.1*	*18.9*	*20.6*	*172.7 ± 36.6*	*120.5 ± 19.4*	*183*	*0.84 ± 0.11*	*0.24 ± 0.05*	*7.8 ± 0.0*	*0.18 ± 0.05*	*4.50 ± NAV*	*10.0 ± 5.0*	*1.00*	*0.97*	*1.00*	*1.00*	*0.92*	*9.9 ± 3.7*	*0.97*	*0.97*	*0.19*	*11.19*
2018 Hualien Earthquake																										
Hualien Port N-1	*NAP*	*0*	*No*	*9.8 ± 2.4*	*1.0 ± 0.9*	*19.6*	*21.2*	*205.2 ± 51.4*	*119.4 ± 28.9*	*148*	*0.58 ± 0.12*	*0.30 ± 0.06*	*6.4 ± 0.1*	*0.19 ± 0.06*	*3.55 ± 0.05*	*5.0 ± 8.6*	*1.00*	*0.97*	*1.00*	*1.10*	*0.92*	*26.6 ± 9.2*	*0.97*	*1.12*	*0.18*	*26.62*

Figure 4.16 a-u presents the distribution of input parameters (e.g. $d_{crt.}$, GWT, γ_{moist}, γ_{wet}, σ_v, σ'_v, C_E, C_R, C_N, $N_{1,60}$, FC, $N_{1,60,CS}$, $V_{s,12m}$, a_{max}, M_w, r_d, $CSR_{\sigma'v,Mw}$, K_σ, K_{Mw}, $CSR_{\sigma'v=1atm,Mw=7.5}$). Some of the descriptive parameters are presented in Figure 4.16 according to case history ID numbers that were assigned for the new case histories (#1-334). The grey circles represent liquefied sites, and circles and grey triangles represent non-liquefied and marginal sites, respectively. The mean and ± standard deviation values of the database for the selected descriptive parameters are shown on the same figures with red solid and red dashed lines, respectively. Several additional parameters exist, but due to page limitations, they will not be presented herein.

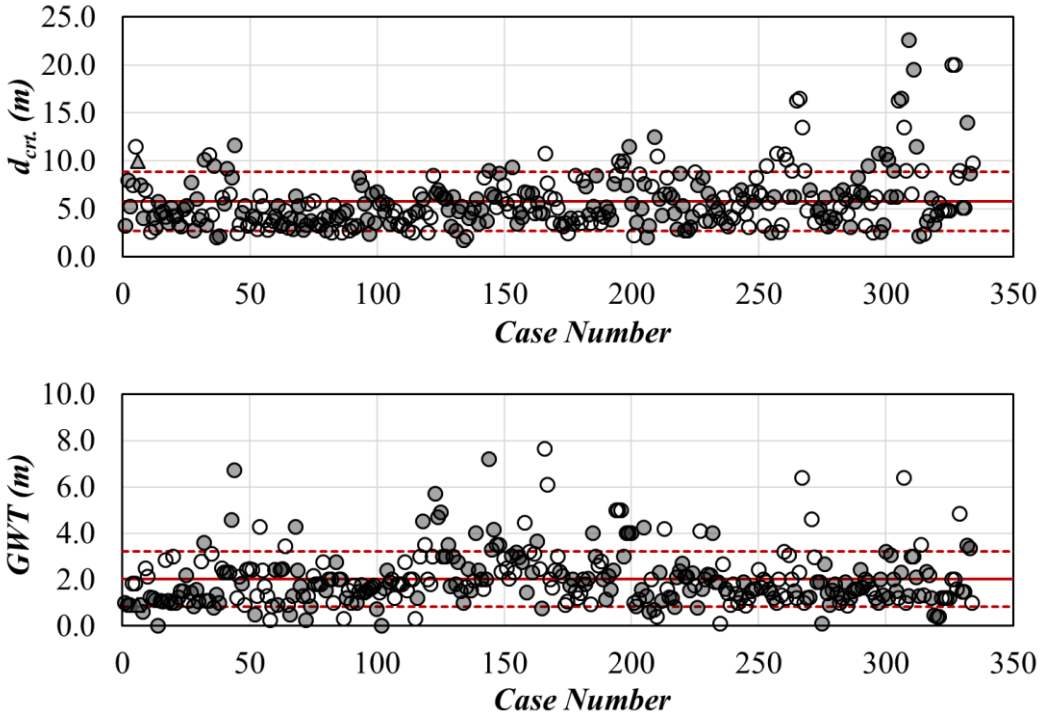


Figure 4.16. Comparison of input parameters a) $d_{crt.}$, b) GWT, c) γ_{moist}, d) γ_{wet}, e) σ_v, f) σ'_v, g) C_E, h) C_R i) C_N, j) $N_{1,60}$, k) FC, l) $N_{1,60,CS}$, m) $V_{s,12m}$, n) a_{max}, o) M_w, p) r_d, r) $CSR_{\sigma'v,Mw}$, s) K_σ, t) K_{Mw}, u) $CSR_{\sigma'v=1atm,Mw=7.5}$.

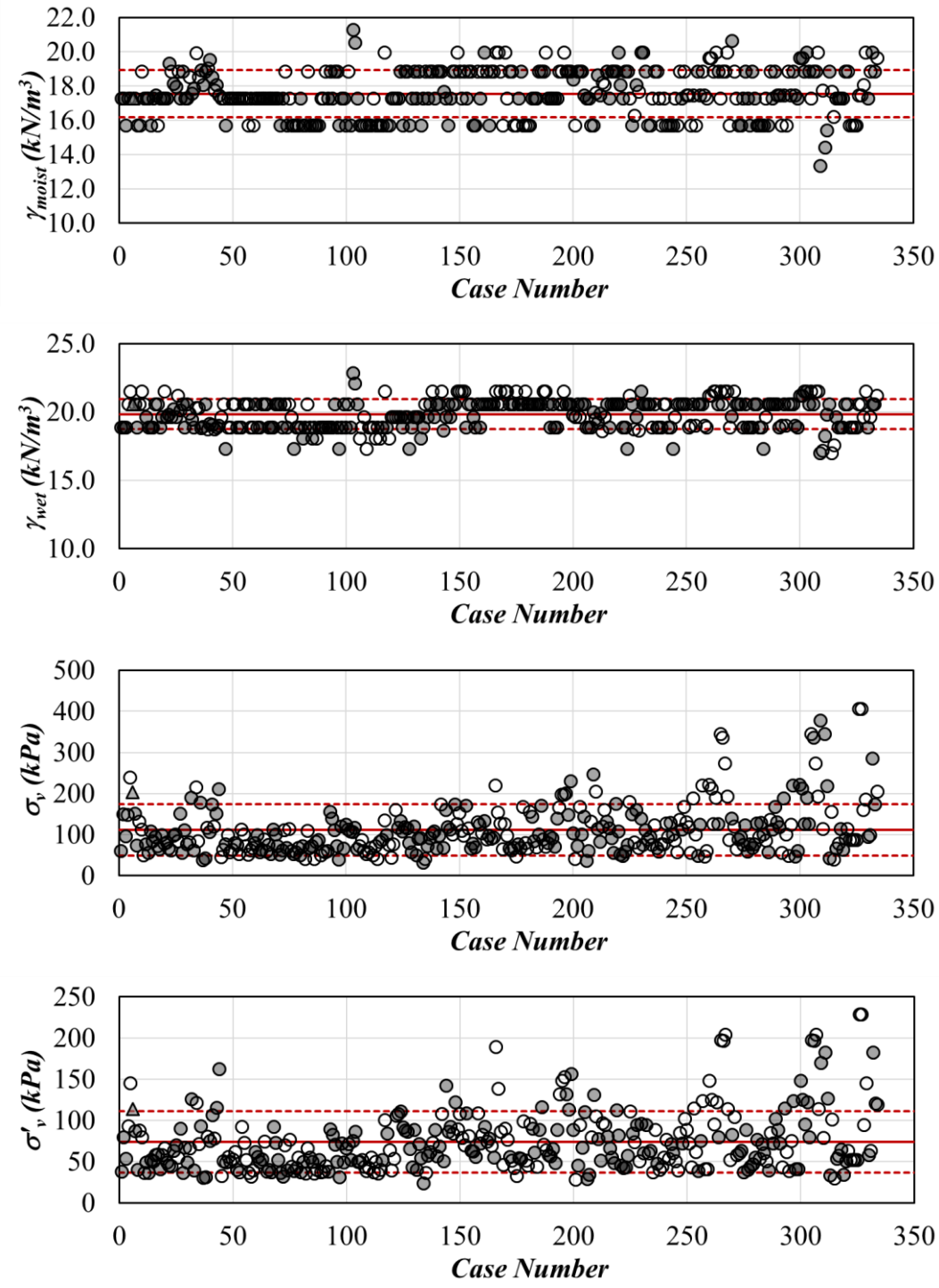


Figure 4.16. (cont'd)

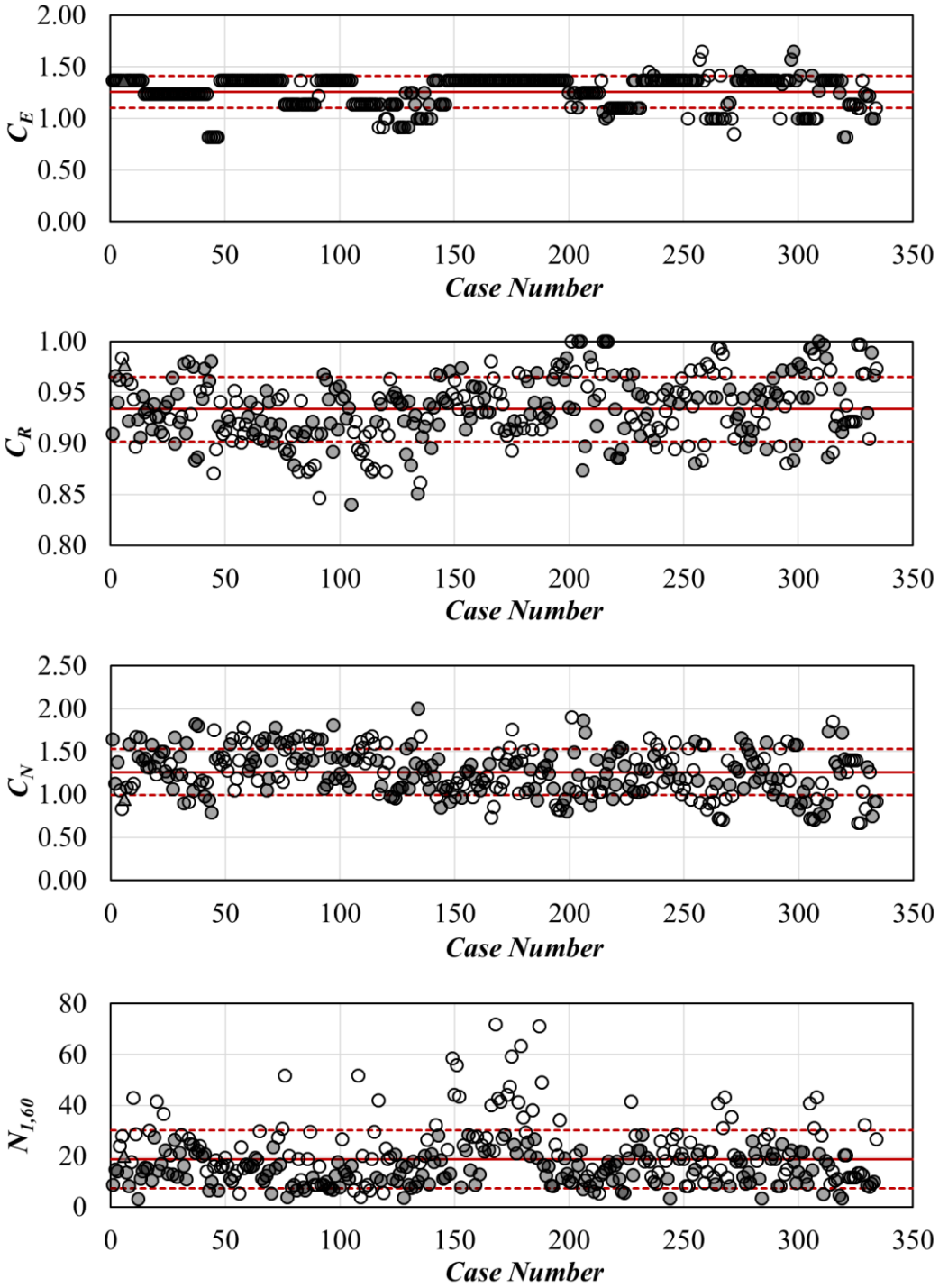


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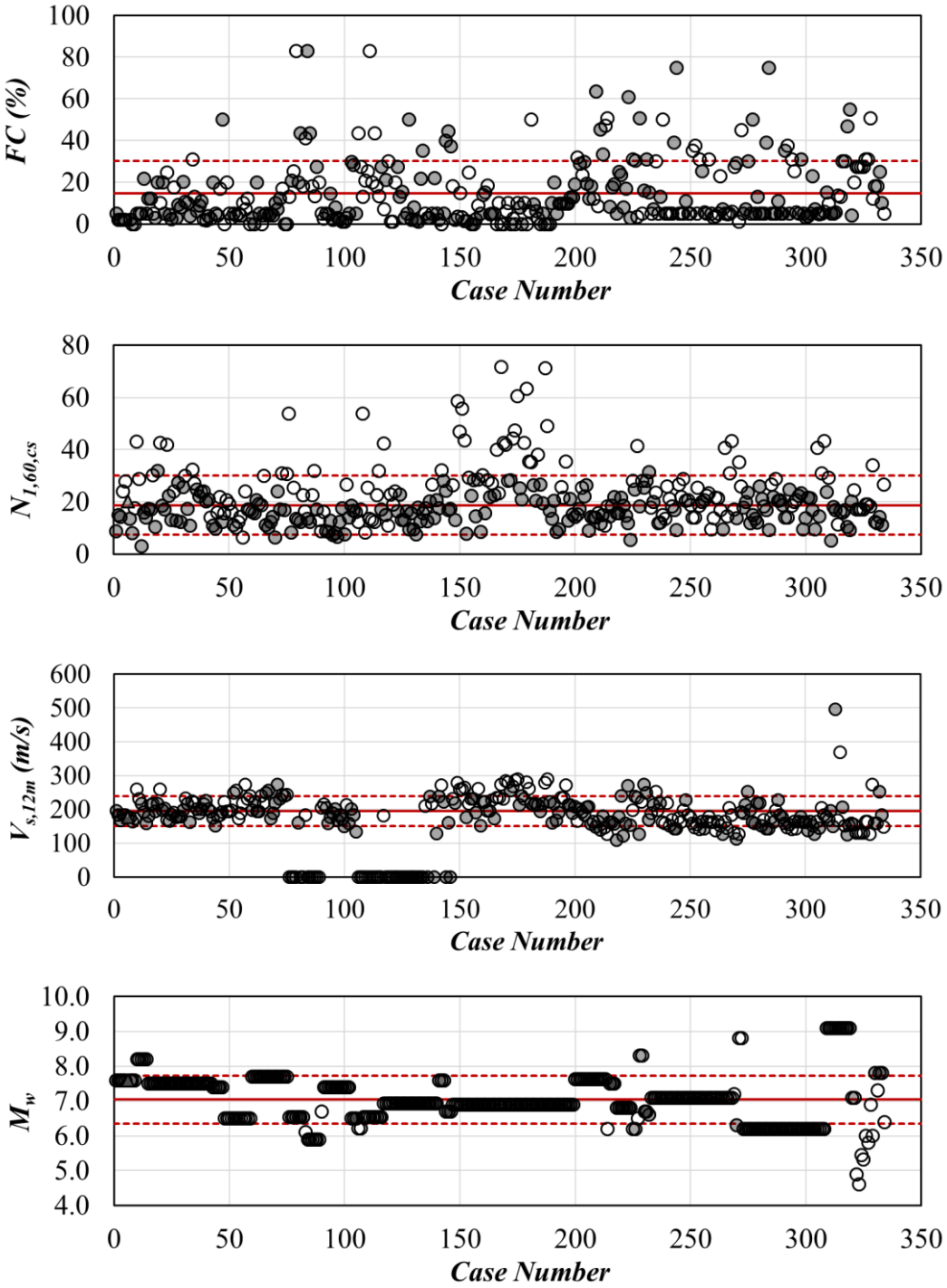


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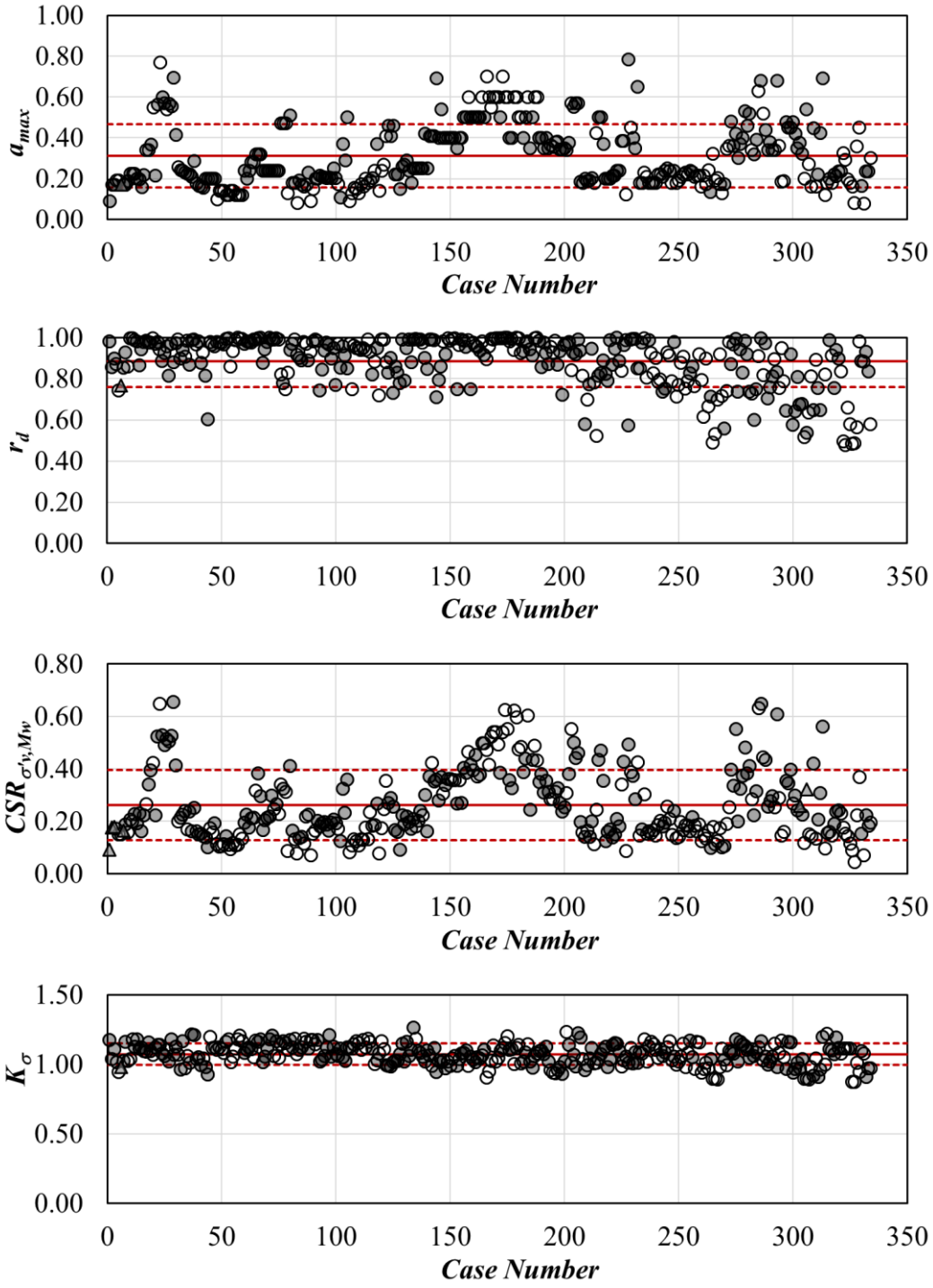


Figure 4.16. (cont'd)

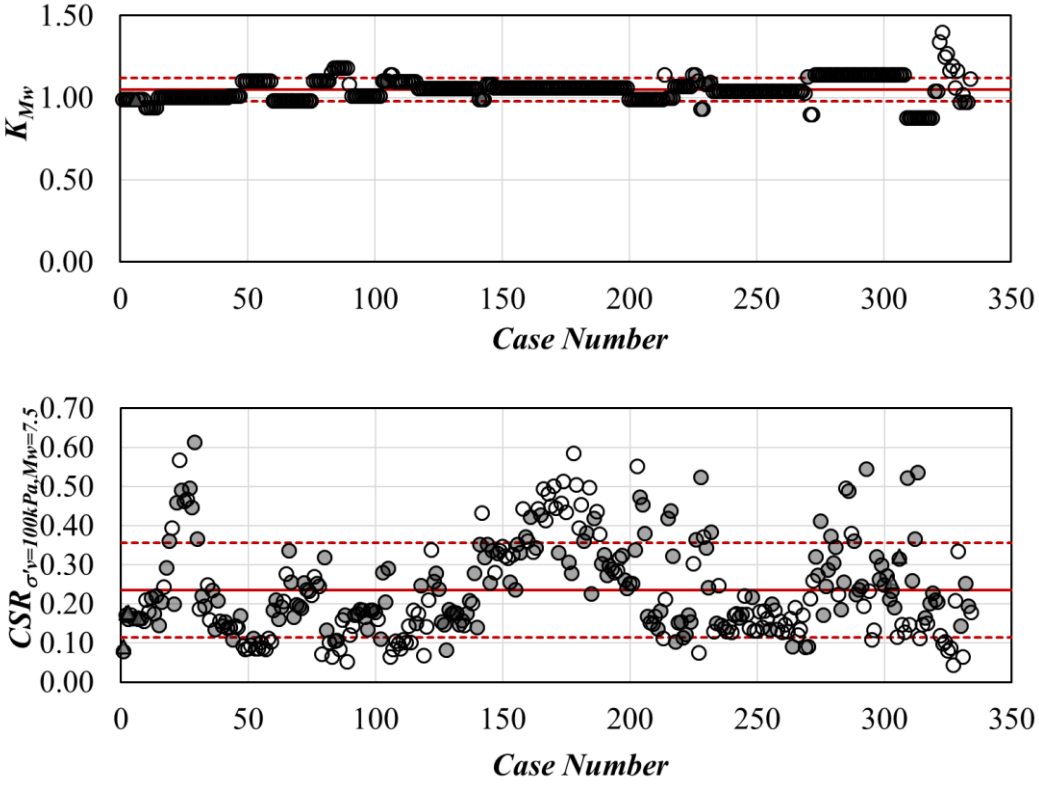


Figure 4.16. (cont'd)

Table 4.7 summarizes the mean and the mean of the standard deviation, minimum and maximum values of some of the input parameters $d_{crt.}$, GWT, γ_{moist}, γ_{wet}, σ_v, σ'_v, SC, GC, CC, FC, C_N, C_R, C_E, $N_{1,60}$, a_{max}, M_w, $V_{s,12m}$, r_d $CSR_{\sigma'v,Mw}$, $N_{1,60,CS}$, K_{Mw}, K_σ, $CSR_{\sigma'v=1atm,Mw=7.5}$ for the new 334 case histories.

Table 4.7. A summary of the average input parameters for the final database.

Parameters	***Mean***	***Mean of the St. Dev.***	***Min.***	***Max.***
$d_{crt.}$ *(m)*	5.8	0.70	1.8	22.6
GWT (m)	2.0	0.2	0.0	7.7
γ_{wet} *(kN/m^3)*	17.6	0.47	13.3	21.3
γ_{sat} *(kN/m^3)*	19.8	0.48	17.0	22.8
σ_v *(kPa)*	111.1	14.2	31.4	405.3
σ'_v *(kPa)*	74.2	7.8	24.1	228.8
r_d	0.884	0.064	0.477	1.029
a_{max} *(g)*	0.312	0.053	0.078	0.784
M_w	7.0	0.07	4.6	9.1
CSR	0.262	0.053	0.045	0.656
GC (%)	3.1	6.1	0.0	50.0
SC (%)	19.6	8.4	0.0	74.6
CC (%)	2.4	2.3	0.0	11.7
FC (%)	14.6	8.5	0.0	83.0
D_{50} *(mm)*	0.321	0.102	0.045	4.500
C_R	0.93	-	0.84	1.00
C_B	1.00	-	1.00	1.15
C_E	1.26	-	0.82	1.65
C_N	1.26	-	0.67	2.00
$(N_1)_{60}$	18.7	3.8	3.1	71.7
$V_{s,12m}$ *(m/s)*	195.1	-	109.7	496.1
$V_{s,30m}$ *(m/s)*	213.4	-	131.2	344.6
K_σ	1.07	-	0.88	1.26
K_{Mw}	1.05	-	0.88	1.40
$CSR_{Mw=7.5,\sigma'v=100kPA}$	0.234	-	0.043	0.614
$N_{1,60,CS}$	20.8	-	3.1	71.7

Figure a-g presents the distribution of some of the input parameters $d_{crt.}$, σ'_v, $N_{1,60}$, a_{max}, M_w, $CSR_{\sigma'v,Mw}$.

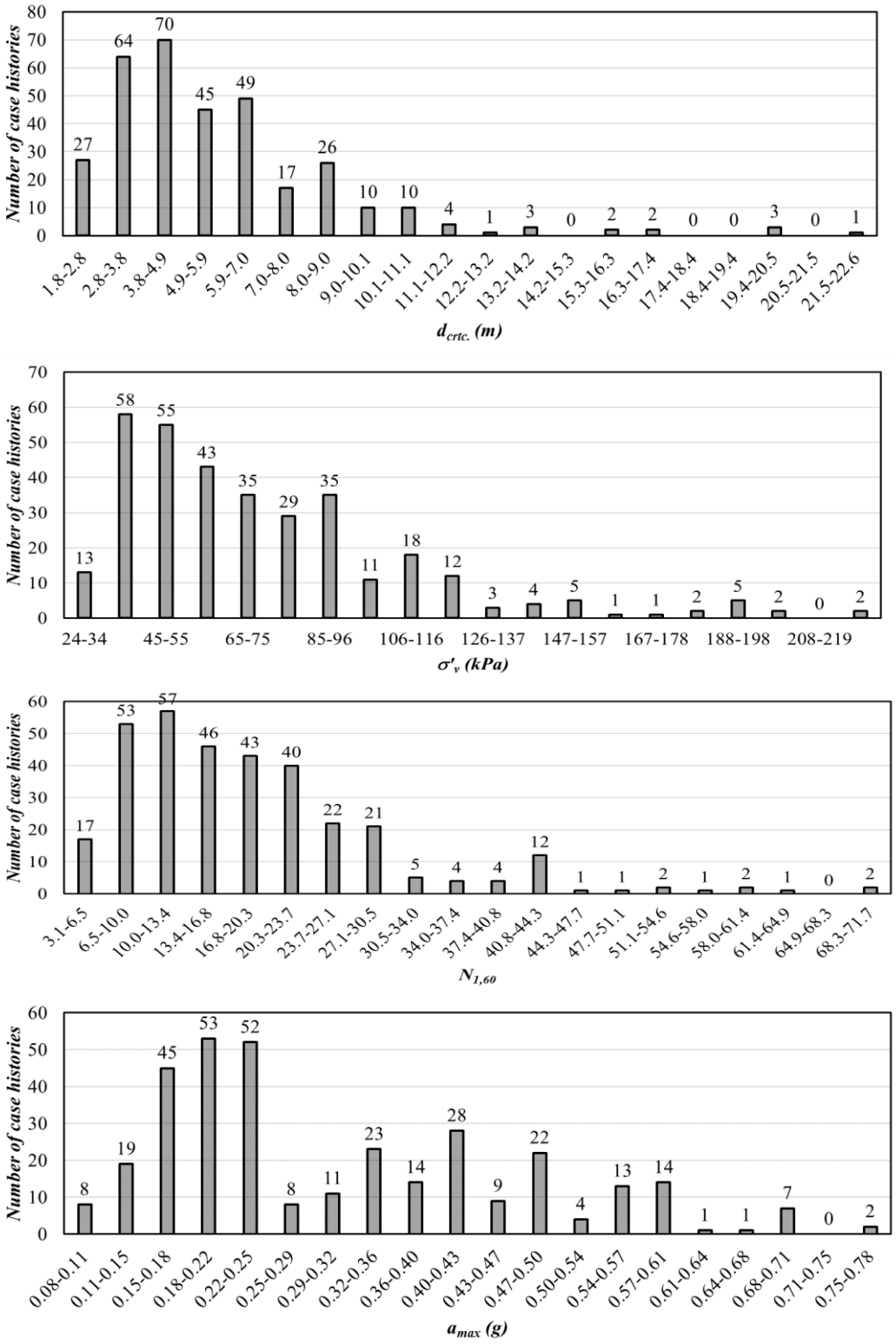


Figure 4.17. The distribution of the parameters a) $d_{crt.}$, b) σ'_v, c) $N_{1,60}$, d) a_{max} , e) M_w, f) $CSR_{\sigma'v,Mw}$.

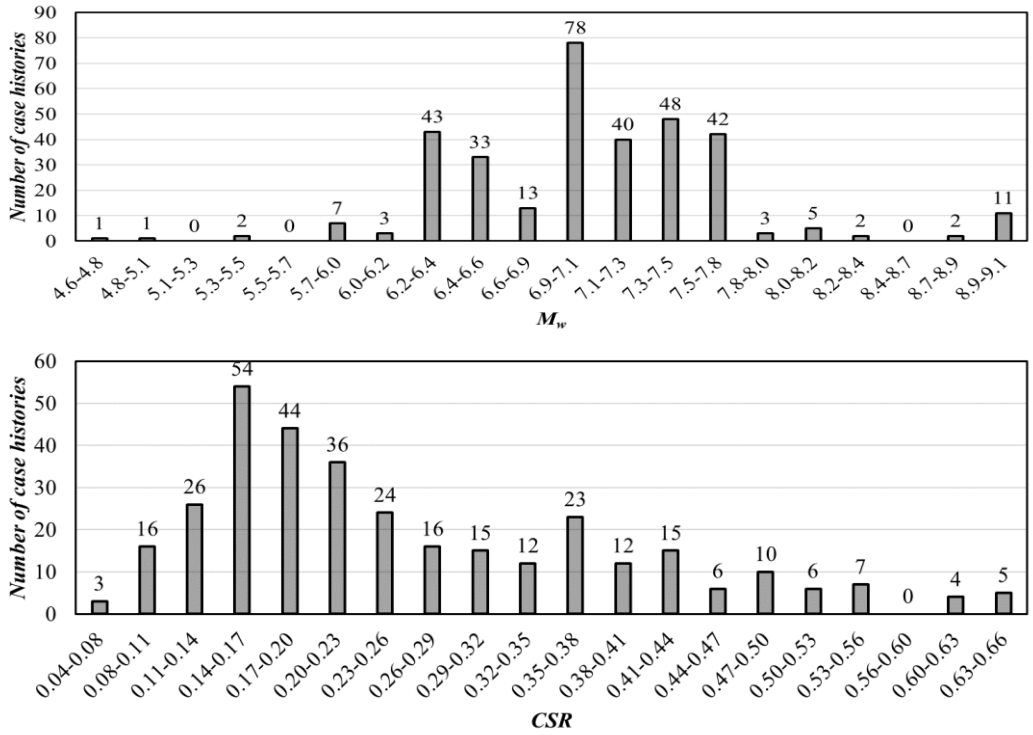


Figure 4.17. (cont'd)

Figure 4.18 presents the mean values of the corrected $N_{1,60}$ versus raw $CSR_{\sigma'v,Mw}$ (not normalized for K_σ, K_{Mw}, K_α effects) data points for the new database which includes 334 case histories.

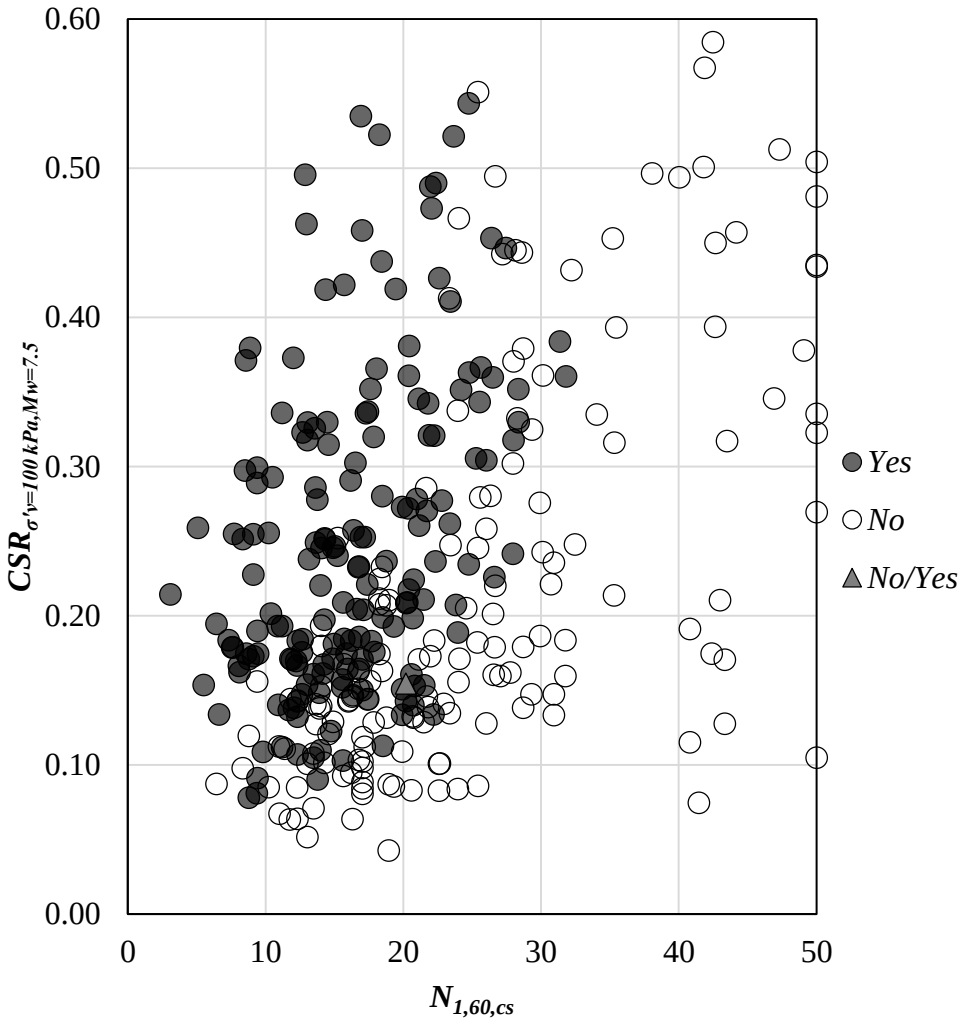


Figure 4.18. Updated SPT catalog (334) case histories on corrected $N_{1,60}$ versus $CSR_{\sigma'v,Mw}$.

Figure 6.17 is prepared to show the distribution of the database for Seed et al. (1985), Cetin et al. (2018a, b), Idriss and Boulanger (2010) and this study. In the mid to high CSR range (0.35 < CSR) a significant number of data points were added with the database compiled in this study.

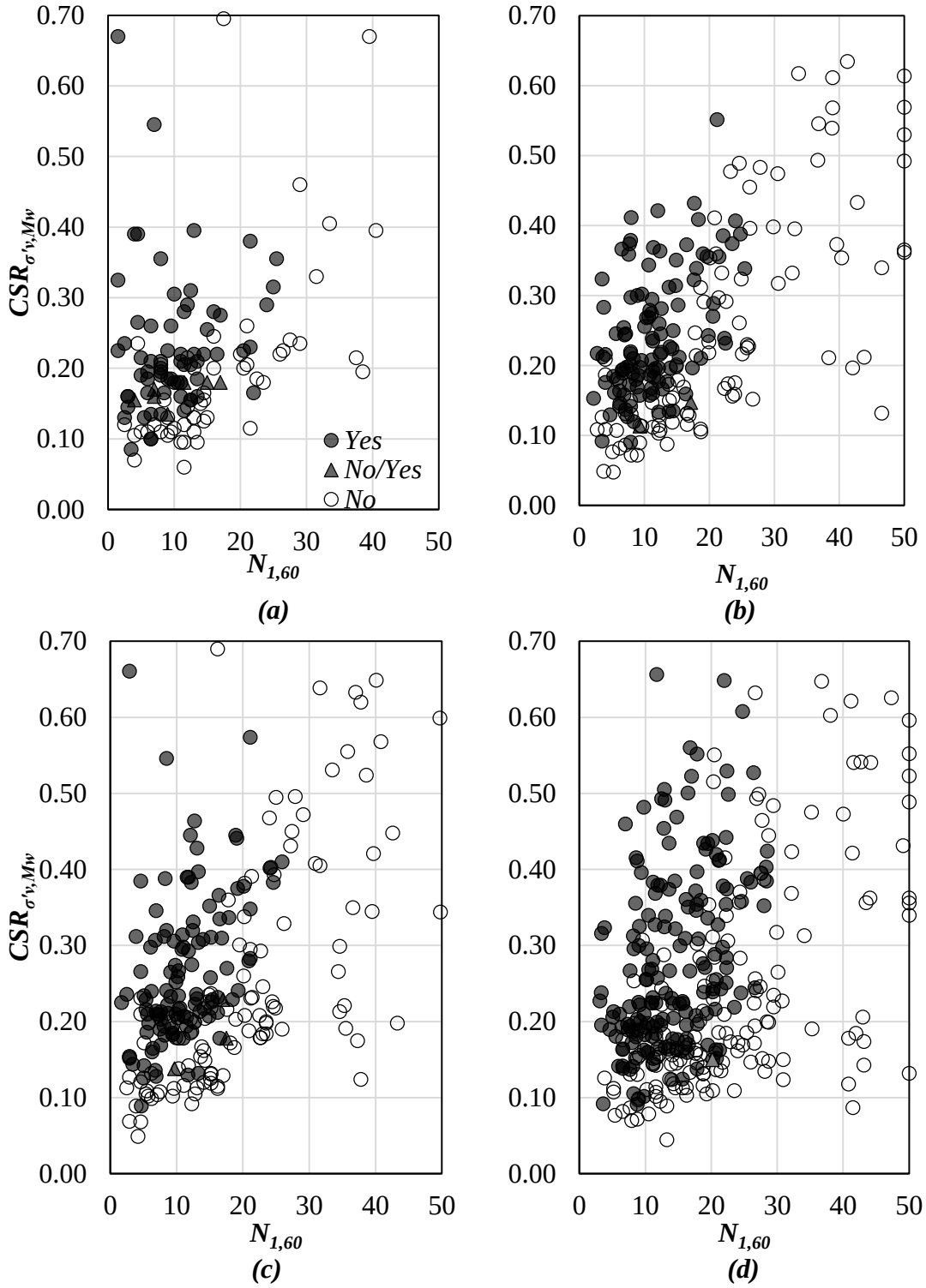


Figure 4.19. a) Seed et al. (1985), b) Cetin et al. (2018a, b), c) Idriss and Boulanger (2010), and d) this study.

Table 4.8 presents a comparison of the mean, mean of the standard deviation, and minimum and maximum values input parameters of Cetin et al. (2018a, b) and this study. Mean of the standard deviation is denoted as "σ^*" in this table.

Table 4.8. Comparison of the mean, mean of the standard deviation, minimum and maximum values input parameters of Cetin et al. (2018a, b) and this study.

Parameters	***CEA 2018***				***This Study***			
	mean	***σ****	***Min.***	***Max.***	***mean***	***σ****	***Min.***	***Max.***
$d_{crt.}$ *(m)*	5.2	0.6	1.1	14.5	5.8	0.7	1.8	22.6
GWT (m)	2.12	0.12	0.0	7.65	2.03	0.18	0.0	7.65
γ_{wet} *(kN/m^3)*	16.9	0.5	9.4	19.6	17.6	0.5	13.3	21.3
γ_{sat} *(kN/m^3)*	19.0	0.5	14.1	21.2	19.8	0.5	17.0	22.8
σ_v *(kPa)*	94.7	10.9	17.7	273.3	111.1	14.2	31.4	405.3
σ'_v *(kPa)*	64.7	5.8	10.4	182.7	74.2	7.8	24.1	228.8
r_d	0.908	0.062	0.491	0.999	0.884	0.064	0.477	1.029
a_{max} *(g)*	0.293	0.061	0.051	0.700	0.312	0.053	0.078	0.784
M_w	7.08	-	5.9	8.30	7.04	0.07	4.6	9.10
CSR	0.249	0.058	0.048	0.634	0.262	0.053	0.045	0.656
GC (%)	-	-	-	-	3.1	6.1	0.0	50.0
SC (%)	-	-	-	-	19.6	8.4	0.0	74.6
CC (%)	-	-	-	-	2.4	2.3	0.0	11.7
FC (%)	15.1	4.0	0.0	91.0	14.6	8.5	0.0	83.0
D_{50} *(mm)*	0.222	0.036	0.000	1.600	0.321	0.102	0.045	4.500
C_R	0.90	-	1.00	1.00	0.93	-	0.84	1.00
C_B	1.00	-	1.00	1.15	1.00	-	1.00	1.15
C_E	1.12	-	0.65	1.30	1.26	-	0.82	1.65
C_N	1.34	-	0.74	2.00	1.26	-	0.67	2.00
$(N_1)_{60}$	16.73	3.20	2.2	65.47	18.75	3.78	3.1	71.74
$V_{s,12m}$ *(m/s)*	192.33	-	121.9	289.56	195.07	-	109.7	496.14
$V_{s,30m}$ *(m/s)*	-	-	-	-	213.36	-	131.2	344.58
$K_{\sigma\ (\text{without cap})}$	1.22	-	0.82	2.15	1.07	-	0.88	1.26
K_{Mw}	1.17	-	0.79	1.75	1.05	-	0.88	1.40
$CSR_{Mw=7.5,\sigma'v=100kPA}$	0.186	-	0.029	0.50	0.234	-	0.043	0.61
$N_{1,60,CS}$	18.20	-	4.95	66.46	20.78	-	3.09	71.74

Some important observations regarding the new case history database are summarized as follows:

1. Critical depth values increased by 11.8 % due to the relatively deeper nature of critical layers in the new database.
2. Total and effective stress increased by 17.4 and 14.8 % which is mainly due to deeper critical layers and slightly increased unit weight protocol.
3. $N_{1,60}$ values increased by 12.1 % due to increased C_E and less pronounced C_R corrections. However, the greatest effect is due to higher $N_{1,60}$ values within the critical layer of the new case histories.
4. Peak ground acceleration, a_{max} values increased by 6.6 % due to high a_{max} levels of the new case history data and events (e.g. 2011 Tohoku earthquake, etc.).
5. $CSR_{Mw,\sigma'v}$ values increased 5.3 % which is mainly due to high a_{max} levels of the new case history data and events (e.g. 2011 Tohoku earthquake, etc.).
6. Event mechanisms were studied and it is observed that the case histories were compiled from thrust, strike-slip, subduction, reverse, mixed (e.g. reverse-strike slip components, etc.) mechanisms by 19 %, 50%, 10%, 13%, and 8% respectively.
7. 85 % of the sites were observed to be located on natural deposits on the other hand 15 % of them are located on man-made fills.

CHAPTER 5

SEISMIC SITE RESPONSE ANALYSIS

5.1 Introduction

Local site conditions strongly influence the characteristics of ground motions. Although the simplified procedure is an effective tool to estimate CSR, the direct estimate of site-specific CSR is possible through site response analyses. Additionally, design codes (e.g. NAP, 2016, etc.) require performing site response analysis to evaluate the intensity-related input parameters. The issue was raised by NAP (2016) as follows: *"it is tempting to assume that, rather than using a simplified equation for r_d to assess the earthquake-induced shear stress, using a more precise analytical method for assessing earthquake-induced shear stress (e.g., a site response analysis) will increase the accuracy of the analysis."*

The updated database includes a number of case history sites, where site and event-specific 1-D site response analyses enable the direct estimation of r_d or CSR. As was discussed in Chapter 4, the updated database consists of case histories from Cetin et al. (2004, 2018a, b) database and new data mostly from recent events. The case history database of Cetin et al. (2004, 2018a, b) was screened and 171 case histories passed the screening criteria of the recent studies. Among these 171 case history, 43 case history has site response analyses performed by Cetin (2000), which were directly used in the development of the updated seismic soil liquefaction triggering models. Additionally, among 163 new case history data, 110 site response analyses (two horizontal components for each case history data) were performed for 55 case histories which provides a better estimate of the CSR term useful for a more accurate model. In total, among 334 case histories, 93 of their site- and event-specific

estimates of CSR or r_d were available after site response analyses and this chapter presents the details of these analyses.

5.2 1-D Seismic Site Response Analysis

The estimation of shear stresses from site response analyses requires more parameters than the simplified procedure. The first step involves the determination of the entire V_s profile along with the strain-dependent nonlinear soil properties and parameters related to bedrock. The second step involves the selection of input ground motions (NAP, 2016).

1-D seismic site response analysis can be performed using software (e.g. SHAKE91 by Idriss (1991), SHAKE by Schnabel et al. (1972), Deepsoil by Hashash et al. (2020), ProShake, etc.). Equivalent linear frequency domain analyses including convolution and deconvolution analyses can be performed with SHAKE91, SHAKE, and ProShake. In addition, 1-D nonlinear time-domain analyses can be performed by Deepsoil software. In all types of site response analyses, the input ground motion is propagated vertically through horizontal layers of soil, whose dynamic properties (damping, stiffness parameters) are modeled. This enables the calculation of surface acceleration time series, response spectra, induced shear stresses, etc. based on the response of the soil site.

The subsequent sections present the details of the equivalent linear total stress, and frequency domain analysis performed for 55 liquefaction case history sites.

5.3 Subsurface Characterization

The subsurface characterization of the liquefaction field case history sites is achieved by jointly assessing the standard penetration, cone penetration, and shear wave velocity test results. All case histories for which site response analyses are performed have these three test data (SPT, CPT, V_s). The construction of the site model was

achieved by considering available field test data and geological conditions. The resulting case-specific soil profiles, which include V_s profiles along with soil layers developed for the case histories are presented in Appendix B for these 55 case history sites.

5.4 Parameter Selection

The parameters required to develop a 1-D site response analysis are V_s (or maximum shear modulus, G_{max}) the thickness of the soil layer, material type, unit weight, soil model plasticity index, PI (%), if applicable. While constructing the site response analysis models, the soil to bedrock or soil to soil sub-layer transitions are smoothed to reduce sharp impedance contrasts, unless field data suggest otherwise. As mentioned in Section 5.3, only the sites where V_s measurements were available, were selected for the site response analyses.

The normalized modulus reduction and damping factors were selected as per Seed et al. (1984) for cohesionless materials, Vucetic and Dobry (1991) for cohesive soils, Rollins et al. (2020) for gravels, and Idriss (1990) for rocks. These curves are shown in Figure 5.1-5.4, respectively.

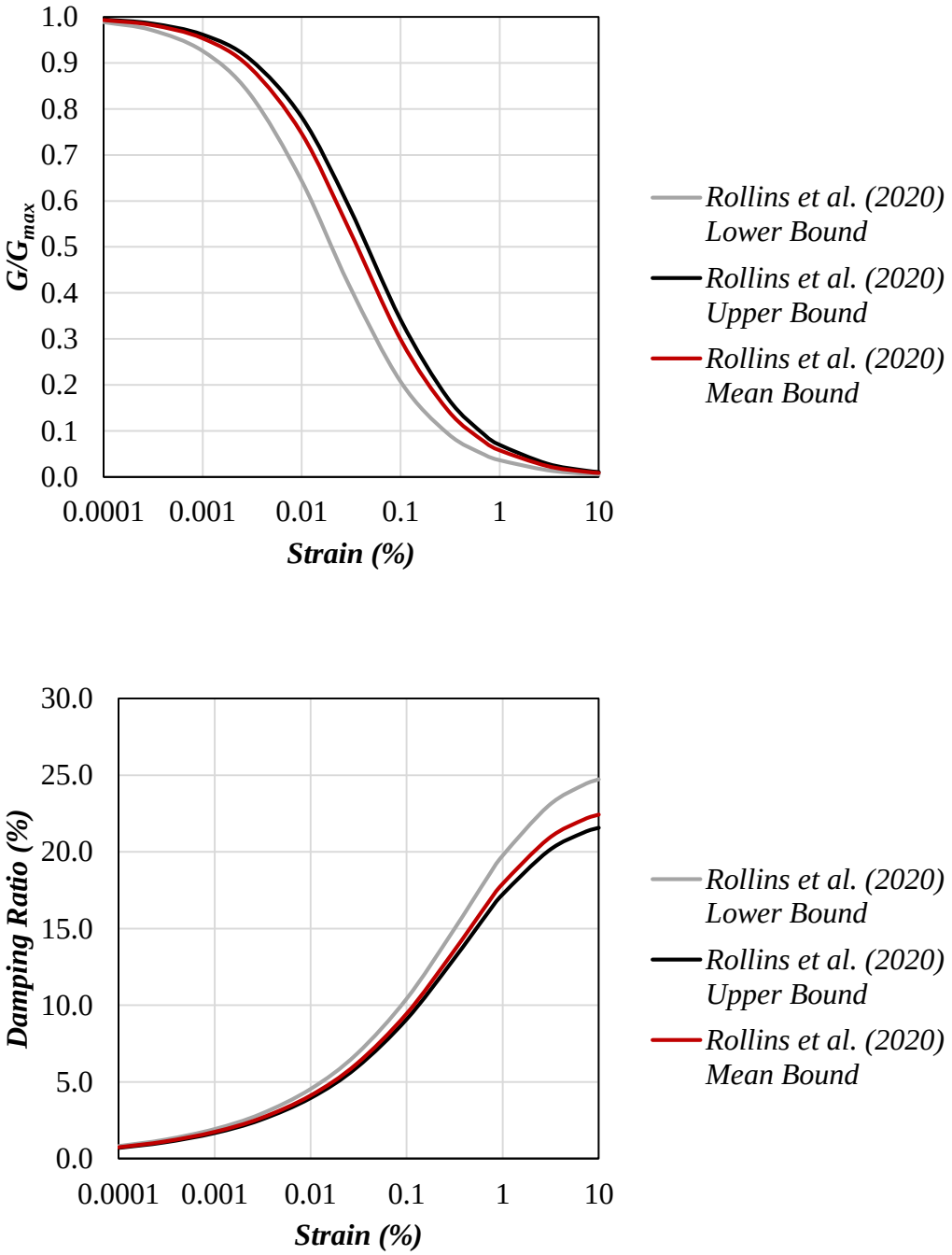


Figure 5.1. Normalized modulus reduction and damping factors for gravels proposed by Rollins et al. (2020).

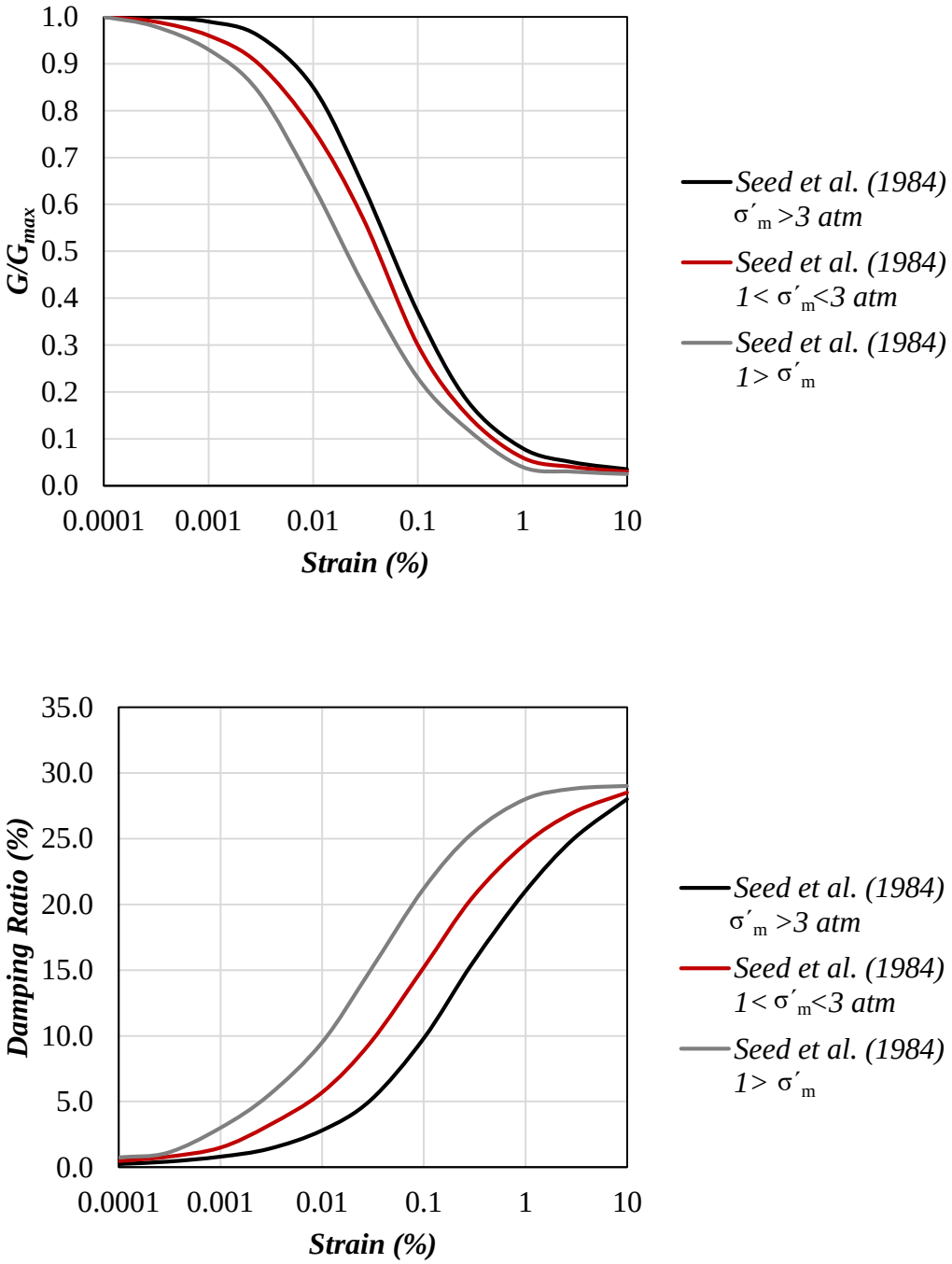


Figure 5.2. Normalized modulus reduction and damping factors for cohesionless soils proposed by Seed et al. (1984) for mean effective stress of σ'_m <1 atm, 1<σ'_m<3 atm and σ'_m>3 atm.

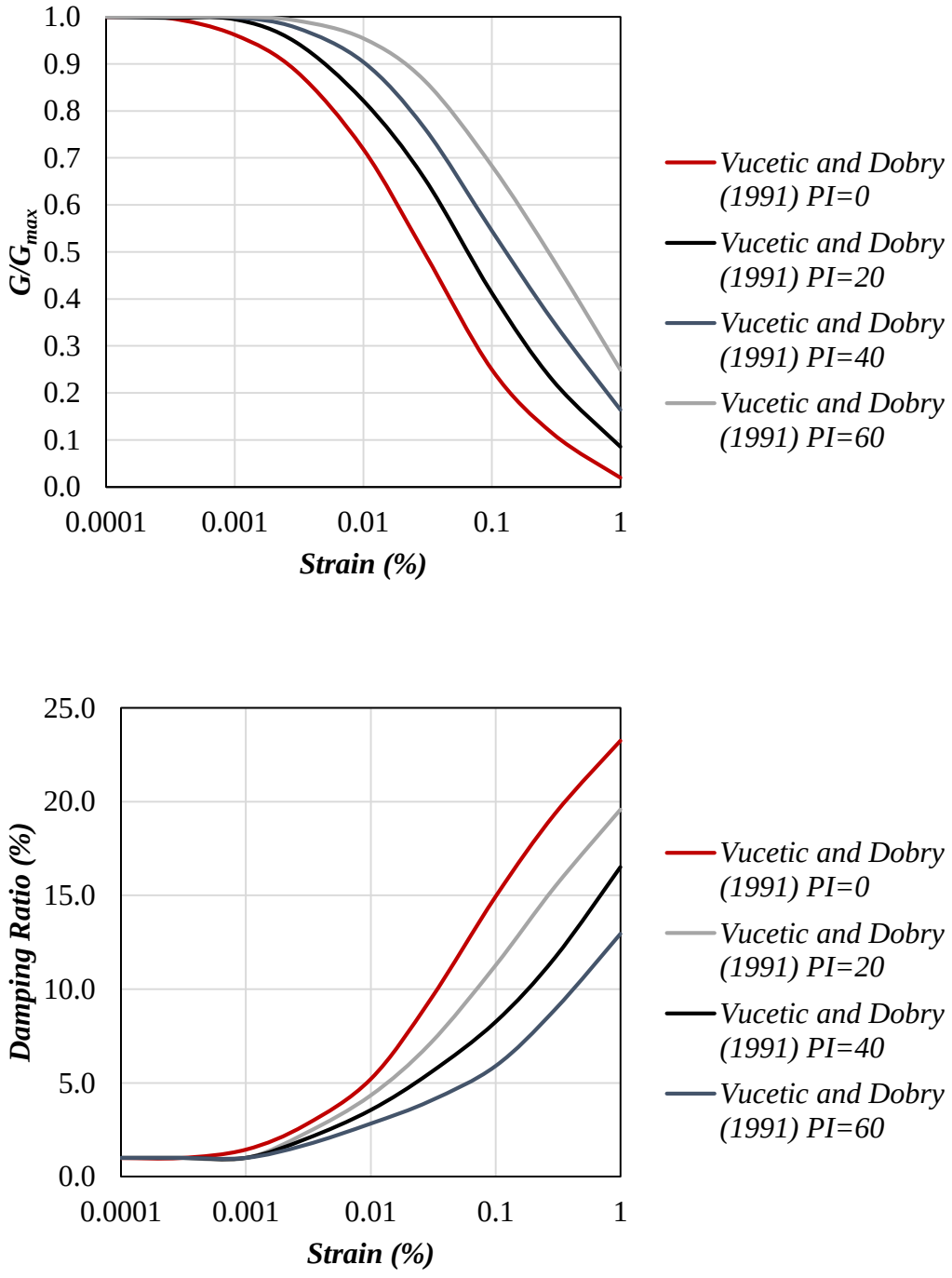


Figure 5.3. Normalized modulus reduction and damping factors for cohesive soils proposed by Vucetic and Dobry (1991) as a function of plasticity index.

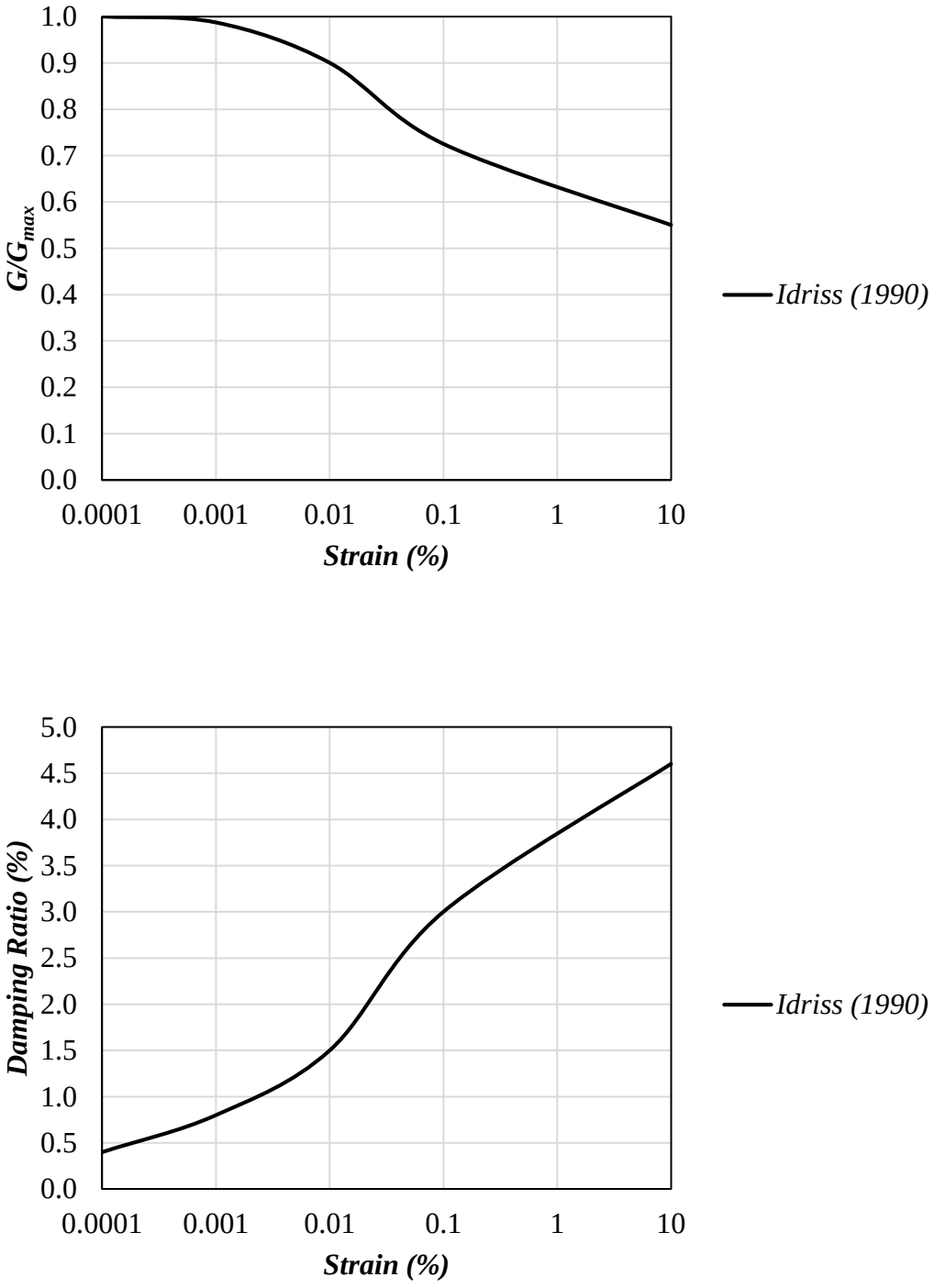


Figure 5.4. Normalized modulus reduction and damping factors for rocks proposed by Idriss (1990).

5.5 Selection of Analyses Type and Input Ground Motion

In order to perform site response analysis, the selection of representative input motions is essential. Based on the location and properties of the site, where the available ground motions were recorded, the site response analysis procedure is modified. It should be noted that the two horizontal components of the recorded ground motions were used as an input for the site response analyses performed for each site. The following conditions were encountered and corollary decisions were made case-specifically.

1. If there exists a strong ground motion recording on the rock outcrop (blue triangle in Figure 5.5) that underlies the soil site of interest, rock outcrop motion is deconvolved (green arrow) and rock within motion (gray triangle) is estimated. Then the rock within motion (gray triangle) is applied to estimate the soil site surface outcrop motion (orange triangle). If SMS is available at the soil site of interest (green triangle), this recorded surface motion and the calculated motions (orange triangle) can be used to compare and calibrate the site model (e.g. Treasure Island and Yerba Island sites, etc.).
2. If the soil site is a vertical array, which means within motions were recorded at certain depths throughout the soil site (purple triangle), these within motions can be used for upward wave propagation assessments and soil site surface outcrop motion (orange triangle) is calculated. Similarly, if a recording station exists, a comparison will enable to calibrate of the soil site model (e.g. Wildlife, etc.).
3. If there exists a strong ground motion recording on the soil site of interest (green triangle) then this surface recording can be deconvolved (green arrow) propagating backward and transferred vertically traveling down through the soil layers and within motions (purple or gray triangle) can be calculated (e.g. CCCC, etc.)

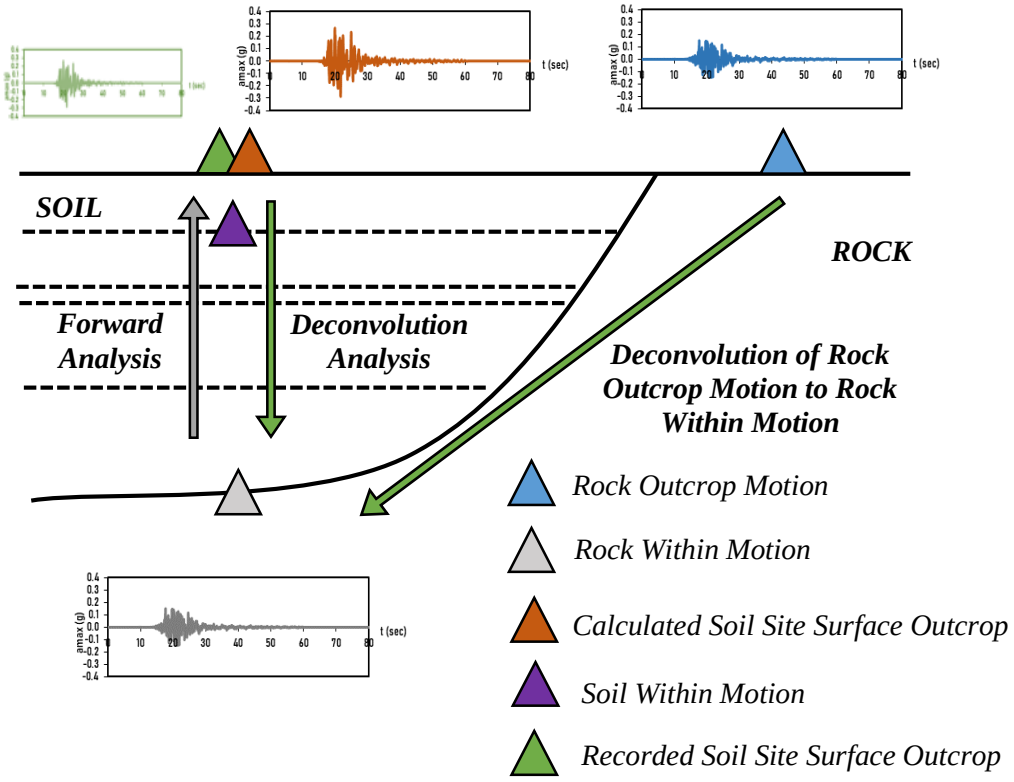


Figure 5.5. Schematic sketch of forward site response and deconvolution analyses.

5.6 Site Response Analysis for New Zealand Case Histories

The 2010 Darfield and 2011 Christchurch earthquakes caused extensive damage due to liquefaction in the city of Christchurch. A significant number of new case histories were compiled from those events for the development of the new database. The final number of case histories reached 72 after excluding 34 of them.

The New Zealand dataset represents good quality data in terms of ground motion characterization. The availability of strong ground motion stations and the digital data shared with the public by GeoNet motivated to perform site response analysis to directly estimate the CSR or r_d levels for those case histories.

There exist 20 SMS in the Christchurch area that recorded 2010 Darfield and 2011 Christchurch earthquake shakings at sites where $V_{s,30m}$ varies between 180-550 m/s. The locations of the SMS are shown in Figure 5.6.

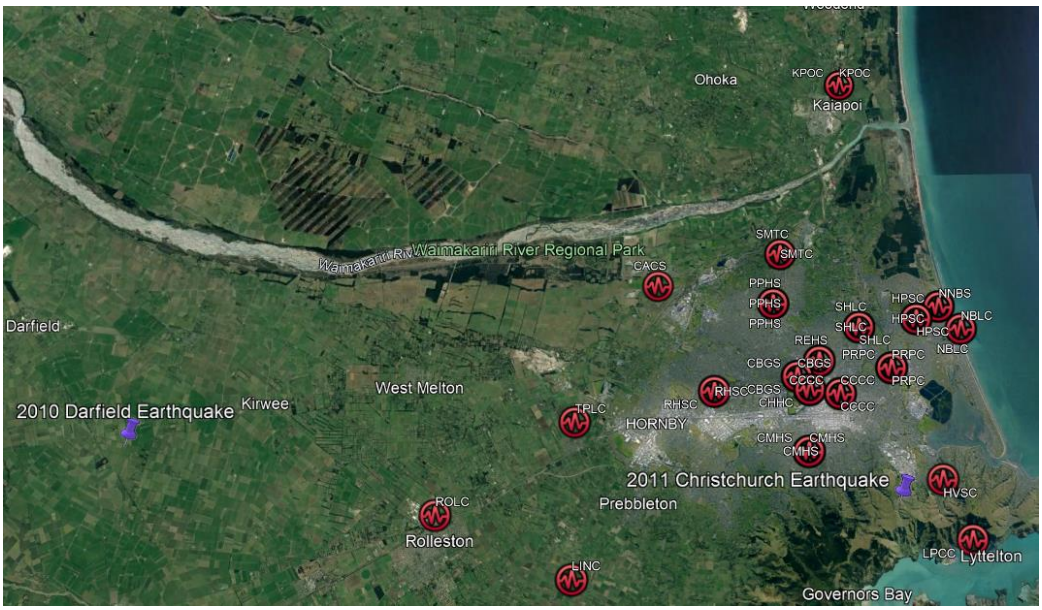


Figure 5.6. Strong ground motion network in Christchurch (purple pins indicated the epicenter of the 2010 Darfield and 2011 Christchurch events)

Field performance of the SMS sites based on the presence or lack of surface manifestation and ground motions after the 2010 Darfield and 2011 Christchurch Earthquakes are summarized by Wotherspoon et al. (2015). Table 5.1 presents the field performance of the SMS sites studied in this study. The frequency shift in the ground motions allows determining the occurrence of liquefaction which is especially invaluable when the surface manifestation was not developed although soil layers are liquefied.

Table 5.1. Field performance of the SMS sites after the 2010 Darfield and 2011 Christchurch Earthquakes.

Stations	*2010 Darfield Earthquake*		*2011 Christchurch Earthquake*	
	Surface Manifestation	*Ground motion indicates liquefaction*	*Surface Manifestation*	*Ground motion indicates liquefaction*
CACS	N	N	N	N
CBGS	N	N	N	Y
CCCC	N	N	Minor	Y
CHHC	N	N	Moderate	Y
CMHS	N	N	Severe	Y
HPSC	Severe	Y	Severe	Y
KPOC	N	N	N	N
NNBS	N	N	N	Y
PPHS	N	N	N	N
PRPC	N	N	Minor	Y
REHS	N	N	N	Y
RHSC	N	N	N	N
SHLC	N	N	Moderate	Y
SMTC	N	N	N	N

Note: N=No, Y=Yes

The strong ground motion records were downloaded from the GeoNet webpage. Representative peak ground acceleration values were calculated based on these records. The two horizontal components of SMS sites for the 2010 Darfield and 2011 Christchurch Earthquakes are summarized in Table 5.2.

Table 5.2. Recorded peak ground acceleration values during the 2010 Darfield and 2011 Christchurch Earthquakes

	2010 Darfield Earthquake		*2011 Christchurch Earthquake*	
Stations	*Component 1*	*Component 2*	*Component 1*	*Component 2*
CACS	0.186	0.198	0.185	0.228
CBGS	0.15	0.174	0.529	0.431
CCCC	0.229	0.202	0.483	0.367
CHHC	0.198	0.153	0.336	0.361
CMHS	0.248	0.237	0.355	0.397
HPSC	0.156	0.113	0.149	0.237
KPOC	0.300	0.344	0.212	0.19
NNBS	0.194	0.187	-	-
PPHS	0.216	0.197	0.217	0.173
PRPC	0.199	0.232	0.665	0.589
REHS	0.238	0.246	0.714	0.366
RHSC	0.189	0.219	0.293	0.25
SHLC	0.175	0.179	0.312	0.342
SMTC	0.16	0.186	0.18	0.143

Specific attention was given to 14 sites, which are potential liquefaction case histories for the SPT catalog. In order to develop site response analysis, the geological conditions were studied for the Christchurch area. The geological cross-sections are compiled from Deschenes (2017) as shown in Figure 5.7. Bedrock layers were encountered at depths of 1.5-2 km, where V_s reaches 2000 m/s. Deep V_s measurements were performed by Cox et al. (2010, 2013) next to SMS sites. The profiles were mix-matched using the V_s measurements of Wotherspoon et al. (2015) for the upper surficial layer of the SMS sites and deep V_s measurements of Cox et al. (2010, 2013). Deconvolution analyses were performed for 14 SMS with deep 1-D soil profiles reaching 1.5-2 km depth. Due to the high linear behavior of the modeled rock layers (e.g. V_s=1100 m/s), it was observed that modeling the SMS until Riccarton gravel formation, lying under the city of Christchurch and most of

the sites of interest, was adequate. As a result, deconvolution analyses were performed with "short" soil profiles, and the surface ground motion was deconvolved to Riccarton Gravel, where the V_s values reach approximately 400-450 m/s.

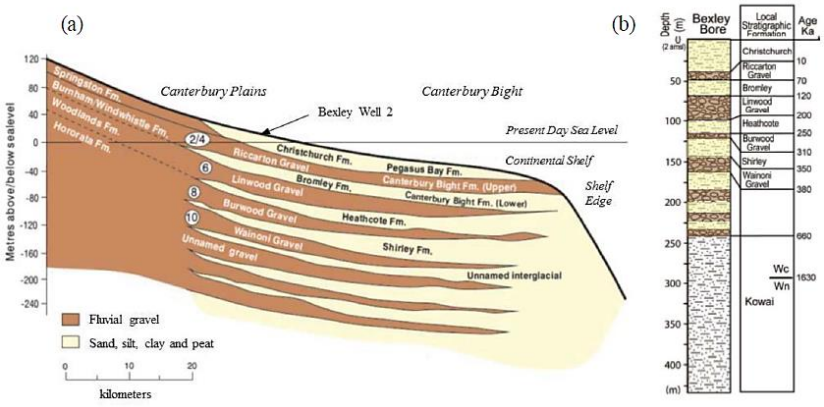
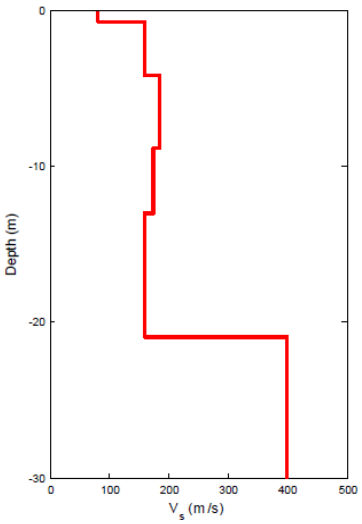


Figure 5.7. The geological cross-section of Christchurch (Deschenes, 2017)

Short (up to 30-45 m) SMS profiles were constructed until each SMS profile reaches Riccarton gravel. The V_s measurements were performed with spectral analysis of surface wave method (SASW) or multi-channel analysis of surface waves (MASW) and the estimated V_s profiles provided by Wotherspoon et al (2015) were digitized. An example SMS site (CBGS) is shown in Figure 5.8.



Depth (m)	V_s (m/s)
0.0	81
0.8	160
4.2	185
8.9	175
13	160
21	400
30	

Figure 5.8. V_s profile given by Wotherspoon et al. (2015) for CBGS.

It was essential to determine gravel content and the depth of relatively stiff gravel layers for New Zealand SMS sites to be able to construct the site response analysis models. Table 5.3 presents a summary of the information related to gravel layers for SMS soil profiles

Table 5.3. Summary of the information related to gravel for SMS soil profiles

Stations	*Depth to V_s=400 m/s (m)*	*Depth to Gravel (m)*	*Shallow Gravel Present*	*Bedrock Encountered*	*V_s at 30m (m/s)*
CACS	7	Surface	NA	N	600
CBGS	21	21	Y	N	400
CCCC	25.2	25	N	N	600
CHHC	22.5	22.5	Y	N	400
CMHS	24.2	13.8	Y	N	400
HPSC	Unkown	36	N	N	350
KPOC	17.4 (reaches 450 m/s)	8.6	Y	N	450
NNBS	Unkown	41	N	N	340
PPHS	19	19	Y	N	400
PRPC	28	28	N	N	400
REHS	20	20	Y	N	400
RHSC	17.4 (reaches 450 m/s)	6.3	NA	N	450
SHLC	27	27	Y	N	400
SMTC	17.9	17.9	Y	N	400

Not: Y=Yes, N=No, NA=Not available

A site is selected to present illustratively the deconvolution analyses performed at SMS sites. Table 5.4 presents the site response analysis profile developed for the CBGS station.

Table 5.4. Site response analysis profile for CBGS

Layer Number	*Material Name*	*Thickness (m)*	*Unit Weight (kN/m^3)*	*V_s (m/s)*	*G_{max} (MPa)*	*Soil Model ID**	*PI (%)*
1	Gravel Fill	0.80	19.6	81.0	13.1	*Rollins et al. (2021) lower*	0.00
2	GW	3.40	19.6	160.0	51.3		0.00
3	SW	4.70	21.2	185.0	74.0	*Seed et al. (1985) mean*	0.00
4	SP-SW-GW	4.10	21.2	190.0	78.1		0.00
5	SM-ML	8.00	21.2	200.0	86.5	*Vucetic and Dobry (1991) PI=7*	7.00
6	Gravel	3.00	21.2	275.0	163.5	*Rollins et al. (2021) mean*	7.00
7	Gravel	3.00	21.2	361.0	281.8		7.00
8	GW	3.00	21.2	400.0	346.0		0.00
9	Riccarton Gravel	4.00	22.0	447.0	448.2	*Rollins et al. (2021) upper*	0.00
10	Riccarton Gravel	7.00	22.0	477.0	510.4		0.00
11	KAYA	0.00	24.0	500.0	611.8	*Idriss (1999)*	0.00

Pro.Shake 2.0 software is used and the recorded ground motion at the CBGS SMS was deconvolved and the within Riccarton gravel motion was obtained, which is located at 41 m. Figure 5.9 presents the summary of the site response analysis for CBGS. This summary includes V_s profile along with soil layering given on the left. Two horizontal components of the recorded motion are given in the upper part of the page and deconvolved within motion at Riccarton gravel motion at the bottom. Response spectra are also plotted to compare the recorded and within motion for 5 % damping at the center. Finally, a_{max}, r_d, CSR, τ_{av} plots were prepared which are

shown on the right. Appendix B presents the site response analysis results of 55 case histories in the same format.

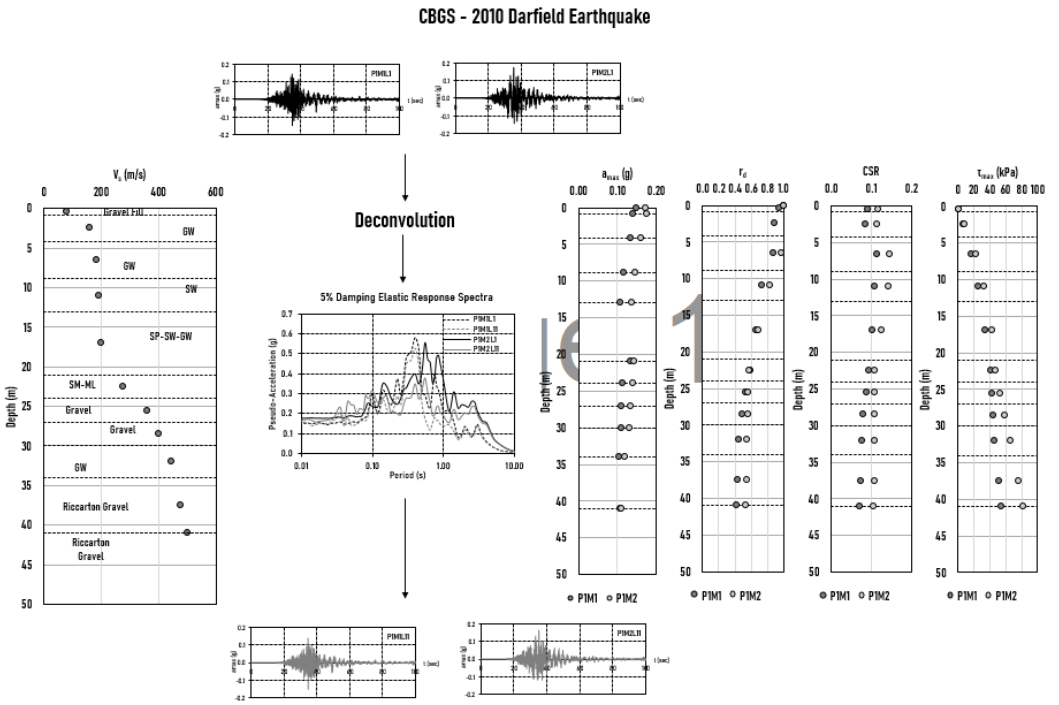


Figure 5.9. Site response analyses result for CBGS

The deconvolution of all the SMS recordings was not possible due to highly nonlinear behavior resulting from high-intensity shaking levels, especially for the 2011 Christchurch event, whose PGA values were much higher than the Darfield event. These site response analyses significantly depend on the input motions and soil profile characterizations as stated by Markham et al. (2015). Table 5.5 presents a summary of the result of deconvolution analyses performed for the SMS in the Christchurch area. As it can be inferred from this table, for most of the sites deconvolution analyses could not be performed for the Christchurch event.

Table 5.5. Summary of the deconvolution analysis at SMS.

Stations	*2010-1*	*2010-2*	*2011-1*	*2011-2*
CACS	✓	✓	✓	✓
CBGS	✓	✓	x	x
CCCC	x	x	x	x
CHHC	✓	✓	x	x
CMHS	x	x	x	x
HPSC	x	x	x	x
KPOC	✓	✓	✓	✓
NNBS	x	x	x	x
PPHS	x	x	x	x
PRPC	x	x	x	x
REHS	x	x	x	x
RHSC	✓	✓	✓	✓
SHLC	✓	✓	x	x
SMTC	x	x	x	x

For the sites where deconvolution analysis was performed successfully, the CSR or r_d are estimated based on the site response analysis result. After having observed that it is not possible to perform deconvolution analyses for all the SMS sites for both events due to the limitation of the available tools, alternative analysis solutions were investigated.

Outcrop rock motions were not recorded in the Christchurch area due to the lack of SMS on rock outcrops, except for Lyttelton Port strong-motion station, LPCC, which is not a good candidate to be rock outcrop motion for the subsequent analyses due to its location. Owing to the fact that the New Zealand database has case history sites other than SMS sites, it becomes essential to select good candidate input ground motions for the site response analyses of the New Zealand sites.

For this purpose, deconvolution analyses were performed at CACS, RHSC, and KPOC. Ground motions at CACS and RHSC are used for the site response analysis of liquefaction case history sites as these SMS exhibit mostly linear soil behavior during both events considering no sign of liquefaction was observed after both events. On the other hand, KPOC was left outside the analysis as it is located in the north of Christchurch which is not a good candidate due to its location on another geological formation and a significant distance from the liquefaction sites. Markham et al. (2016) confirm the selection of CACS and RHSC to be input ground motion for the liquefaction case history sites in Christchurch.

Before performing site response analysis for the SMS where deconvolution could not be executed properly, a scaling factor is applied to CACS and RHSC ground motions to consider the site to source distance and site effects. Ground motion prediction equations were used to calculate the scale factor and for this purpose event parameters were first determined. 2010 Darfield Earthquake (M_w 7.1) occurred on a strike-slip fault and the rupture reached the surface (Z_{TOR}=0). The dip angle and the width of the fault are estimated as 82º and 10 km by Elliott et al. (2012). 2011 Christchurch Earthquake (M_w 6.2) occurred on a reverse blind fault where Z_{TOR} was 0.5 km. The dip angle and the width of the fault are 64º and 6.5 km. The site locations and fault ruptures were integrated with Google Earth and rupture distances were measured. These distances were also compared with the distances given in Wotherspoon et al (2015) and judged to be very similar. Table 5.6 summarizes the rupture distances (R_{rup} and R_{jb}) of the SMS' for the 2010 Darfield and 2011 Christchurch earthquake events.

Table 5.6. Rupture distance of the SMS for the 2010 Darfield and 2011 Christchurch earthquake events.

Stations	*2010 Darfield Earthquake*		*2011 Christchurch Earthquake*	
	R_{rup} *(km)*	R_{jb} *(km)*	R_{rup} *(km)*	R_{jb} *(km)*
CACS	11.7	9.7	12.8	12.7
CBGS	14.4	13.9	4.7	4.6
CCCC	16.2	15.9	2.8	2.6
CHHC	14.7	14.3	3.8	3.7
CMHS	14	13.9	1.4	1
HPSC	21.7	21	3.9	3.8
KPOC	27.6	25.7	17.4	17.3
NNBS	23.1	22.4	3.8	3.7
PPHS	15.3	14.1	8.6	8.6
PRPC	19.3	19	2.5	2.3
REHS	15.8	15.2	4.7	4.6
RHSC	10	9.4	6.5	6.5
SHLC	18.6	17.9	5.1	5
SMTC	17.5	16	10.8	10.7

Scaling factors were calculated by using Abrahamson and Silva (2014) ground motion prediction equation. While calculating the scaling factor between (CACS or RHSC) and the targeted site (CCCC, CHHC, etc.), the differences in $V_{s,30,}$ and rupture distance (R_{rup}, R_{jb}, etc) were evaluated. Table 5.7 and Table 5.8 presents the factors to transfer CACS and RHSC stations' ground motions to the corresponding SMS respectively. KPOC station was left outside these analyses as it is located further away from Christchurch and on a different geological formation. Additionally, deconvolution analyses were successfully performed for KPOC, hence the results were used directly to estimate CSR values.

Table 5.7. Scaling factors calculated to transfer CACS deconvolved motion to the listed sites for the 2010 Darfield and 2011 Christchurch events

	Scale factor	
Stations	*2010 Darfield Earthquake*	*2011 Christchurch Earthquake*
CBGS	0.87	2.02
CCCC	0.80	2.44
CHHC	0.86	2.21
CMHS	0.89	2.72
HPSC	0.64	2.19
NNBS	0.64	2.28
PPHS	0.84	1.45
PRPC	0.71	2.57
REHS	0.82	2.09
SHLC	0.72	2.01
SMTC	0.76	2.01

Table 5.8. Scaling factors calculated to transfer RHSC deconvolved motion to the listed sites for the 2010 Darfield and 2011 Christchurch events

	Scale factor	
Stations	*2010 Darfield Earthquake*	*2011 Christchurch Earthquake*
CBGS	0.79	1.20
CCCC	0.73	1.45
CHHC	0.78	1.31
CMHS	0.81	1.61
HPSC	0.58	1.30
NNBS	0.58	1.35
PPHS	0.76	0.86
PRPC	0.64	1.53
REHS	0.74	1.24
SHLC	0.66	1.19
SMTC	0.69	0.72

The upward propagation analyses were performed for all the SMS sites by using CACS and RHSC ground motions. The predicted surface ground motions were compared with the recorded motions at the SMS. An example is shown in Figure 5.10 which presents a comparison of the recorded and the calculated motions at CBGS. The dashed line shows the predicted surface motion at the CBGS station by using the CACS and the solid lines are the recorded ground motions at CBGS. Figure 5.11 presents the residuals plot for these analyses. The vertical axis on this plot is $\ln(S_{a,\,observed}/S_{a,\,predicted})$. As it can be inferred from both figures, the recorded motions are higher than what is calculated by site response analysis. Especially for the Christchurch event, this was a typical observation which indicates that due to high-intensity levels of 0.4 and 0.5 g, the site response analyses face a limitation. Equivalent linear analysis accuracies drop beyond strain levels of 0.1 to 1 %. As Christchurch event produce high-intensity shaking, these levels are well exceeded.

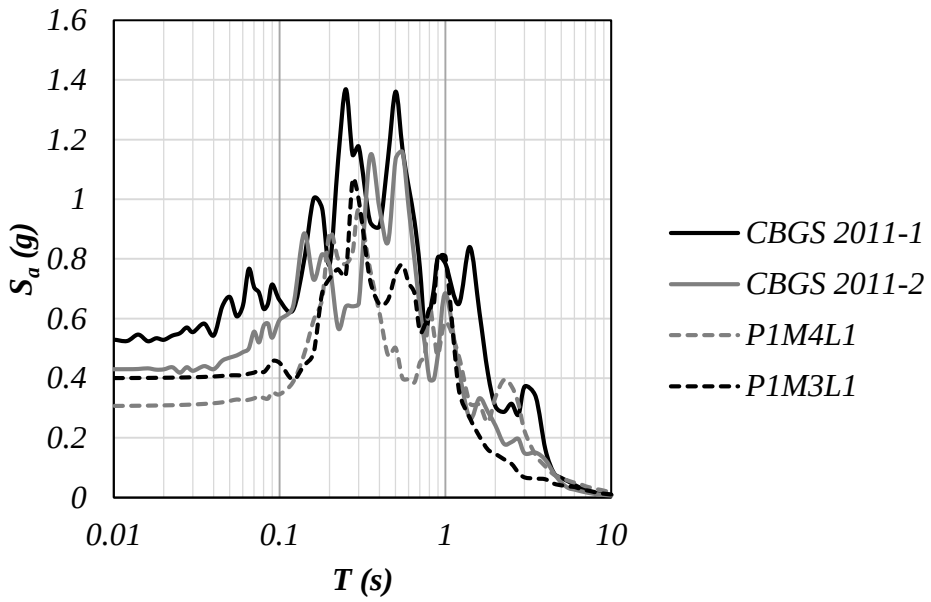


Figure 5.10. The comparison of predicted and calculated 5% damped response spectra at CBGS for the two horizontal components (dashed line represents the calculated motion by ProShake and the solid lines are the recorded surface motions at CBGS)

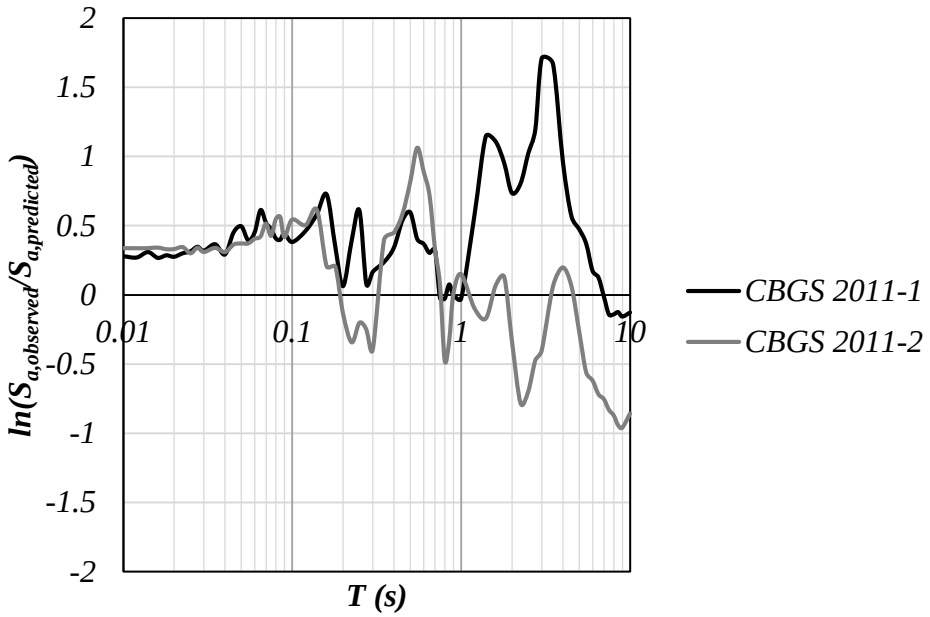


Figure 5.11. Residual plot at CBGS buT using CACS as input motions for the two horizontal components.

The same analyses were repeated for all SMS with RHSC ground motions and residuals were also calculated. These analyses were used to select the input motion of CACS or RHSC by considering the average residuals $ln(S_{a,observed}/S_{a,predicted})$. Table 5.9 and Table 5.10 presents the average of the residuals for all periods, periods up to 0.5 sec, and PGA (T=0). Although it is important to match the PGA values in these analyses, the spectral acceleration match was also important to evaluate the site response. Hence the least error coming from either CACS or RHSC was selected to be used in the site response analysis.

Table 5.9. Average of the residuals for the two horizontal components of the 2010 Darfield and 2011 Christchurch Earthquakes by using CACS within motions.

	2010 Component 1	*2010 Component 2*	*2011 Component 1*	*2011 Component 2*
CBGS		*average(ln($S_{a,observed}/S_{a,predicted}$))*		
All Periods	-0.284	-0.075	0.384	0.129
Periods up to 0.5 sec	-0.035	0.009	0.343	0.325
PGA	-0.007	0.075	0.279	0.340
CCCC		*average(ln($S_{a,observed}/S_{a,predicted}$))*		
All Periods	0.172	0.126	0.193	0.112
Periods up to 0.5 sec	0.438	0.197	0.135	0.244
PGA	0.489	0.265	0.127	0.218
CHHC		*average(ln($S_{a,observed}/S_{a,predicted}$))*		
All Periods	0.139	-0.322	0.094	0.185
Periods up to 0.5 sec	0.137	-0.022	-0.001	0.252
PGA	0.234	-0.025	-0.075	0.259
CMHS		*average(ln($S_{a,observed}/S_{a,predicted}$))*		
All Periods	-0.160	-0.008	-0.299	-0.256
Periods up to 0.5 sec	0.403	0.234	-0.210	0.063
PGA	0.367	0.244	-0.320	0.041
HPSC		*average(ln($S_{a,observed}/S_{a,predicted}$))*		
All Periods	0.126	-0.190	-0.654	-0.073
Periods up to 0.5 sec	0.103	-0.142	-0.759	-0.002
PGA	0.124	-0.146	-0.956	-0.126
NNBS		*average(ln($S_{a,observed}/S_{a,predicted}$))*		
All Periods	0.109	0.126	-	-
Periods up to 0.5 sec	0.374	0.293	-	-
PGA	0.301	0.256	-	-

Table 5.9. (cont'd)

PPHS		*average($ln(S_{a,observed}/S_{a,predicted})$)*		
All Periods	-0.040	-0.072	-0.124	-0.070
Periods up to 0.5 sec	0.161	0.102	-0.379	-0.231
PGA	0.224	0.118	-0.439	-0.230
PRPC		*average($ln(S_{a,observed}/S_{a,predicted})$)*		
All Periods	0.195	0.341	0.505	0.477
Periods up to 0.5 sec	0.516	0.558	0.627	0.751
PGA	0.475	0.531	0.564	0.698
REHS		*average($ln(S_{a,observed}/S_{a,predicted})$)*		
All Periods	0.112	0.339	0.734	0.217
Periods up to 0.5 sec	0.438	0.582	0.788	0.403
PGA	0.370	0.544	0.846	0.363
SHLC		*average($ln(S_{a,observed}/S_{a,predicted})$)*		
All Periods	-0.109	-0.095	-0.069	0.177
Periods up to 0.5 sec	-0.029	-0.053	-0.309	0.241
PGA	-0.045	-0.041	-0.435	0.176
SMTC		*average($ln(S_{a,observed}/S_{a,predicted})$)*		
All Periods	0.156	0.222	0.085	-0.111
Periods up to 0.5 sec	0.468	0.423	0.068	-0.014
PGA	0.360	0.413	0.012	-0.099

Table 5.10. Average of the residuals for the two horizontal components of 2010 Darfield and 2011 Christchurch Earthquakes by using RHSC within motions.

	2010 Component 1	*2010 Component 2*	*2011 Component 1*	*2011 Component 2*
CBGS	*average(ln($S_{a,observed}/S_{a,predicted}$))*			
All Periods	-0.006	0.110	0.653	0.516
Periods up to 0.5 sec	0.049	0.028	0.811	0.590
PGA	0.007	0.025	0.796	0.643
CMHS	*average(ln($S_{a,observed}/S_{a,predicted}$))*			
all periods	0.079	0.157	-0.209	0.072
periods up to 0.5 s	0.418	0.221	-0.002	0.259
PGA	0.323	0.169	-0.074	0.254
CCCC	*average(ln($S_{a,observed}/S_{a,predicted}$))*			
all periods	0.409	0.303	0.401	0.392
periods up to 0.5 s	0.464	0.197	0.523	0.352
PGA	0.442	0.190	0.551	0.325
CHHC	*average(ln($S_{a,observed}/S_{a,predicted}$))*			
all periods	0.415	-0.140	0.245	0.477
periods up to 0.5 s	0.213	-0.014	0.292	0.379
PGA	0.277	-0.084	0.267	0.376
HPSC	*average(ln($S_{a,observed}/S_{a,predicted}$))*			
all periods	0.457	-0.024	-0.465	0.178
periods up to 0.5 s	0.276	-0.158	-0.397	0.065
PGA	0.285	-0.259	-0.564	-0.046
NNBS	*average(ln($S_{a,observed}/S_{a,predicted}$))*			
all periods	0.468	0.314	-	-
periods up to 0.5 s	0.588	0.317	-	-
PGA	0.503	0.221	-	-
PPHS	*average(ln($S_{a,observed}/S_{a,predicted}$))*			
all periods	0.239	0.115	0.008	0.145
periods up to 0.5 s	0.249	0.112	-0.092	-0.219
PGA	0.276	0.057	-0.096	-0.239

Table 5.10. (cont'd)

PRPC		*average($ln(S_{a,observed}/S_{a,predicted})$)*		
all periods	0.434	0.506	0.599	0.730
periods up to 0.5 s	0.540	0.532	0.860	0.826
PGA	0.434	0.438	0.814	0.785
SHLC		*average($ln(S_{a,observed}/S_{a,predicted})$)*		
all periods	0.315	0.159	0.061	0.324
periods up to 0.5 s	0.284	0.071	-0.048	0.156
PGA	0.282	0.052	-0.131	0.058
SMTC		*average($ln(S_{a,observed}/S_{a,predicted})$)*		
all periods	0.419	0.405	0.188	0.222
periods up to 0.5 s	0.546	0.463	0.302	0.171
PGA	0.457	0.439	0.241	0.125

The results of the analyses for the 2010 Darfield and 2011 Christchurch events are summarized in Table 5.11. CACS, PPHS, PRPC, and REHS sites were excluded from the dataset due to reasons discussed in Chapter 4 hence their analysis results were not presented here.

Table 5.11. Summary of the results for SMS in Christchurch area.

Stations	*2010 Darfield Earthquake*	*2011 Christchurch Earthquake*
CBGS	Deconvolution	F1
CCCC	F1	F1
CHHC	F1	F1
CMHS	F2	F2
HPSC	F1	F1
KPOC	Deconvolution	Deconvolution
NNBS	F1	F1
RHSC	Deconvolution	Deconvolution
SHLC	Deconvolution	F2
SMTC	F1	F1

[*] *F1: Upward Propagation Analysis by using CACS as input motion,*

F2: Upward Propagation Analysis by using RHSC as input motion.

The same procedure discussed above is followed for the field case history sites in Christchurch other than SMS sites. Forward analyses were performed and the selection of input motion (CACS or RHSC) was made considering the proximity of SMS to the case history site. Site models are constructed by implementing the V_s profiles, which were retrieved from the ongoing study of "V_s based seismic soil liquefaction triggering database" (personal communication with Dr. Robert Kayen) or McLaughlin (2017) study.

The closest distance to rupture is again estimated to calculate the scale factors. Table 5.12 presents a summary of the rupture distance for the sites.

Table 5.12. Rupture distance for the case history sites in Christchurch for the 2010 Darfield and 2011 Christchurch Earthquakes.

Site	*2010 Darfield Earthquake R_{jb} (km)*	*2011 Christchurch Earthquake R_{jb} (km)*
Wharenui	12.1	4.9
29 Charles	16.8	1.6
Hillsborough Park	18.1	0.8*
Rydal Reserve	12.9	1.5
Barrington	13.6	2.4
Hillmorten High School	11.6	3.2
Avondale Park	20.1	3.9
Eqc4 Avondale	19.9	4.6
Avondale Playground-Avd07	19.8	3.8
Carisbrooke Playground	21.5	2.6
20 Corhampton Street	21.7	2.5
KAN09	25.6	16.9
KAN19	26	16.7
Normas Road	14.3	6.9
Heaton Norman Interm School	14,1	6.5
Palinurus road	19.4	0.5*
Ti Rakau Reserve	20	0.5*
St Albans Catholic School	15.3	6.2
Harrington Park	11.5	5.2
St Teresa School	11.8	5.7

*Hanging wall site

Table 5.12. (cont'd)

Site	*2010 Darfield Earthquake*	*2011 Christchurch Earthquake*
Sabina Playground	17.9	5.2
Shirley Interm School	17.8	4.6
Rawhiti Domain	22.5	2.6
Eqc6 Bexley	22.4	2.1
Z2-4	15.2	3.6
Z4-4	15.8	3.6
Z2-6	15.4	3.9

An illustrative site response analysis example is presented in this section. Case history 20 Corhampton Street will be presented as an example site. Figure 5.12 shows the location of the site (-43.511608, 172.711428) where liquefaction is observed in the form of sand boils on the surface of the street, backyards, and playground park after the 2011 Christchurch earthquake along with the in-situ field test investigation locations (SPT, CPT, and V_s) as given by McLaughlin (2017).

Borehole data and SCPT results were downloaded from NZGD as shown in Figure 5.12. The test results include SPT, CPT, and V_s data. CPT and V_s test results were obtained from McLaughlin (2017) as shown in Figure 5.13 and the borehole data is retrieved from New Zealand Geotechnical Database (NZGD) as shown in Figure 5.14 which is performed by Tonkin and Taylor.



Figure 5.12. 20 Corhampton Street site plan after the 2011 Christchurch Earthquake showing the field test data (McLaughlin, 2017)

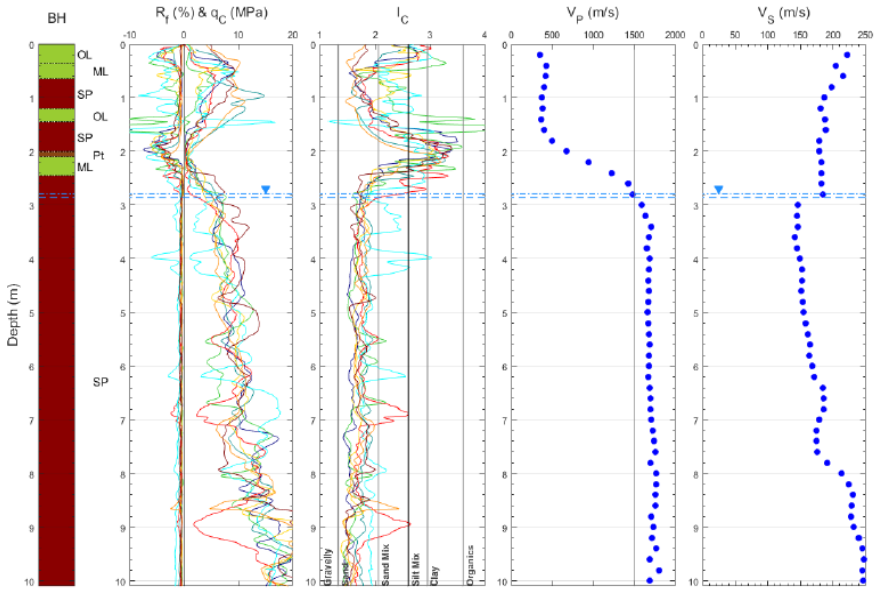


Figure 5.13. 20 Corhampton Street CPT and V_s test data along with sonic borehole data shown on the left (McLaughlin, 2017)

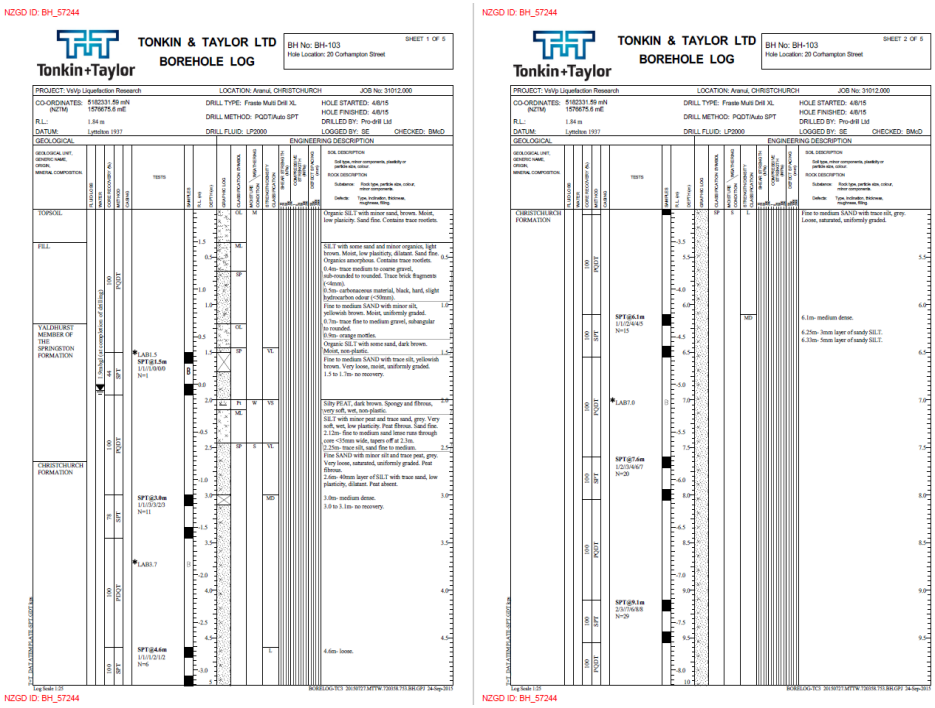


Figure 5.14. 20 Corhampton Street borehole data (NZGD ID: BH_57244) retrieved from NZGD.

Soil stratigraphy and site geology were investigated and the site model is constructed as shown in Table 5.13 considering CPT, SPT, and V_s test results. The upper soil layer consists of sandy materials SP and SW, which are followed by Riccarton gravel. Based on these evaluations, a site response model was formed and Figure 5.15 presents the 20 Corhampton Street shear wave velocity profile along with soil layering graphically.

Table 5.13. 20 Corhampton Street site response analysis model.

Layer Number	*Material Name*	*Thickness (m)*	*Unit Weight (kN/m^3)*	*V_s (m/s)*	*G_{max} (MPa)*	*Soil Model ID*	*PI (%)*
1	SP	3.00	17.7	191.0	66.0	Seed et al. (1984) lower	0
2	SP	3.00	18.3	152.4	43.3		0
3	SP	1.90	18.3	177.3	58.7		0
4	SP	2.10	18.3	230.9	99.5	Seed et al. (1984) mean	0
5	SW	1.00	18.3	240.0	107.5		0
6	SW	2.00	18.3	260.0	126.1		0
7	SW	2.00	18.3	280.0	146.3		0
8	SW	2.00	18.3	300.0	167.9		0
9	SW	8.00	18.3	320.0	191.1		0
10	SW	5.00	18.3	350.0	228.6		0
11	SW	6.00	18.3	374.0	261.0	Seed et al. (1984) upper	0
12	Riccarton Gravel	3.00	18.3	374.0	261.0	Rollins et al. (2020)	0
13	Riccarton Gravel	10.00	21.0	446.0	426.0		0
14	Rock	0.00	24.0	500.0	611.8	Idriss (1990)	0

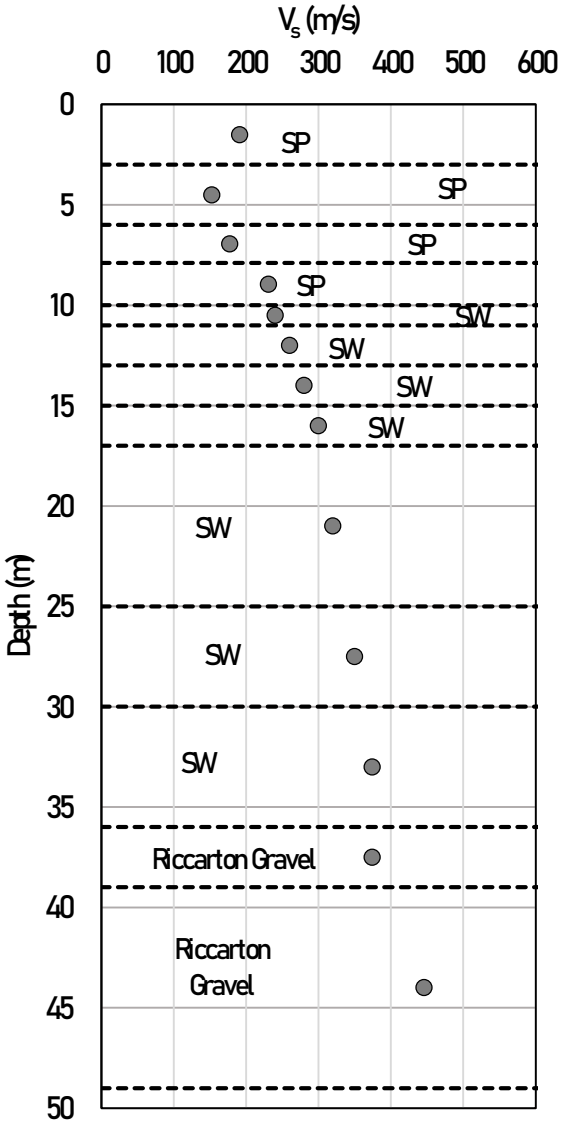


Figure 5.15. 20 Corhampton Street V_s profile along with soil layering.

Figure 5.16 a and b present the estimated surface recordings for the two horizontal components at the 20 Corhampton Street site for the 2011 Christchurch Earthquake event, and Figure 5.16 c and d show the within motions at Riccarton Gravel level. Figure 5.17 presents the response spectra comparing the estimated surface motion at the 20 Corhampton Street site and the within motions.

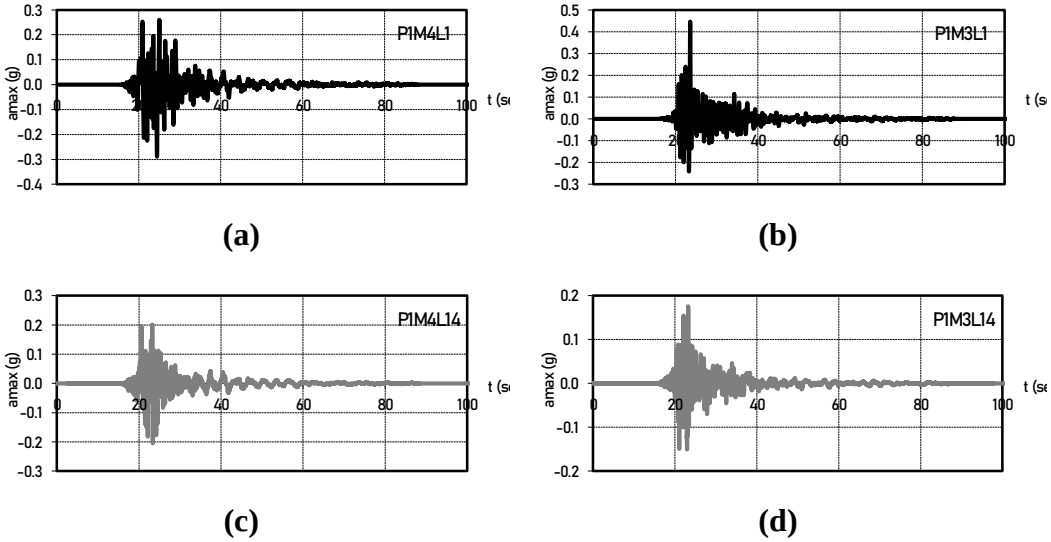


Figure 5.16. Site response analysis result at 20 Corhampton Street for the 2011 Christchurch Earthquake. (P1M3L14, P1M4L14 are within motions, P1M3L1, and P1M4L1 are soil outcrop motions estimated with the site response analysis at 20 Corhampton Street by using CACS as input motion)

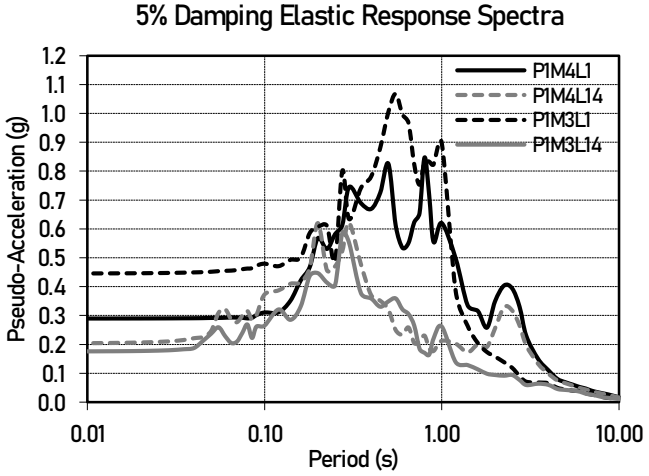


Figure 5.17. Response spectra comparing the estimated surface motions and within motion used as input at 20 Corhampton Street for the 2011 Christchurch Earthquake.

Figure 5.18 presents a_{max}, r_d, CSR, and τ_{max} plots along with depth for the two horizontal components obtained from the results of the site response analysis at the 20 Corhampton Street site for the 2011 Christchurch earthquake.

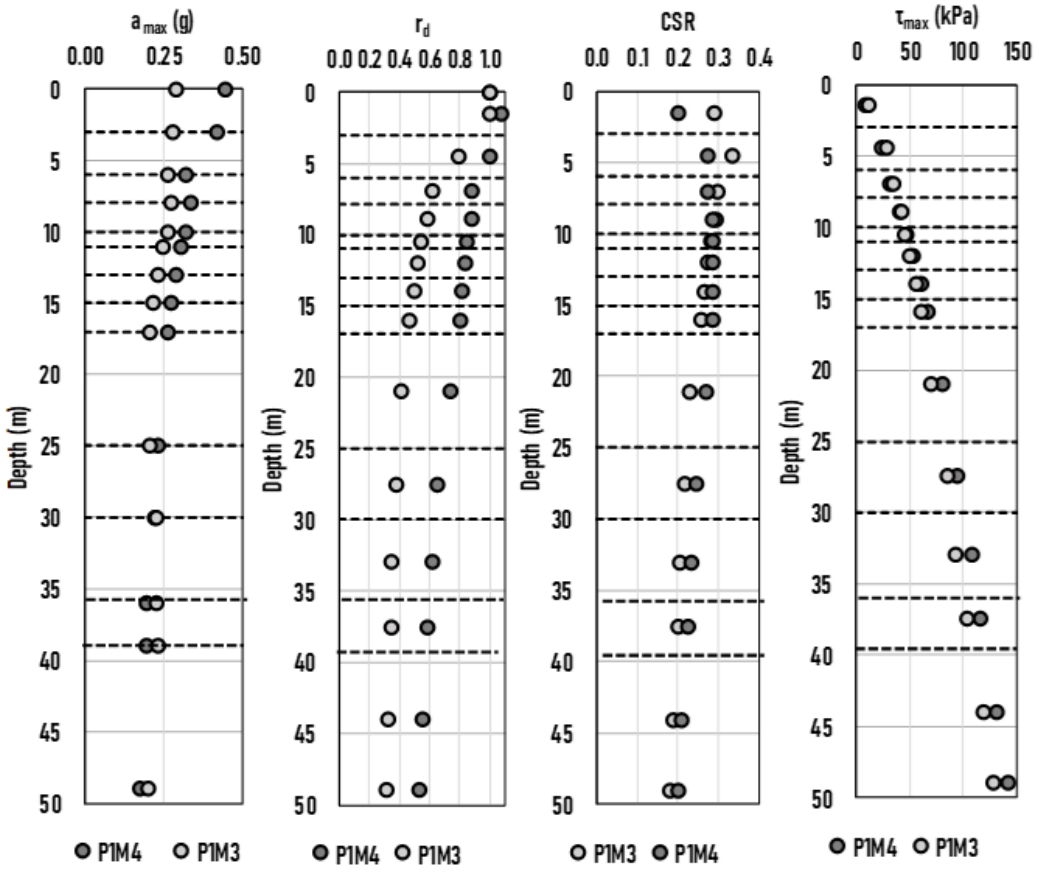


Figure 5.18. a_{max}, r_d, CSR, and τ_{max} plots versus depth for the two horizontal components at the 20 Corhampton Street site for the 2011 Christchurch earthquake.

Figure 5.19 presents a summary of the site response analyses performed for the 20 Corhampton Street site after the 2011 Christchurch earthquake. Appendix B presents the site response analysis results of 55 case histories in the same format.

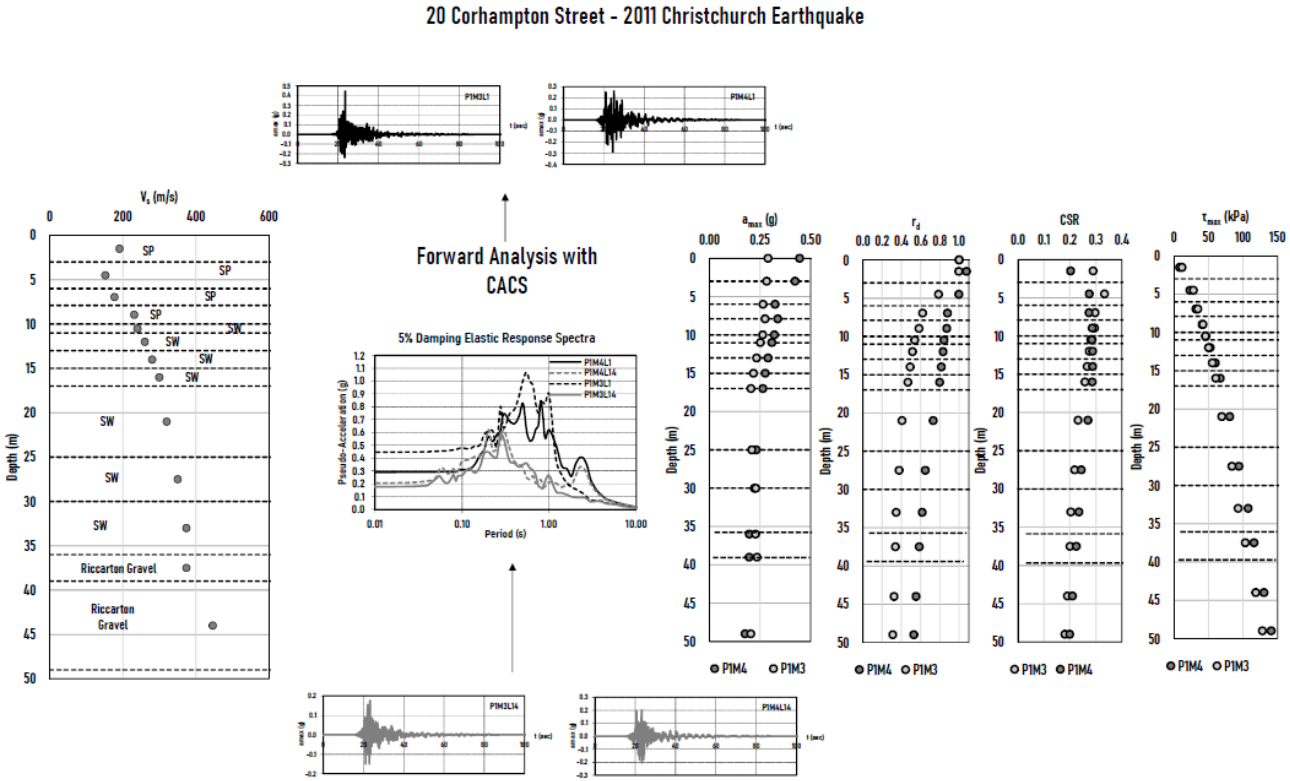


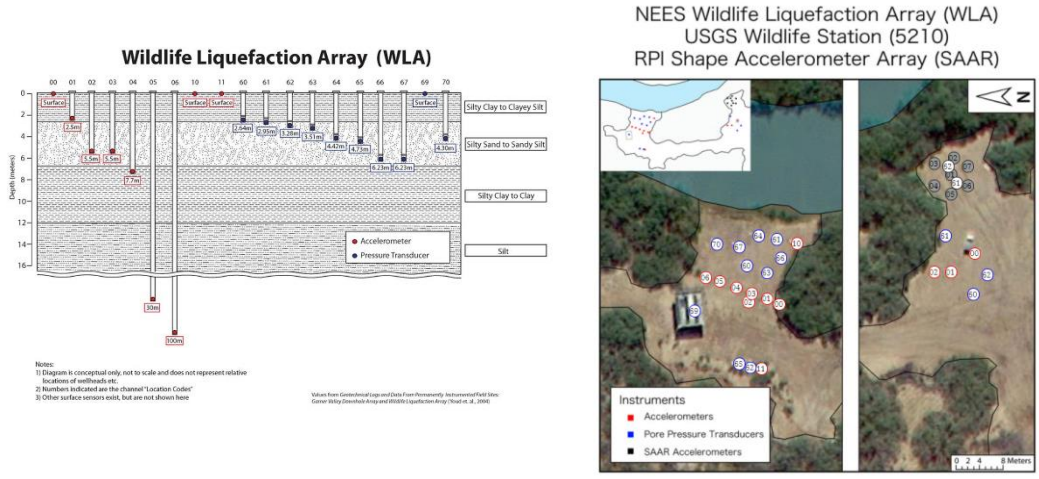
Figure 5.19. Summary of 20 Corhampton Street site response analysis results for the 2011 Christchurch earthquake.

For some of the case history sites, the site response analysis PGA values are not informants with the event and site-specific GMPE predictions. A possible reason for this is that beyond strain levels of 1 % site response predictions are not reliable. For those case histories, PGA is directly estimated based on site- and event-specific GMPE models developed coupled with site response-based r_d values estimation of CSR.

For example, a_{max} was reported as 0.48 g by McLaughlin (2017) after the 2011 Christchurch earthquake based on the conditional distributions described by Green et al. (2014) and Bradley (2014) at 20 Corhampton Street. On the other hand, the geometric mean of the two horizontal components ($a_{max,1}$=0.446 and $a_{max,2}$=0.289g) is calculated as a_{max}=0.359 g based on site response analysis. Due to the limitations of the accurate estimation of a_{max} for the high-intensity levels, the geometric mean of the r_{d1}=0.77 and r_{d2}=0.99 is calculated as r_d=0.87 which is used for the processing of case history data. For comparison purposes, r_d is also calculated based on Cetin and Seed (2004) as 0.94. Finally, a_{max} which was reported as 0.48 g by McLaughlin (2017) is used in the interpretation of the case history not the geometric mean of the two horizontal components which is calculated as a_{max}=0.359 g based on site response analysis.

5.7 Site Response Analysis: Wildlife USA Case Histories

Additional site response analyses were performed for Wildlife vertical array site. Wildlife is a ground motion monitoring and liquefaction research site. The site was included in the legacy case history catalogs previously. The cross-section of the Wildlife site and the accelerometer and pressure transducer are shown in Figure 5.20 a and the top view in Figure 5.20 b. CPT, SPT, and V_s data along with laboratory experiments are available at the site.



(a) (b)

Figure 5.20. Cross-section and the top view of the Wildlife site http://www.nees.ucsb.edu/facilities/wla

Case history data are compiled from the 2010 El Mayor-Cucapah (Baja) Earthquake, and the 2012 Brawley Earthquake sequence (M=4.9, 4.61, 5.32, 5.44). The presence of acceleration time histories at the bottom of the liquefiable silty sand layer (6.4. m) and ground surface (0.0 m) enables the calibration of the site response model. Equivalent linear site response analyses were performed with the calibrated model and the CSR values are directly estimated from the site response analysis results.

Soil stratigraphy and site geology were investigated and the site model is constructed as shown in Table 5.14 considering CPT, SPT, and V_s test results. The upper soil layer consists of as silt layer with PI=7%, which is followed by the silty sand layer which is the potentially liquefiable layer for the Wildlife site. Based on these evaluations, a site response model was formed and Figure 5.21 presents the Wildlife shear wave velocity profile along with soil layering graphically.

Table 5.14. Wildlife site response analysis model.

Layer Number	*Material Name*	*Thickness (m)*	*Unit Weight (kN/m^3)*	*V_s (m/s)*	*G_{max} (MPa)*	*Soil Model ID*	*PI (%)*
1	Silt	0.27	15.6	87	12		7
2	Silt	0.47	15.6	96	15	Vucetic and Dobry (1990)	7
3	Silt	0.79	15.6	96	15		7
4	Silt	0.76	17	92	15		7
5	Silty sand	0.76	17	107	20		0
6	Silty sand	0.75	17	110	21		0
7	Silty sand	0.75	17	113	22	Seed et al. (1984) mean	0
8	Silty sand	0.72	17	122	26		0
9	Silty sand	0.75	17	132	30		0
10	Silty sand	0.79	17	140	34		0
11	Silty clay	0.91	17	152	40	Vucetic and Dobry (1990)	29
12	Silty clay	1.00	17	170	50		29

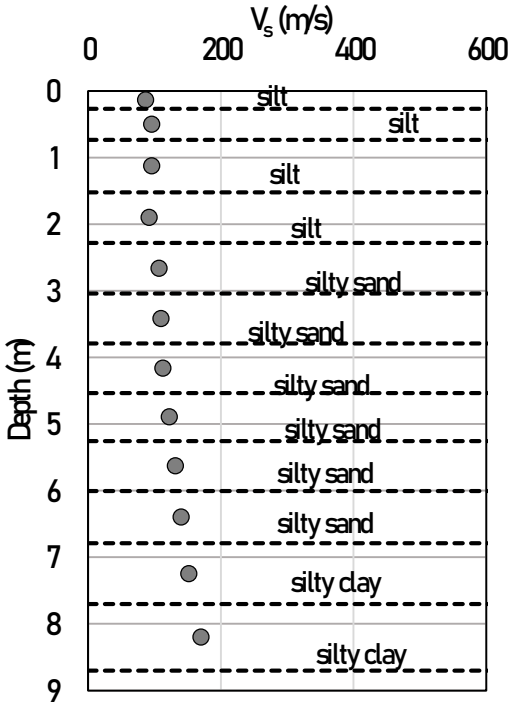


Figure 5.21. Wildlife V_s profile along with soil layering.

Figure 5.22 presents a summary of the deconvolution analyses performed for the Wildlife site after the 2012 Brawley earthquake M_w=4.61.

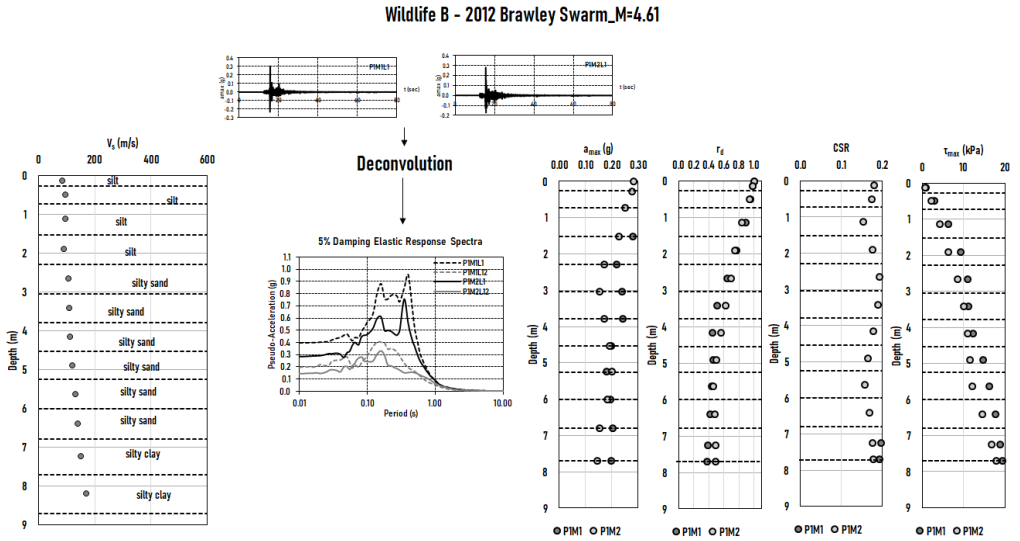


Figure 5.22. Summary of Wildlife site response analysis results for the 2012 Brawley earthquake M_w=4.61.

Appendix B presents the results of the site response analyses for the 5 case histories (e.g. 2010 El Mayor-Cucapah (Baja) Earthquake, and the 2012 Brawley Earthquake sequence M=4.9, 4.61, 5.32, 5.44).

CHAPTER 6

DEVELOPMENT OF SEISMIC SOIL LIQUEFACTION TRIGGERING RELATIONSHIPS

6.1 Introduction

The development of probabilistic seismic soil liquefaction triggering relationships requires the determination of a mathematical expression. In this chapter, the development of mathematical expressions for seismic soil liquefaction triggering problems will be explained. This chapter also presents a new probabilistic model for seismic soil liquefaction triggering by using the updated database. New magnitude scaling factor, K_{Mw}, overburden stress, K_{σ}, and fines content correction $\Delta N_{1,60}$ were regressed, which will be presented here. The last part of the chapter presents a comparison between the available liquefaction triggering relationships in the literature and the model presented in this study.

6.2 Development of Probabilistic Liquefaction Triggering Curves

Probabilistic seismic soil liquefaction triggering boundaries are proposed by various research groups (e.g. Liao et. al., 1988, Liao and Lum, 1998, Youd and Noble, 1997, Cetin et. al., 2004, 2018, etc.). The procedure to develop SPT-based probabilistic liquefaction triggering relationships as defined in Cetin (2000) study is implemented in this thesis by searching several other model alternatives. A brief summary of the procedure will be presented next.

6.2.1 Development of Mathematical Expression for Seismic Soil Liquefaction

Bayesian analysis, which is developed by Thomas Bayes in 1793, is an approach that links prior information of a parameter to a posterior probability. The Bayesian updating equation was given originally by Lindley (1985) and Der Kiureghian (1991) and later presented in Equation 6.1 by Cetin (2000).

$$f_{\theta}(\theta|x) = c \cdot L(\theta|x) \cdot f'_{\theta}(\theta) \quad (6.1)$$

Where $L(\theta|x)$ is the likelihood function, c is a normalization constant, θ is the unknown model parameters, $f'_{\theta}(\theta)$ is the prior distribution of these parameters, and $f_{\theta}(\theta|x)$ is the posterior distribution calculated by Bayesian analysis.

Since maximum likelihood assessment will establish the basis of our proposed probabilistic model, the main emphasis was given to the development of the likelihood function.

6.2.2 Likelihood Function for Seismic Soil Liquefaction Triggering

The mathematical model for seismic soil liquefaction triggering includes some observable descriptive parameters and a set of model coefficients, which are used to define the boundary curves that separate the liquefied and non-liquefied field observations. The pioneering study of Seed et al. (1985) presented the deterministic seismic soil liquefaction triggering curves, where the observable variables are $N_{1,60}$, FC, and CSR. Later, Cetin (2000) added two new variables σ'_v and M_w. The mathematical expression for seismic soil liquefaction proposed by Cetin (2000) is given in Equation 6.2.

$$\hat{g}\left(N_{1,60}, CSR, M_w, FC, \sigma'_v, \theta\right) = N_{1,60}(1 + \theta_1 FC) - \theta_2 \ln(M_w) - \theta_3 \ln(\sigma'_v) + \theta_4 FC + \theta_5 - \theta_6 \ln(CSR) \quad (6.2)$$

where $N_{1,60}$, FC, M_w, σ'_v, CSR are observable input parameters, $\theta_1 \ldots \theta_6$ are the set of model coefficients.

The formulation presented in Equation 6.2 is the limit state surface, which defines the boundary of seismic soil liquefaction and the "failure" which, in this case, the occurrence of liquefaction, is denoted with g<0 and "nonfailure" which is non-liquefaction with g>0. The selected formulation of the limit state surface is a simplification that includes 5 descriptive variables (e.g. $N_{1,60}$, FC, M_w, σ'_v, CSR), however, there exist some other parameters that are known to affect seismic soil liquefaction. For example, as stated in Cetin (2000) the grain size distribution most probably influences the liquefaction potential. Nevertheless, additional yet important other parameters are not included in Equation 6.1 or the expression may not have the ideal functional form, hence the model error, ε is introduced to account for these as given by Equation 6.3.

$$g\left(N_{1,60}, CSR, M_w, FC, \sigma'_v, \varepsilon, \theta\right) = N_{1,60}(1 + \theta_1 FC) - \theta_2 \ln(M_w) - \theta_3 \ln(\sigma'_v) + \theta_4 FC + \theta_5 - \theta_6 \ln(CSR) + \varepsilon \quad (6.3)$$

Cetin (2000) expressed the likelihood of observing "k" liquefied sites and "n" non-liquefied sites as the multiplication of their probabilities as given by Equation 6.4 assuming that all the descriptive variables $N_{1,60}$, CSR, M_w, FC, and σ'_v as exact variables and statistically independent.

$$L(\theta, \eta | x_i) \propto \prod_{i=1}^{k} P\left(g\left(N_{1,60,i}, CSR_i, M_{w,i}, FC_i, \sigma'_{v,i}, \varepsilon_i, \theta\right) < 0\right) \cdot \prod_{i=k+1}^{k+n} P\left(g\left(N_{1,60,i}, CSR_i, M_{w,i}, FC_i, \sigma'_{v,i}, \varepsilon_i, \theta\right) > 0\right) \quad (6.4)$$

where θ terms were model coefficients, x_i is the descriptive variables (e.g. $N_{1,60}$, FC, M_w, etc.), and ε is the model uncertainty for the i^{th} case.

In order to develop an unbiased model, the model uncertainty term is assumed to be normally distributed with a zero mean and standard deviation of σ_ε. Hence the likelihood function is expressed as given in Equation 6.5.

$$L(\theta, \sigma_\varepsilon | x_i) \propto$$
$$\prod_{i=1}^{k} \Phi\left(-\frac{\hat{g}(N_{1,60}, CSR, M_w, FC, \sigma'_v, \theta)}{\sigma_\varepsilon}\right) \cdot \prod_{i=k+1}^{k+n} \Phi\left(\frac{\hat{g}(N_{1,60,i}, CSR_i, M_{w,i}, FC_i, \sigma'_v, \theta)}{\sigma_\varepsilon}\right) \quad (6.5)$$

where Φ denotes the standard normal cumulative distribution function.

However, observable variables $N_{1,60}$, FC, M_w, σ'_v, CSR are not exact parameters and they include measurement errors. Hence, the uncertainties related to measurement errors of those parameters need to be taken into account to develop a probabilistic model. For that purpose, measurement errors of descriptive variables are investigated. Each parameter in the mathematical expression for seismic soil liquefaction involves aleatory variabilities. Chapter 3 explains how the parametrical uncertainties were calculated or estimated systematically for all the input parameters. The error terms of these input parameters (e.g. error of $N_{1,60}$ in the i^{th} observation, $e_{N_{1,60,i}}$, error of ln(CSR) in the i^{th} observation $e_{\ln(CSR)_i}$ etc.) were expressed with a mean value and a zero-mean random error term by Cetin (2000) based on the assumption that error terms are normally distributed (e.g. $f(e_{N_{1,60}}) = N(0, \sigma_{N_{1,60}})$, $f(e_{\ln(CSR)}) = N(0, \sigma_{\ln(CSR)})$, etc.).

The total uncertainty in the mathematical expression can be articulated as the sum of the error of the model variance, σ_ε^2 and observation varience σ_e^2 as given in Equation 6.6.

$$\sigma_{tot,i}^2 = \sigma_\varepsilon^2 + \sigma_e^2 = \sigma_\varepsilon^2 + \sigma_{e_{N_{1,60,i}}}^2 + \sigma_{e_{M_{w,i}}}^2 + \sigma_{e_{\ln(\sigma'_{v,i})}}^2 + \sigma_{e_{FC_i}}^2 + \sigma_{e_{\ln(CSR_i)}}^2 \quad (6.6)$$

6.2.3 Sampling Bias of the Observations

During the reconnaissance studies which are an essential part of data collection for seismic soil liquefaction field performance, researchers tend to focus on liquefied areas which eventually produces more liquefied field case history data than the non-liquefied. Cetin (2000) took into account this sampling bias and applied weighing factors to balance the liquefaction and non-liquefaction field observation in the

modeling efforts so that the resultant model is not biased by the occurrence of liquefaction. The weighting factor as proposed by Cetin (2000) is w_{nonliq}/w_{liq}=1.5 and implemented a factor of w_{nonliq}=1.2 for the non-liquefied case histories and w_{liq}=0.8 for the liquefied ones. Cetin et al. (2018) proposed a separate weighing factor for the 1995 Kobe Earthquake case history dataset which was approximately 25 % of the database to prevent event-based bias in the model.

Inspired by these proposals, the weighting schema is reconsidered. The current database size has expanded and in the final database there exist 179 liquefied and 154 non-liquefied case histories and it is concluded that the weighing factors given by Cetin (2000) as w_{nonliq}=1.2 and w_{liq}=0.8 to be used in this study while in the modeling efforts, the sum of the likelihood of liquefied and non-liquefied case histories was checked to be balanced. Additionally, to prevent event-specific bias of the model development, separate weighting factors were applied to the 1976 Tangshan, 1995 Kobe, 2010 Darfield, and 2011 Christchurch Earthquakes as 0.25, 0.25, 0.50, and 0.50, respectively, based on the large number of case histories compiled for these events for the current database.

6.2.4 Parametrical Error Terms

As discussed in Section 6.2.2, observable variables $N_{1,60}$, FC, M_w, σ'_v, CSR are "inexact" and they include measurement errors. Chapter 3 explains how the parametrical uncertainties were estimated systematically for all the input parameters. This section recalls how the measurement errors of $N_{1,60}$ and CSR are calculated.

Taylor's Expansion is utilized as described by Der Kiureghian (1991) and Cetin (2000) to calculate the mean and variance of the terms. Taylor's expansion series are the infinite sum of terms expressed in terms of derivatives of a function to calculate a specific value of the function. First-order approximations of Taylor's expansion give the mean and variance of a parameter. The procedure is well defined in Cetin (2000), which will not be repeated herein.

The mean value of $N_{1,60}$ is calculated with the function given in Equation 6.7 considering the uncertainties in the correction terms (e.g. C_N, C_E, etc.) are small and negligible.

$$\mu_{N_{1,60}} \cong \mu_N \cdot C_N \cdot C_E \cdot C_R \cdot C_B \cdot C_S \tag{6.7}$$

The square of the coefficient of variation (c.o.v.), $\delta^2_{(N_1)_{60}}$ can be expressed as the sum of the squared c.o.v. of the individual variables. Considering the correction terms uncertainties are small, $\delta^2_{(N_1)_{60}}$ can be simplified as shown in Equation 6.8.

$$\delta^2_{(N_1)_{60}} \cong \delta^2_N + \delta^2_{C_N} + \delta^2_{C_E} + \delta^2_{C_B} + \delta^2_{C_R} + \delta^2_{C_S} \cong \delta^2_N \rightarrow \delta_{(N_1)_{60}} \cong \delta_N \tag{6.8}$$

Similarly, the mean and c.o.v. of CSR are calculated as shown in Equations 6.9 and 6.10. The total and effective stress in this equation are not independent variables, hence the second-order moment about the mean is calculated as $2\rho_{\sigma'_{vo}\sigma_{vo}}.\delta_{\sigma_{vo}}.\delta_{\sigma'_{vo}}$ and subtracted from the first order c.o.v. Chapter 3 presents how the mean and c.o.v. of the total and effective stress and the covariance of the two terms are calculated, which will not be repeated here.

$$\mu_{CSR} = 0.65\left(\frac{\mu_{a_{max}}}{g}\right)\left(\frac{\mu_{\sigma_{vo}}}{\mu_{\sigma'_{vo}}}\right)\mu_{r_d} \tag{6.9}$$

$$\delta^2_{CSR} \cong \delta^2_{a_{max}} + \delta^2_{r_d} + \delta^2_{\sigma_{vo}} + \delta^2_{\sigma'_{vo}} - 2\rho_{\sigma'_{vo}\sigma_{vo}}.\delta_{\sigma_{vo}}.\delta_{\sigma'_{vo}} \tag{6.10}$$

In the likelihood function given in Equation 6.2, the CSR term is given as ln(CSR). The mean and standard deviation of the term ln(CSR) is calculated by log transformation by Cetin (2000) considering CSR is log-normally distributed around μ_{CSR} with a standard deviation of σ_{CSR} which means ln(CSR) is normally distributed ($S = \ln(CSR) = N(\lambda_s, \zeta_s)$) with around the mean value of $\lambda_s = \ln(\mu_{CSR}) - \frac{1}{2}\zeta_s^2$ with a standard deviation of $\zeta_s = \sqrt{\ln(1 + \delta^2_{CSR})}$ where $\delta_{CSR} = \frac{\sigma_{CSR}}{\mu_{CSR}}$.

The above-mentioned procedure is applied and the mean and variance of the input parameters are calculated which forms the basis of the probabilistic assessment of seismic soil liquefaction triggering models. a and b present the case histories with mean and ± one standard deviation of $N_{1,60}$ and CSR values following the procedures defined in this chapter for the liquefied, non-liquefied, and marginal case histories.

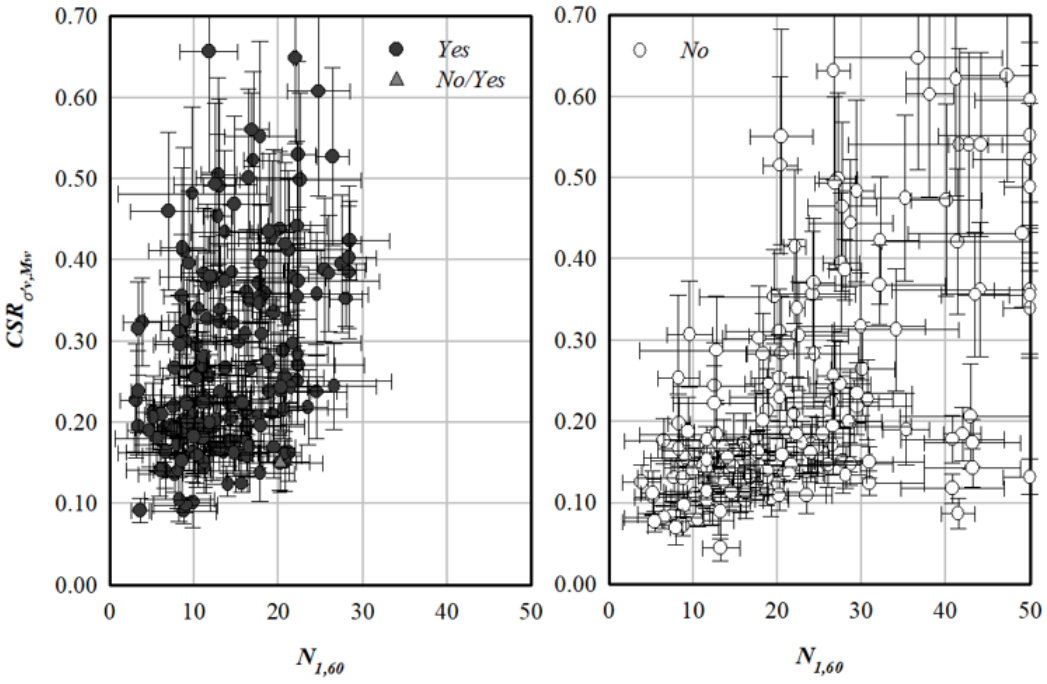


Figure 6.1. Mean and ± one standard deviation the database a) liquefied and marginal, b) non-liquefied case histories.

6.3 Probabilistic Liquefaction Triggering Curves

The limit state function given in Equation 6.2 defines the boundary surface that separates liquefaction and non-liquefaction field performance. The probability of liquefaction including the model error, model coefficients, and input parameters can be calculated as given in Equation 6.11 as proposed by Cetin (2000).

$$P(g(\Gamma,\Theta,\varepsilon)<0)=\int_{g(\Gamma,\Theta,\varepsilon)<0}\varphi(\varepsilon|\sigma_\varepsilon)\cdot f(\Gamma)\cdot d\varepsilon\cdot d\,\Theta\cdot d\sigma_\varepsilon\cdot d\Gamma \qquad (6.11)$$

Where φ is the normal distribution function, Θ are model coefficients $(\theta_1, \ldots . \theta_6)$ and input parameters, $\Gamma = (N_{1,60}, CSR, FC, M_w, \sigma'_v)$. A closed-form solution of the probability of liquefaction where g<0 is given in Equation 6.12.

$$P(g(\Gamma, \Theta, \varepsilon) < 0) = \Phi\left(-\frac{N_{1,60}(1+\theta_1 FC)-\theta_2 \ln(M_w)-\theta_3 \ln\left(\frac{\sigma'_v}{P_a}\right) +\theta_4 FC+\theta_5-\theta_6 \ln(CSR))}{\sigma_\varepsilon}\right) \quad (6.12)$$

where Φ is the standard normal cumulative distribution function.

Maximum likelihood estimation (MLE) is a method that is implemented to determine the model coefficients and the model error term, by maximizing the likelihood of each case history liquefaction performance. The total likelihood is maximized for seismic soil liquefaction triggering, which is estimated by using the MLE method by regressing the model coefficients and the model error term.

Several different limit state models are studied to better estimate the seismic soil liquefaction triggering. The first attempt is made to repeat the Cetin et al. (2004, 2018) model which will be referred to as Model-1. The search for better model alternatives is continued. Among various limit state alternatives studied in this study, two additional models (Model-2 and Model-3) will also be discussed in detail. The limit state functions given in Table 6.1 is used to develop seismic soil liquefaction triggering relationships for Model-1, Model-2, and Model-3. Different than Model-1, the relative density dependency in fines correction was omitted for Model-2 and 3 where the resultant fines correction is a function of fines content only. The only difference between Model-2 and Model-3 is the interpretation of overburden stress correction (C_N) applied on SPT blow counts. Relative density dependency on the C_N relationship is studied in Model-2, where the C_N relationship is regressed based on the field case history data by using Equations 6.13 (a) and (b). The stress exponent is described as a function of N_{60} rather than $N_{1,60}$ to avoid iterative convergence in the estimations. Two sets of stress exponents are regressed separately for clean sands

(SP, SW) and silty soils (SM, SP-SM, SW-SM, and ML). On the other hand, for Model-1 and 3, the stress exponent, m in the C_N relationship is taken as 0.5 consistent with the NCEER (1997) recommendations.

$$C_N = \left(\frac{P_a}{\sigma'_v}\right)^m \quad \text{where } m = \theta_7 - \theta_8 \cdot \sqrt{N_{60}}\ for\ clean\ sands \tag{6.13a}$$

$$m = \theta_{12} - \theta_{13} \cdot \sqrt{N_{60}}\ for\ silty\ soils \tag{6.13b}$$

Table 6.1. Limit state function alternatives for Model-1, 2, and 3.

Model	*Limit state function alternatives*
1	$g(N_{1,60}, CSR, M_w, FC, \sigma'_v, \varepsilon, \theta) = N_{1,60}(1+\theta_1 FC) - \theta_2 \ln(M_w) - \theta_3 \ln(\sigma'_v) + \theta_4 FC + \theta_5 - \theta_6 \ln(CSR) + \varepsilon$
2&3	$g(N_{1,60}, CSR, M_w, FC, \sigma'_v, \varepsilon, \theta) = N_{1,60} + \frac{\theta_9}{(1+\exp(-\theta_{10} \cdot FC - \theta_{11}))} - \theta_2 \cdot \ln(M_w) - \theta_3 \cdot \ln(\sigma'_v) + \theta_5 - \theta_6 \cdot \ln(CSR) + \varepsilon$

The probability of liquefaction and the cyclic resistance ratio functions for Model-1, Model-2, and Model-3 are summarized in Table 6.2.

Table 6.2. Probability of liquefaction and the cyclic resistance ratio functions for Model-1, 2, and 3.

Model	*Probability of liquefaction and the cyclic resistance ratio*
1	$P_L = \Phi\left(-\frac{N_{1,60}(1+\theta_1 FC) - \theta_2 \ln(M_w) - \theta_3 \ln\left(\frac{\sigma'_v}{P_a}\right) + \theta_4 FC + \theta_5 - \theta_6 \ln(CSR))}{\sigma_\varepsilon}\right)$ $CRR = \exp\left(\frac{N_{1,60}(1+\theta_1 FC) - \theta_2 \ln(M_w) - \theta_3 \ln\left(\frac{\sigma'_v}{P_a}\right) + \theta_4 FC + \theta_5 + \sigma_\varepsilon \Phi^{-1}(P_L))}{\theta_6}\right)$
2&3	$P_L = \Phi\left(-\frac{N_{1,60} + \frac{\theta_9}{(1+\exp(-\theta_{10} \cdot FC - \theta_{11}))} - \theta_2 \cdot \ln(M_w) - \theta_3 \cdot \ln\left(\frac{\sigma'_v}{P_a}\right) + \theta_5 - \theta_6 \cdot \ln(CSR))}{\sigma_\varepsilon}\right)$ $CRR_{\sigma'_v, M_w} = \exp\left(\frac{N_{1,60} + \frac{\theta_9}{(1+\exp(-\theta_{10} \cdot (FC) - \theta_{11}))} - \theta_2 \cdot \ln(M_w) - \theta_3 \cdot \ln\left(\frac{\sigma'_v}{P_a}\right) + \theta_5 + \sigma_\varepsilon \cdot \Phi^{-1}(P_L))}{\theta_6}\right)$

Maximum likelihood estimation (MLE) is used to determine the model coefficients and the model error term. Table 6.3 summarizes the resulting parameters for the new database implementing the functional form of Model-1, -2, and -3. Additionally, the sum of the likelihood of non-liquefied, liquefied, and all case histories and median probability for all model alternatives are calculated and presented in Table 6.3.

Table 6.3. Resulting parameters (i.e.: $\theta_1, \theta_2, ... \sigma_e$) using Model-1, -2, and -3.

Assessment/Model Parameters	*Model 1*	*Model 2*	*Model 3*
$w_{liq.}$	0.8	0.8	0.8
$w_{non\text{-}liq.}$	1.2	1.2	1.2
$W_{Tangshan}$ & w_{Kobe}	0.25	0.25	0.25
$W_{Darfield}$ & $w_{Christchurch}$	0.5	0.5	0.5
θ_1	0.0022	-	-
θ_2	10.2887	8.1876	9.2814
θ_3	2.3190	2.8853	2.195
θ_4	0.1889	-	-
θ_5	-21.8024	-23.9234	-23.5277
θ_6	13.7399	12.392	13.4758
θ_7	-	0.7721	-
θ_8	-	0.077	-
θ_9	-	7.0043	7.177
θ_{10}	-	0.1677	0.1861
θ_{11}	-	13.075	13.2132
θ_{12}	-	0.7565	-
θ_{13}	-	0.0971	-
σ_e	4.40	2.82	3.54
Sum Likelihood of Nonliquefied Case Histories	-48.69	-48.18	-48.35
Sum Likelihood of Liquefied Case Histories	-47.39	-47.56	-48.03
Sum Likelihood of All Case Histories	-99.08	-98.72	-99.40
Median Probability	65.18	65.28	65.09

Figure 6.2, Figure 6.3, and Figure 6.4 present seismic soil liquefaction probability contours corresponding to 5%, 20%, 50%, 80%, and 95% probabilities using the mean values of model parameters as summarized in Table 6.3 for Model-1, -2, and -3, respectively. The factor of safety values corresponding to the probability of liquefaction of 5 % to 95 % is shown on the same plots.

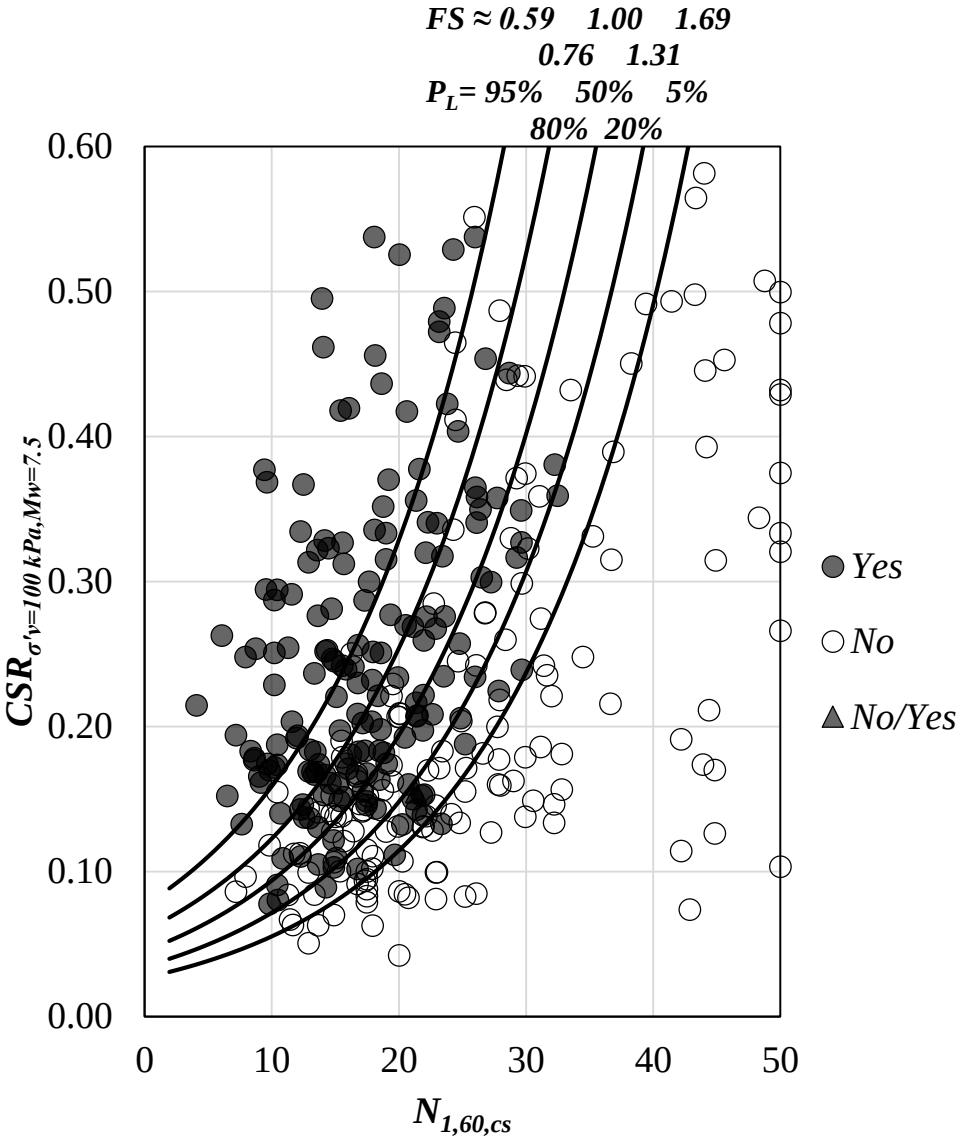


Figure 6.2. Liquefaction triggering curves (Model-1) for the new database.

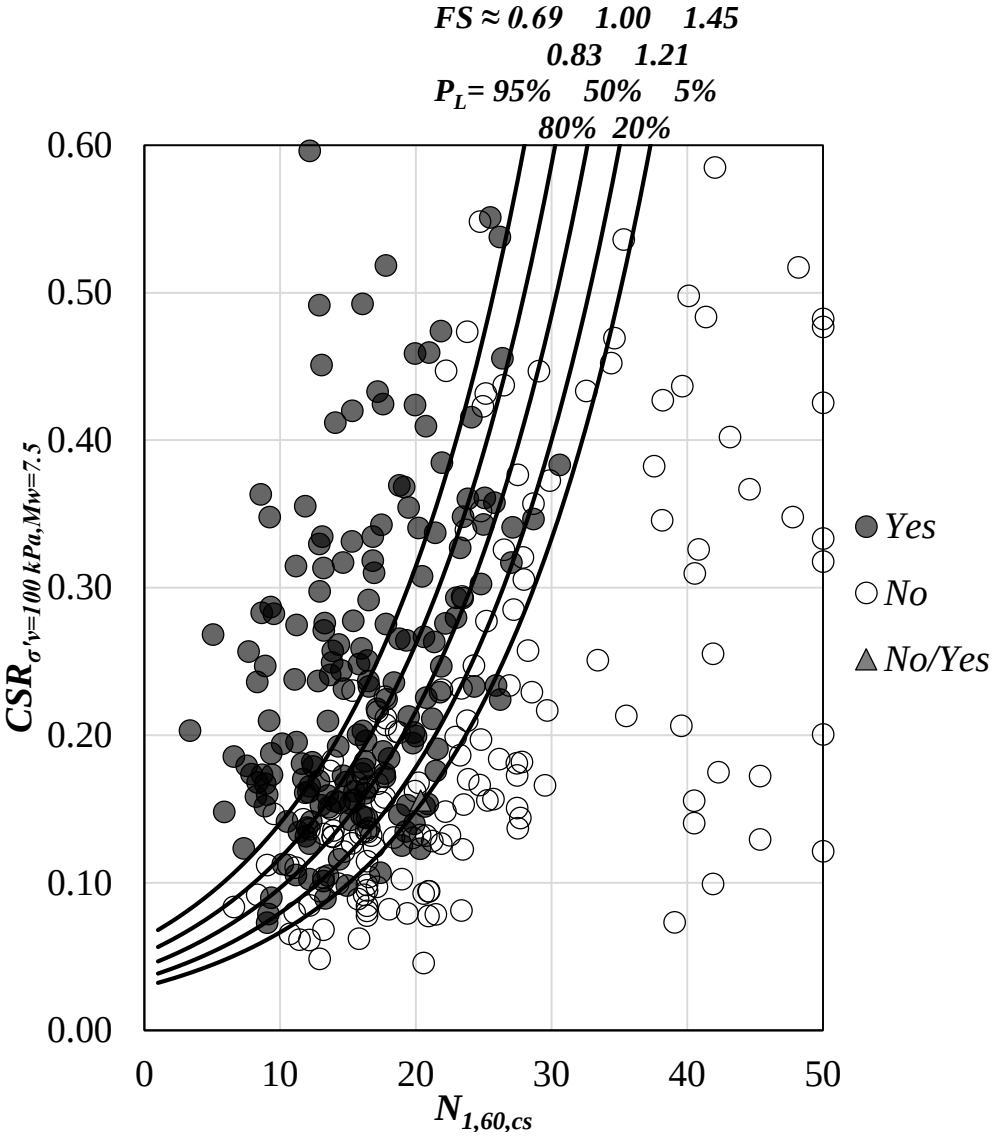


Figure 6.3. Liquefaction triggering curves (Model-2) for the new database.

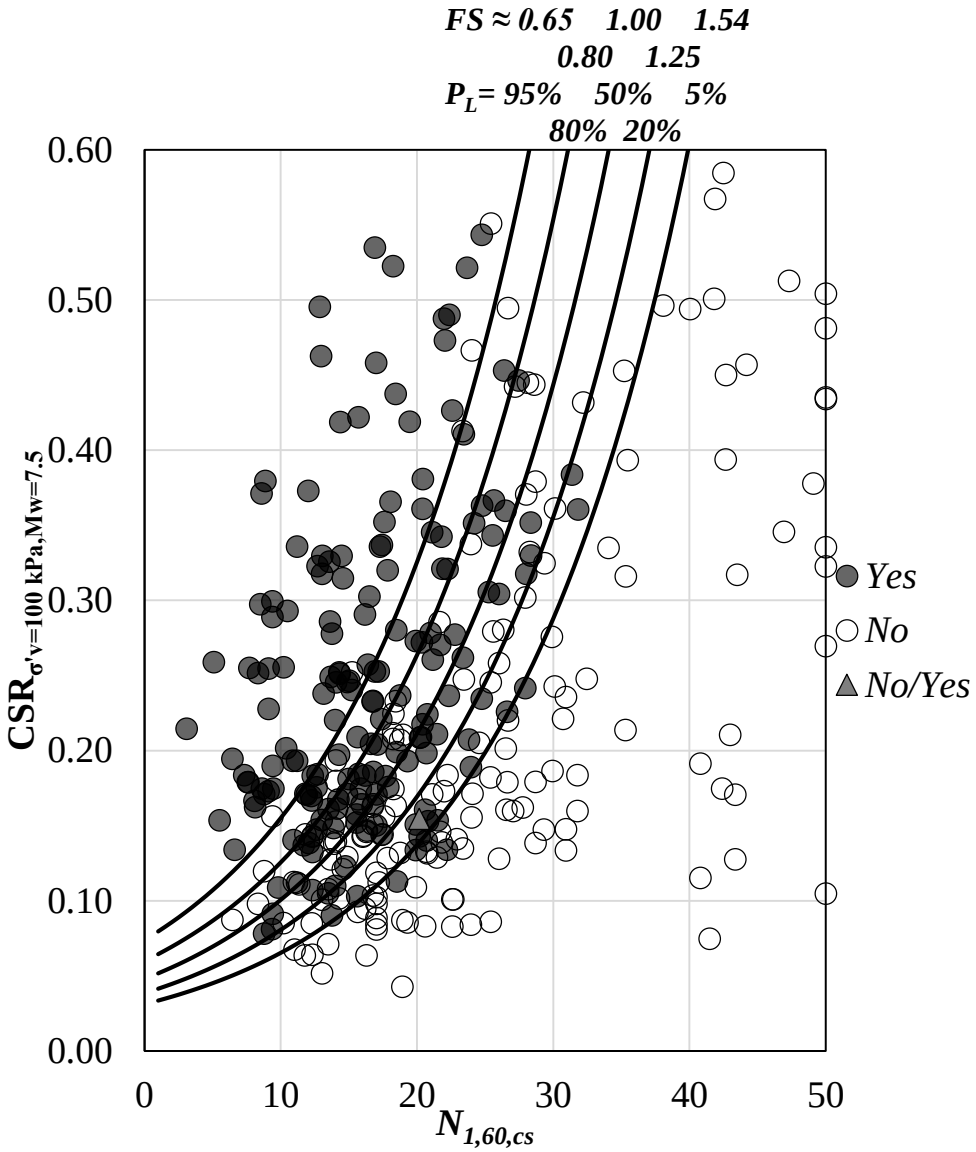


Figure 6.4. Liquefaction triggering curves (Model-3) for the new database.

The best expression is not necessarily the model with the least model error term. However, from a statistical point of view, the highest median probability of observation is an indication of a better functional form. Similarly, the model with the maximum value of the likelihood function can be judged as the best model. When the maximum value of the likelihood function (e.g. Model-1:-99.08, Model-2:-98.72, and Model-3: -99.40) or median probabilities (e.g. Model-1: 65.18 %, Model-2: 65.28 % and Model-3: 65.09 %) of the model alternatives is compared, the

performance of all the functional forms results is comparable. The resultant standard deviation of the model uncertainty terms is 4.40, 2.82, and 3.54 for Model-1, -2, and -3, respectively. When compared to the model error term of Cetin et al. (2018) (e.g. 2.95, etc.), Model-1 and -3 (e.g. 4.40, and 3.54) has higher model uncertainty term, on the other hand, the model error in Model-2 (e.g. 2.82) is smaller. When the model alternatives are compared following observations can be made:

- Model error term, σ_e is lesser for Model-2 (2.82) when compared to Model-1 (4.40) and Model-3 (3.54). The median probability of making case history observations correctly (either as liquefied or as non-liquefied) by Model-1 is about 65.18 % which suggests a better functional form, as compared to 65.28 by Model-2 and 65.09 % by Model 3.
- The position of the probability of liquefaction 50 % curve is very similar for Model-1, Model-2, and Model-3, except for a slight shift in the high $N_{1,60,cs}$ region of $N_{1,60,cs}$>25 blows/30cm for Model-2, as presented in Figure 6.5.

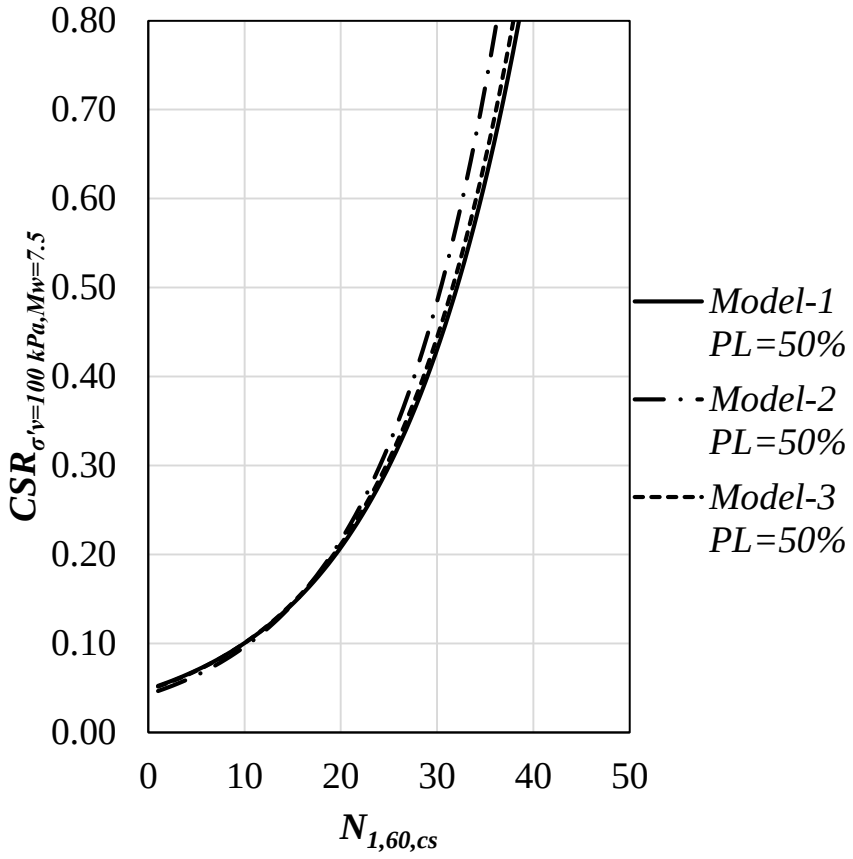


Figure 6.5. Comparison between the probability of liquefaction 50% curve for Model-1, -2, and -3.

- Magnitude duration, overburden stress, and fines content corrections estimated by Models 1, 2, and 3 are almost the same as presented in Figures 6.6-6.8, respectively. It should be noted that K_σ corrections for Models 1 and 3 are less pronounced for the effective stress range smaller than 100 kPa, as compared to Model-2.

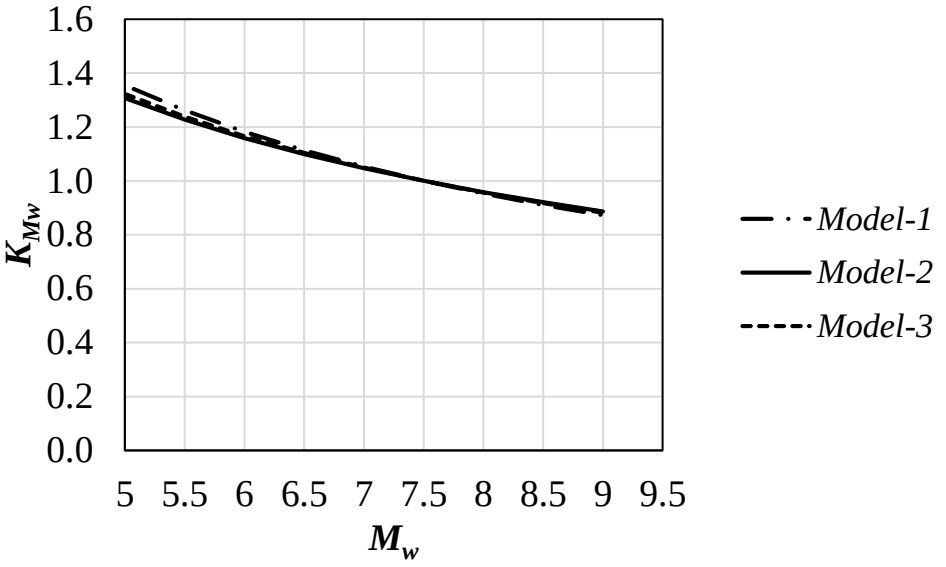


Figure 6.6. Comparison of K_{Mw} corrections for Model-1, -2, and -3.

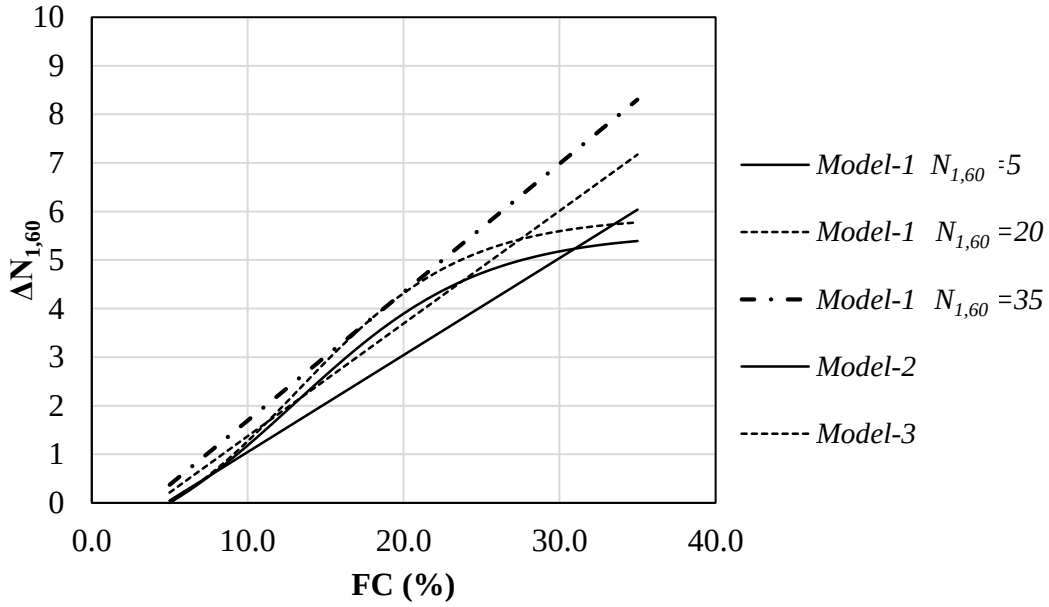


Figure 6.7. Comparison of fines corrections for Model-1, -2, and -3.

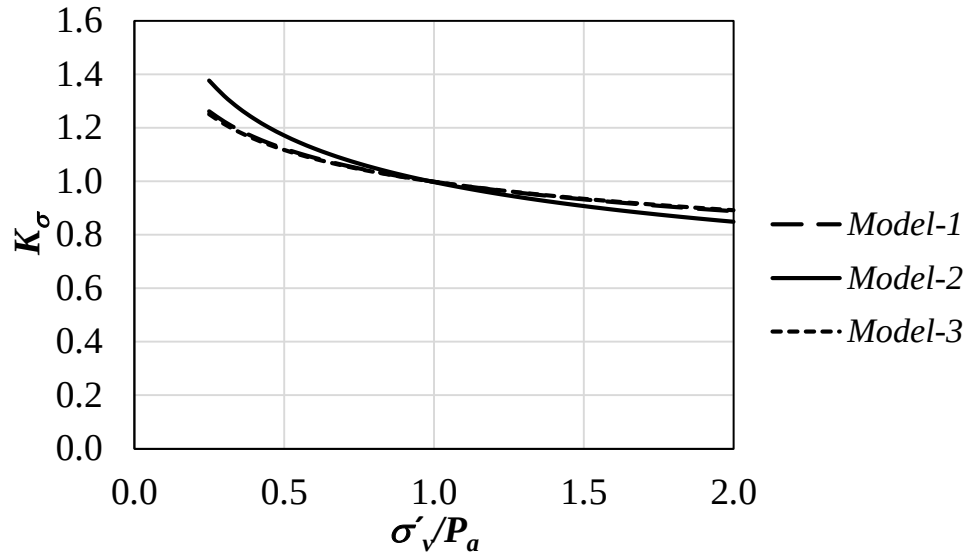


Figure 6.8. Comparison of K_σ corrections for Model-1, -2, and -3.

- Overburden stress correction for Model-1, 2, and 3 are compared in Figure 6.9. As mentioned before, the stress exponent, m in the C_N relationship is regressed as a function of N_{60} for clean sands and silty soils in Model-2. On the other hand, the stress exponent, m is reserved as 0.5 for Model-1 and 3 as suggested by Liao and Whitmann (1986). When Figure 6.9 is examined, it can be inferred that the stress exponent for silty soils is lesser than for clean sands when the exponent is regressed based on the field case histories. In the literature, various research groups worked on stress exponents, and there exist two different views. Two contradicting views will be discussed here to illustrate the different approaches available in the literature. Cetin and Isık (2007) study conclude that silty soils' stress exponent is higher than sands and lower than clays. Their conclusions are based on the CPT data compiled from thick homogeneous sand, silt, and clay layers, chamber laboratory tests, and numerical simulations. On the other hand, Deger (2014) concluded that the stress exponent for silts is lesser than clean sands based on the field data they have collected from dam sites. In their study assuming that the alluvial foundation soils beneath the dam site are uniform, SPT blow counts obtained

under varying confining stresses were compared to assess the stress exponent. Further study is needed to resolve these differences.

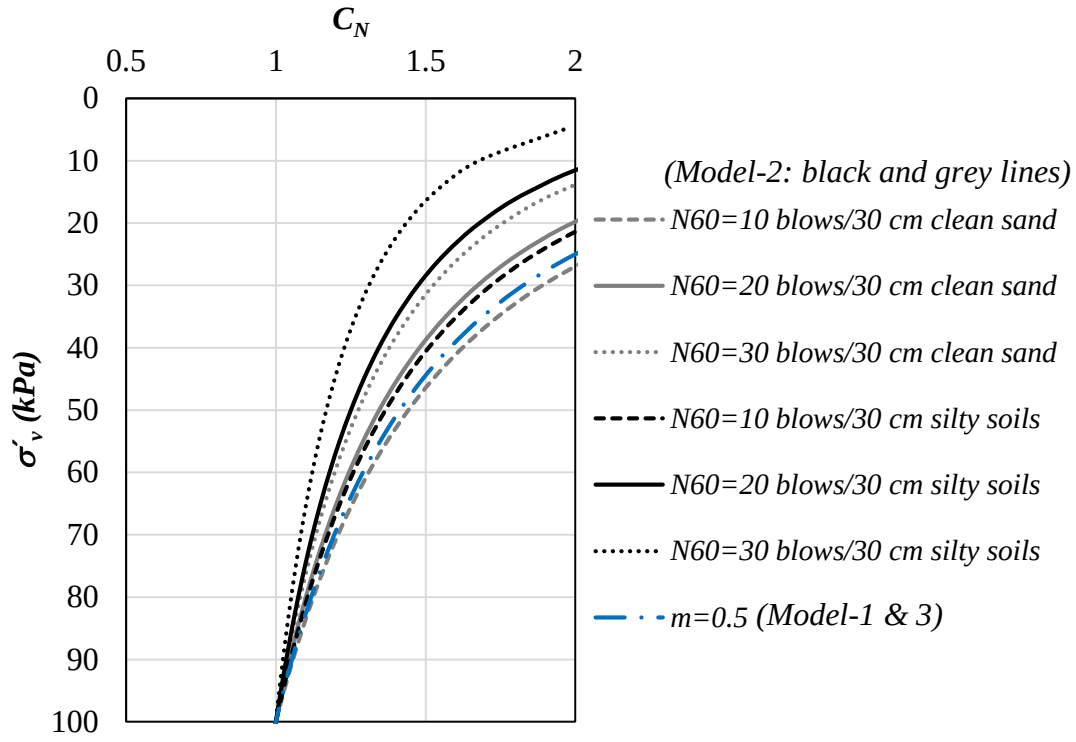


Figure 6.9. Comparison of the regressed overburden correction factor (C_N) for clean sands and silty soils as a function of N_{60} in Model-1, 2, and 3.

Unfortunately, the statistical assessment results do not indicate a significantly superior performance between the predictions by either Model 1, 2, and Model 3; hence all models are suggested to be equally applicable in forward assessments. However until further research is conducted to resolve the issue regarding the overburden stress corrections for silts and sands, Model-2 is not recommended to be used in engineering practice.

Equation 6.14 and 6.15 presents the probability of liquefaction and CRR boundary equations for Model-3 which is proposed to be used in forward engineering applications. Equations 6.16 - 6.20 present the overburden correction, magnitude

duration, fines content corrections, and overburden correction for SPT regressed and determined based on the field data for the new database.

$$P_L = \Phi\left(-\frac{N_{1,60}+\frac{7.1770}{(1+\exp(-0.1861\cdot FC-13.2132))}-9.2814\cdot\ln(M_w)-2.1950\cdot\ln\left(\frac{\sigma'_v}{P_a}\right)-23.5277-13.4758\cdot\ln(CSR))}{3.54}\right) \quad (6.14)$$

$$CRR_{\sigma'_v,M_w} = \exp\left(\frac{N_{1,60}+\frac{7.1770}{(1+\exp(-0.1861\cdot FC-13.2132))}-9.2814\cdot\ln(M_w)-2.1950\cdot\ln\left(\frac{\sigma'_v}{P_a}\right)-23.5277+3.54\cdot\Phi^{-1}(P_L))}{13.4758}\right) \quad (6.15)$$

where $\Phi^{-1}(P_L)$ is the inverse of the standard cumulative normal distribution (i.e. mean = 0, and standard deviation = 1). The command in Microsoft Excel for this function is "NORMINV (P_L,0,1)"

$$K_\sigma = \left(\frac{\sigma'_v}{P_a}\right)^{-\frac{\theta_3}{\theta_6}} = \left(\frac{\sigma'_v}{P_a}\right)^{-\frac{2.1950}{13.4758}} = \left(\frac{\sigma'_v}{P_a}\right)^{-0.1629} \quad \text{lim: } 0.9 < K_\sigma < 1.3 \quad (6.16)$$

$$K_{M_w} = \left(\frac{M_w}{7.5}\right)^{-\frac{\theta_2}{\theta_6}} = \left(\frac{M_w}{7.5}\right)^{-\frac{9.2814}{13.4758}} = \left(\frac{M_w}{7.5}\right)^{-0.6888} \text{lim: } 4.6 < M_w < 9.1 \quad (6.17)$$

$$CSR_{\sigma'_v=1atm,M_w=7.5,\alpha=0} = CSR_{\sigma'_v,M_w,\alpha}\cdot\frac{1}{K_\sigma}\cdot\frac{1}{K_{M_w}}\cdot\frac{1}{K_\alpha} \quad \text{lim: } CSR_{\sigma'_v=1atm,M_w=7.5,\alpha=0} \leq 0.6 \quad (6.18)$$

$$\Delta_{N_{1,60,cs}} = \frac{\theta_9}{(1+\exp(-\theta_{10}\cdot FC-\theta_{11}))} - \theta_{5,1} = \frac{7.1770}{(1+\exp(-0.1861\cdot FC-13.2132))} - 1.2791 \quad (6.19)$$

$$\text{lim: } 5\% < FC < 35\%$$

$$C_N = \left(\frac{P_a}{\sigma'_v}\right)^{0.5} \leq 2.0 \quad (6.20)$$

As discussed in Cetin et al. (2018c), the factor of safety values corresponding to the probability of liquefaction can be calculated based on the assumption that P_L=50% corresponds to FS=1.0 as given by Equation 6.21.

$$FS = \frac{CRR(P_L = 50\%)}{CRR\ (P_L)} = \exp\left(\frac{-\sigma_\varepsilon\cdot\Phi^{-1}(P_L)}{\theta_6}\right) = \exp\left(\frac{-3.54\cdot\Phi^{-1}(P_L)}{13.4758}\right) = \exp\left(-0.2627\cdot\Phi^{-1}(P_L)\right) \quad (6.21)$$

Incorporating the random errors in descriptive variables of each case history data diminishes the overall model uncertainty. Figure 6.10a compares Model-3 boundary curves without incorporating the random errors of input parameters (e.g. FC, a_{max}, d_{crt}, σ'_v, CSR, M_w, etc.). In Figure 6.10b, random errors in case history input parameters are considered. The figures reveal how the uncertainty of the model has decreased which in turn leads to a narrower range between P_L of 5 – 95 %. As specified by Cetin (2000) "*models without incorporating the uncertainties of descriptive parameters is:*

1. Conservatively biased for "high risk group" soils, (i.e. : P_L > 50 %)

2. Unconservatively biased for "low risk group" soils, (i.e. : P_L < 50 %)."

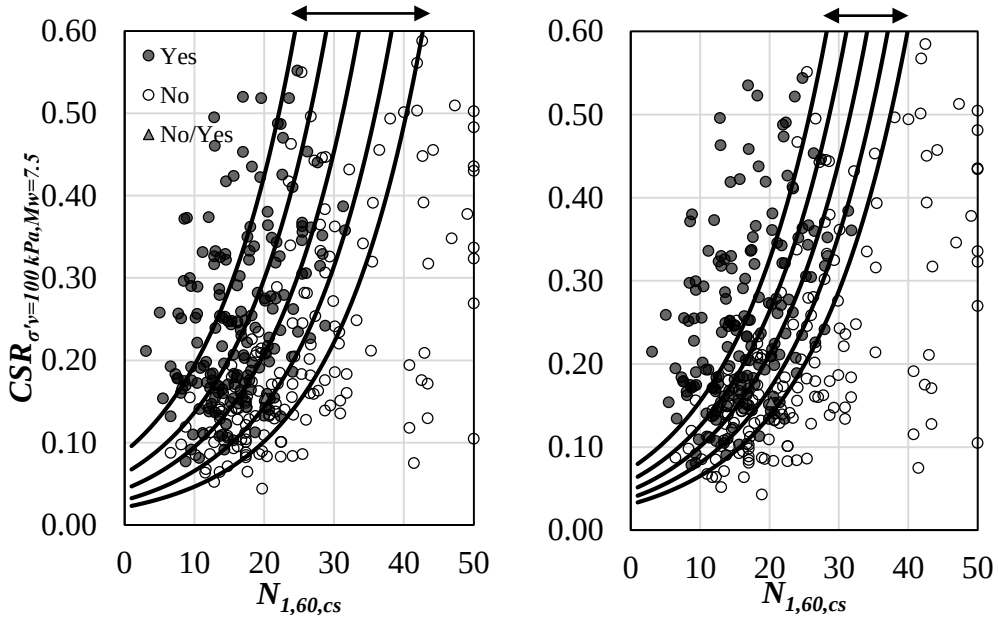


Figure 6.10. Seismic soil liquefaction triggering relationships (Model-3) is developed by a) not incorporating, and b) incorporating errors in input parameters.

In order to understand the influence of weighting factors for liquefied and non-liquefied case histories, the model is also regressed by not applying the weighting factors of 0.8 and 1.2 for liquefied and non-liquefied case histories. Figure 6.11

presents the seismic soil liquefaction triggering relationships for 5%, 20%, 50%, 80%, and 95% probability of liquefaction triggering. The results of this exercise show that the effect of weighting factors has a relatively minor impact on the location of the triggering relationships. However not addressing this bias is technically not acceptable hence applying the weighting factors of 0.8 and 1.2 for liquefied and non-liquefied case histories is recommended.

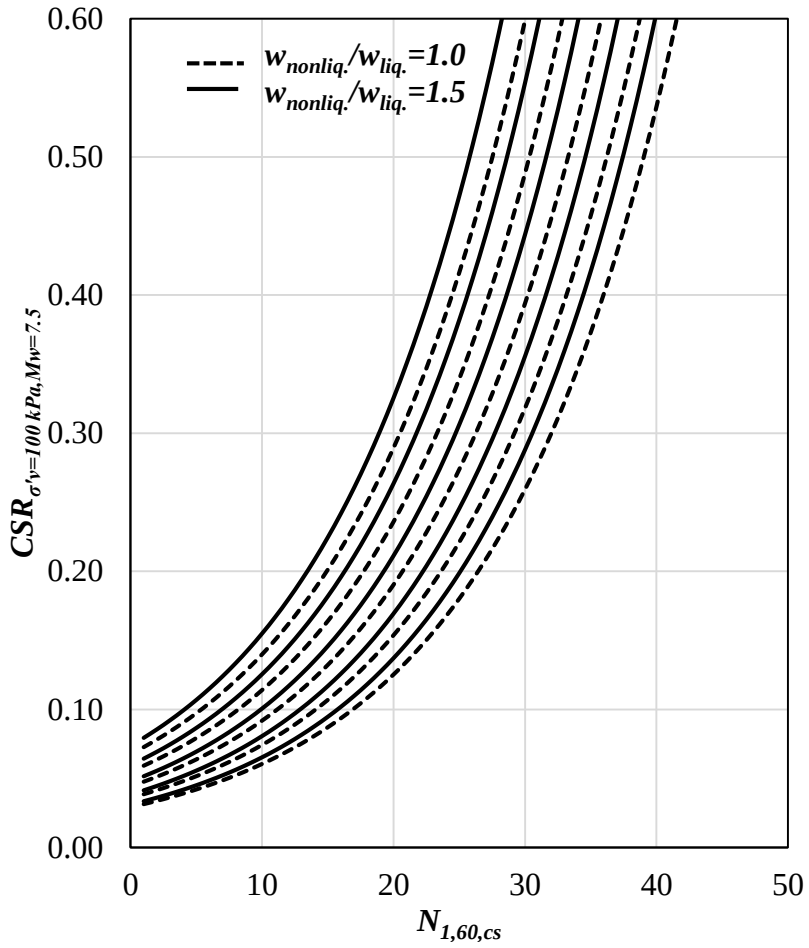


Figure 6.11. Seismic soil liquefaction triggering relationships (Model-3) developed by a) applying, b) not applying weighting factors liquefied and non-liquefied field case histories.

Figure 6.12 presents the overburden stress, K_σ corrections determined based on the new field case history database by using Model-3 along with cyclic laboratory results

of Montgomery et al. (2014) and undrained cyclic simple shear test results of Cetin and Bilge (2013). The undrained cyclic simple shear test results of Cetin and Bilge (2013) indicated that K_σ correction is a function of cyclic shear strain level, γ_{max} of 1 and 6% at which triggering of liquefaction or cyclic mobility occurs. Based on this study, it is expected that with different levels of γ_{max} values, K_σ correction is to be slightly changing and the relationship between K_σ and $N_{1,60,cs}$ is expected. It was attempted to regress K_σ correction as a function of $N_{1,60,cs}$ in this study, however, no observable correlation was seen. Hence the K_σ correction which is regressed based on the field case history database is recommended to be used in engineering applications. The resulting correlation is in good agreement with the behavior suggested by laboratory test results. It is recommended to use the proposed K_σ correction within the vertical effective stress range of the case history database.

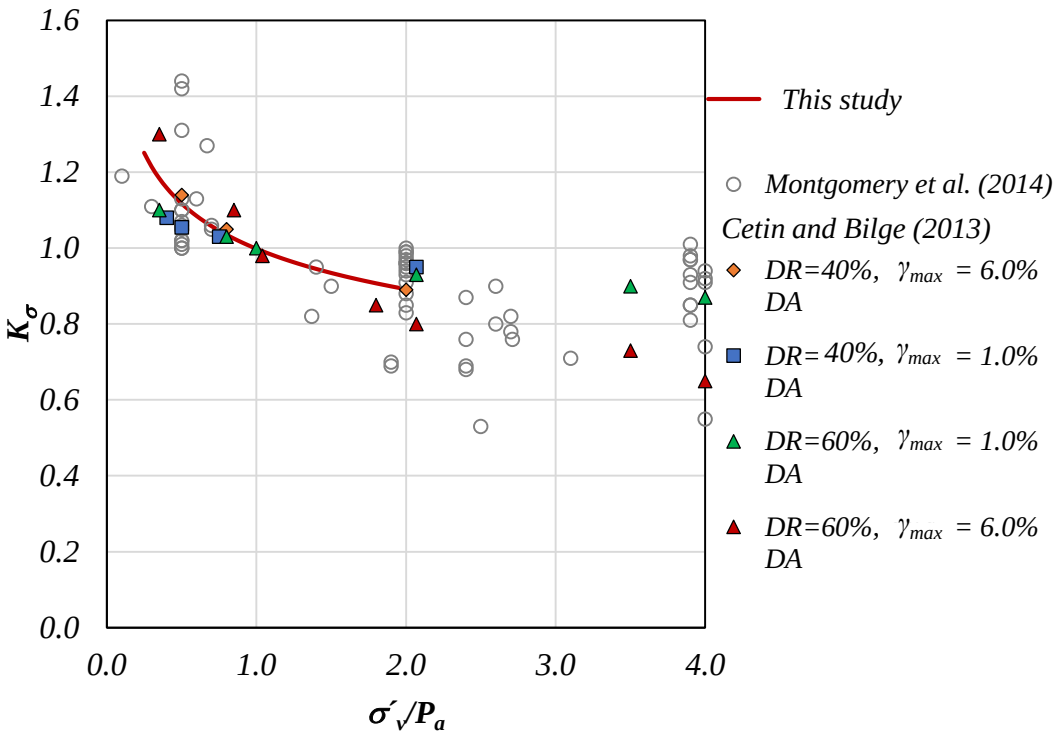


Figure 6.12. Proposed K_σ correction (Model-3) along with laboratory data by Montgomery et al. (2014) and Cetin and Bilge (2013).

Figure 6.13a presents a comparison of K_σ corrections by Cetin et al. (2004, 2018) and this study which are determined based on the field case history database, and Idriss and Boulanger (2014) based on cyclic laboratory test data. Figure 6.13b presents the distribution of the number of case histories compiled for this thesis and Cetin et al. (2018) for a normalized effective stress range of 0.25 bins. As indicated by the figure, the number of case history data is significantly increased over the range of 50-125 kPa.

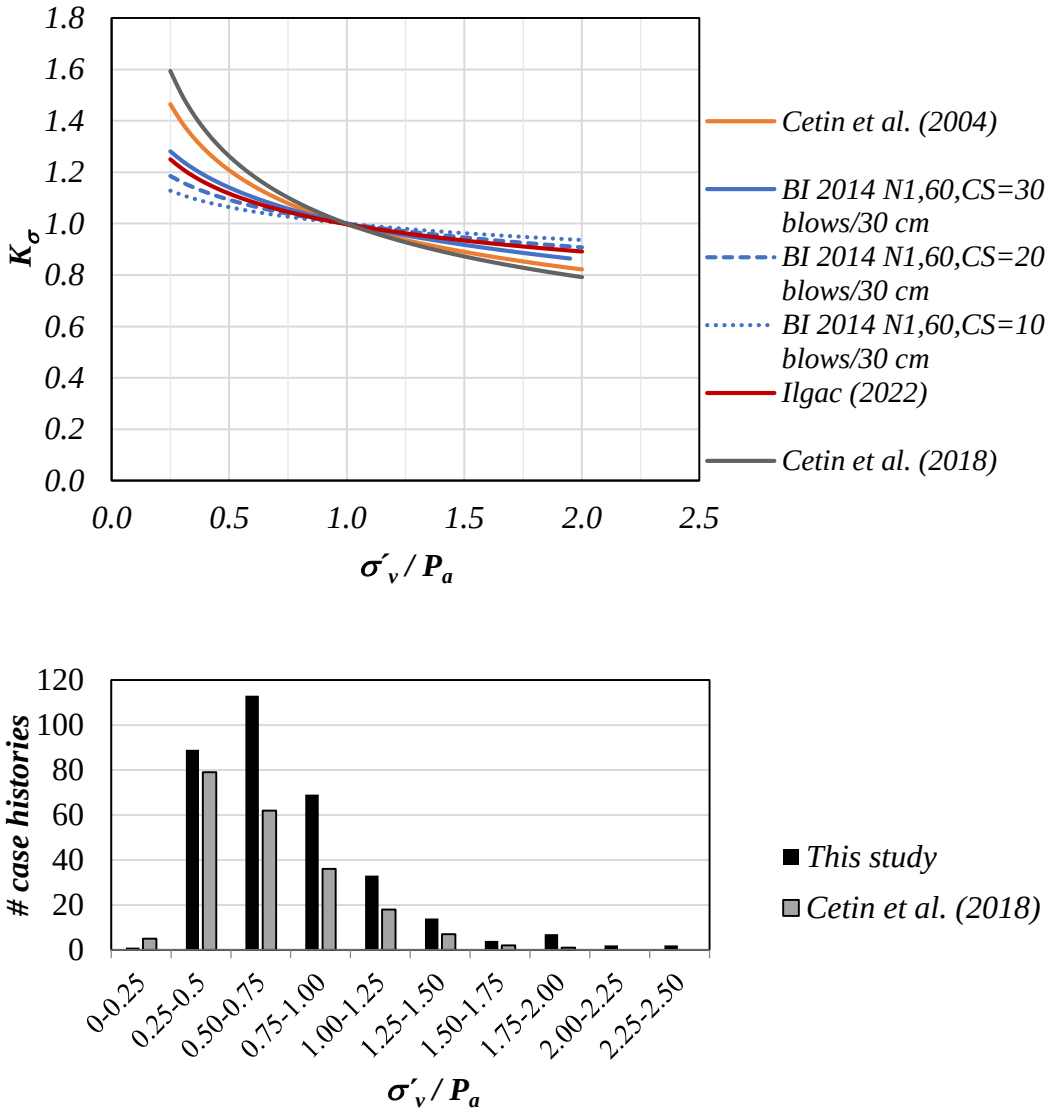


Figure 6.13. Proposed K_σ correction with the available literature and cyclic laboratory test data.

Figure 6.16 presents the magnitude (duration), K_{Mw} correction developed based on the new field case history database in this study. Several other research groups studied K_{Mw} correction based on laboratory data and/or field case history database. Figure 6.15 presents a comparison of available literature and K_{Mw} corrections developed for this study. K_{Mw} correction of Cetin et al. (2004, 2018) is fully based on a large number of case history data. On the other hand, Cetin and Bilge (2012) cyclic shear strain-dependent and Boulanger and Idriss (2014) relative density-dependent K_{Mw} correction are based on laboratory test results. Considering that the average moment magnitude of the new database is approximately 7.0, the difference in K_{Mw} corrections based on different approaches is relatively small. However, in the small magnitude range, the variation among different research groups is large. The new K_{Mw} correction is based on a wider range of M_w and it is applicable for the events $4.5<M_w<9.1$.

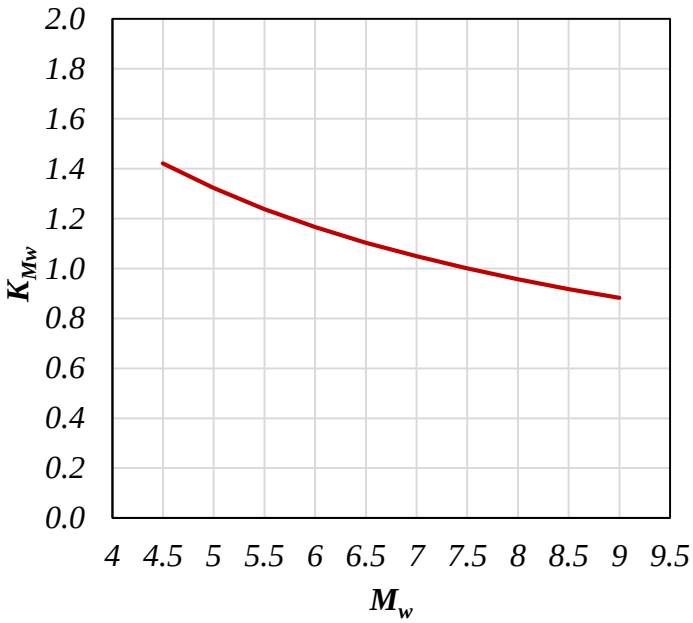


Figure 6.14. Proposed K_{Mw} correction (Model-3).

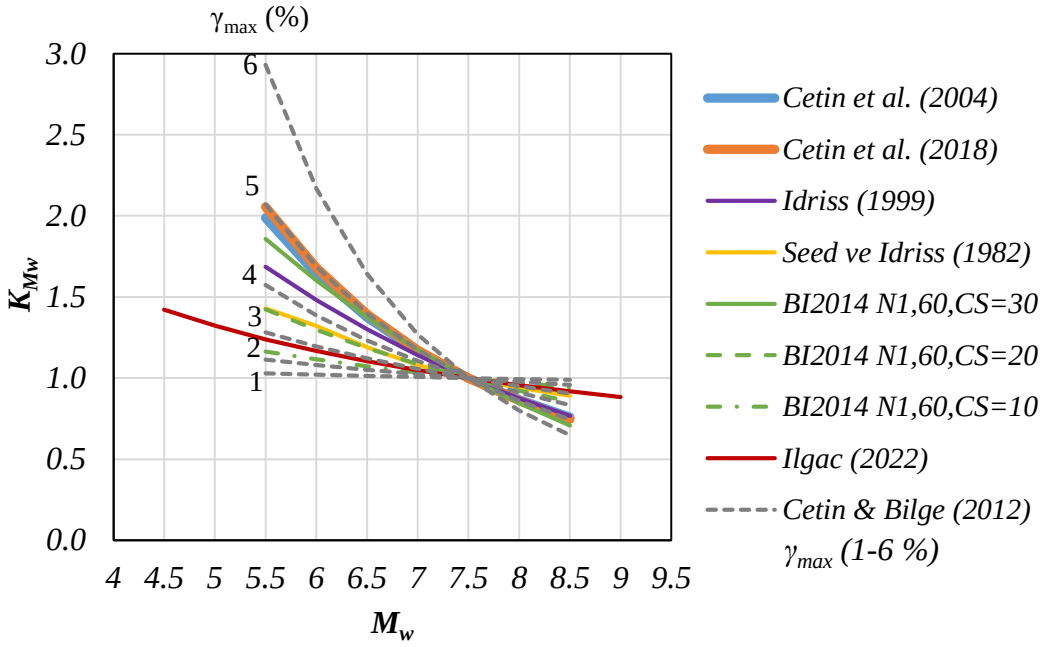


Figure 6.15. Proposed K_{Mw} correction with available literature.

Figure 6.16 presents fines content correction ($\Delta N_{1,60}$) developed based on the new field case history database for this study.

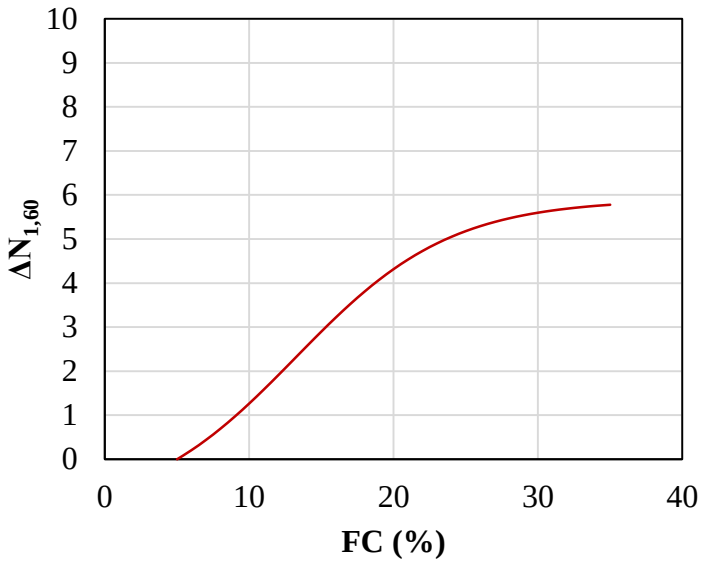


Figure 6.16. Proposed fines content correction (Model-3)

Figure 6.17 presents a comparison of fines correction developed based on the regression analysis of the field case history database compiled in this study with the available literature. As it can be inferred from this figure, the majority of the case histories consist of soil layers with fines content in the range of 5-35 %. Hence the proposed fines correction is applicable for the 5-35% fines content range. The new fines correction is equal to 0 for FC < 5%, reaches a maximum value of 6 for FC > 35%, and is comparable with the available literature.

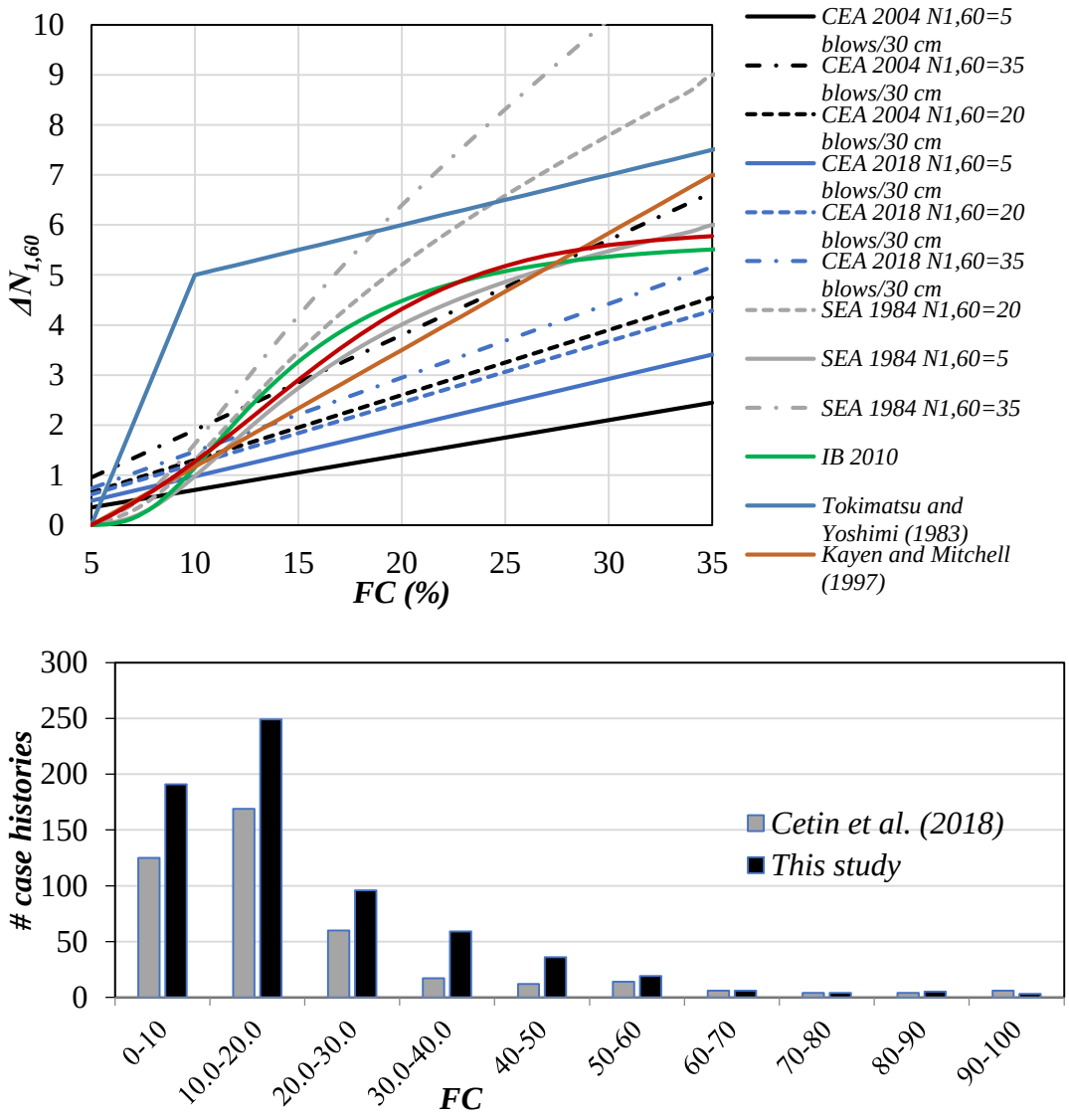


Figure 6.17. Proposed fines content correction with the available literature.

6.4 Recommended Use of the Correlation

This section presents an example of how the proposed new seismic soil liquefaction triggering relationships can be used in forward engineering applications. Figure 6.18 presents a typical potentially liquefiable site where the input parameters are summarized in the same figure. It should be noted that in forward engineering assessments the input parameters will be selected by the users hence it is particularly important to follow the protocols described in Chapter 3 in selecting those terms.

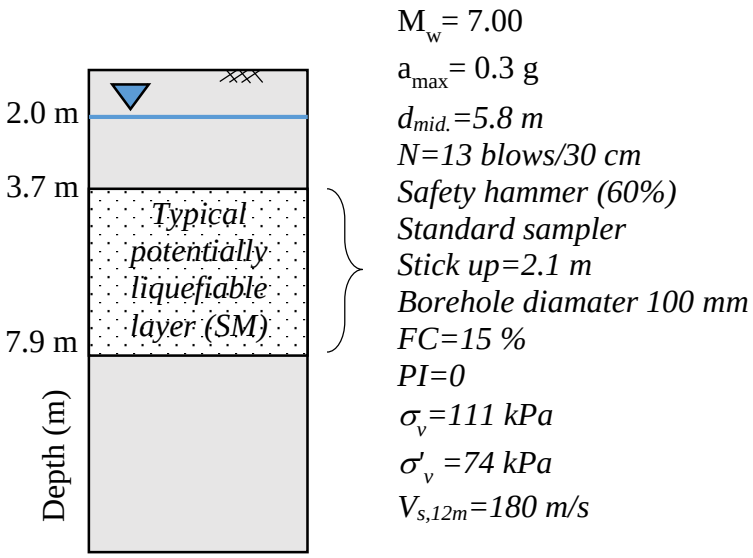


Figure 6.18. A “typical" potentially liquefiable layer.

Two approaches can be taken in calculating the triggering of liquefaction by using the new proposed method. The first approach is to use the chart solutions given in Figure 6.4, Figure 6.12, Figure 6.14, and Figure 6.16. The second approach is to use the equations given in 6.14-6.21. The latter approach will be used in this example.

For the “typical" potentially liquefiable layer given in Figure 6.18, the factor of safety against liquefaction, $FS_{liq.}$, and probability of liquefaction, P_L will be calculated to illustrate the application of the proposed probabilistic-based seismic soil liquefaction triggering model. The first step is to calculate CSR given by Seed and Idriss (1972) as site response analysis was not performed at the site. In order to estimate the CSR at the mid-depth of the liquefiable layer, the mass participation

ratio should be calculated as the other parameters to estimate CSR are given in the example. r_d value at the 5.8 m depth is calculated as shown in Equation 6.22 as proposed by Cetin and Seed (2004) for depths smaller than 20 m.

$$d < 20m, r_d = \frac{\left[1+\frac{-23.013-2.949\cdot 0.3+0.999\cdot 7+0.0525\cdot 180}{16.258+0.201\cdot e^{0.341\cdot(-5.8+0.0785\cdot 180+7.586)}}\right]}{\left[1+\frac{-23.013-2.949\cdot 0.3+0.999\cdot 7+0.0525\cdot 180}{16.258+0.201\cdot e^{0.341\cdot(0.0785\cdot 180+7.586)}}\right]} = 0.899 \quad (6.22)$$

$CSR_{\sigma'_v,M_w}$ is calculated as 0.263 by entering a_{max}, σ'_v, σ_v, and r_d as shown in Equation 6.23.

$$CSR_{\sigma'_v,M_w} = 0.65 \cdot \left(\frac{0.3g}{g}\right) \cdot \left(\frac{111}{74}\right) \cdot 0.899 = 0.263 \quad (6.23)$$

$CSR_{\sigma'_v=1atm,M_w=7.5,\alpha=0}$ is the normalized $CSR_{\sigma'_v,M_w}$ for reference state of σ'_v= 1 atm and M_w=7.5. Equations 6.24-25 present the calculation of K_σ and K_{Mw} corrections and $CSR_{\sigma'_v=1atm,M_w=7.5,\alpha=0}$.

$$K_\sigma = \left(\frac{74}{100}\right)^{-0.1629} = 1.05 < 1.6 \quad (6.24)$$

$$K_{M_w} = \left(\frac{7}{7.5}\right)^{-0.6888} = 1.049 \quad (6.25)$$

$$CSR_{\sigma'_v=1atm,M_w=7.5,\alpha=0} = CSR_{\sigma'_v,M_w,\alpha} \cdot \frac{1}{K_\sigma} \cdot \frac{1}{K_{M_w}} \cdot \frac{1}{K_\alpha} \quad (6.26)$$

$$= 0.263 \cdot \frac{1}{1.05} \cdot \frac{1}{1.049} \cdot \frac{1}{1} = 0.239 < 0.6$$

The second step is the calculation of standard penetration test blow counts corrected for overburden, energy, equipment, and procedural factors ($N_{1,60}$) and then fines content corrected value, $N_{1,60,cs}$. Correction for hammer energy ratio (C_E), rod length (C_R), sampler (C_S), borehole diameter (C_N), fines correction ($\Delta_{N_{1,60,cs}}$) hence corresponding $N_{1,60}$ and $N_{1,60,cs}$ are calculated as given in Equations 6.27-34. Hammer energy efficiency is given as 60 % in the example. If hammer efficiency values were not provided, energy efficiency should be selected as discussed in Section 3.2.17.4 for the new correlations recommended in this study. (e.g. automatic hammer as 82 %, etc.)

$$C_E = \frac{ER}{60\%} = \frac{60}{60} = 1.0 \quad (6.27)$$

$C_S = 1.0$ for the standard sampler (6.28)

$C_B = 1.0$ for borehole diameter 100 mm (6.29)

$$C_R = 1 - 0.274 \cdot e^{-0.063 \cdot (5.8+2.1)} = 0.95 \quad (6.30)$$

$$N_{60} = N \cdot C_S \cdot C_B \cdot C_E \cdot C_R = 13 \cdot 1 \cdot 1 \cdot 1 \cdot 0.95 = 12 \text{ blows/30 cm} \quad (6.31)$$

$FC = 15\% \rightarrow$ silty soils

$$C_N = \left(\frac{100}{74}\right)^{0.5} = 1.16 < 2.0 \quad (6.32)$$

$$N_{1,60} = N_{60} \cdot C_N = 12 \cdot 1.16 = 14 \text{ blows/30 cm} \quad (6.33)$$

$$N_{1,60,cs} = N_{1,60} + \Delta_{N_{1,60,cs}} \quad (6.34)$$

$$= 14 + \frac{7.117}{(1+exp(-0.1861 \cdot 15 - 13.2132))} - 1.2791 = 17\ blows/30\ cm$$

Next, the cyclic resistance ratio $CRR_{\sigma'_v,M_w}$ and $CRR_{\sigma'_v=1atm,M_{w=7.5}}$ are calculated as 0.189 and 0.172 as presented in Equations 6.35 and 6.36. The factor of safety can be calculated either using $CRR_{\sigma'_v,M_w}$ and $CSR_{\sigma'_v,M_w}$ or $CRR_{\sigma'_v=1atm,M_w=7.5}$ and $CSR_{\sigma'_v=1atm,M_w=7.5}$ as shown in Equation 6.37.

$$CRR_{\sigma'_v,M_w} = \quad (6.35)$$

$$\exp\left(\frac{14+\frac{7.1770}{(1+\exp(-0.1861 \cdot 15 - 13.2132))} - 9.2814 \cdot \ln(7) - 2.1950 \cdot \ln\left(\frac{74}{100}\right) - 23.5277 + 3.54 \cdot \Phi^{-1}(0.5))}{13.4758}\right) = 0.189$$

$$CRR_{\sigma'_v=1atm,M_{w=7.5}} = \quad (6.36)$$

$$\exp\left(\frac{14+\frac{7.1770}{(1+\exp(-0.1861 \cdot 15 - 13.2132))} - 9.2814 \cdot \ln(7.5) - 2.1950 \cdot \ln\left(\frac{100}{100}\right) - 23.5277 + 3.54 \cdot \Phi^{-1}(0.5))}{13.4758}\right) = 0.172$$

$$FS = \frac{CRR}{CSR} = \frac{CRR_{\sigma'_v,M_w}}{CSR_{\sigma'_v,M_w}} = \frac{CRR_{\sigma'_v=1atm,M_w=7.5}}{CSR_{\sigma'_v=1atm,M_w=7.5}} = \frac{0.189}{0.263} = \frac{0.172}{0.239} = 0.72 \quad (6.37)$$

The probability of liquefaction is calculated as 90 % given in Equation 6.38.

$$P_L = \quad (6.38)$$

$$\Phi\left(-\frac{14+\frac{7.1770}{(1+\exp(-0.1861 \cdot 15 - 13.2132))} - 9.2814 \cdot \ln(7) - 2.1950 \cdot \ln(74/100) - 23.5277 - 13.4758 \cdot \ln(0.263))}{3.54}\right) =$$

89.54%

An alternative approach to calculating $FS_{liq.}$ from P_L is shown in Equation 6.39 which gives the same value calculated in Equation 6.37.

$$FS = \exp\left(-0.2627 \cdot \Phi^{-1}(0.8954)\right) = 0.72 \quad (6.39)$$

6.5 Comparison of the New Liquefaction Triggering Relationships with the Available Literature

This section presents a comparison between the available seismic soil liquefaction triggering relationships of Seed et. al (1985), Cetin et. al. (2004, 2018), Idriss and Boulanger (2012), hereafter will be referred to as SEA 1985, CEA 2004, CEA 2018, and IB 2012 and this study. Figure 6.19 and Figure 6.20 present a comparison of the SEA 1985 (deterministic), CEA 2004, CEA 2018, IB 2012, and this study for P_L=15% and P_L=50%, respectively.

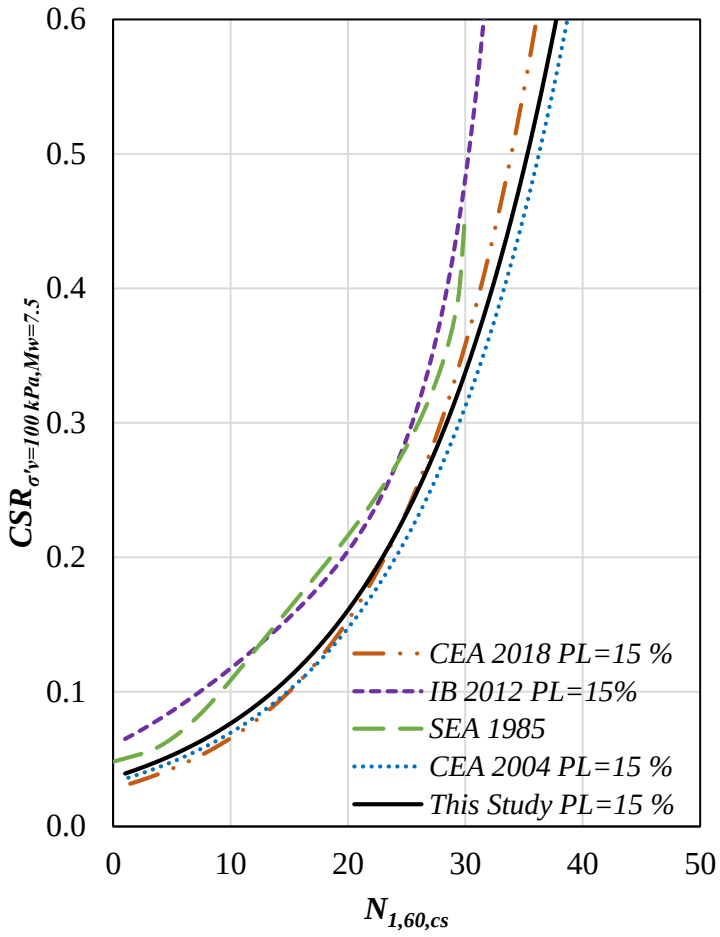


Figure 6.19. Comparison of the new seismic soil liquefaction triggering relationship (Model-3) with CEA 2004, CEA 2018, and IB 201) for P_L=50%, and the deterministic model of SEA 1985.

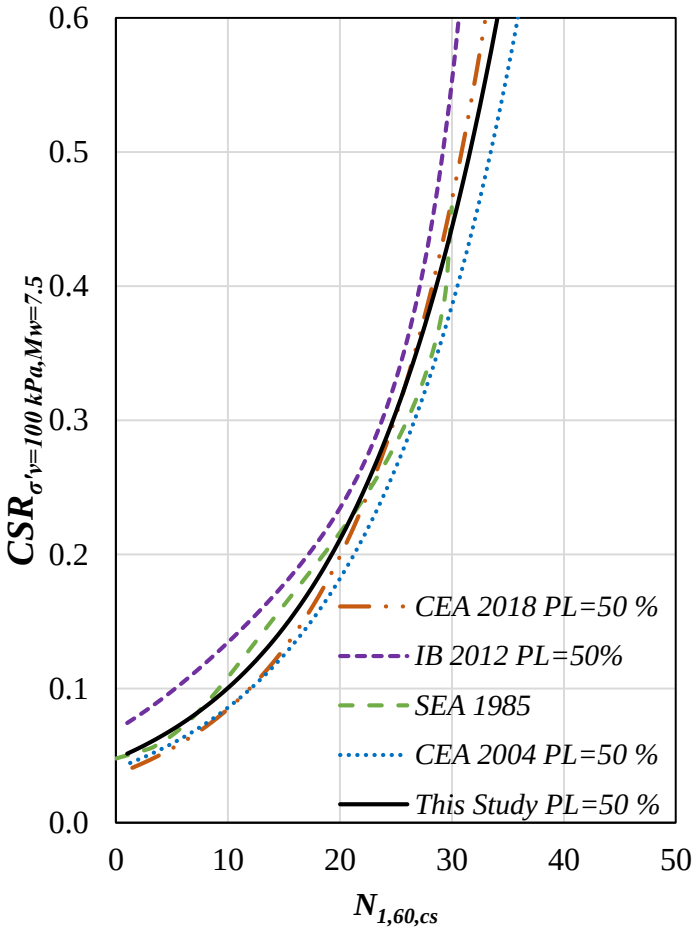


Figure 6.20. Comparison of the new seismic soil liquefaction triggering relationship (Model-3) with CEA 2004, CEA 2018, and IB 2012) for P_L=15%, and the deterministic model of SEA 1985.

The position of the new seismic soil liquefaction triggering boundary (Model-3) is slightly above CEA 2004 and CEA 2018 and below IB 2012, when both figures are examined. However, as discussed extensively in Cetin et al (2018)b, the comparison of the available models considering the position of the curves on $N_{1,60,cs}$ versus $CRR_{\sigma'v=100\ kPa,Mw=7.5}$ alone do not reflect the level of conservatism. The interpretation of case history processing and utilized correction terms has a strong influence on the application of these models along with the position of the boundary curves. As a

result, the comparison between the available liquefaction triggering relationships should only be evaluated on specific examples.

When the available models are compared, it is observed that the most significant difference is in the range where $N_{1,60,cs}$ are smaller than 20 blows/30cm. As extensively discussed in Cetin et al. (2018b) the reason for the differences between the available models are due to the differences in:

- case history processing protocols
- r_d relationships
- K_σ, K_{Mw}, and $\Delta N_{1,60,cs}$ corrections
- truncations of K_σ relationships
- probabilistic analysis to develop the triggering relationships
- probabilistic treatment in the development of K_σ, K_{Mw}, and $\Delta N_{1,60}$ relationships.

In conclusion, an updated probabilistic seismic soil liquefaction triggering model is studied based on a large number of case history database which includes the events that occurred in the last 25 years. The resultant boundary curve provides updated K_σ, K_{Mw}, and $\Delta N_{1,60}$ correction terms. The updated probabilistic seismic soil liquefaction triggering model gives comparable results with Cetin et al. (2018) curves and the difference between Idriss and Boulanger (2012), especially in the low $N_{1,60,cs}$ range of 0-20 blows/30cm which is the critical region for liquefaction triggering assessment is still valid.

In forward engineering assessments, the consistent application of the chosen seismic soil liquefaction triggering models is important which can be achieved by systematically applying the set of correction factors and following the protocols offered by the same research group.

CHAPTER 7

SUMMARY & CONCLUSIONS

7.1 Summary and Conclusions

This thesis aimed to extend the current SPT-based seismic soil liquefaction case history database efforts and develop a probabilistic-based seismic soil liquefaction triggering model. Figure 7.1 presents the recommended seismic soil liquefaction probability contours corresponding to 5%, 20%, 50%, 80%, and 95% probabilities.

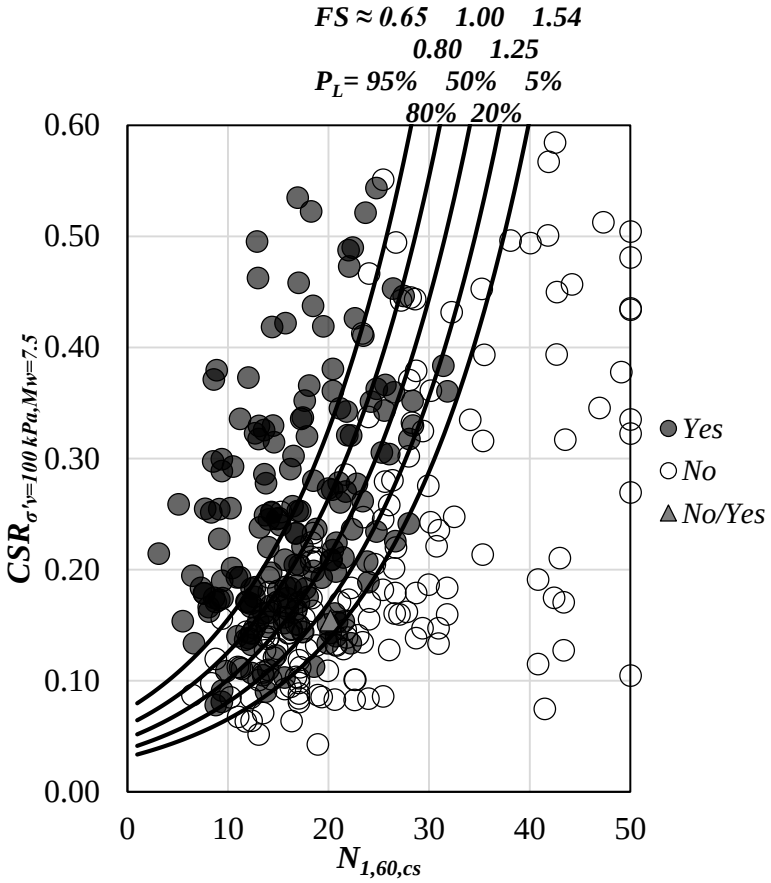


Figure 7.1. Liquefaction triggering curves (Model-3) for the new database.

Table 7.1 presents the probability of liquefaction and CRR boundary equations for the recommended model which is proposed to be used in forward engineering applications. Table 7.1 also summarizes the overburden correction, magnitude duration, and fines content corrections regressed and determined based on the field data for the new database.

Table 7.1. Summary of the proposed seismic soil liquefaction triggering model equations.

Seismic soil liquefaction triggering model equations

$$P_L = \Phi\left(-\frac{N_{1,60}+\frac{7.1770}{(1+\exp(-0.1861\cdot FC-13.2132))}-9.2814\cdot\ln(M_w)-2.1950\cdot\ln\left(\frac{\sigma'_v}{P_a}\right)-23.5277-13.4758\cdot\ln(CSR))}{3.54}\right)$$

$$CRR_{\sigma'_v,M_w} = \exp\left(\frac{N_{1,60}+\frac{7.1770}{(1+\exp(-0.1861\cdot FC-13.2132))}-9.2814\cdot\ln(M_w)-2.1950\cdot\ln\left(\frac{\sigma'_v}{P_a}\right)-23.5277+3.54\cdot\Phi^{-1}(P_L))}{13.4758}\right)$$

$$K_\sigma = \left(\frac{\sigma'_v}{P_a}\right)^{-\frac{\theta_3}{\theta_6}} = \left(\frac{\sigma'_v}{P_a}\right)^{-\frac{2.1950}{13.4758}} = \left(\frac{\sigma'_v}{P_a}\right)^{-0.1629} \quad lim: 0.8 < K_\sigma < 1.6$$

$$K_{M_w} = \left(\frac{M_w}{7.5}\right)^{-\frac{\theta_2}{\theta_6}} = \left(\frac{M_w}{7.5}\right)^{-\frac{9.2814}{13.4758}} = \left(\frac{M_w}{7.5}\right)^{-0.6888} \quad lim: 4.6 < M_w < 9.1$$

$$CSR_{\sigma'_v=1atm,M_w=7.5,\alpha=0} = CSR_{\sigma'_v,M_w,\alpha}\cdot\frac{1}{K_\sigma}\cdot\frac{1}{K_{M_w}}\cdot\frac{1}{K_\alpha}$$

$$lim: CSR_{\sigma'_v=1atm,M_w=7.5,\alpha=0} \le 0.6$$

$$\Delta_{N_{1,60,cs}} = \frac{\theta_9}{(1+\exp(-\theta_{10}\cdot FC-\theta_{11}))} - \theta_{5,1} = \frac{7.1770}{(1+\exp(-0.1861\cdot FC-13.2132))} - 1.2791$$

$$lim: 5\% < FC < 35\%$$

$$C_N = \left(\frac{P_a}{\sigma'_v}\right)^{0.5} \le 2.0$$

$$C_R = 1 - 0.274\cdot e^{-0.063\cdot L} \pm 0.059 \quad (L \text{ in feet})$$

Following is a brief summary of the main findings of this study:

- An extensive case history database where 334 liquefaction field data is compiled and used to develop a new set of relationships by using statistical methods considering the uncertainty of input parameters.

- The legacy field case history database of Cetin et al. (2018) is re-evaluated considering the developments in the correction of SPT and CSR.
- A large number of "new" field case history data is compiled and the dataset presented here involves case histories that are not a part of any previous catalog which is believed to contribute to the database development efforts significantly.
- A new protocol with a high standard is established for the processing of case history data.
- The database documents the available case history data consistently with ongoing CPT and V_s case history data processing.
- The potentially liquefiable soil layers in the updated database are composed of occasional gravelly and silty critical layers in addition to sandy layers which picture a wide range of liquefiable materials in nature.
- When the overall average of the input parameters is studied, it is observed that the new database studied a wide range of moment magnitude ($4.6<M_w<9.1$) and intensity ($0.078< a_{max}<0.784$) levels.
- The extended database includes a significant number of data in the mid-to-high CSR range ($0.35<CSR<0.6$).
- Site response analyses are conducted to estimate the PGA and r_d, when possible. As a result, in forward engineering assessment, the application of site response-based CSR estimation is possible by using the updated seismic soil liquefaction triggering boundary similar to Cetin et al. (2004, 2018).
- The resulting relationships provide an updated understanding of the short rod and hammer efficiency corrections. The resultant C_R correction revealed that the previous short rod corrections overestimated the effect of short rod effects. Similarly, hammer energy efficiency values are recommended to be more pronounced than previously postulated. For safety and automatic hammers, if energy measurements are not available, hammer efficiency is recommended as 66 and 82 %, respectively.

- The new liquefaction triggering model defines the occurrence of liquefaction based on observed surface manifestation (e.g. sand boils, etc.), and ground motion frequency shifts. It emphasizes that the occurrence of liquefaction may not always be associated with the occurrence of surface manifestation but liquefaction may occur in the soil layer where surface manifestations are not observed.
- A new fines correction was offered which suggested a slightly higher fines correction. This is due to the increased number of liquefiable layers with higher fines content or silt layer.
- New K_{Mw} and K_{σ} corrections were regressed based on the field case history database which is in good agreement with the behavior observed in the laboratory
- When comparing the available liquefaction triggering models, a direct comparison based on the location of the curves on $N_{1,60}$ vs CSR space does not necessarily indicate a relationship is more conservative than the other ones. The comparison can only be made based on the calculated FS and P_L levels for a specific site. In forward engineering assessments, the consistent application of the chosen seismic soil liquefaction triggering models is important which can be achieved by using consistently the set of correction factors and following the protocols offered by the same research group.

7.2 Future Recommendations

The following studies would improve the assessment of seismic soil liquefaction triggering:

- Subsurface investigation with high-quality laboratory testing is required to better assess fines content corrections.
- Further study is needed to resolve the overburden stress exponent for clean sands and silty soils.

- The availability of new case history data and new input parameters (e.g. gravel content, number of cycles, etc.) may enable addressing new aspects of seismic soil liquefaction triggering for future works.
- The influence of drainage conditions in liquefaction assessments should be studied.
- Crust layer corrections should be included in the assessment of seismic soil liquefaction triggering.
- Performance-based assessment of seismic soil liquefaction triggering should be targeted.

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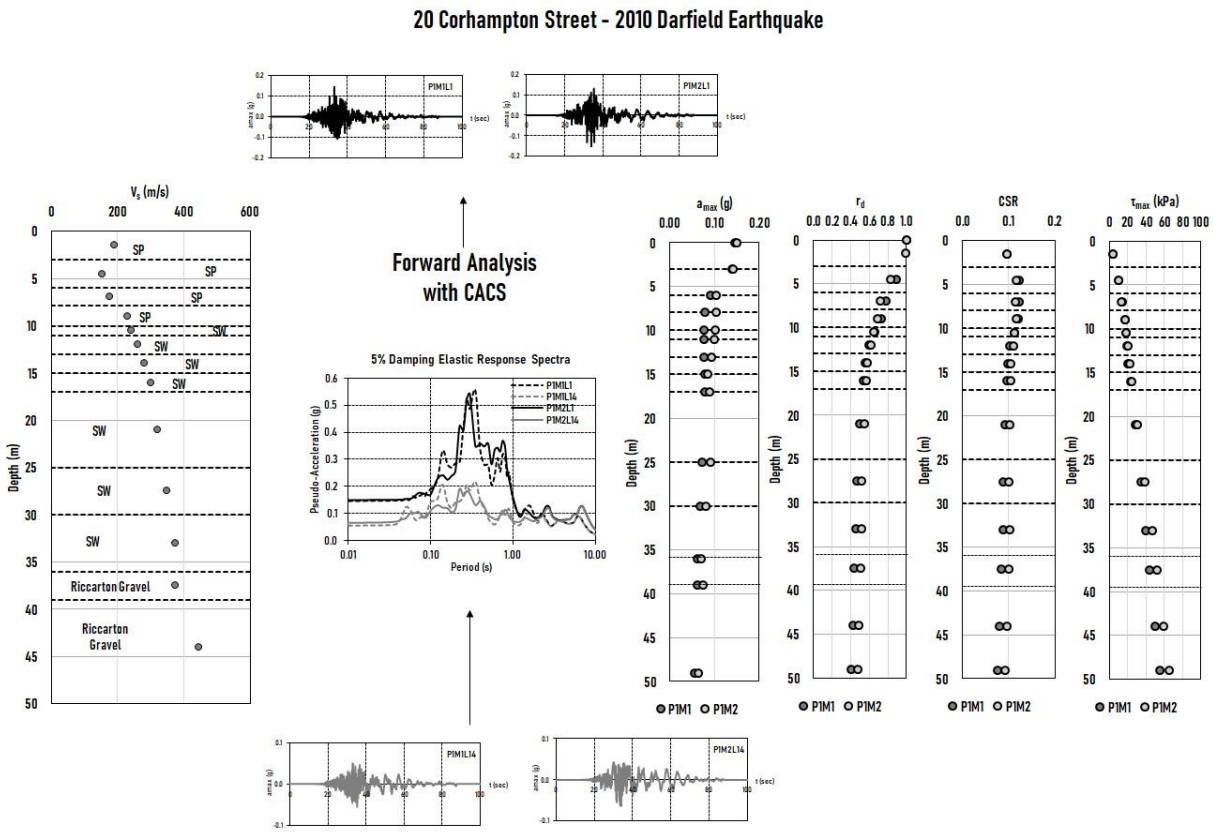
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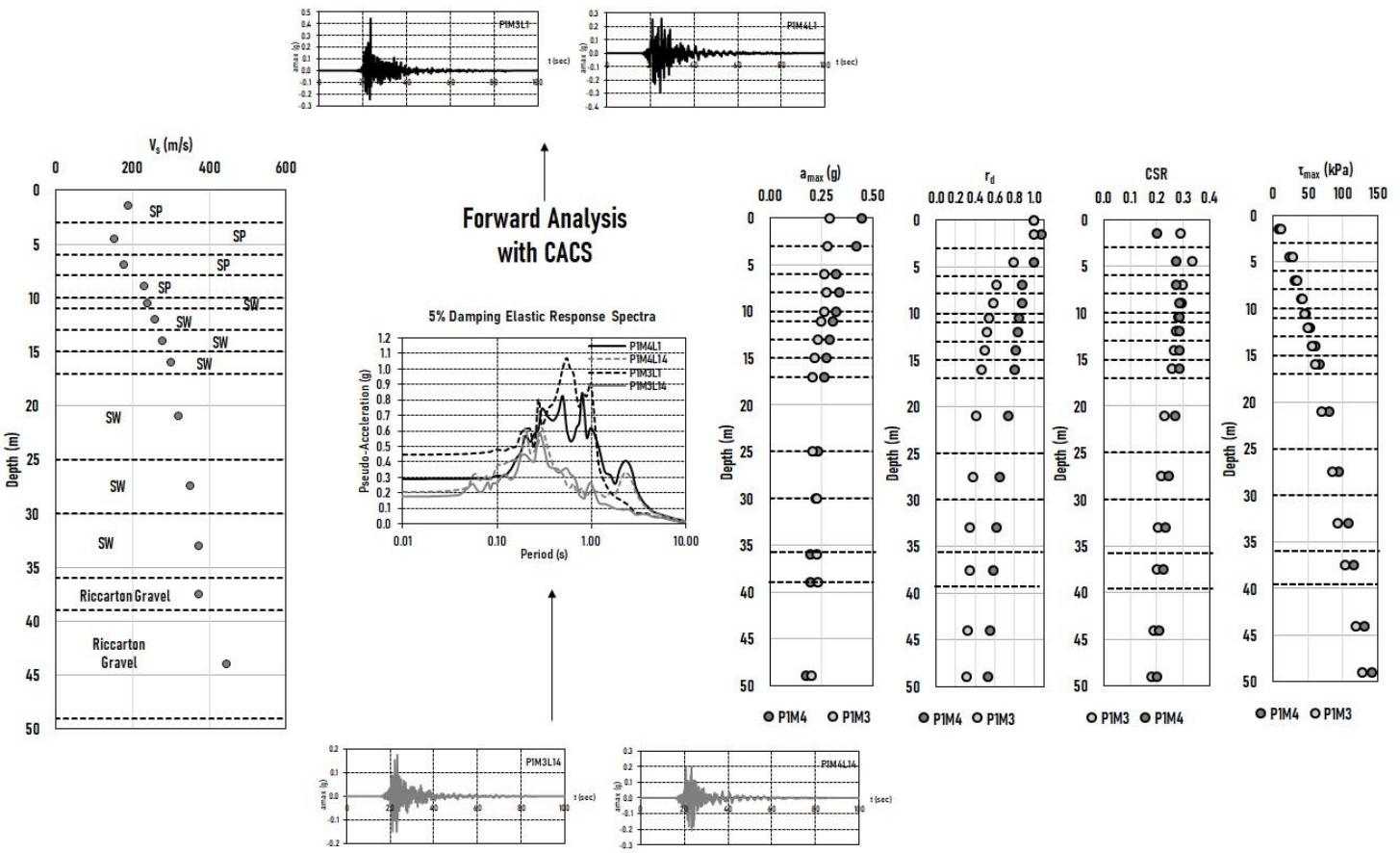
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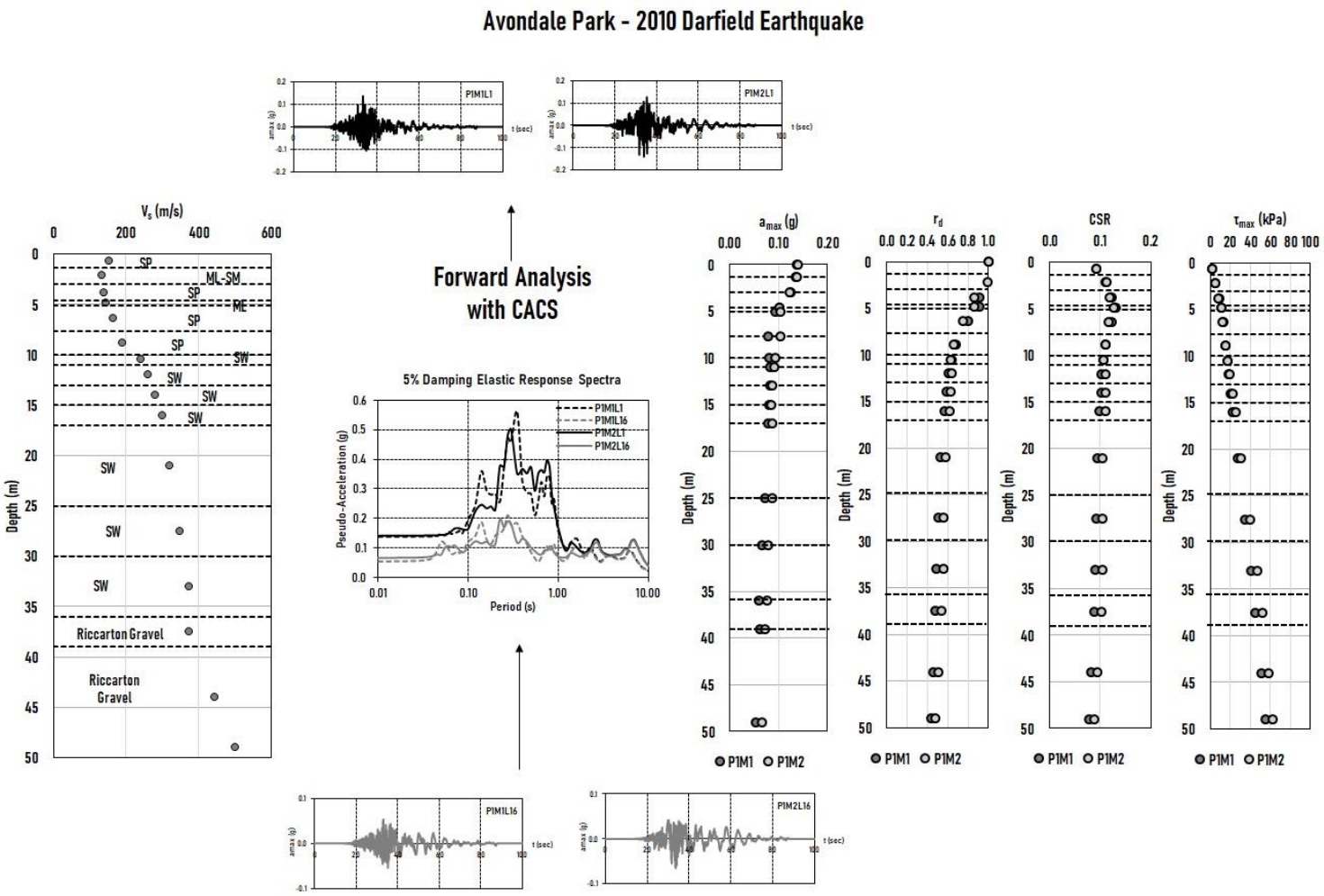
APPENDICES

A. Site Response Analysis

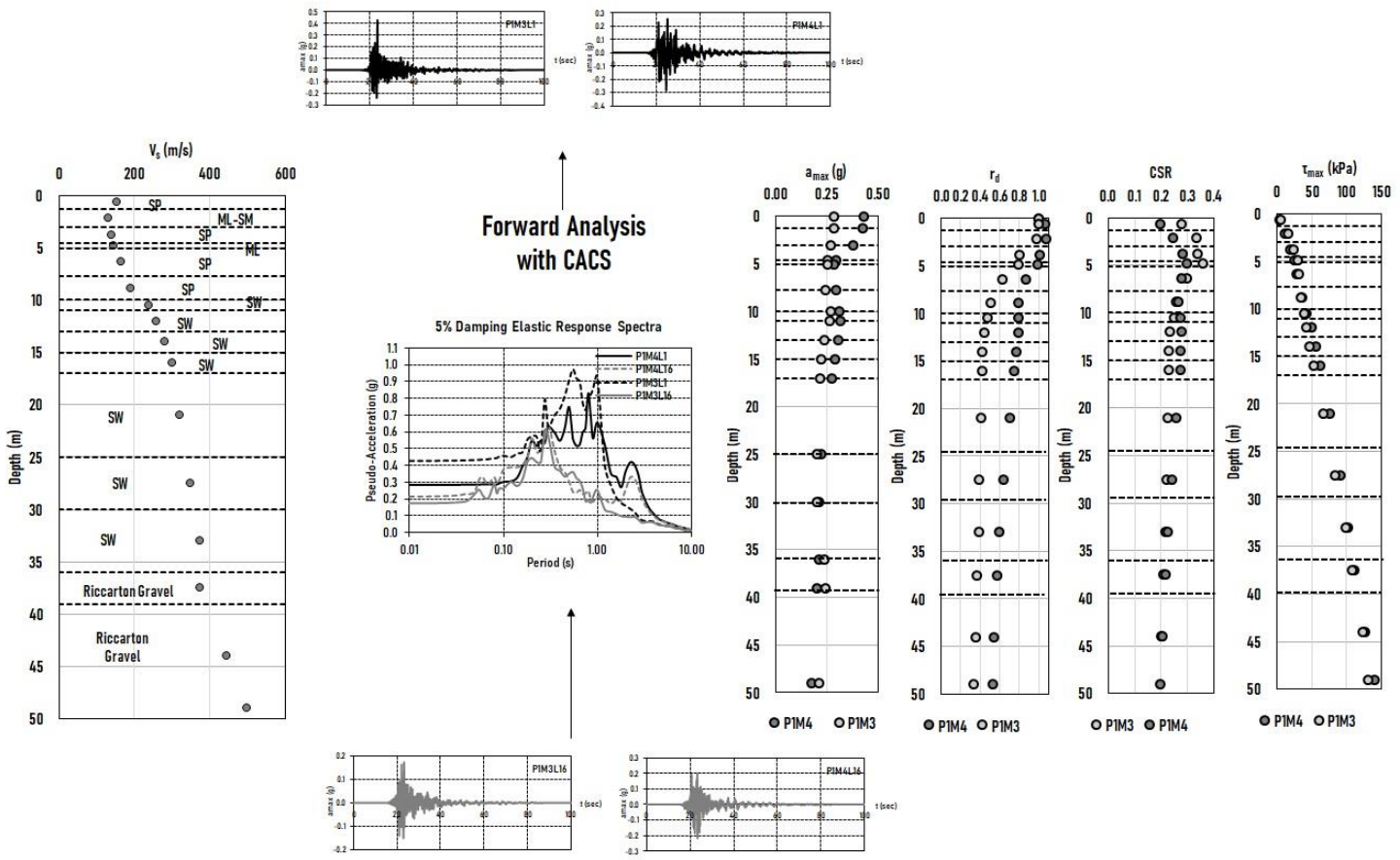


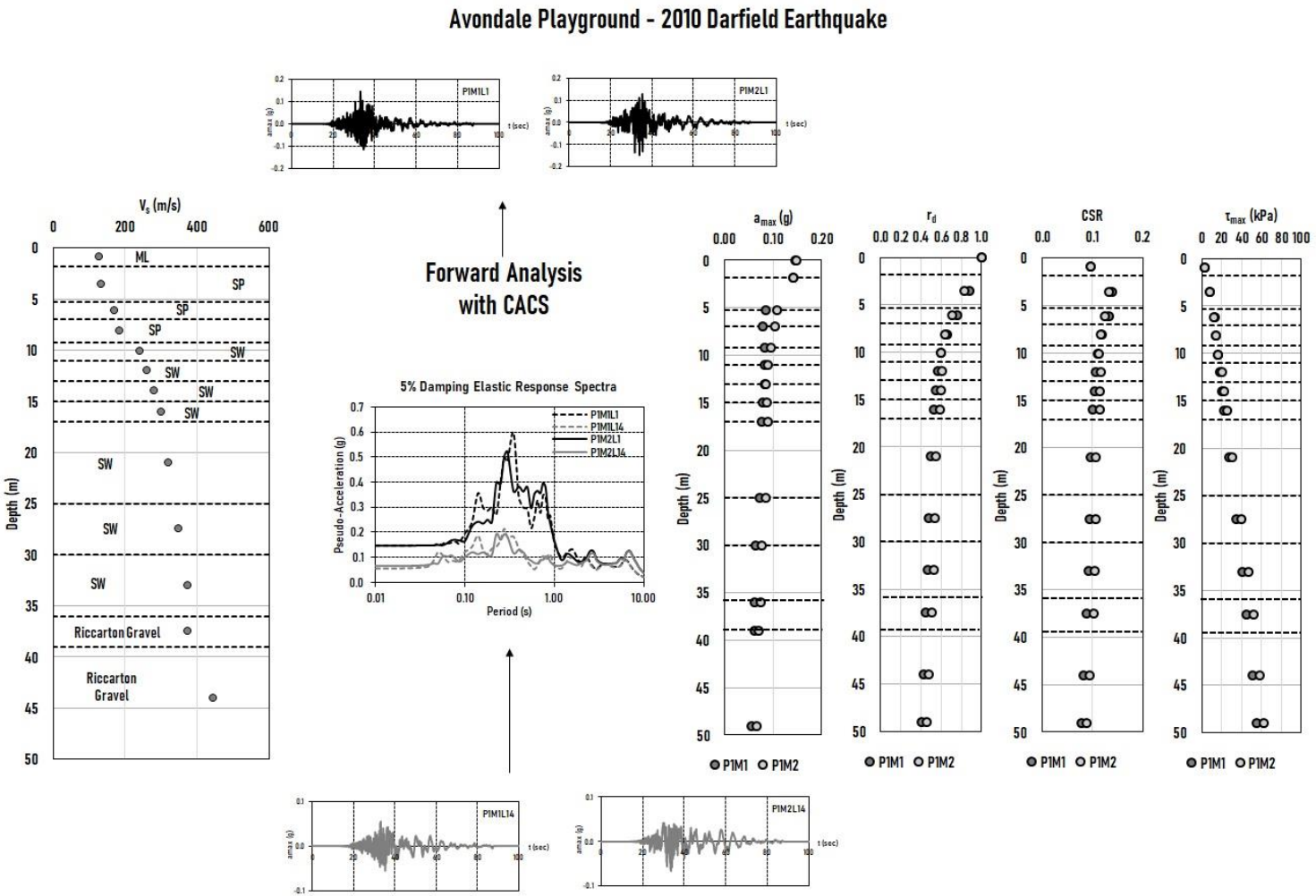
20 Corhampton Street - 2011 Christchurch Earthquake



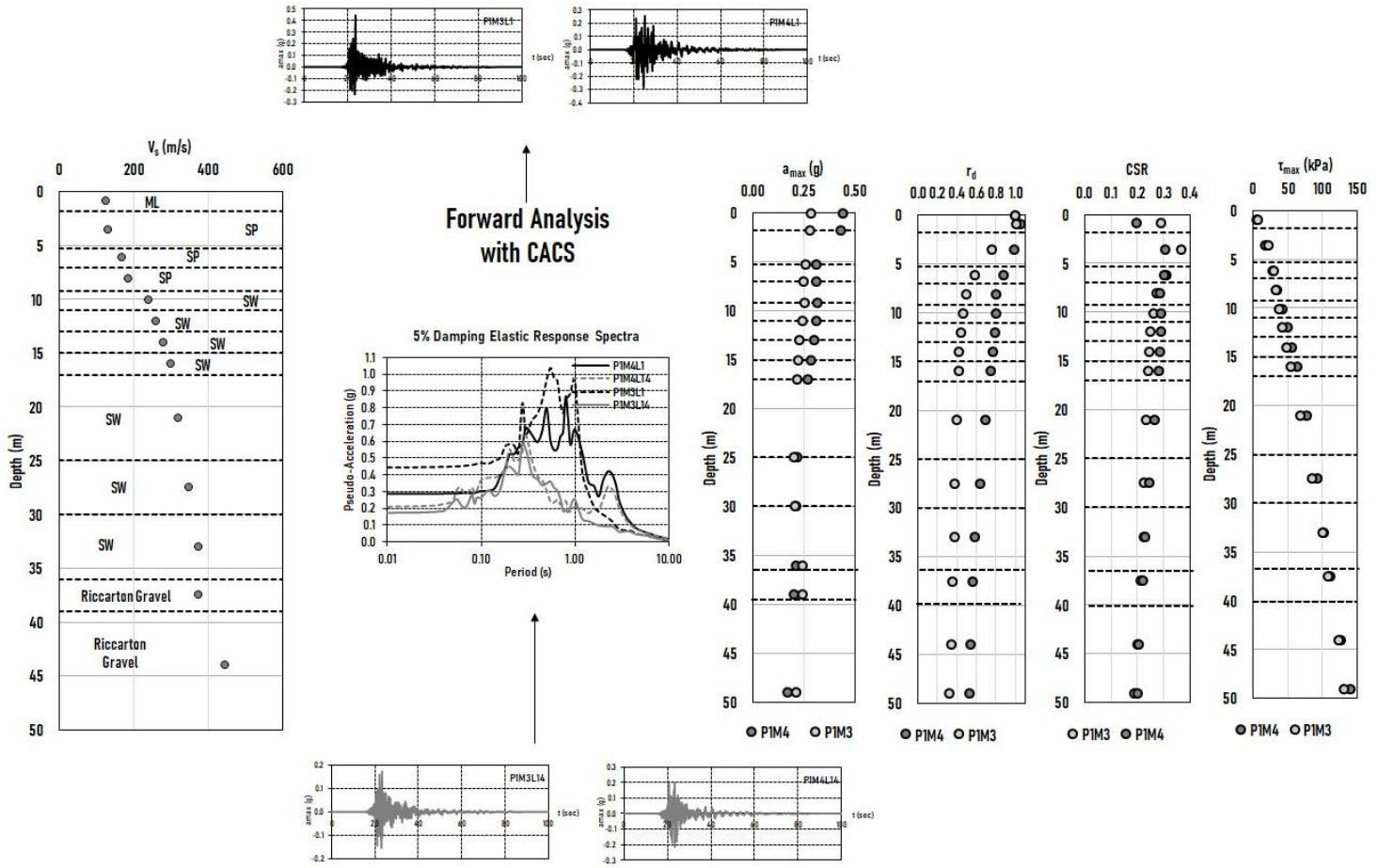

Avondale Park - 2010 Darfield Earthquake
P1M1L1
P1M2L1
Forward Analysis with CACS
5% Damping Elastic Response Spectra
P1M1L1
P1M1L16
P1M2L1
P1M2L16
Pseudo-Acceleration (g)
Period (s)
P1M1L16
P1M2L16
Vs (m/s)
Depth (m)
SP
ML-SM
ME
SW
Riccarton Gravel
amax (g)
rd
CSR
τmax (kPa)
P1M1
P1M2

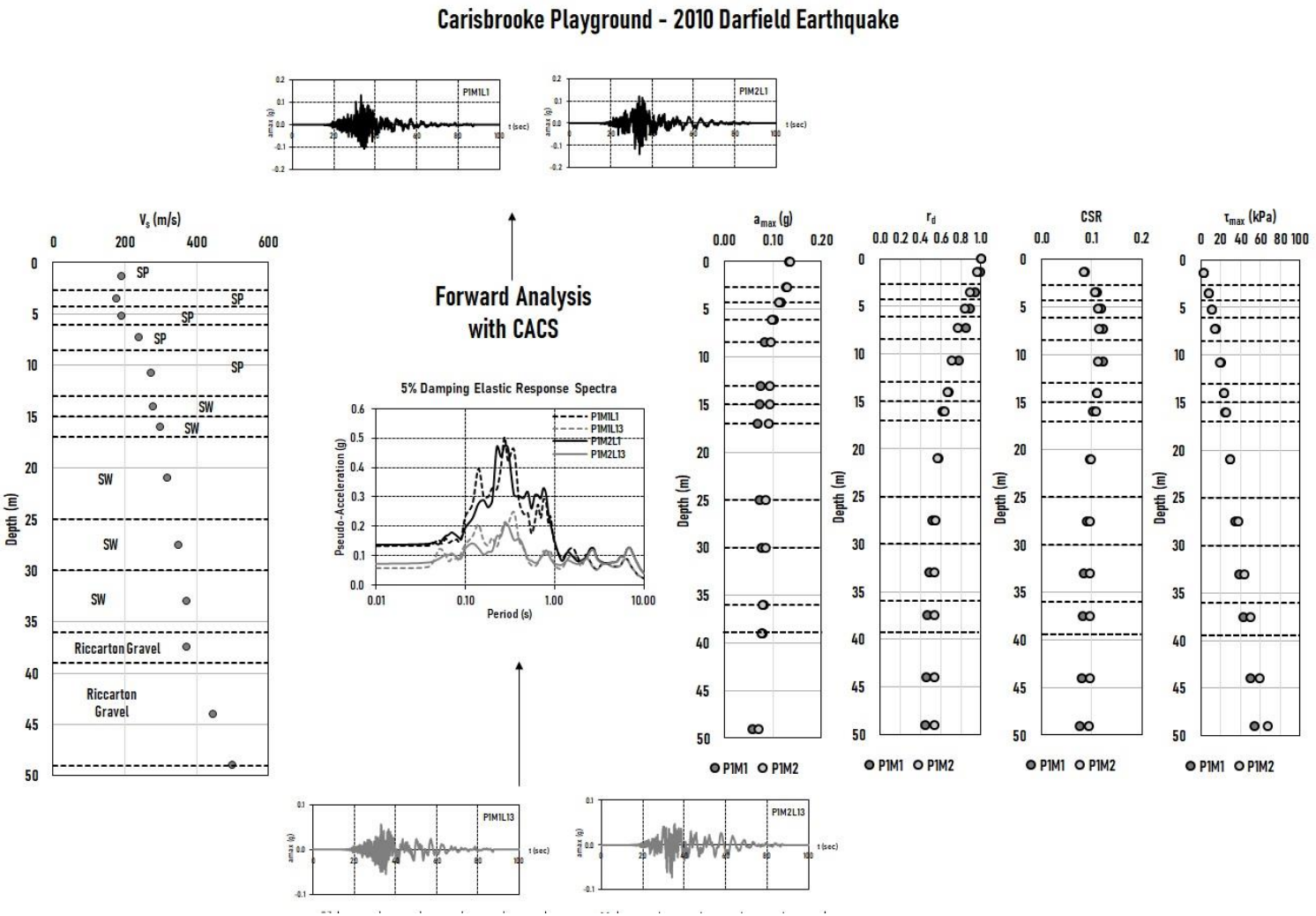
Avondale Park - 2011 Christchurch Earthquake



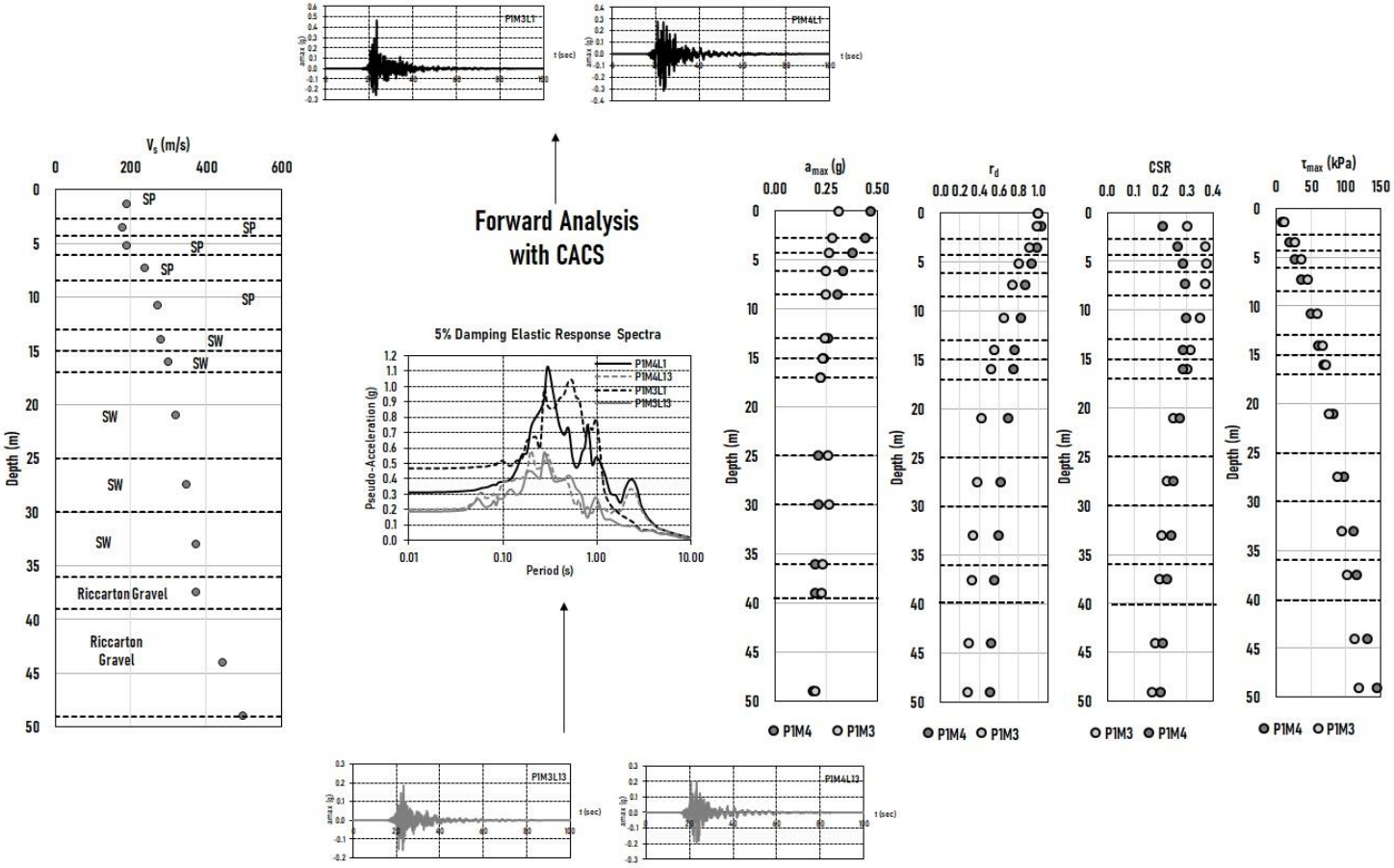

Avondale Playground - 2010 Darfield Earthquake
P1M1L1
P1M2L1
Forward Analysis with CACS
5% Damping Elastic Response Spectra
P1M1L1
P1M1L14
P1M2L1
P1M2L14
Pseudo-Acceleration (g)
Period (s)
V_s (m/s)
Depth (m)
ML
SP
SW
Riccarton Gravel
Riccarton Gravel
a_{max} (g)
r_d
CSR
τ_{max} (kPa)
P1M1
P1M2
P1M1L14
P1M2L14

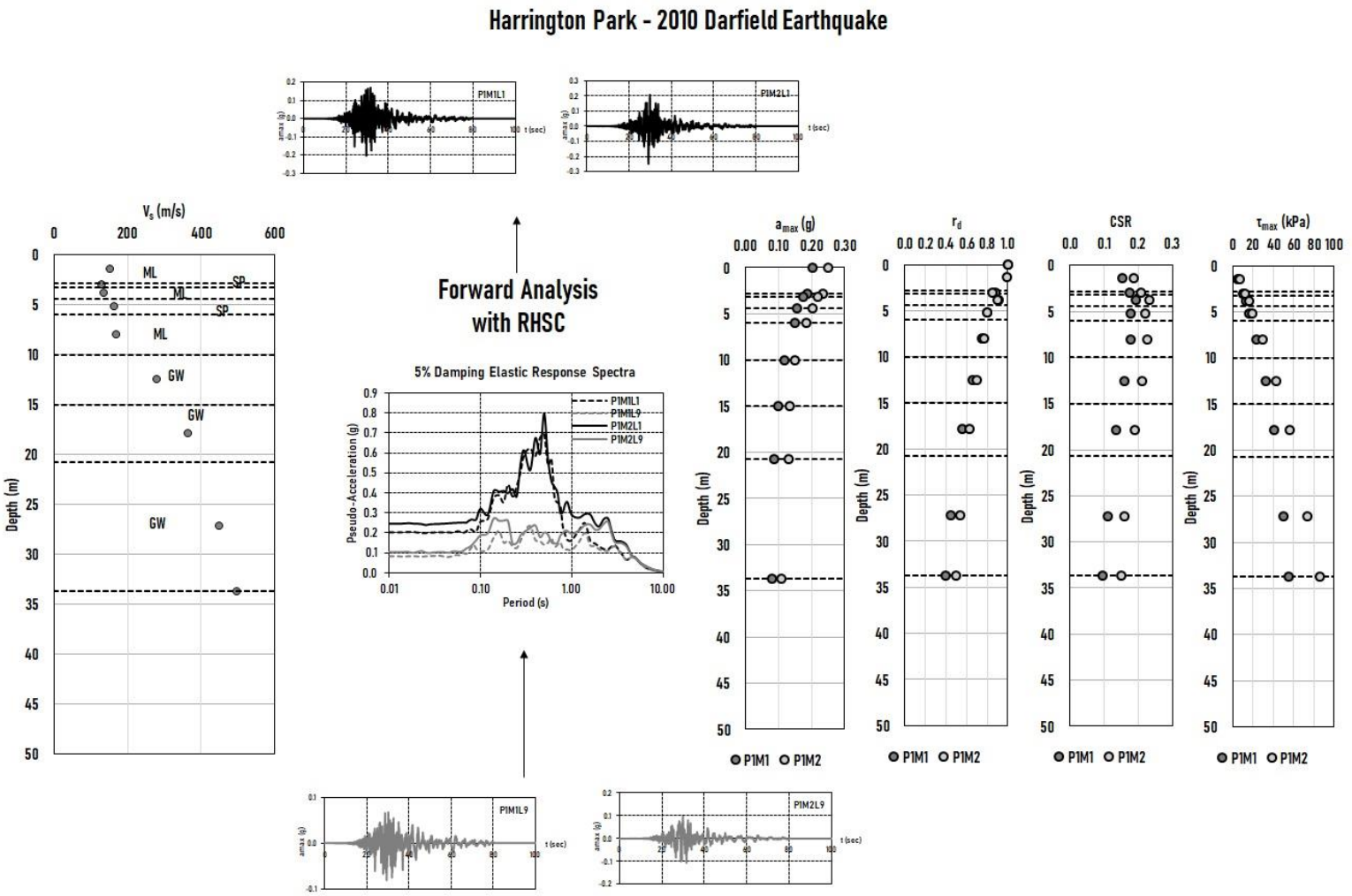
Avondale Playground - 2011 Christchurch Earthquake

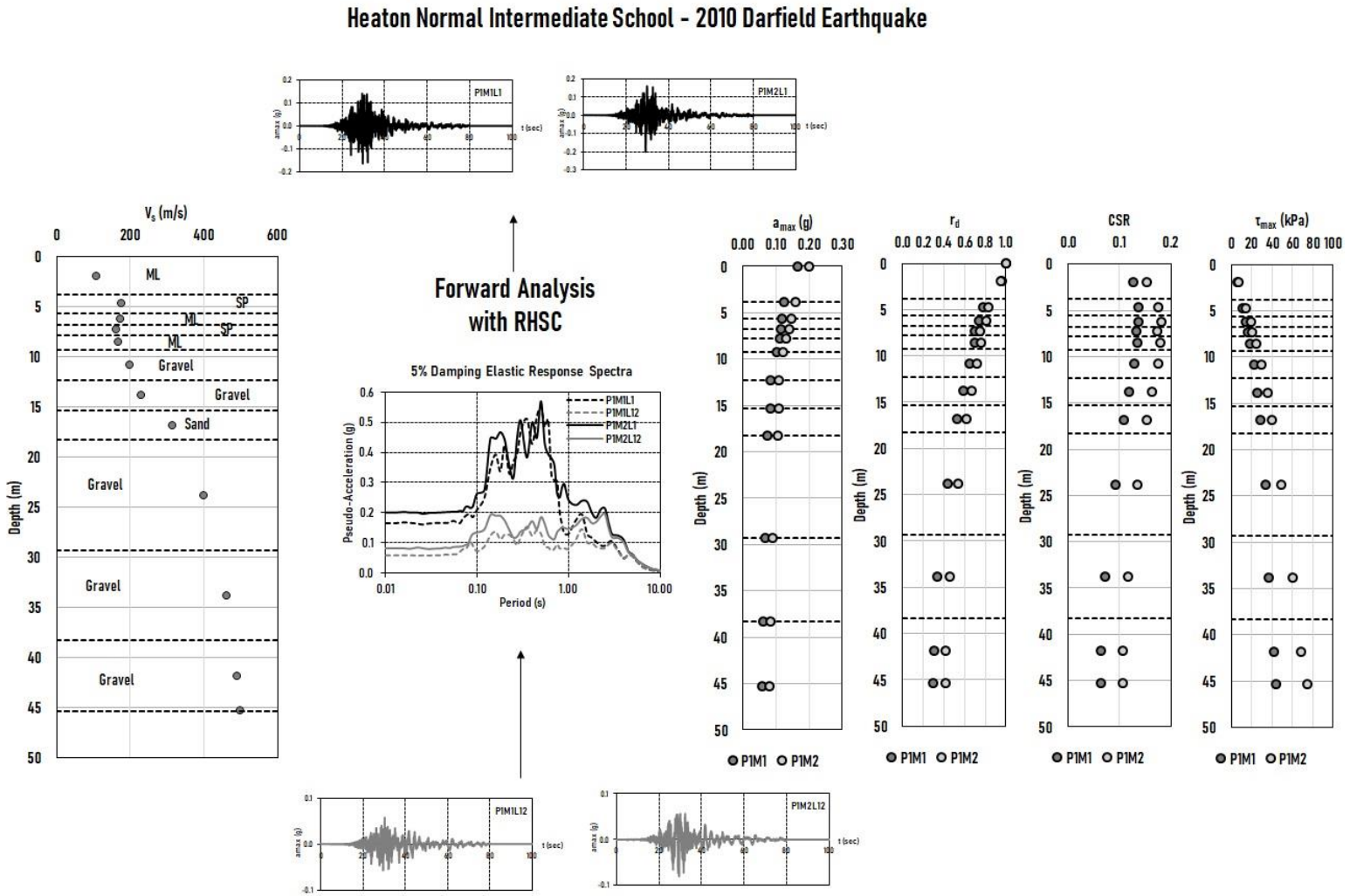


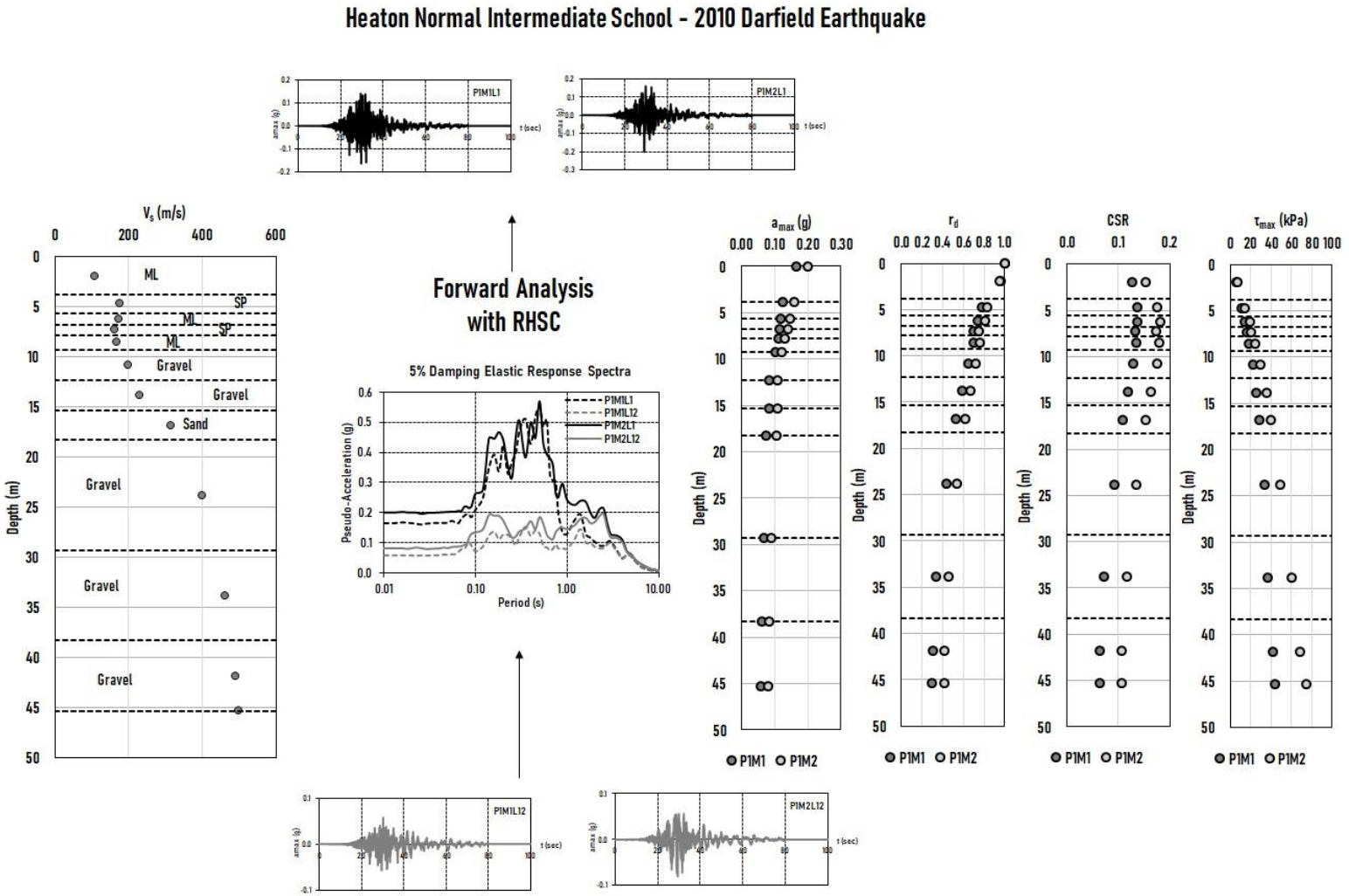

Carisbrooke Playground - 2010 Darfield Earthquake
P1M1L1
P1M2L1
Forward Analysis with CACS
5% Damping Elastic Response Spectra
P1M1L1
P1M1L13
P1M2L1
P1M2L13
Pseudo-Acceleration (g)
Period (s)
V_s (m/s)
Depth (m)
SP
SW
Riccarton Gravel
Riccarton Gravel
a_{max} (g)
r_d
CSR
τ_{max} (kPa)
P1M1
P1M2
P1M1L13
P1M2L13

Carisbrooke Playground - 2011 Christchurch Earthquake

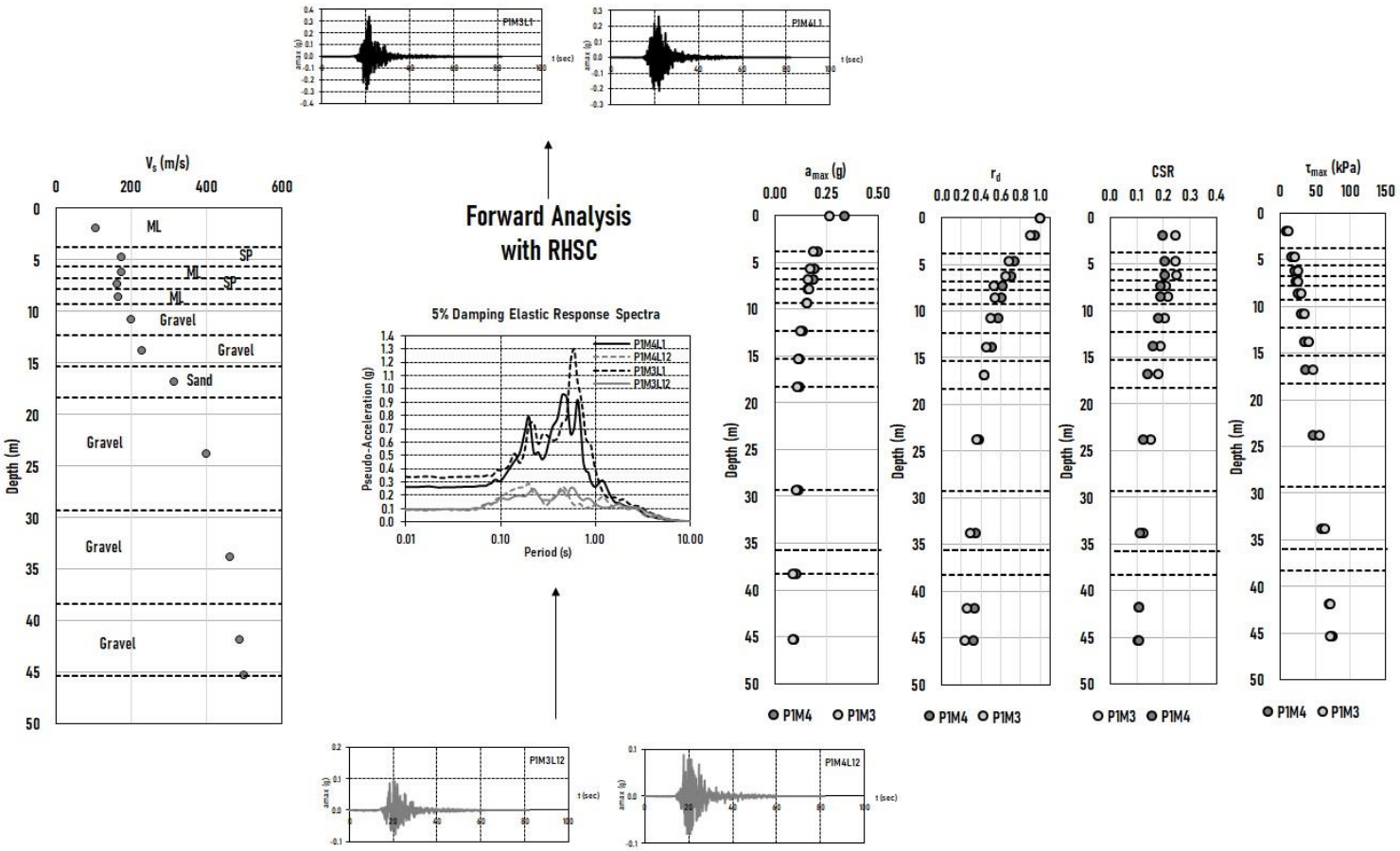


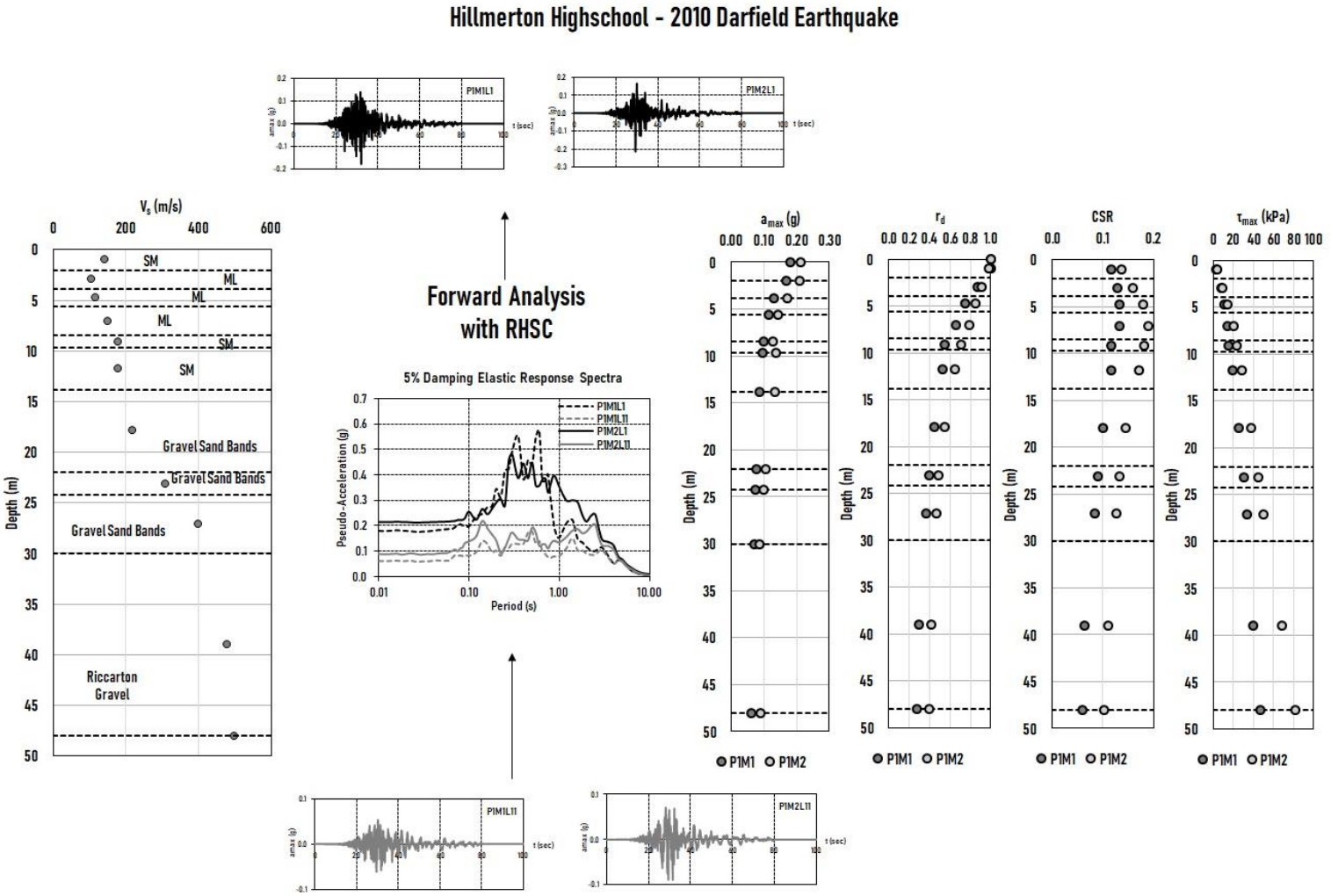

Harrington Park - 2010 Darfield Earthquake
P1M1L1
P1M2L1
Forward Analysis
with RHSC
5% Damping Elastic Response Spectra
P1M1L1
P1M1L9
P1M2L1
P1M2L9
Pseudo-Acceleration (g)
Period (s)
P1M1L9
P1M2L9
V_s (m/s)
ML
SP
GW
Depth (m)
a_{max} (g)
r_d
CSR
τ_{max} (kPa)
P1M1
P1M2


Heaton Normal Intermediate School - 2010 Darfield Earthquake
P1M1L1
P1M2L1
Forward Analysis with RHSC
5% Damping Elastic Response Spectra
P1M1L1
P1M1L12
P1M2L1
P1M2L12
Pseudo-Acceleration (g)
Period (s)
P1M1L12
P1M2L12
t (sec)
V_s (m/s)
ML
SP
Gravel
Sand
Depth (m)
a_{max} (g)
r_d
CSR
τ_{max} (kPa)
P1M1
P1M2

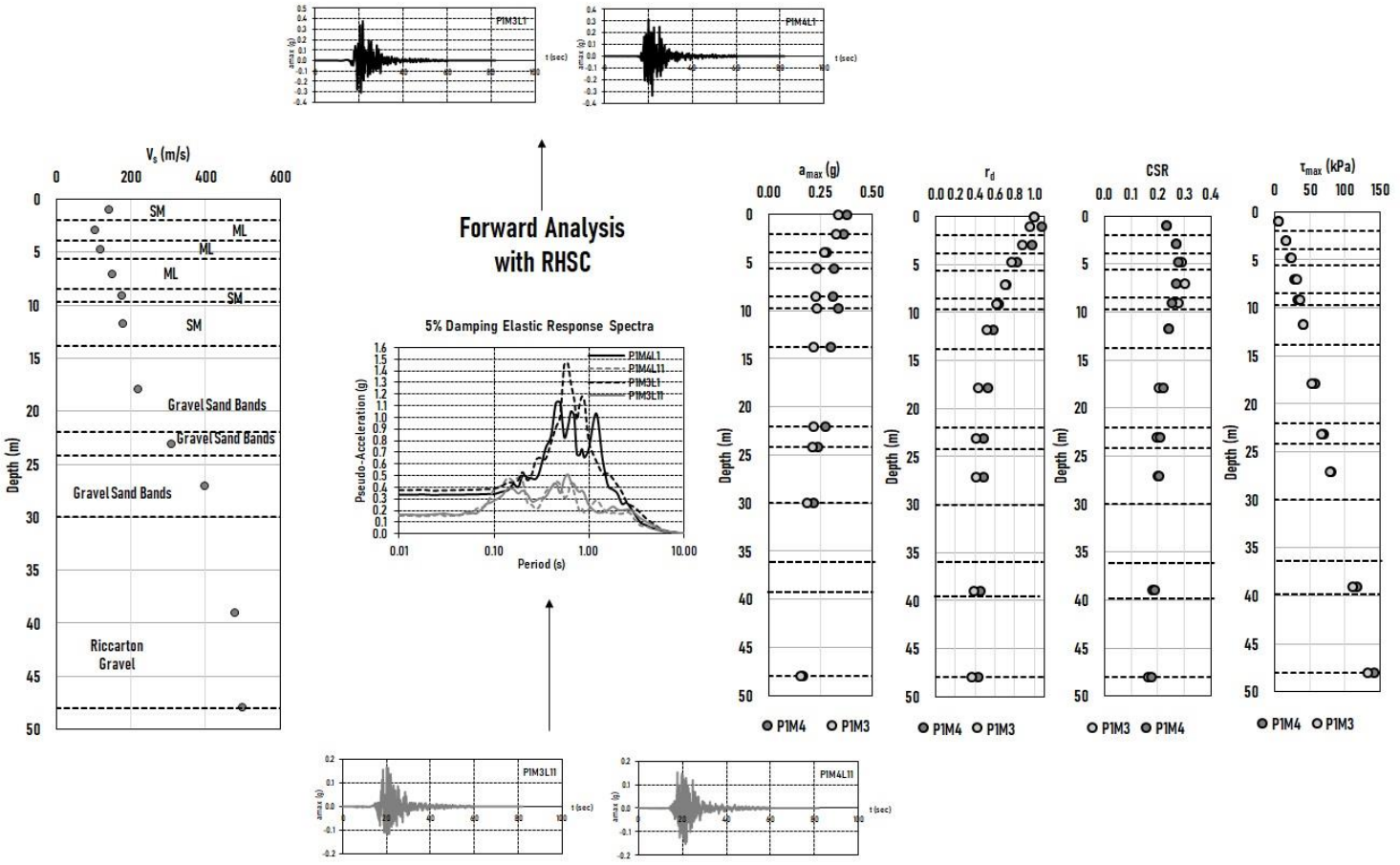

Heaton Normal Intermediate School - 2010 Darfield Earthquake
P1M1L1
P1M2L1
Forward Analysis with RHSC
5% Damping Elastic Response Spectra
P1M1L1
P1M1L12
P1M2L1
P1M2L12
Pseudo-Acceleration (g)
Period (s)
P1M1L12
P1M2L12
Vs (m/s)
ML
SP
ML
SP
ML
Gravel
Gravel
Sand
Gravel
Gravel
Gravel
Depth (m)
amax (g)
rd
CSR
τmax (kPa)
P1M1 P1M2

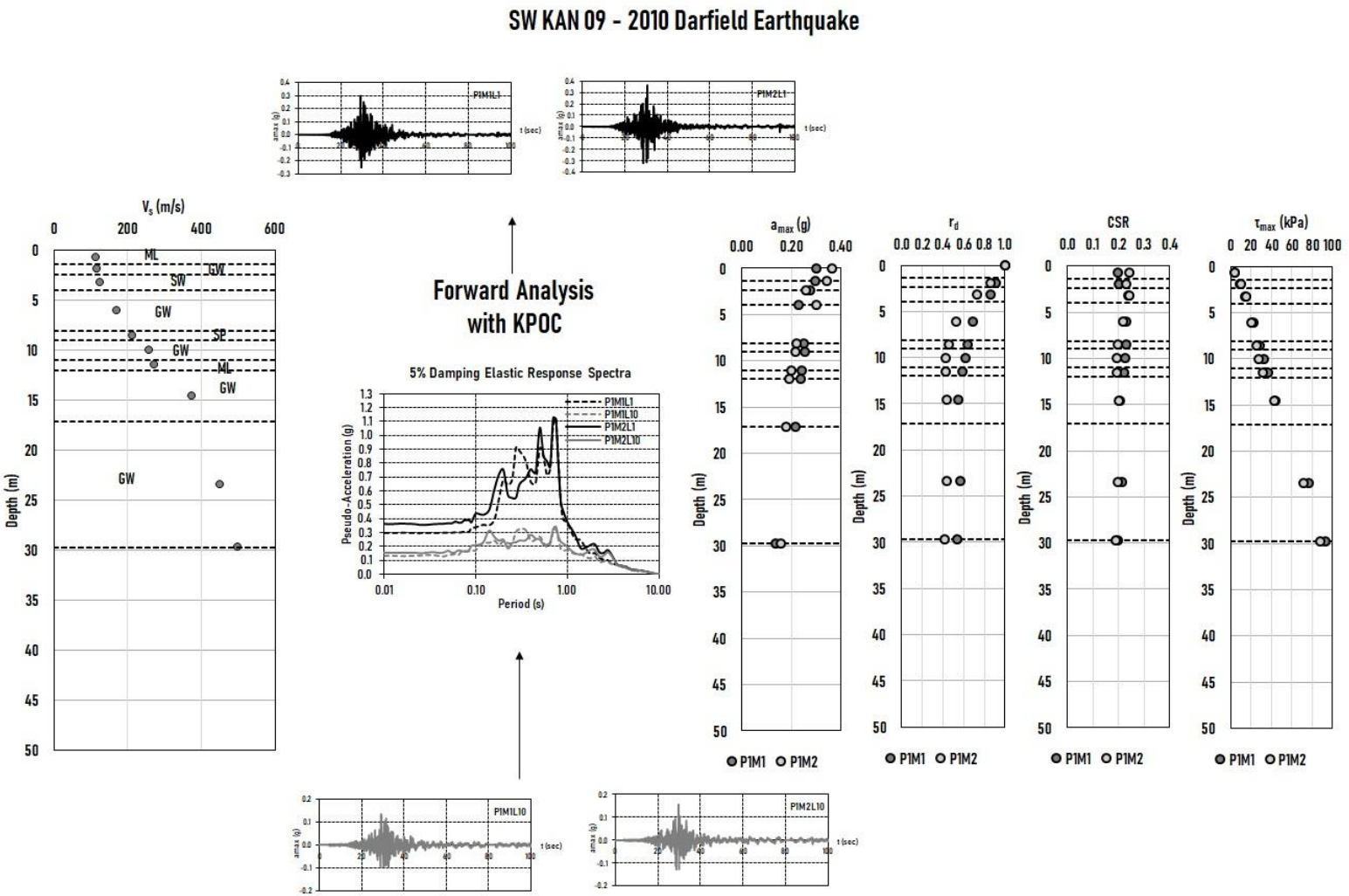
Heaton Normal Intermediate School- 2011 Christchurch Earthquake



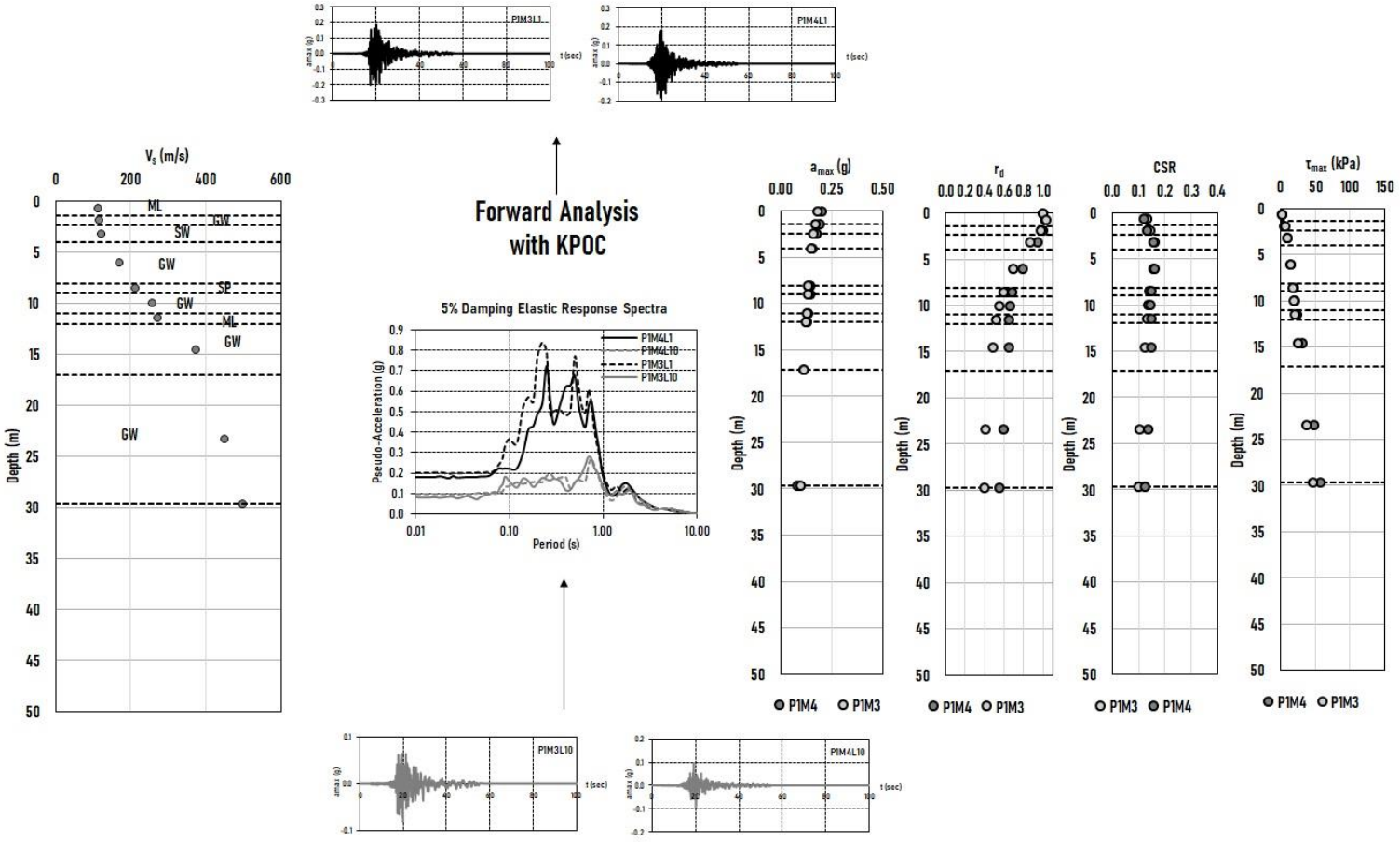

Hillmerton Highschool - 2010 Darfield Earthquake
P1M1L1
P1M2L1
P1M1L11
P1M2L11
Forward Analysis with RHSC
5% Damping Elastic Response Spectra
Pseudo-Acceleration (g)
Period (s)
V_s (m/s)
Depth (m)
SM
ML
Gravel Sand Bands
Riccarton Gravel
a_{max} (g)
r_d
CSR
τ_{max} (kPa)
P1M1
P1M2

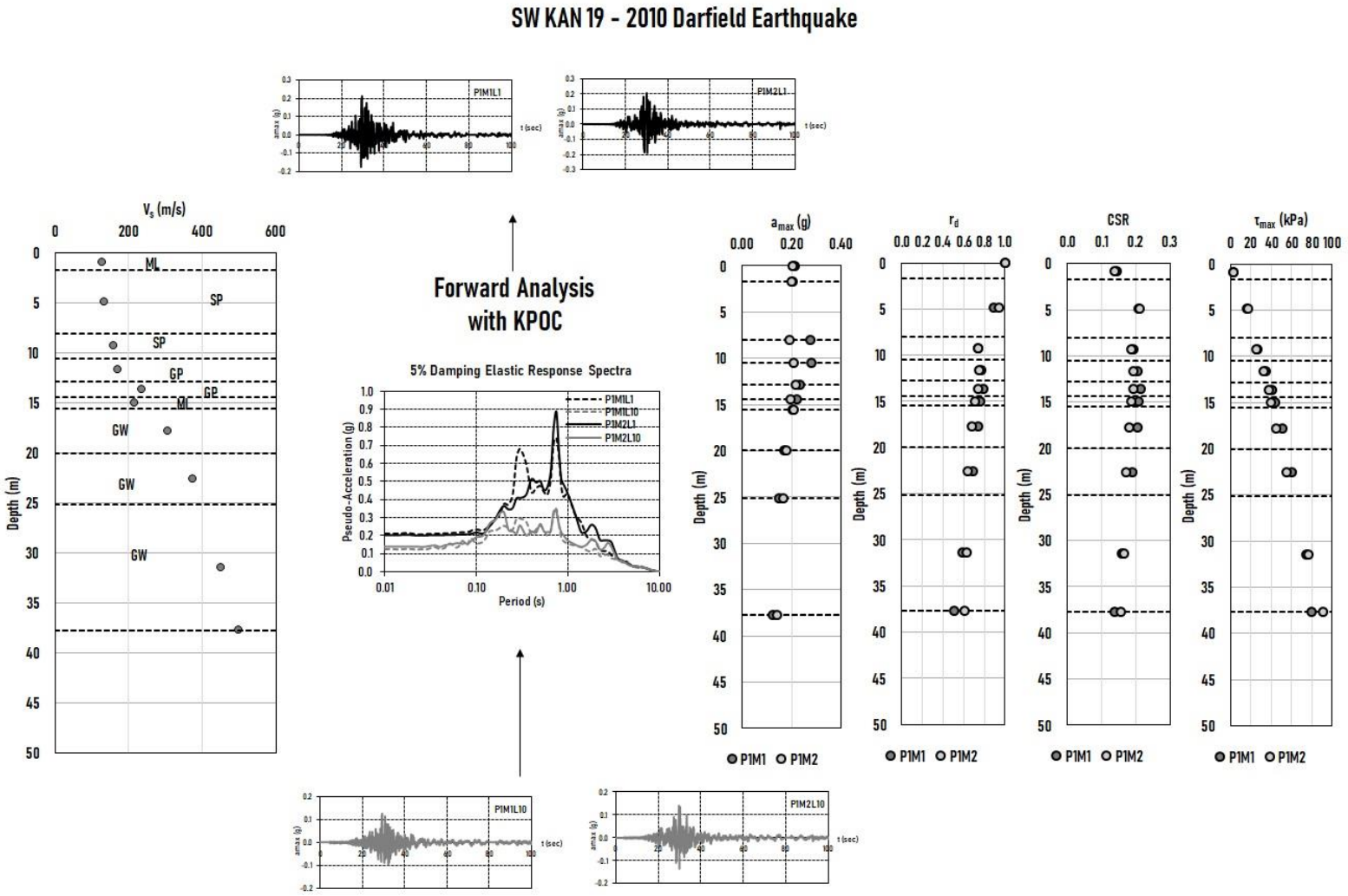
Hillmerton Highschool - 2011 Christchurch Earthquake



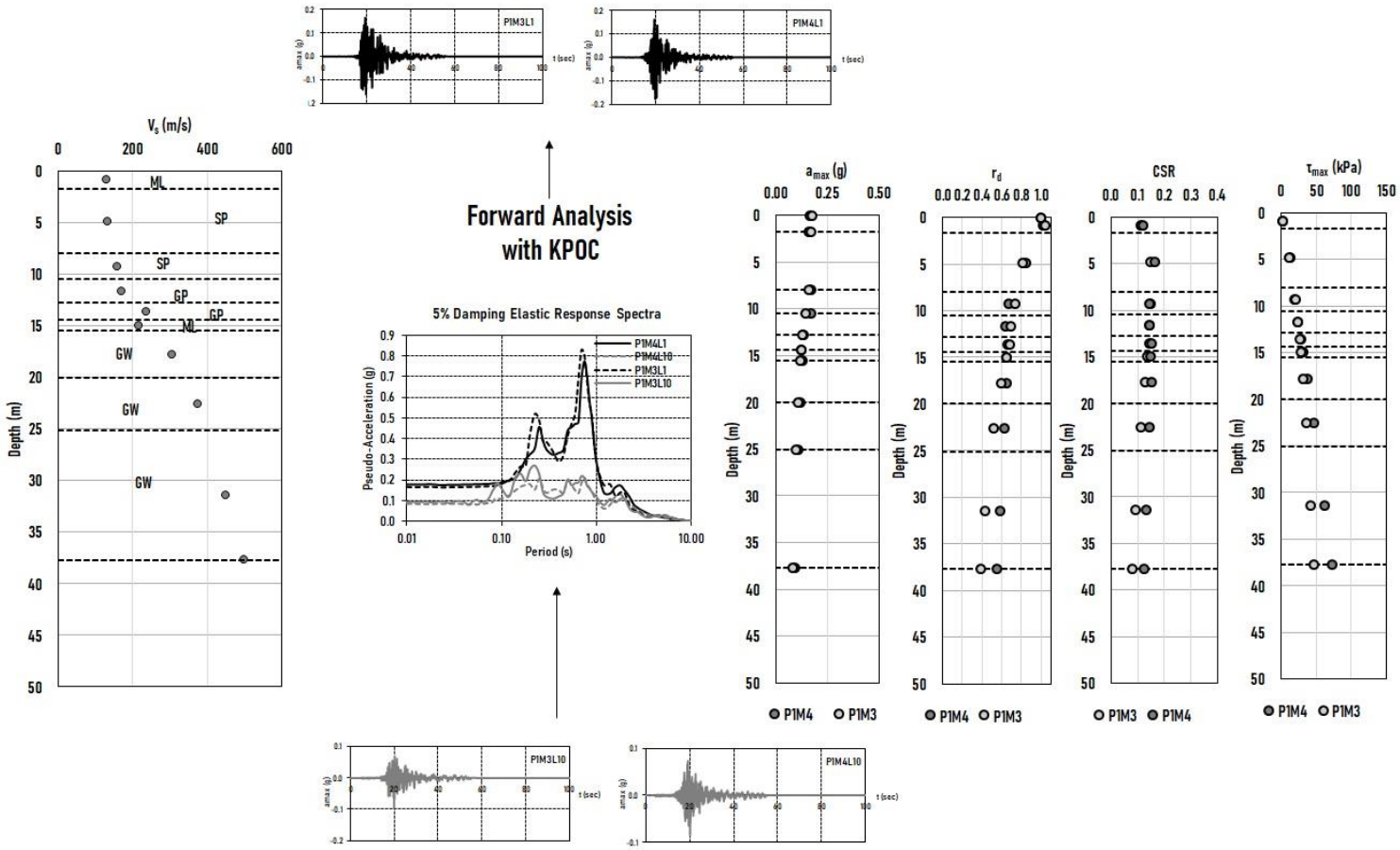

SW KAN 09 - 2010 Darfield Earthquake
P1M1L1
P1M2L1
Forward Analysis with KPOC
5% Damping Elastic Response Spectra
P1M1L1
P1M1L10
P1M2L1
P1M2L10
Pseudo-Acceleration (g)
Period (s)
V_s (m/s)
Depth (m)
ML
GW
SW
GW
SP
GW
ML
GW
GW
a_{max} (g)
r_d
CSR
τ_{max} (kPa)
P1M1
P1M2
P1M1L10
P1M2L10

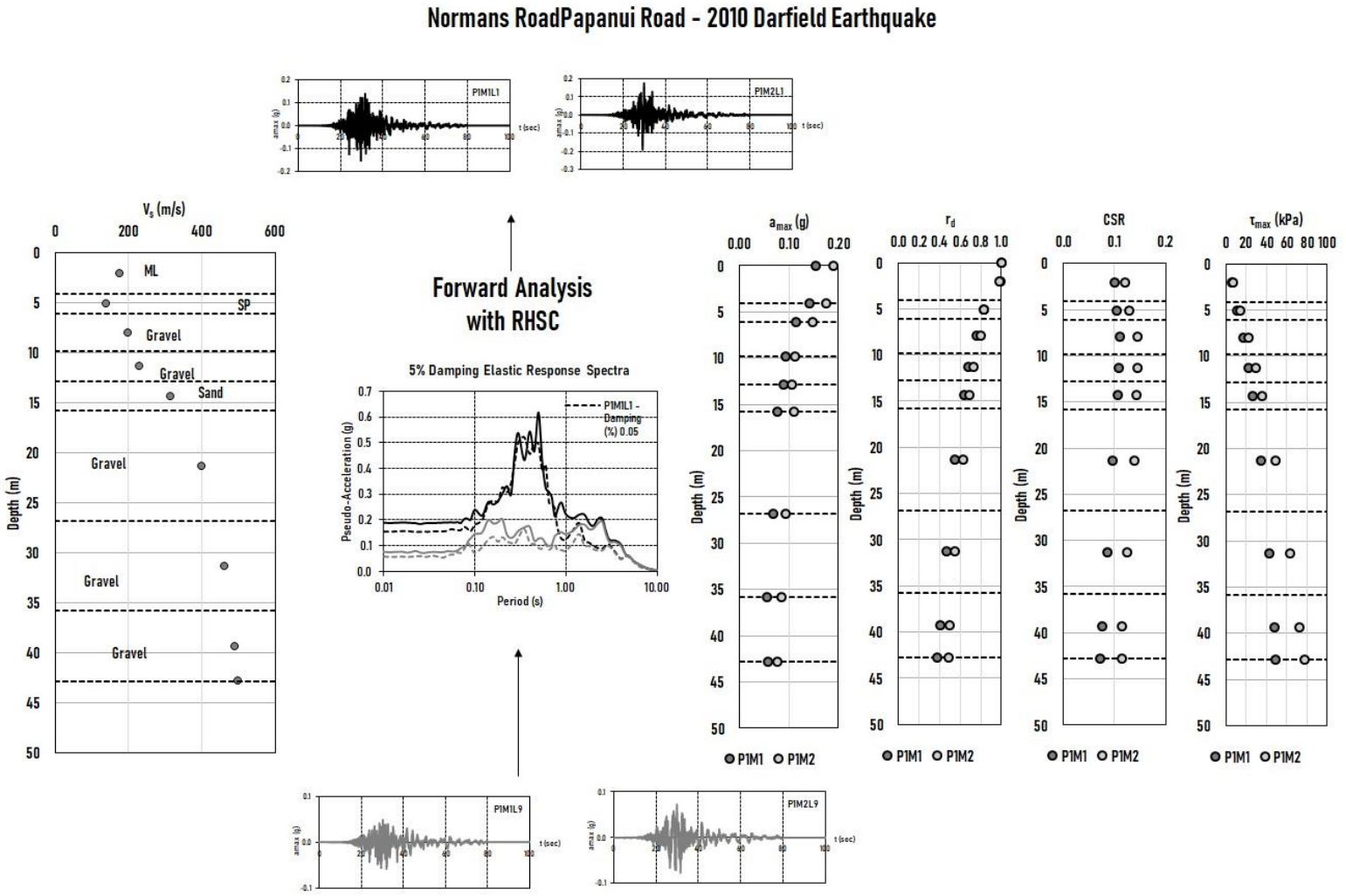
SW KAN 09 - 2011 Christchurch Earthquake



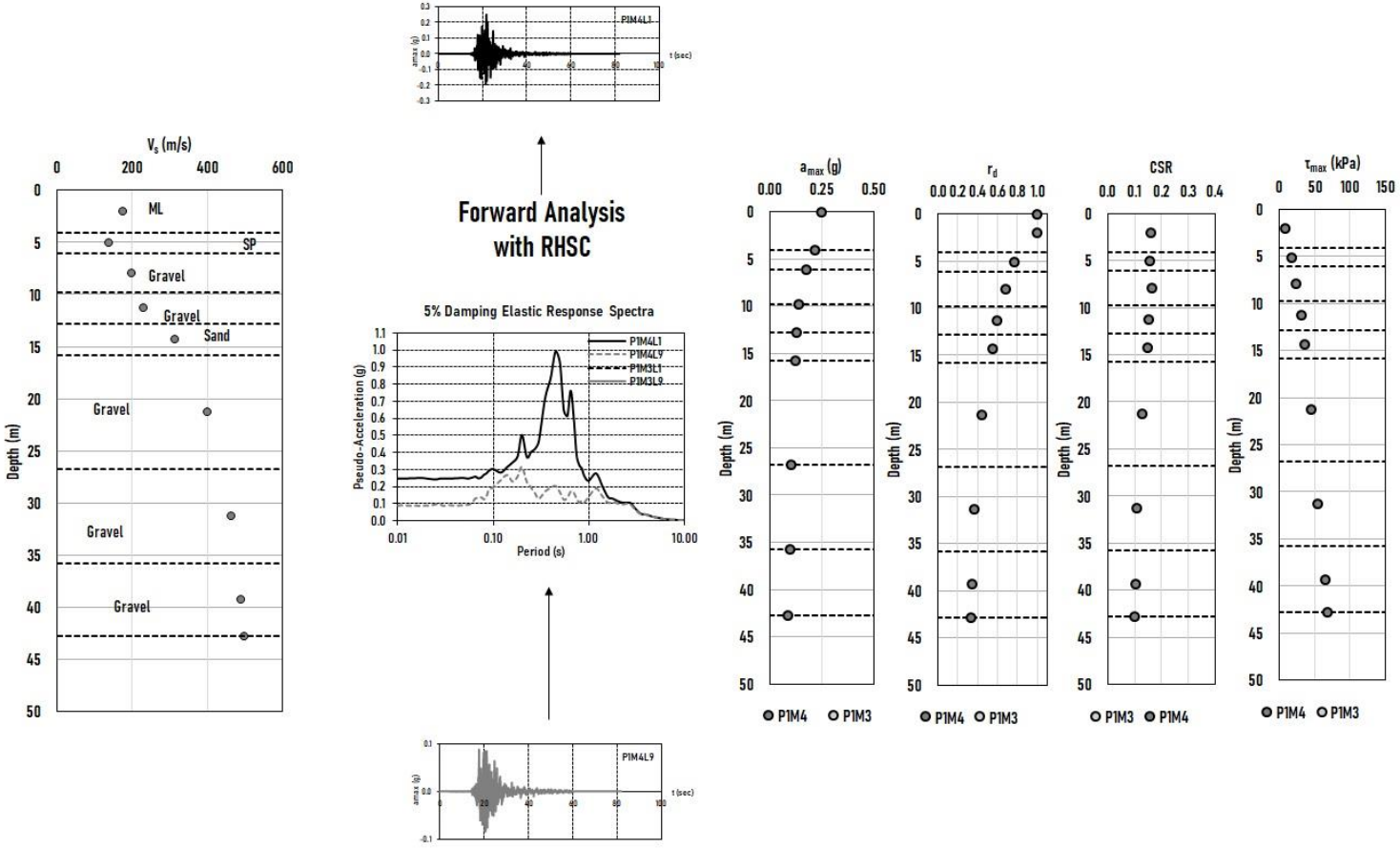

SW KAN 19 - 2010 Darfield Earthquake
P1M1L1
P1M2L1
Forward Analysis with KPOC
5% Damping Elastic Response Spectra
P1M1L1
P1M1L10
P1M2L1
P1M2L10
Pseudo-Acceleration (g)
Period (s)
V_s (m/s)
Depth (m)
ML
SP
SP
GP
GP
ML
GW
GW
GW
a_{max} (g)
r_d
CSR
τ_{max} (kPa)
P1M1 P1M2
P1M1L10
P1M2L10
t (sec)

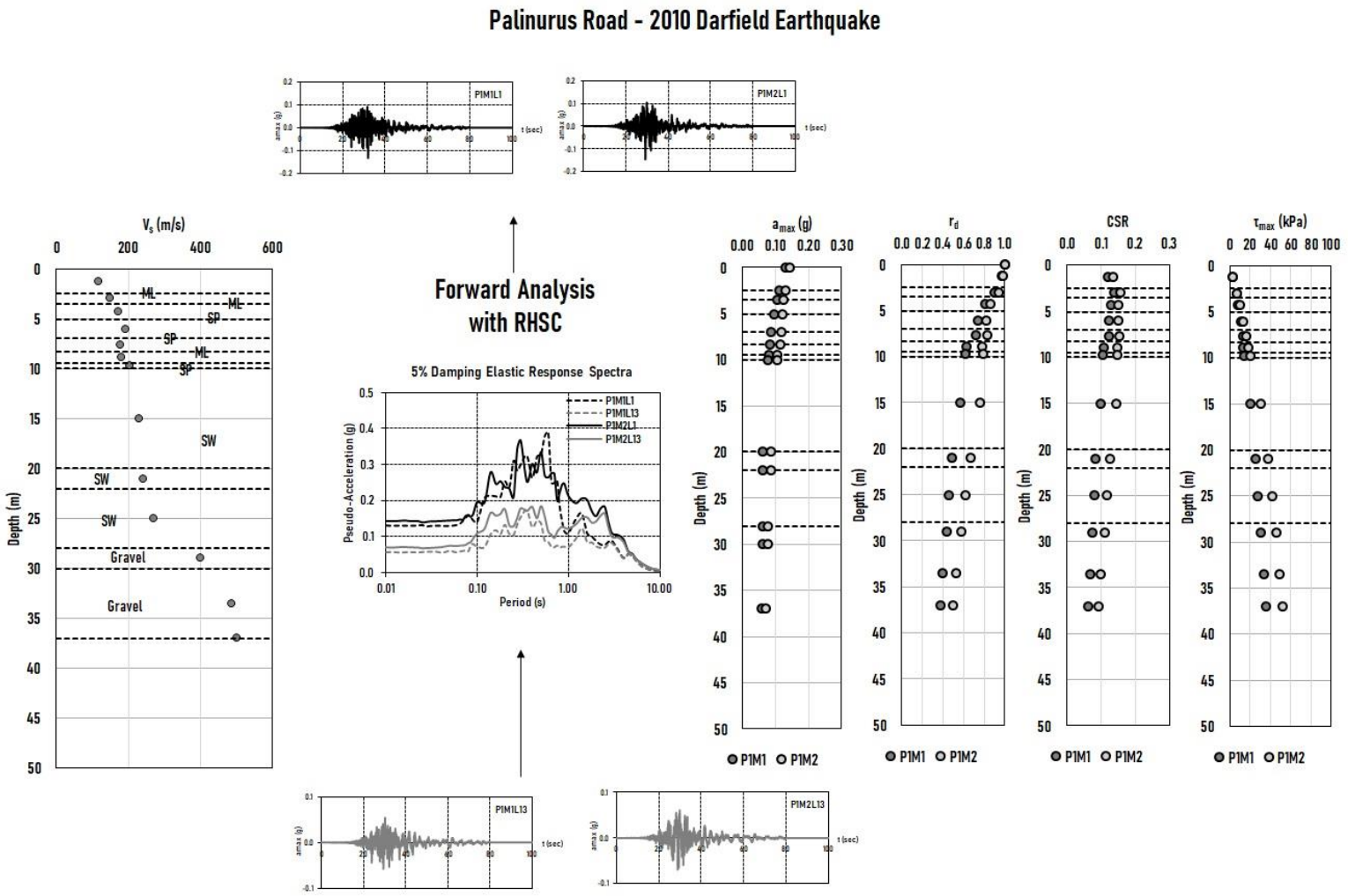
SW KAN 19 - 2011 Christchurch Earthquake



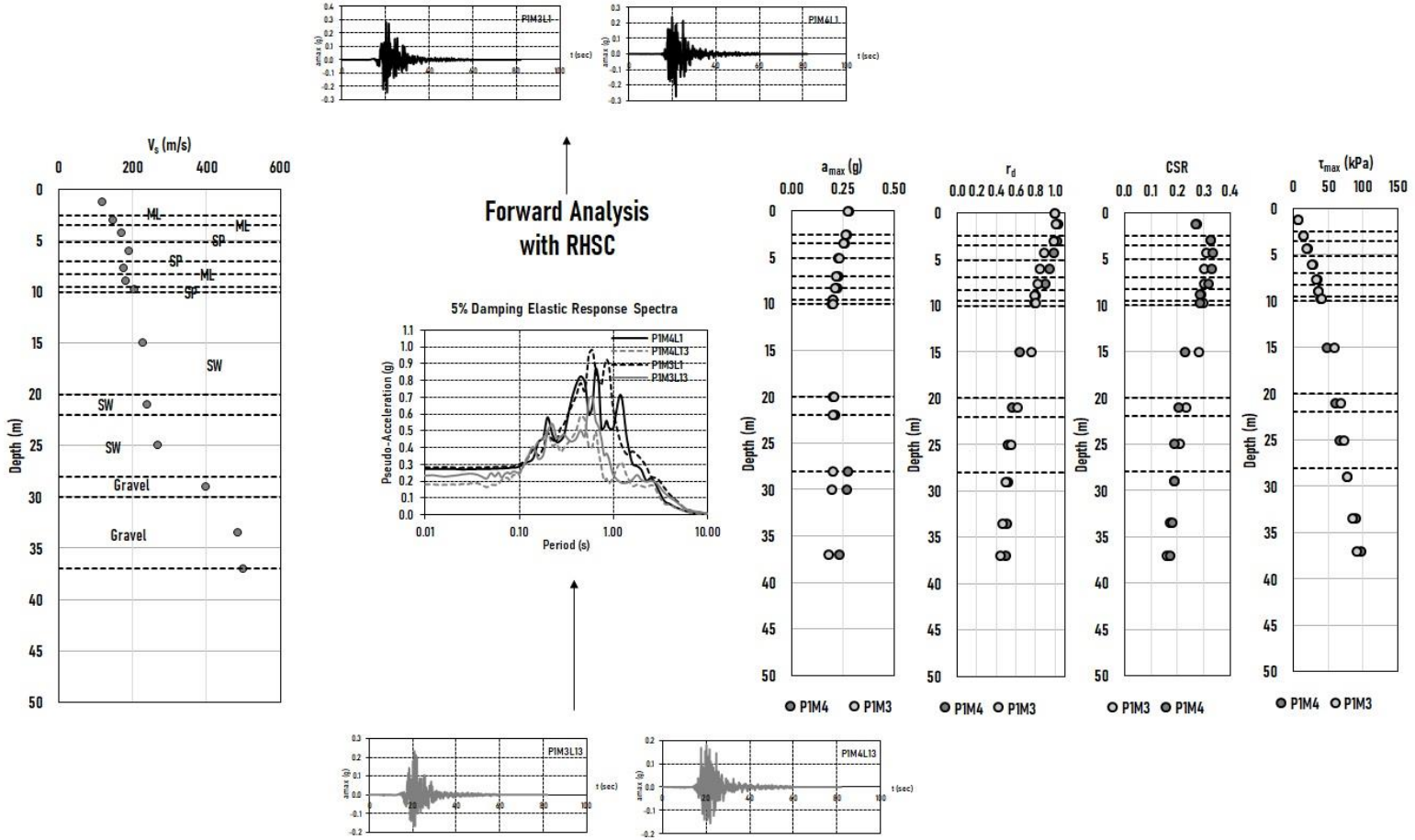

Normans RoadPapanui Road - 2010 Darfield Earthquake
P1M1L1
P1M2L1
Forward Analysis with RHSC
5% Damping Elastic Response Spectra
P1M1L1 - Damping (%) 0.05
Pseudo-Acceleration (g)
Period (s)
Vs (m/s)
ML
SP
Gravel
Gravel
Sand
Gravel
Gravel
Gravel
Depth (m)
amax (g)
rd
CSR
τmax (kPa)
P1M1
P1M2
P1M1L9
P1M2L9
t (sec)

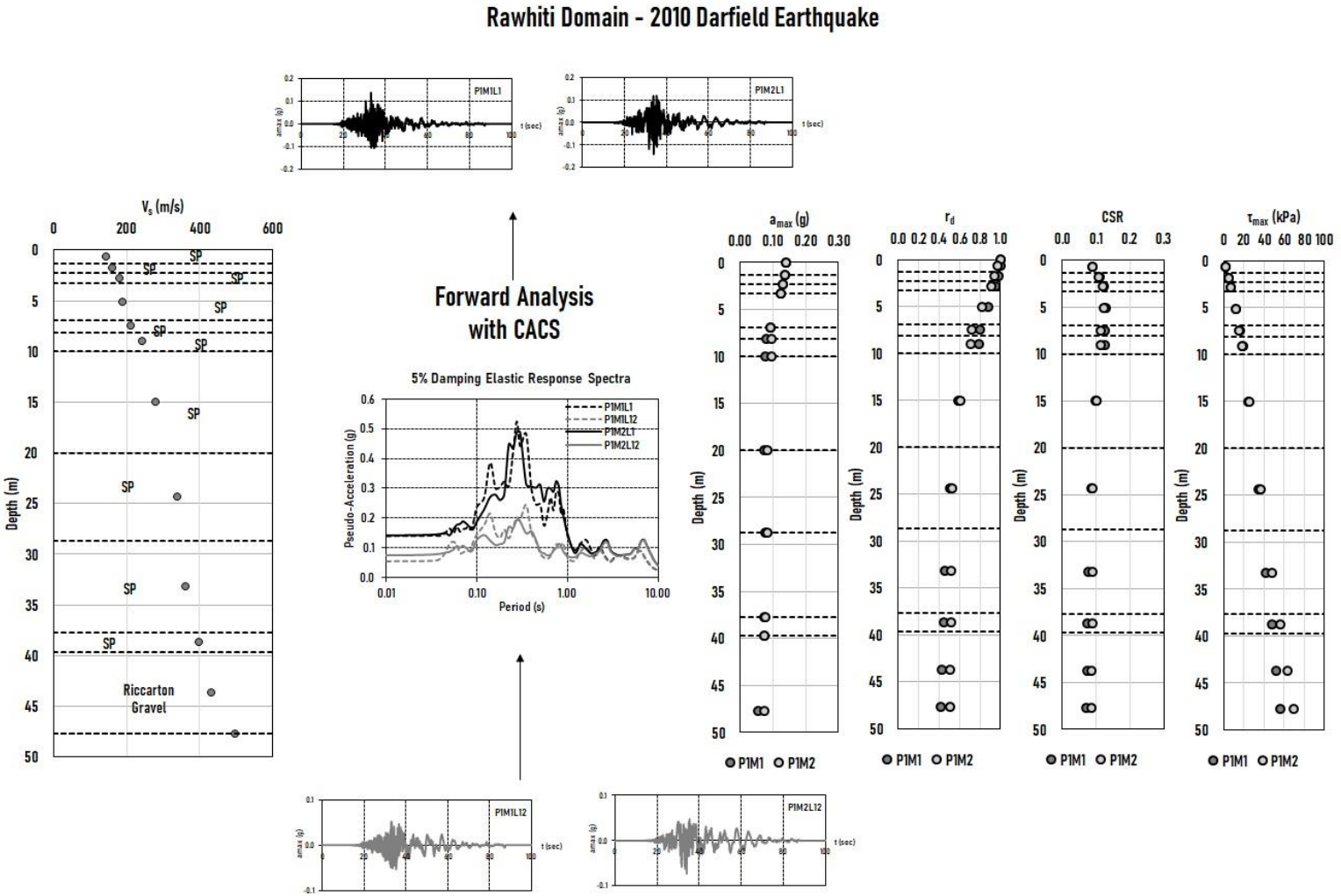
Normans RoadPapanui Road - 2011 Christchurch Earthquake

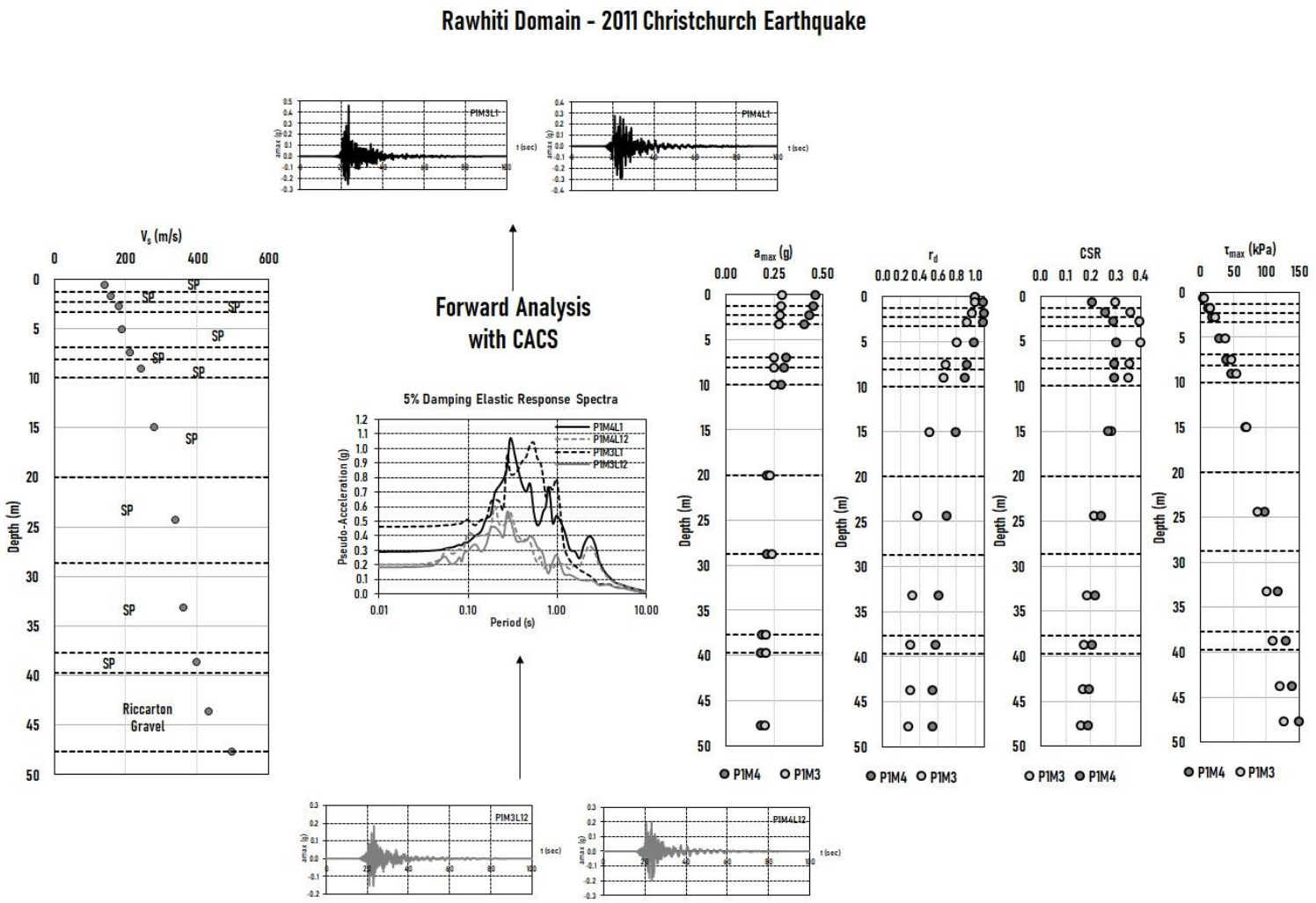


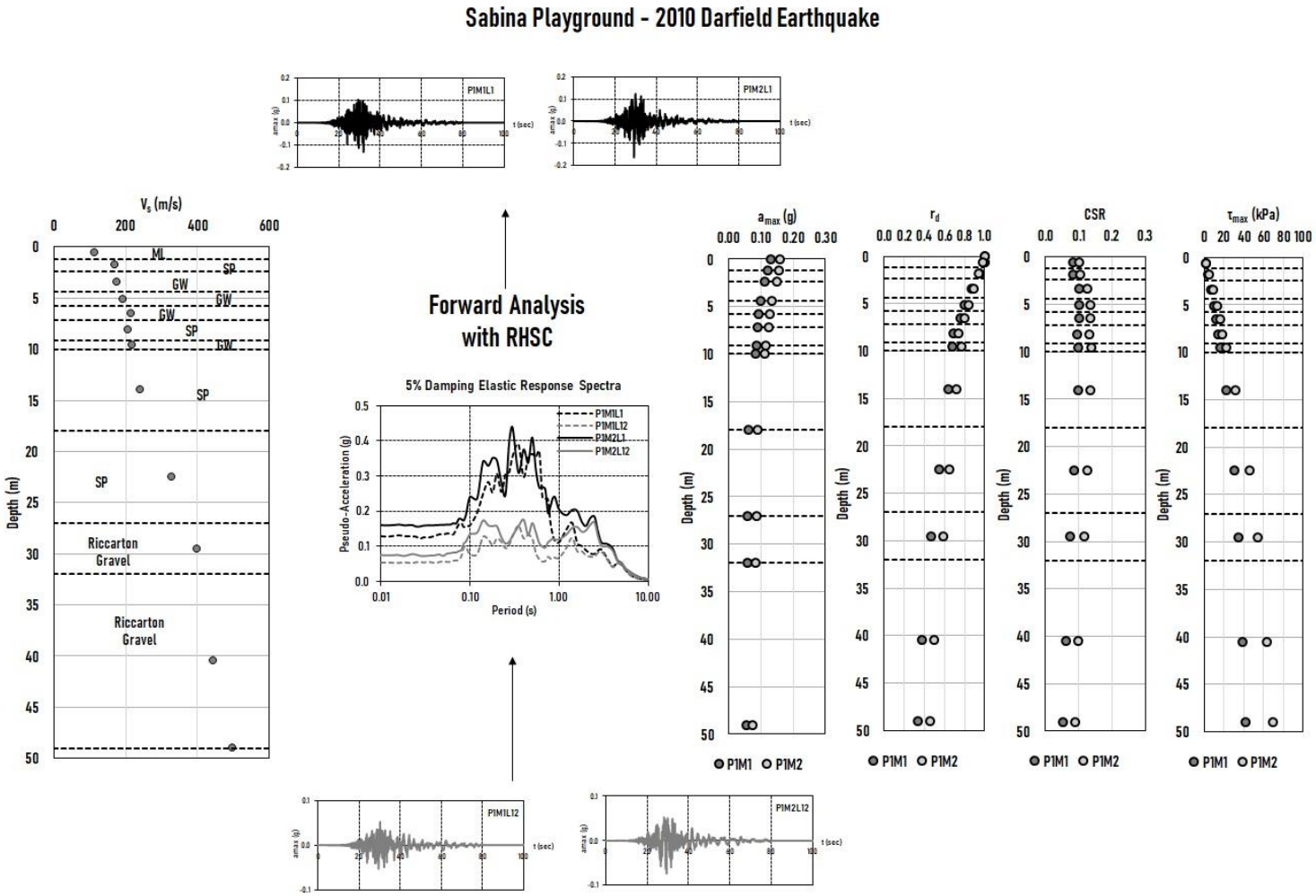

Palinurus Road - 2010 Darfield Earthquake
P1M1L1
P1M2L1
Forward Analysis with RHSC
5% Damping Elastic Response Spectra
P1M1L1
P1M1L13
P1M2L1
P1M2L13
Pseudo-Acceleration (g)
Period (s)
P1M1L13
P1M2L13
Vs (m/s)
Depth (m)
ML
SP
SW
Gravel
amax (g)
rd
CSR
τmax (kPa)
P1M1
P1M2

Palinurus Road - 2011 Christchurch Earthquake

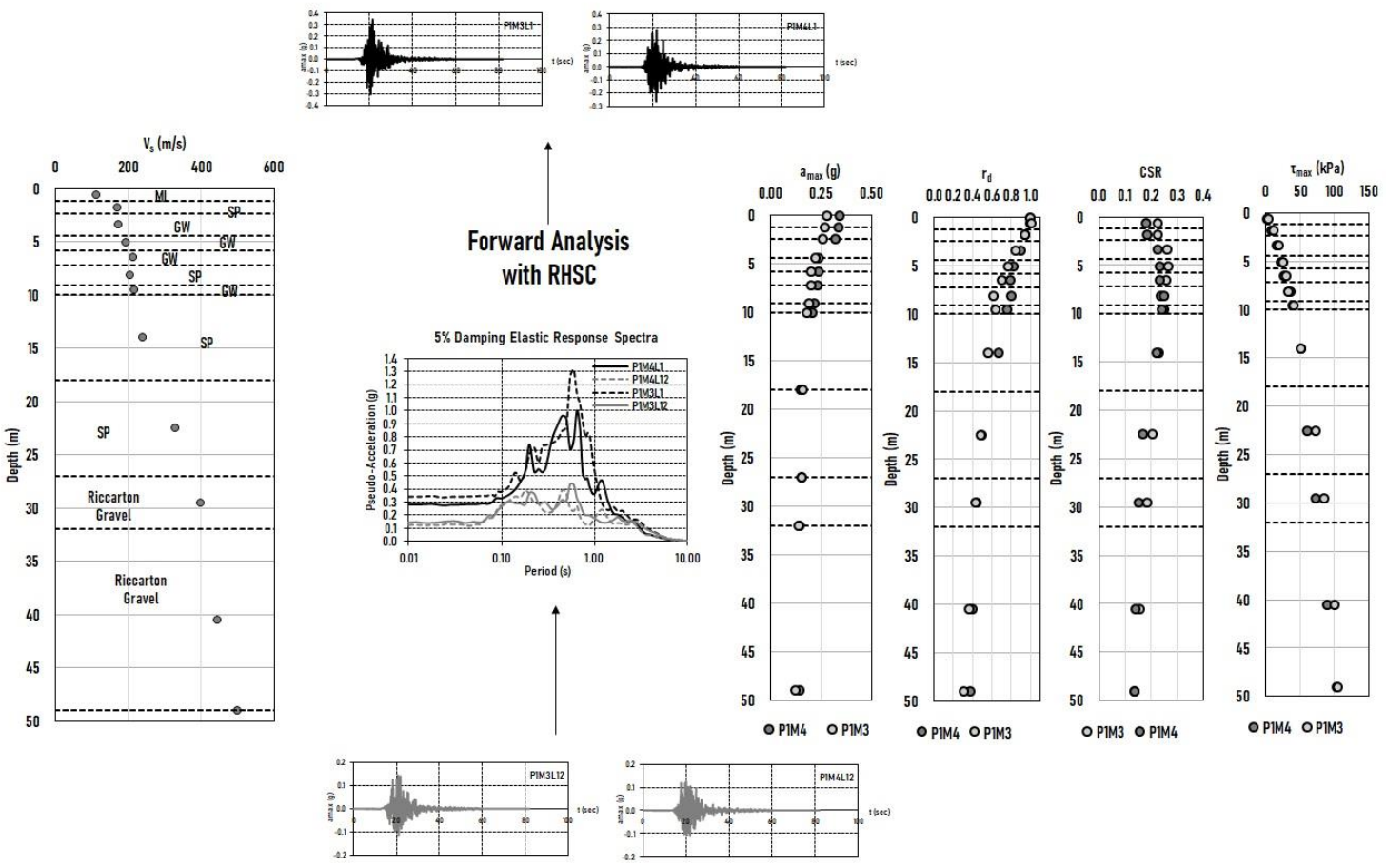


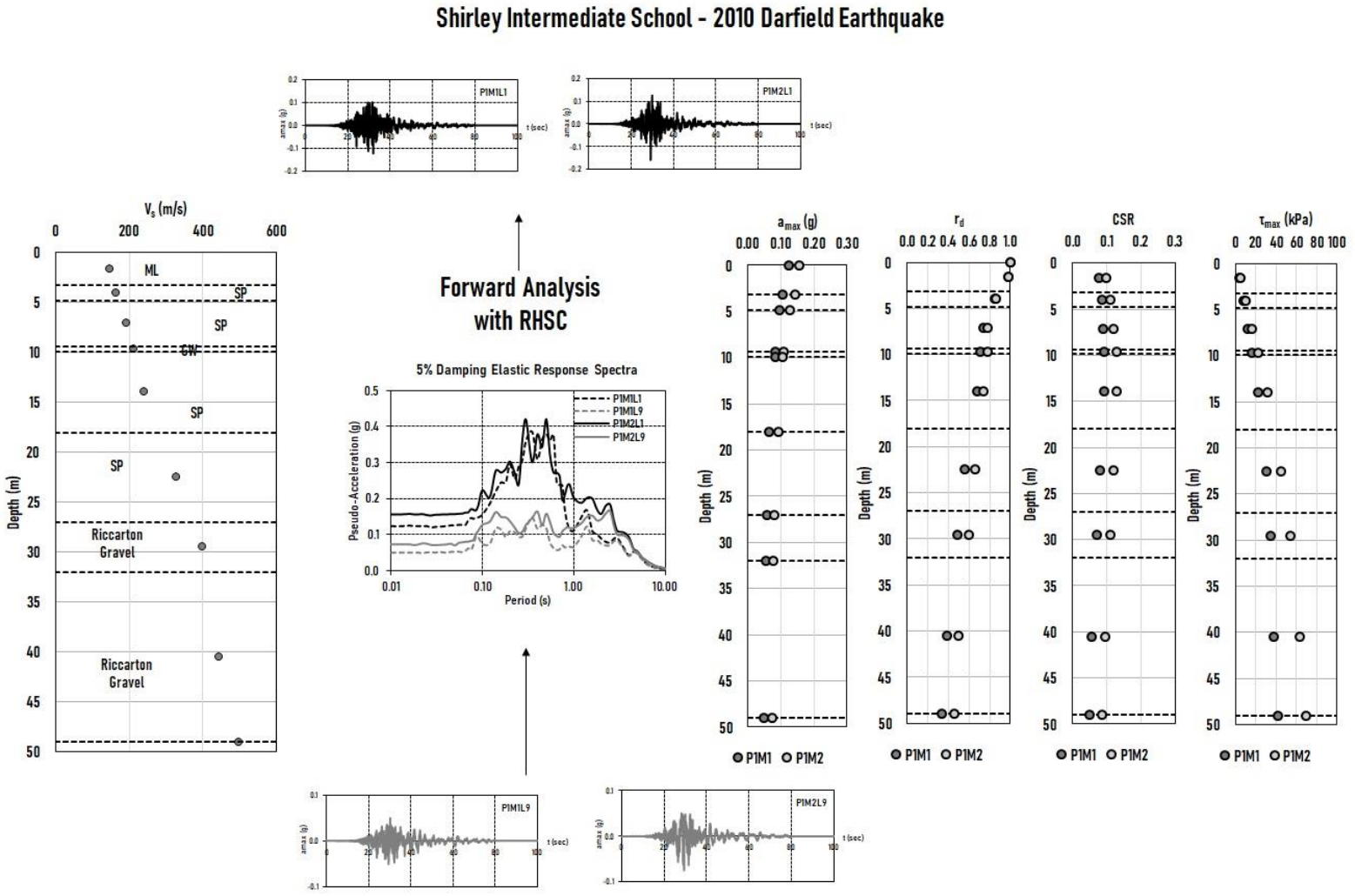

Rawhiti Domain - 2010 Darfield Earthquake
P1M1L1
P1M2L1
Forward Analysis with CACS
5% Damping Elastic Response Spectra
P1M1L1
P1M1L12
P1M2L1
P1M2L12
Pseudo-Acceleration (g)
Period (s)
Vs (m/s)
Depth (m)
SP
Riccarton Gravel
amax (g)
rd
CSR
τmax (kPa)
P1M1
P1M2
P1M1L12
P1M2L12


Rawhiti Domain - 2011 Christchurch Earthquake
P1M3L1
P1M4L1
t (sec)
Forward Analysis with CACS
5% Damping Elastic Response Spectra
P1M4L1
P1M4L12
P1M3L1
P1M3L12
Pseudo-Acceleration (g)
Period (s)
V_s (m/s)
Depth (m)
SP
Riccarton Gravel
a_{max} (g)
r_d
CSR
τ_{max} (kPa)
P1M4
P1M3
P1M3L12
P1M4L12

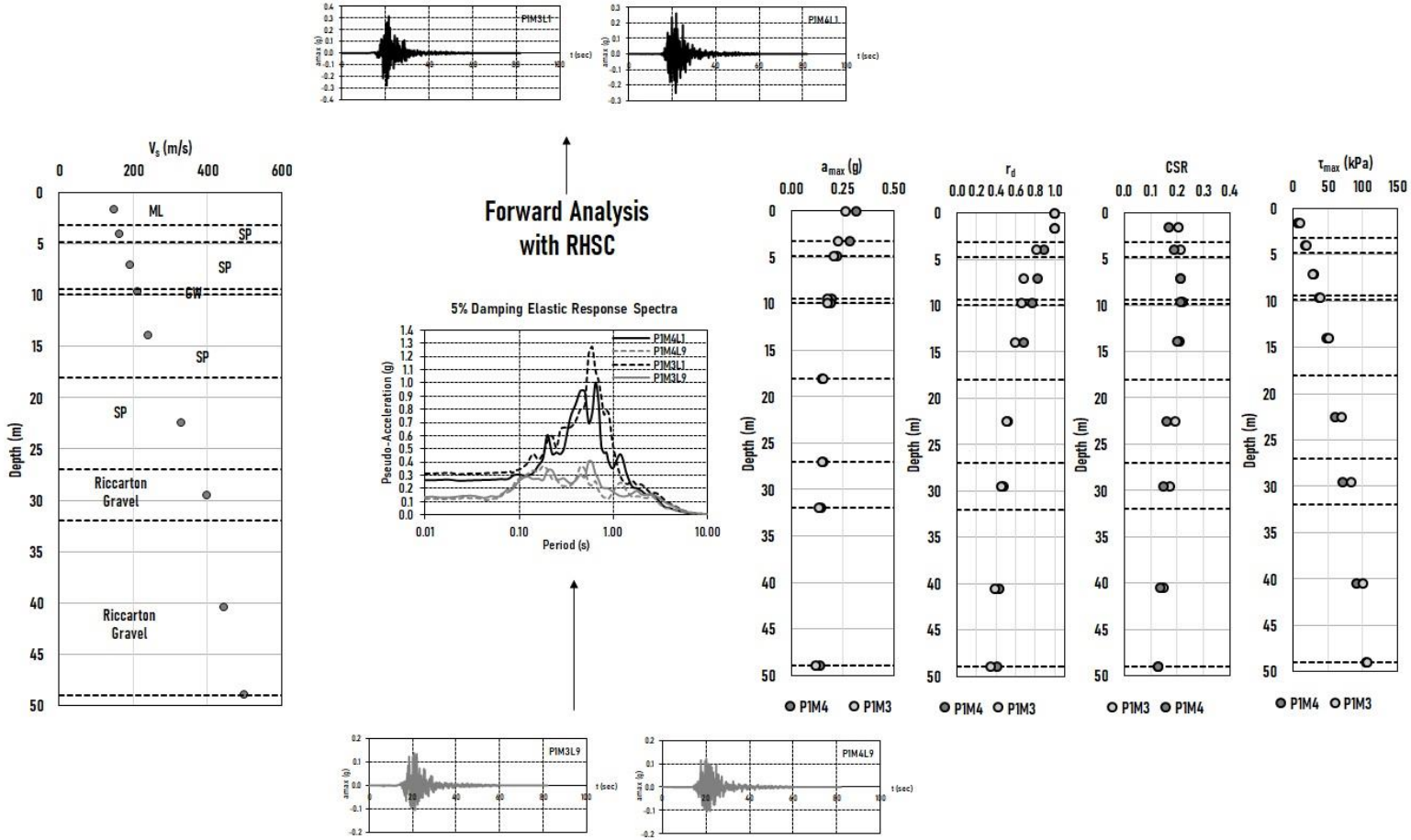

Sabina Playground - 2010 Darfield Earthquake
P1M1L1
P1M2L1
Forward Analysis
with RHSC
5% Damping Elastic Response Spectra
P1M1L1
P1M1L12
P1M2L1
P1M2L12
Pseudo-Acceleration (g)
Period (s)
V_s (m/s)
Depth (m)
ML
GW
SP
Riccarton
Gravel
a_{max} (g)
r_d
CSR
τ_{max} (kPa)
P1M1
P1M2
P1M1L12
P1M2L12

Sabina Playground - 2011 Christchurch Earthquake

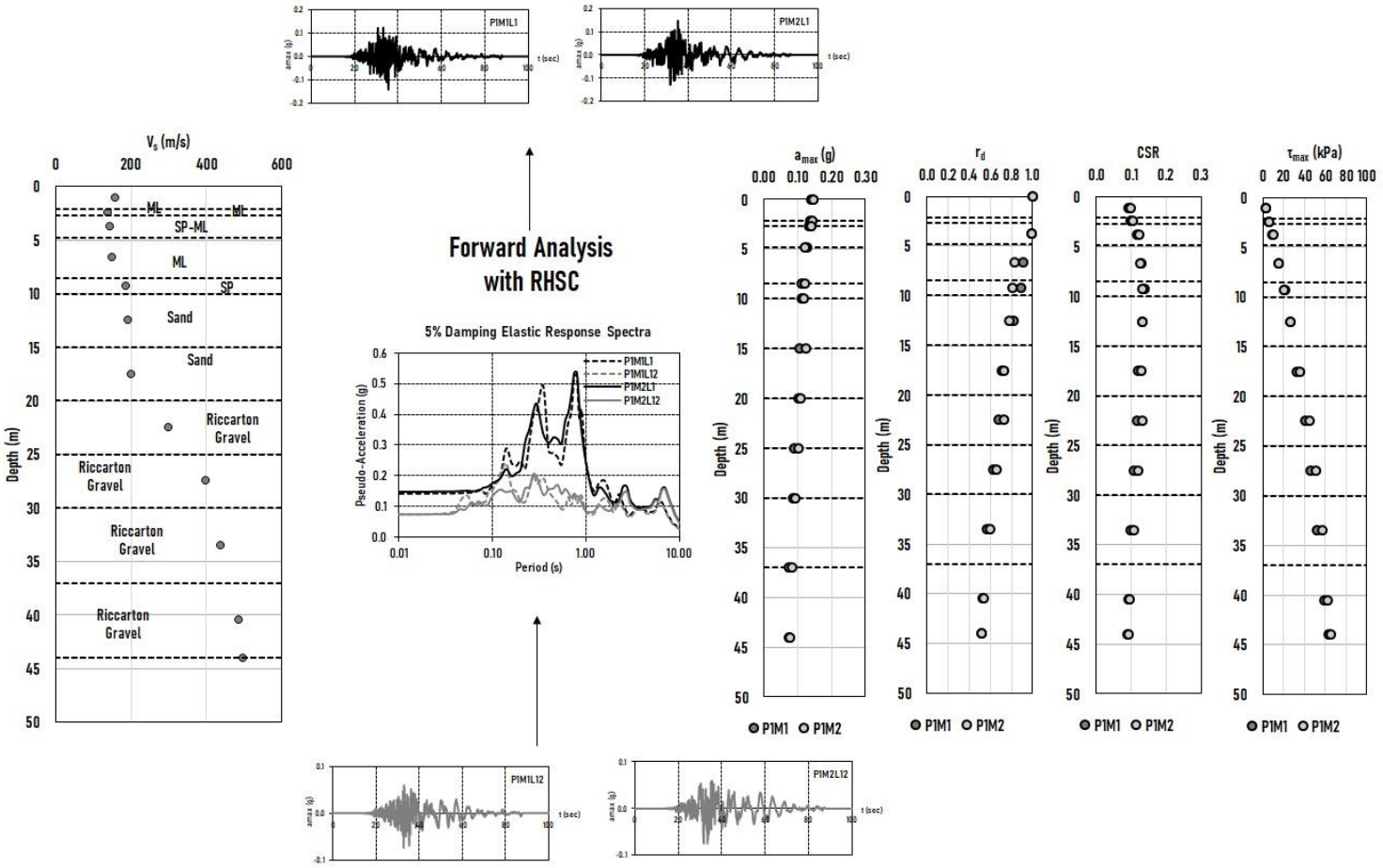



Shirley Intermediate School - 2010 Darfield Earthquake
P1M1L1
P1M2L1
Forward Analysis with RHSC
5% Damping Elastic Response Spectra
P1M1L1
P1M1L9
P1M2L1
P1M2L9
Pseudo-Acceleration (g)
Period (s)
P1M1L9
P1M2L9
t (sec)
V_s (m/s)
ML
SP
SP
GW
SP
SP
Riccarton Gravel
Riccarton Gravel
Depth (m)
a_{max} (g)
r_d
CSR
τ_{max} (kPa)
P1M1
P1M2

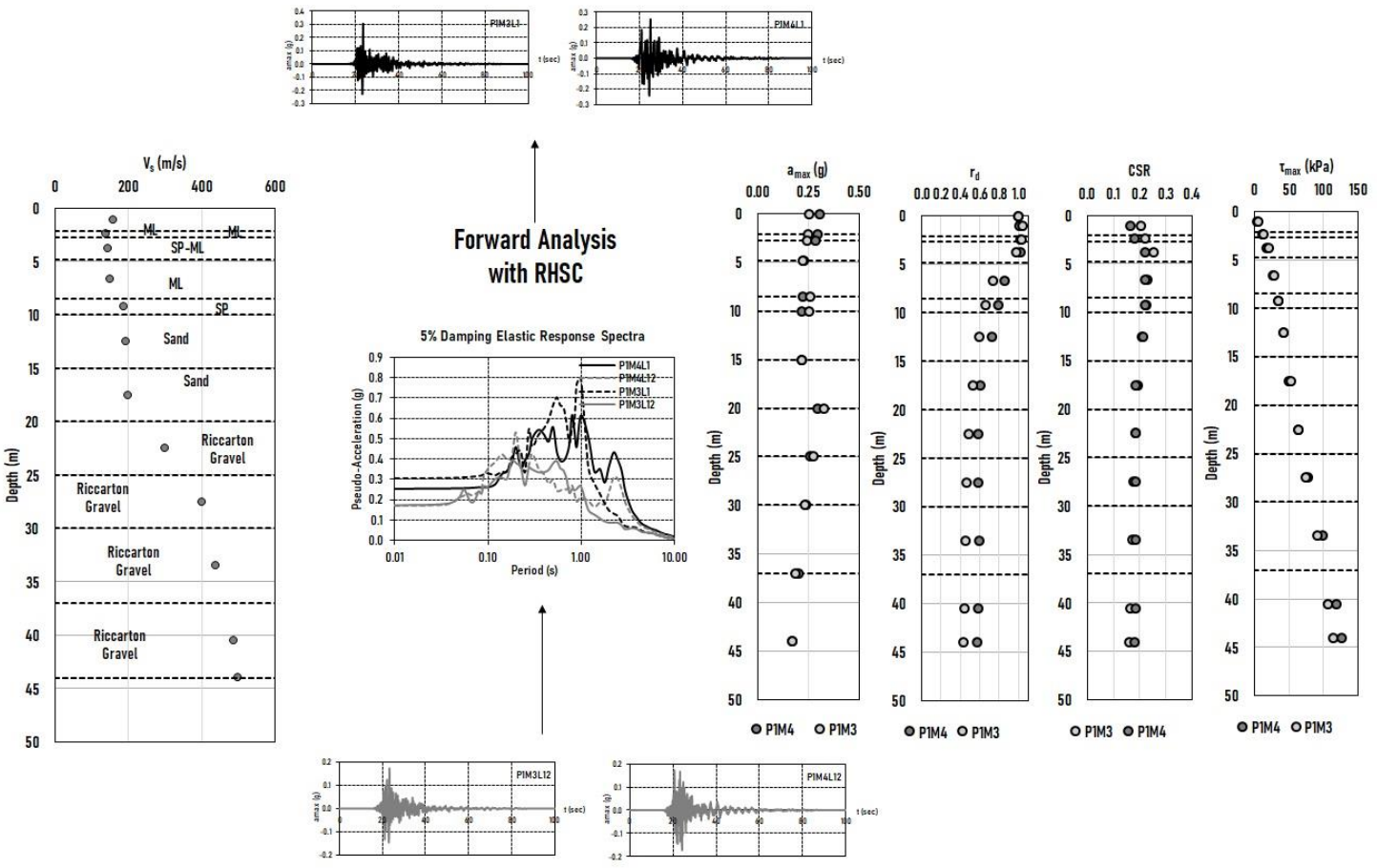
Shirley Intermediate School - 2011 Christchurch Earthquake

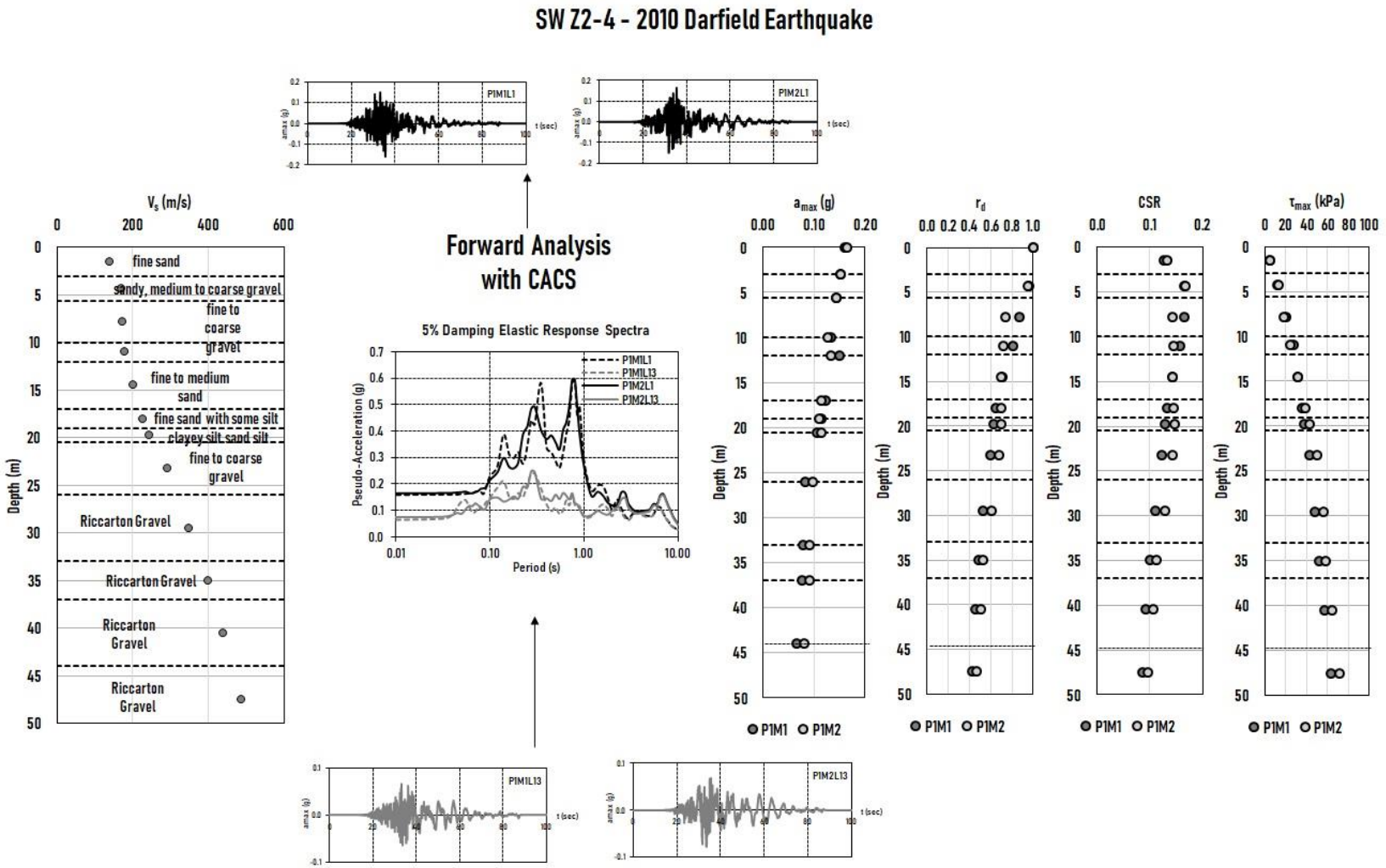


St. Albans Catholic School - 2010 Darfield Earthquake

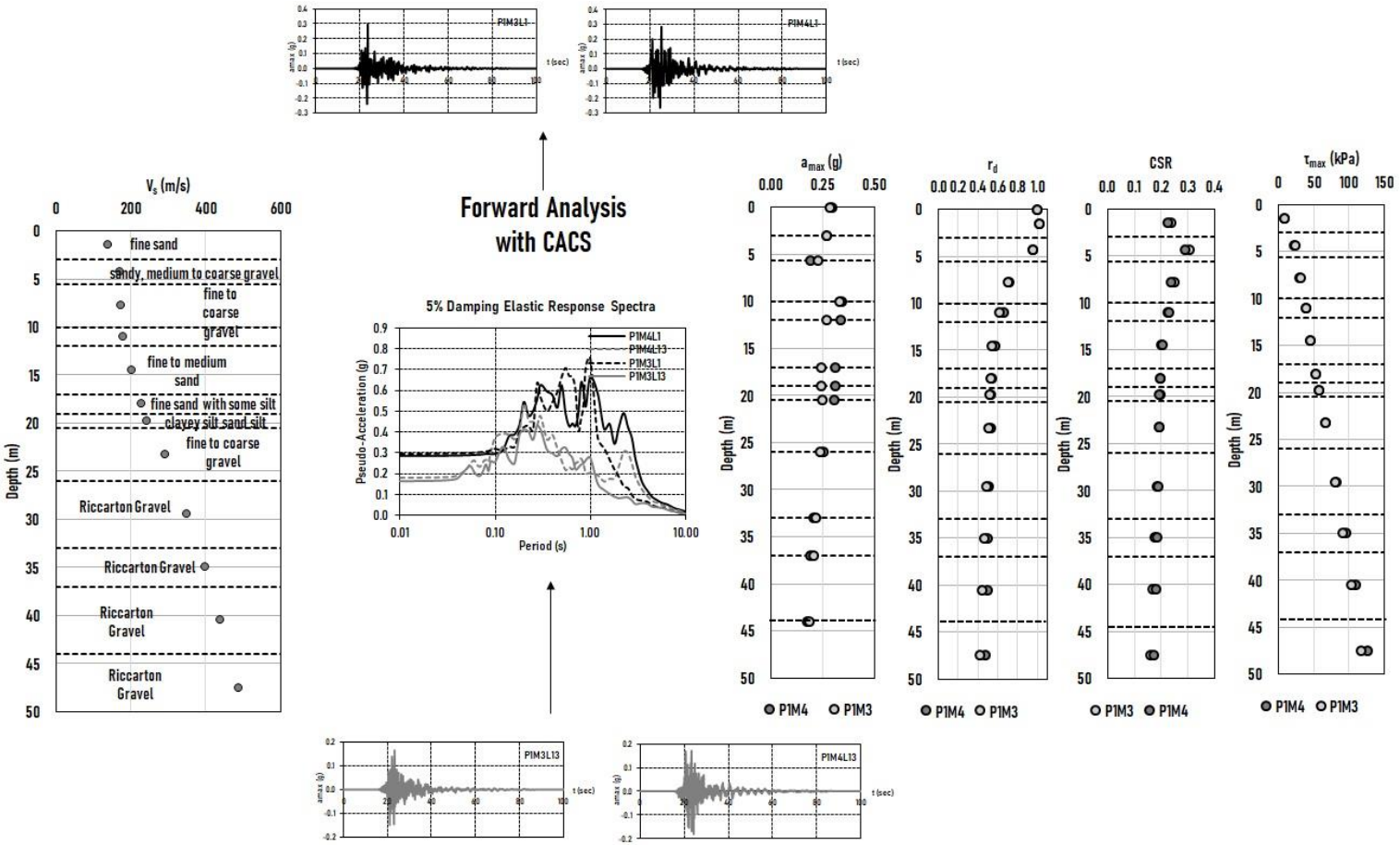


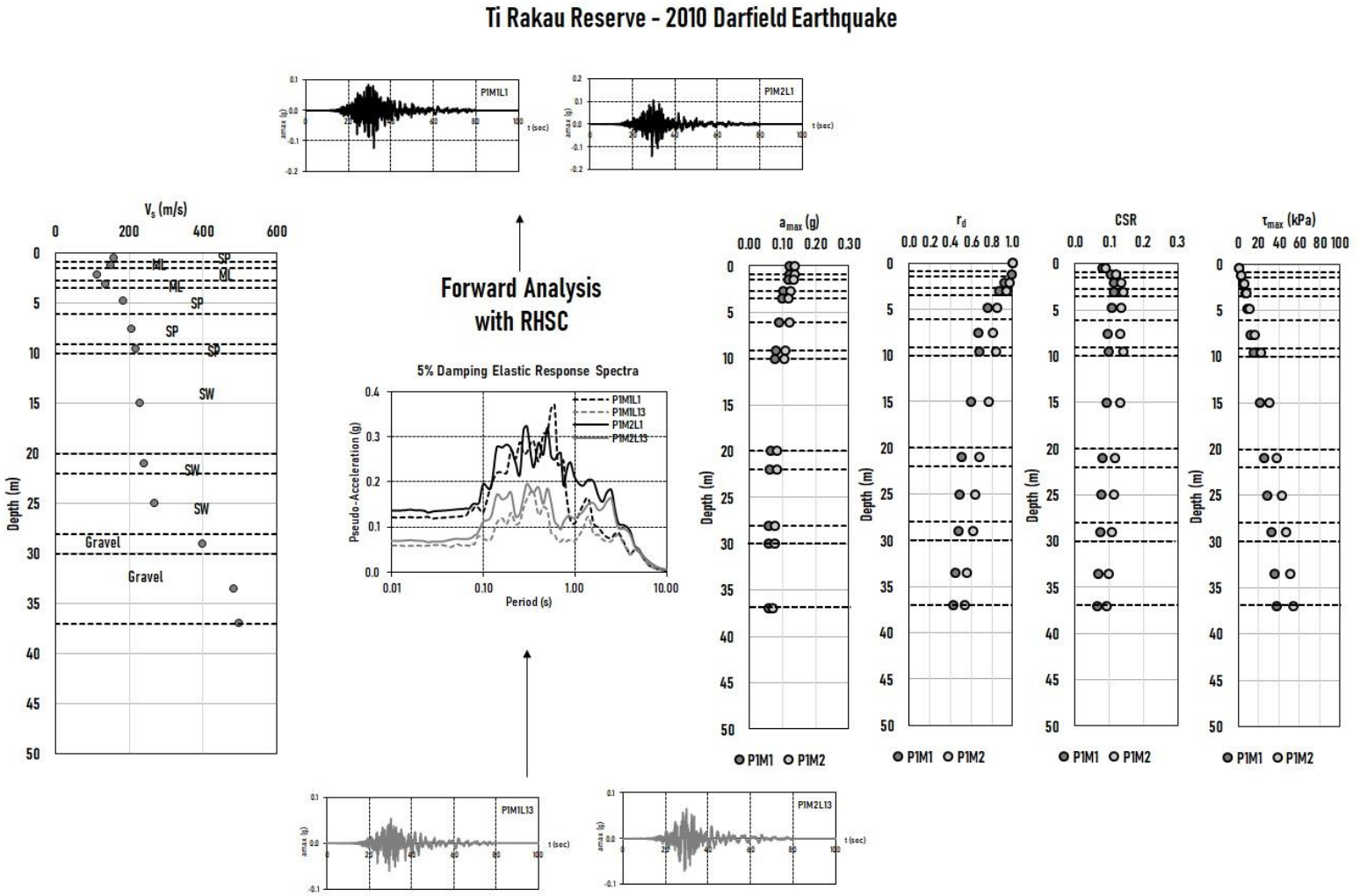
St. Albans Catholic School - 2011 Christchurch Earthquake

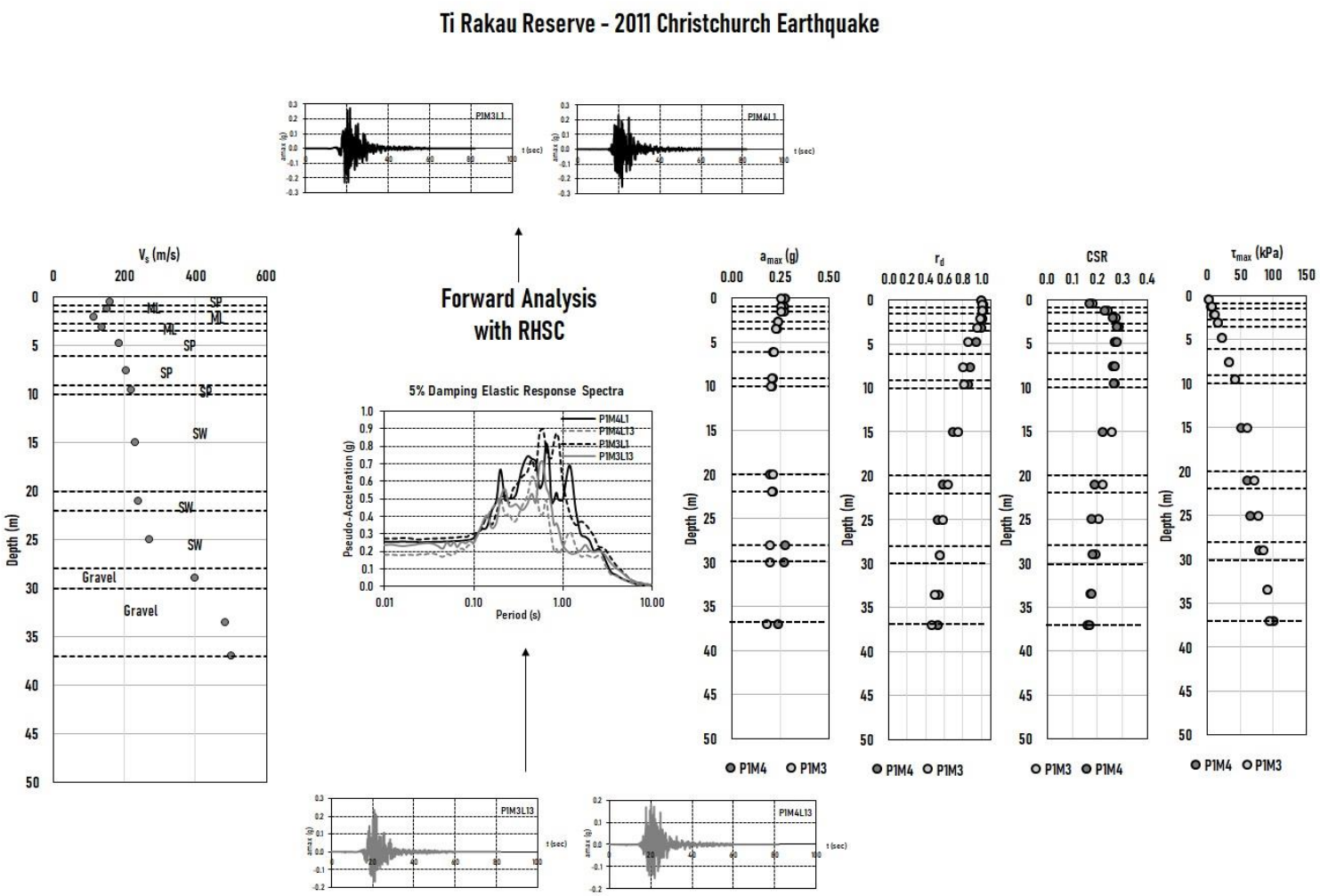


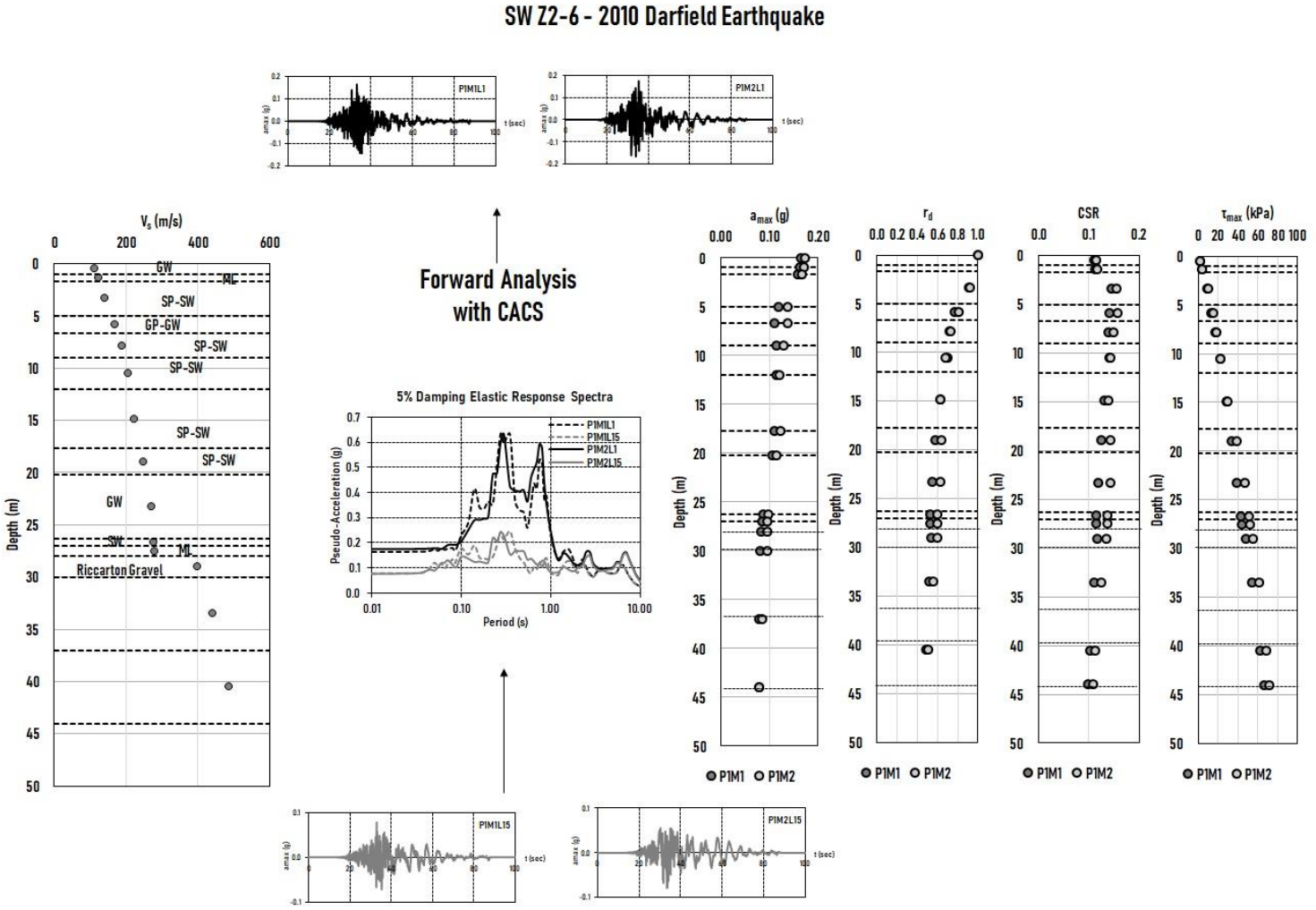

SW Z2-4 - 2010 Darfield Earthquake
P1M1L1
P1M2L1
Forward Analysis with CACS
5% Damping Elastic Response Spectra
P1M1L1
P1M1L13
P1M2L1
P1M2L13
Pseudo-Acceleration (g)
Period (s)
P1M1L13
P1M2L13
t (sec)
Vs (m/s)
fine sand
sandy, medium to coarse gravel
fine to coarse gravel
fine to medium sand
fine sand with some silt
clayey silt sand silt
fine to coarse gravel
Riccarton Gravel
Riccarton Gravel
Riccarton Gravel
Riccarton Gravel
Depth (m)
amax (g)
rd
CSR
τmax (kPa)
P1M1
P1M2

SW Z2-4 - 2011 Christchurch Earthquake

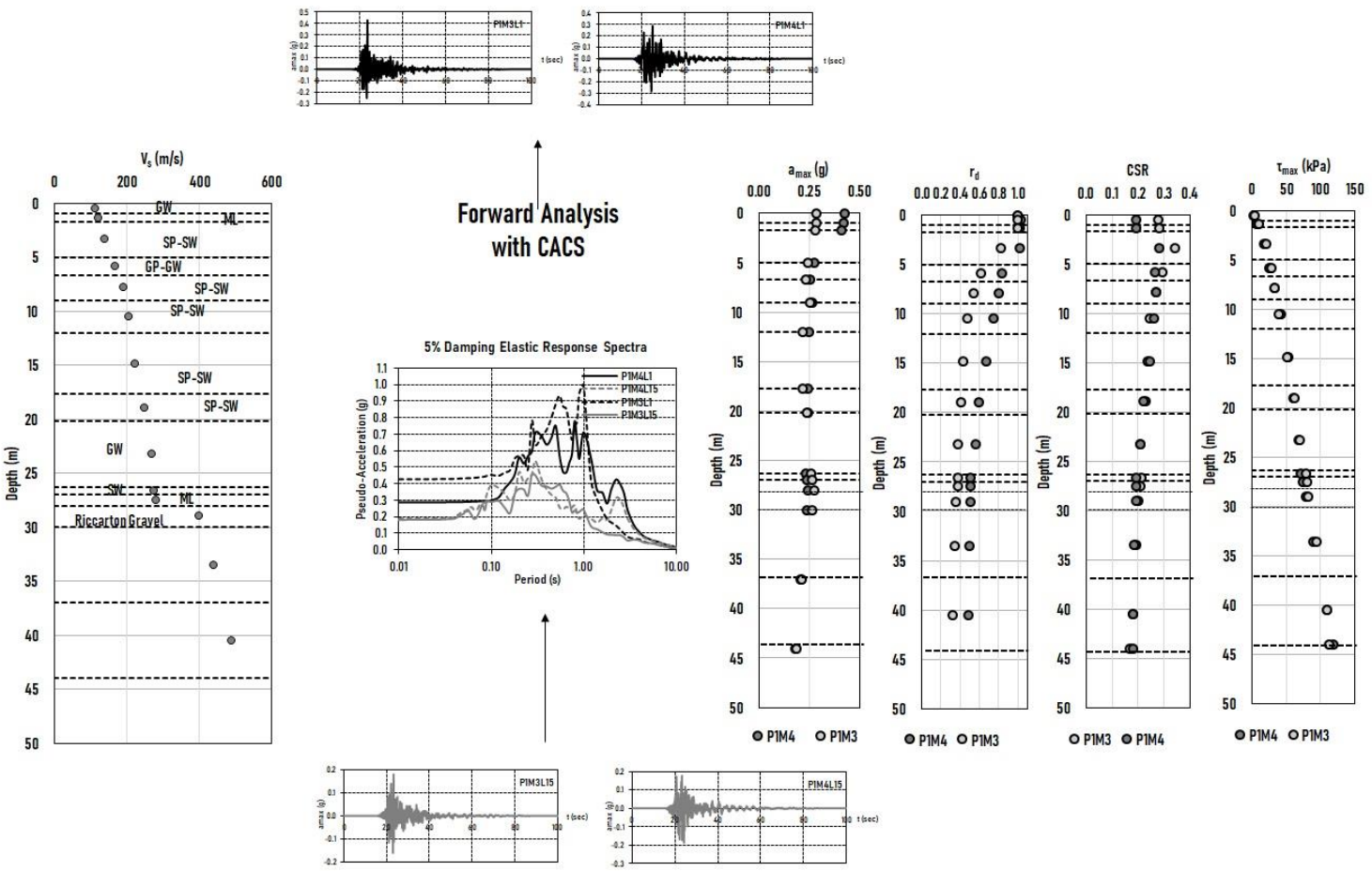


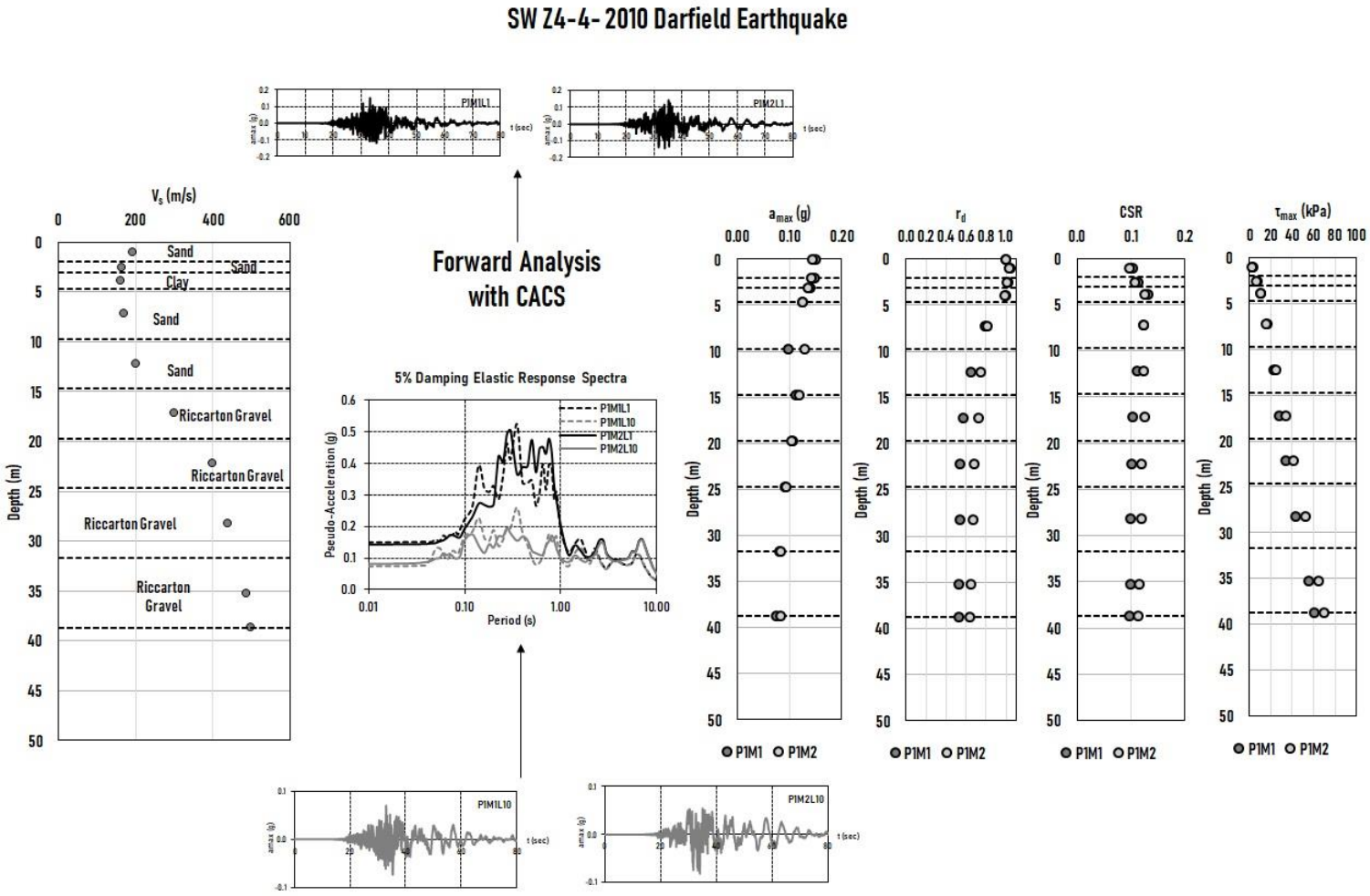

Ti Rakau Reserve - 2010 Darfield Earthquake
P1M1L1
P1M2L1
Forward Analysis with RHSC
5% Damping Elastic Response Spectra
P1M1L1
P1M1L13
P1M2L1
P1M2L13
Pseudo-Acceleration (g)
Period (s)
V_s (m/s)
Depth (m)
Gravel
a_{max} (g)
r_d
CSR
τ_{max} (kPa)
P1M1 P1M2
P1M1L13
P1M2L13


Ti Rakau Reserve - 2011 Christchurch Earthquake
P1M3L1
P1M4L1
Forward Analysis with RHSC
5% Damping Elastic Response Spectra
P1M4L1
P1M4L13
P1M3L1
P1M3L13
Pseudo-Acceleration (g)
Period (s)
V_s (m/s)
Depth (m)
Gravel
a_{max} (g)
r_d
CSR
τ_{max} (kPa)
P1M4
P1M3
P1M3L13
P1M4L13

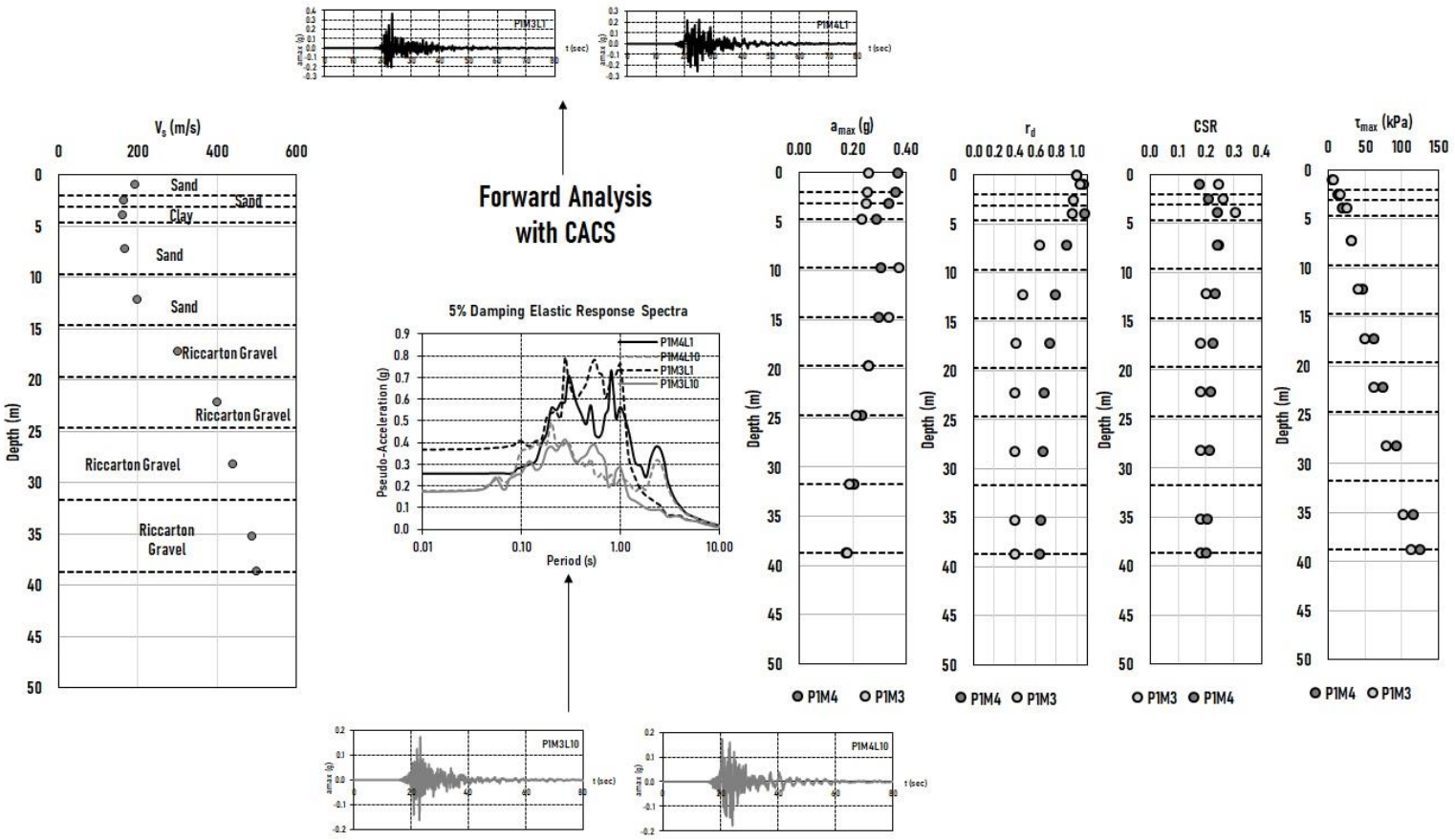

SW Z2-6 - 2010 Darfield Earthquake
P1M1L1
P1M2L1
Forward Analysis with CACS
5% Damping Elastic Response Spectra
P1M1L1
P1M1L15
P1M2L1
P1M2L15
Pseudo-Acceleration (g)
Period (s)
P1M1L15
P1M2L15
Vs (m/s)
GW
ML
SP-SW
GP-GW
SP-SW
SP-SW
SP-SW
SP-SW
GW
SW
ML
Riccarton Gravel
Depth (m)
amax (g)
rd
CSR
τmax (kPa)
P1M1
P1M2

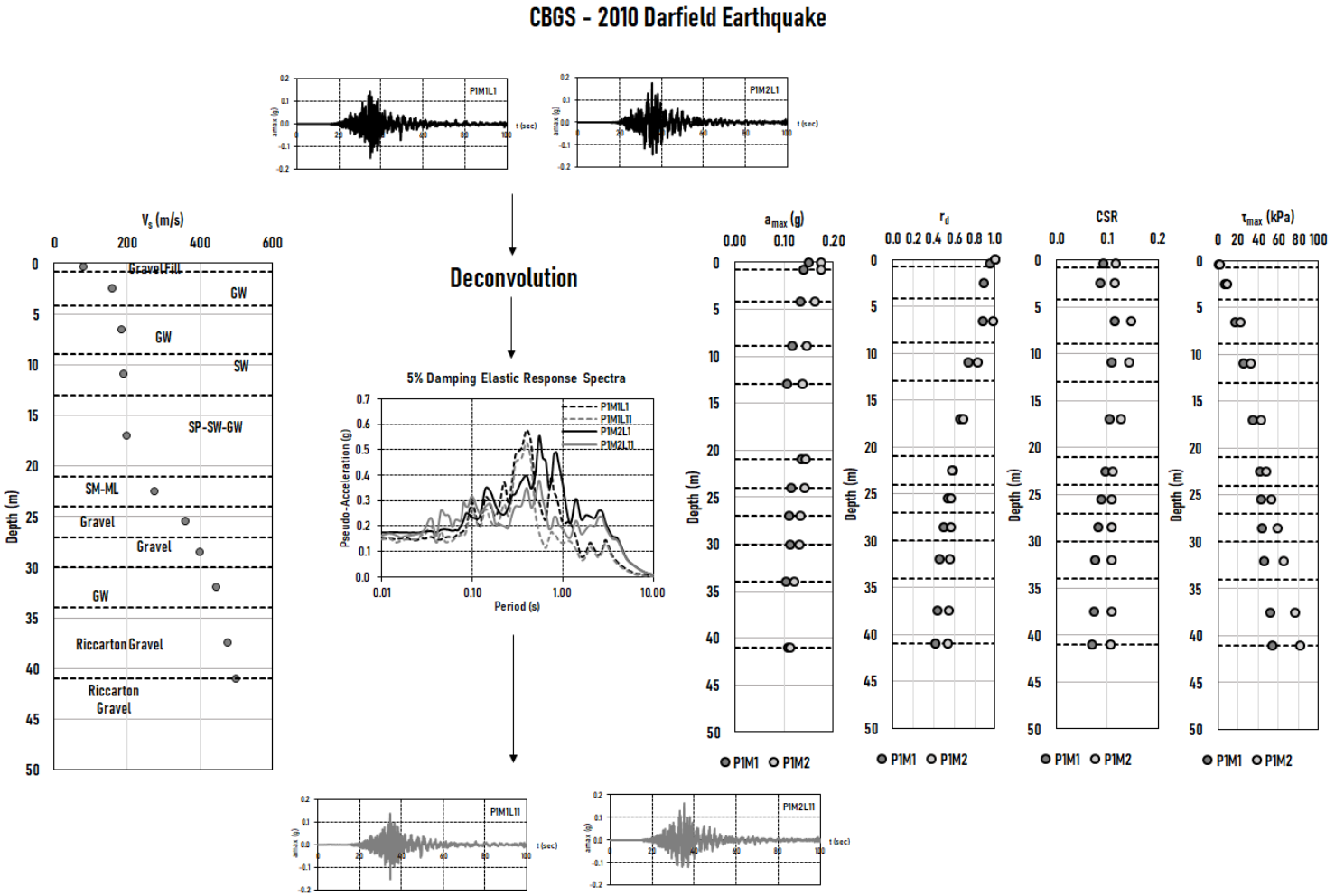
SW Z2-6 - 2011 Christchurch Earthquake

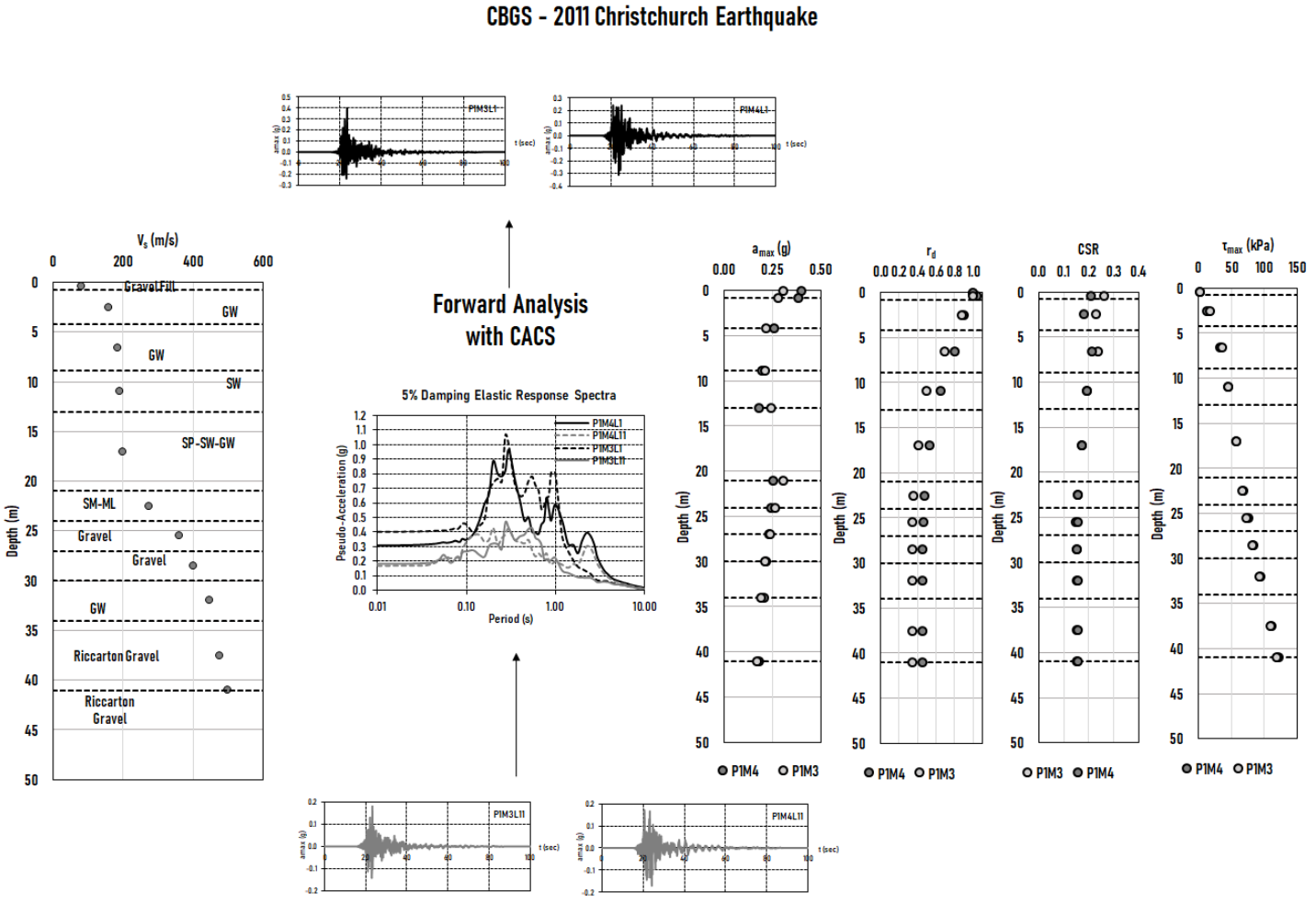


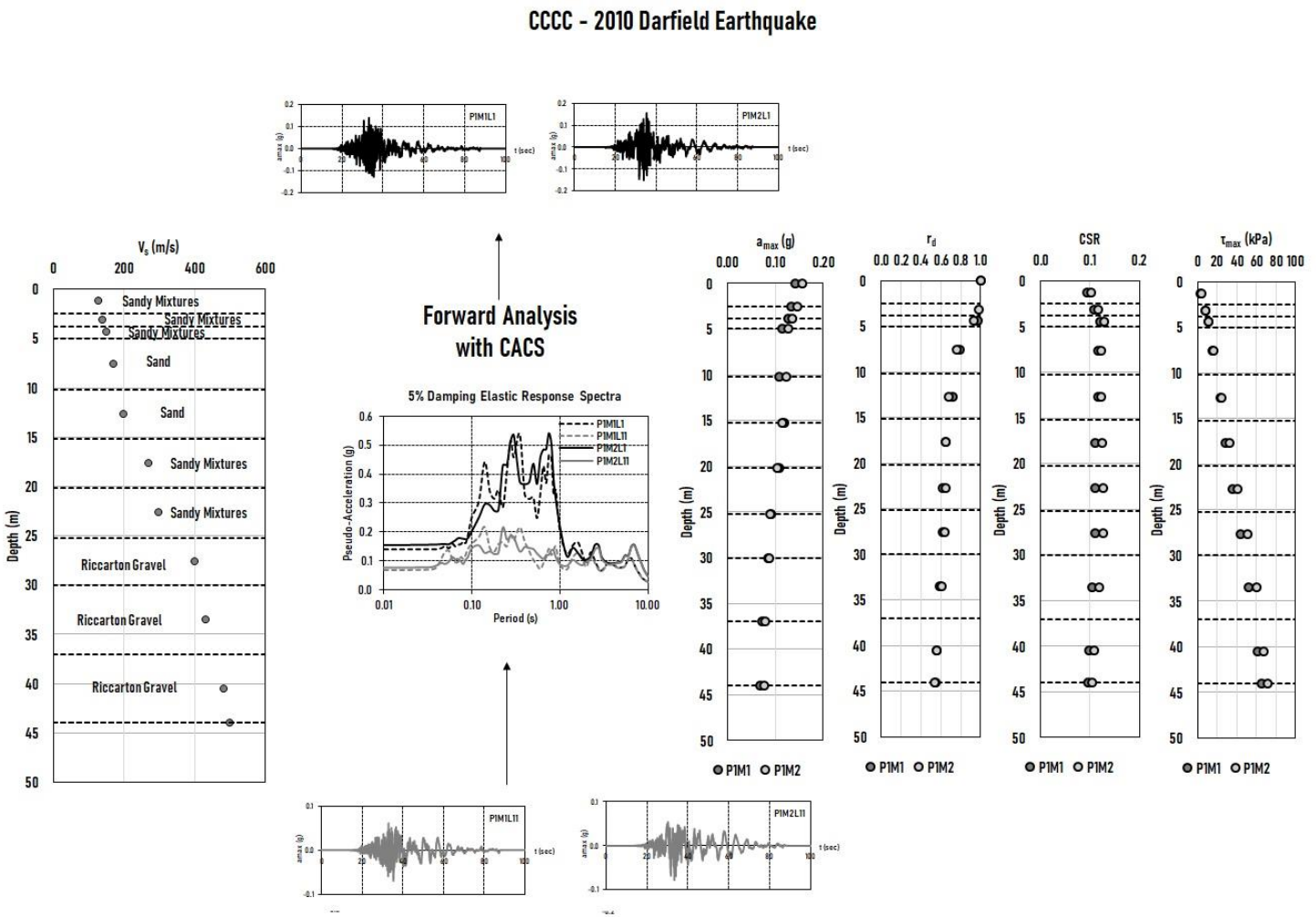

SW Z4-4- 2010 Darfield Earthquake
P1M1L1
P1M2L1
Forward Analysis
with CACS
Vs (m/s)
Sand
Clay
Riccarton Gravel
5% Damping Elastic Response Spectra
P1M1L1
P1M1L10
P1M2L1
P1M2L10
Pseudo-Acceleration (g)
Period (s)
amax (g)
rd
CSR
τmax (kPa)
Depth (m)
P1M1
P1M2
P1M1L10
P1M2L10

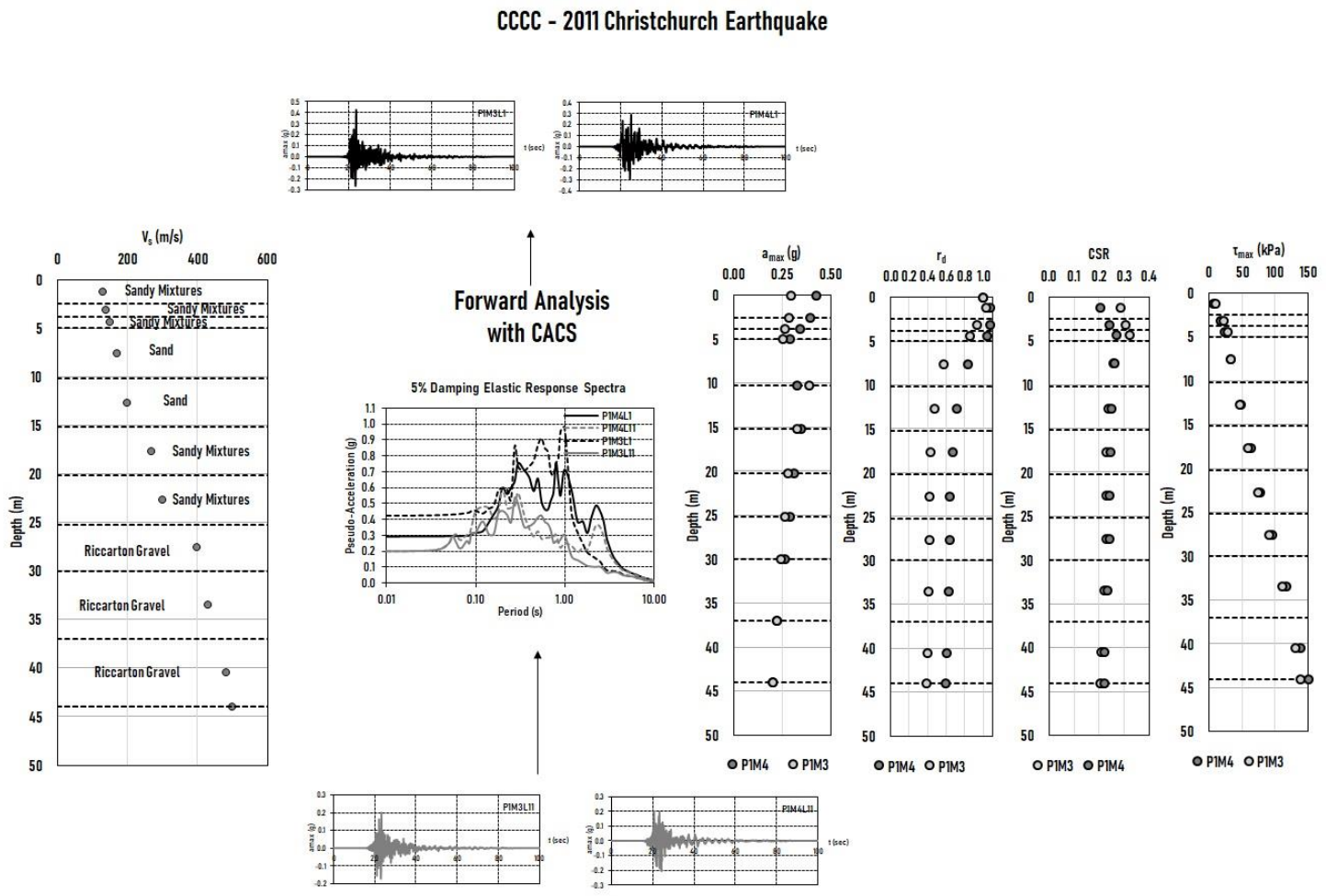
SW Z4-4- 2011 Christchurch Earthquake

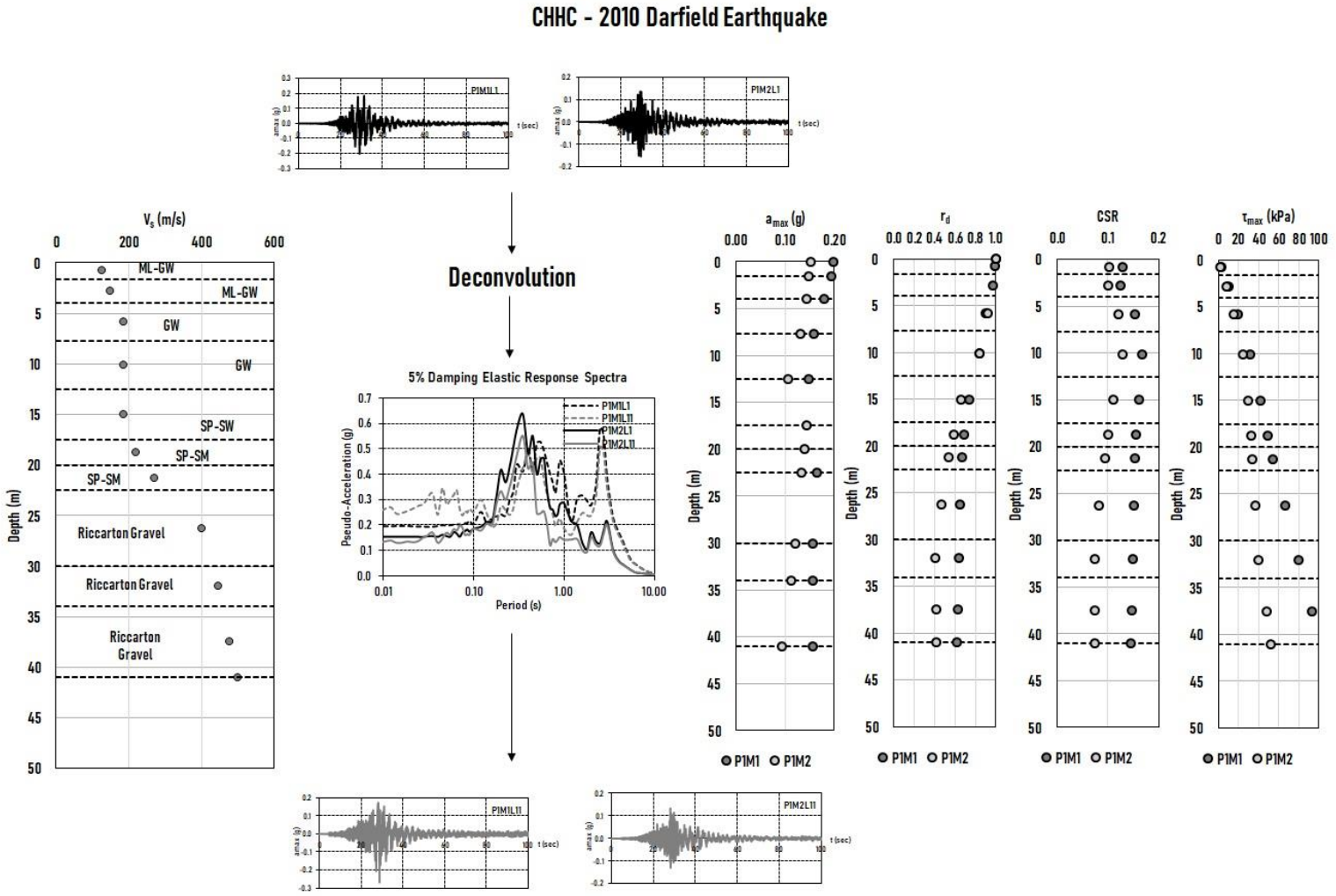


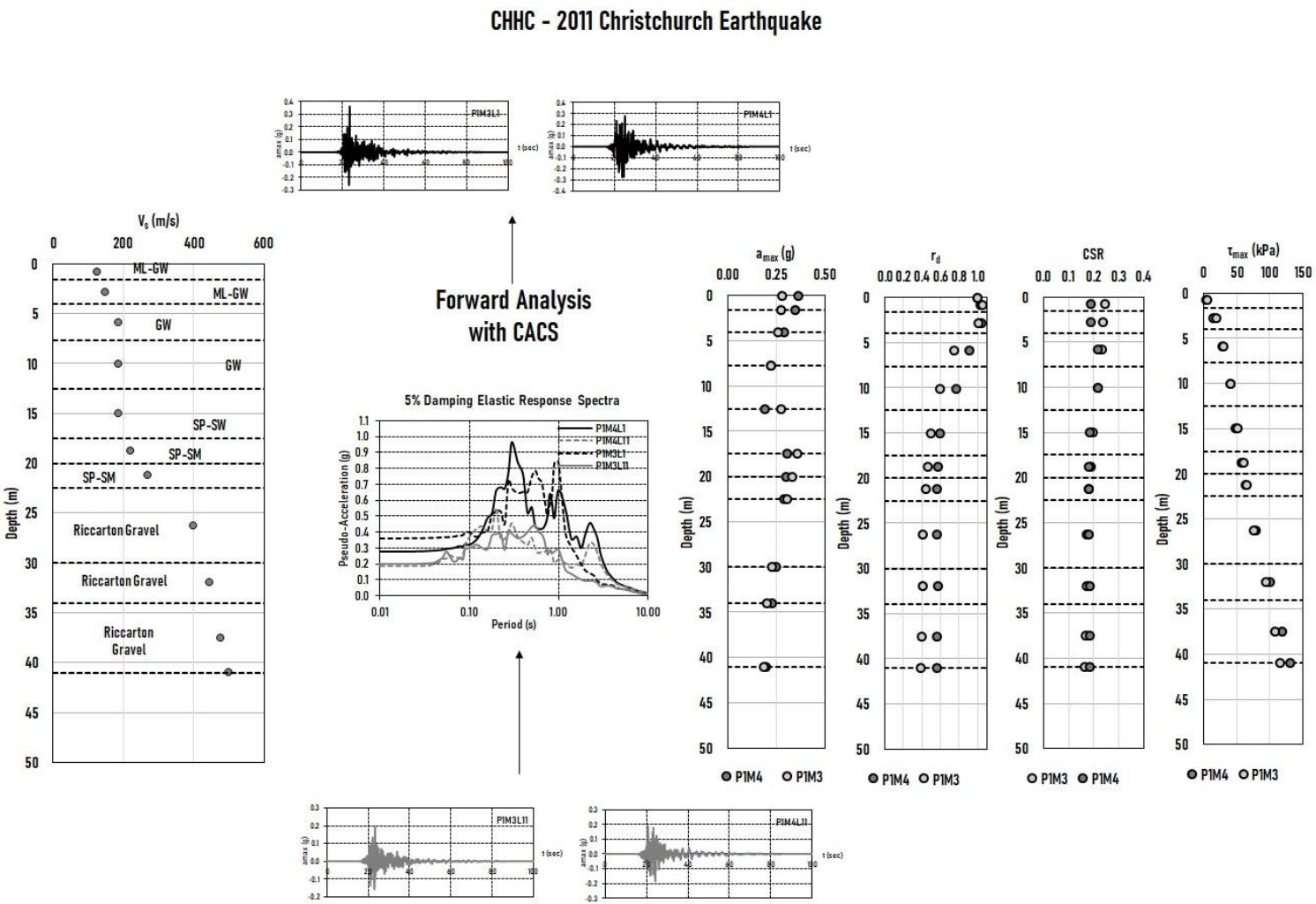

CBGS - 2010 Darfield Earthquake
P1M1L1
P1M2L1
t (sec)
Deconvolution
5% Damping Elastic Response Spectra
Pseudo-Acceleration (g)
Period (s)
P1M1L1
P1M1L11
P1M2L1
P1M2L11
V_s (m/s)
Depth (m)
Gravel Fill
GW
GW
SW
SP-SW-GW
SM-ML
Gravel
Gravel
GW
Riccarton Gravel
Riccarton Gravel
a_{max} (g)
r_d
CSR
τ_{max} (kPa)
P1M1
P1M2
P1M1L11
P1M2L11

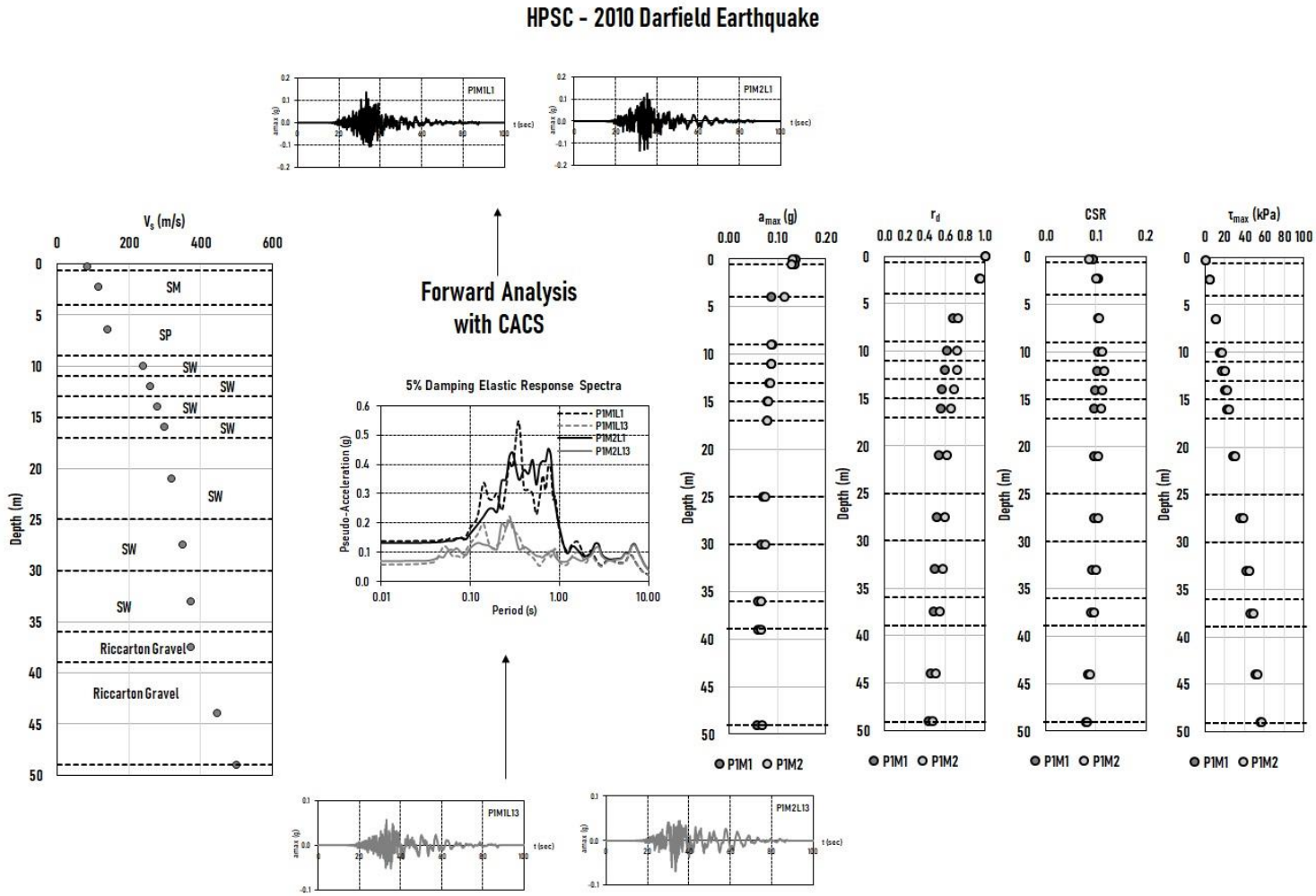

CBGS - 2011 Christchurch Earthquake
P1M3L1
P1M4L1
Forward Analysis with CACS
5% Damping Elastic Response Spectra
P1M4L1
P1M4L11
P1M3L1
P1M3L11
Pseudo-Acceleration (g)
Period (s)
P1M3L11
P1M4L11
Vs (m/s)
Gravel Fill
GW
GW
SW
SP-SW-GW
SM-ML
Gravel
Gravel
GW
Riccarton Gravel
Riccarton Gravel
Depth (m)
amax (g)
rd
CSR
τmax (kPa)
P1M4
P1M3

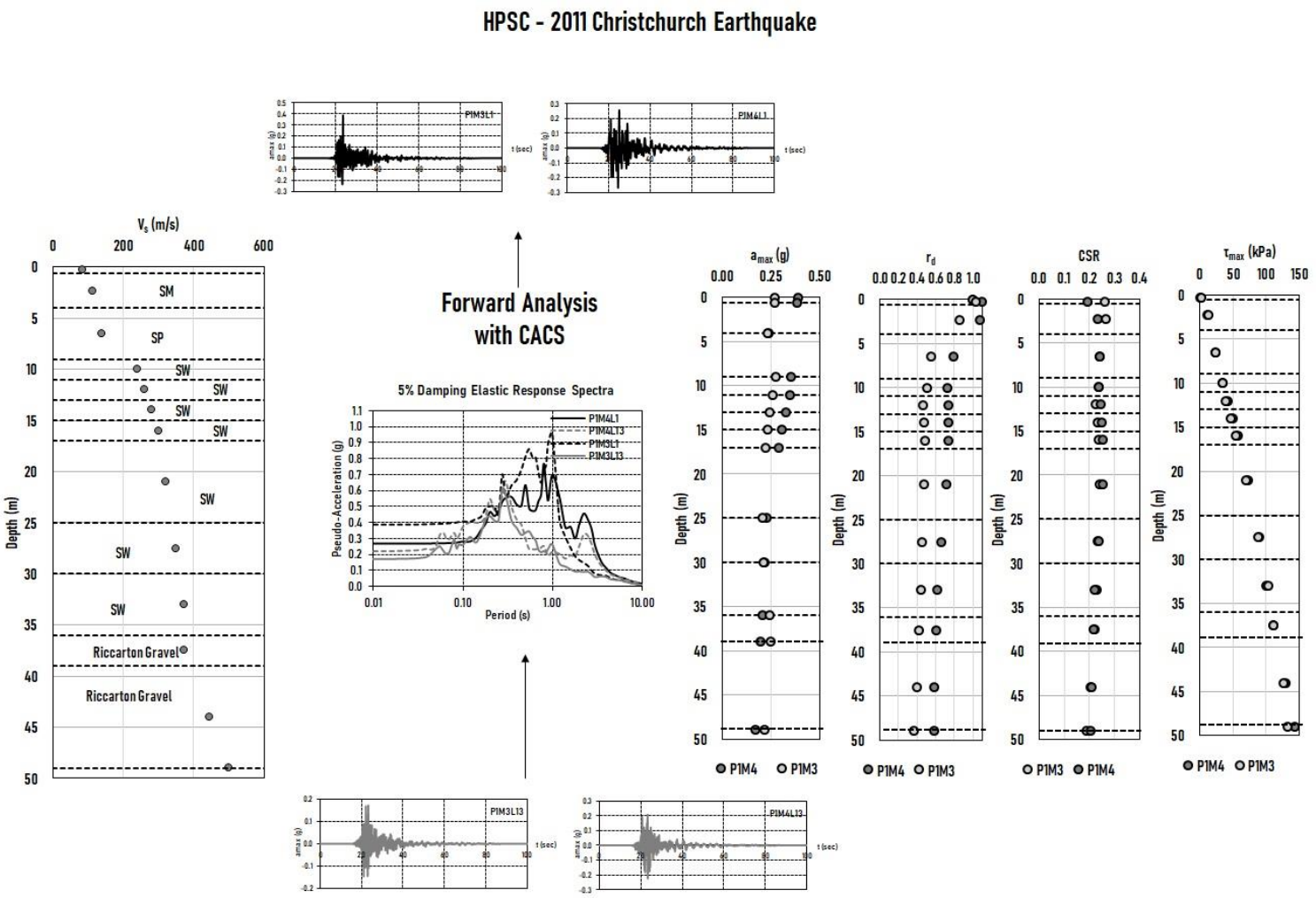

CCCC - 2010 Darfield Earthquake
P1M1L1
P1M2L1
Forward Analysis with CACS
5% Damping Elastic Response Spectra
P1M1L1
P1M1L11
P1M2L1
P1M2L11
Pseudo-Acceleration (g)
Period (s)
P1M1L11
P1M2L11
Vs (m/s)
Depth (m)
Sandy Mixtures
Sandy Mixtures
Sandy Mixtures
Sand
Sand
Sandy Mixtures
Sandy Mixtures
Riccarton Gravel
Riccarton Gravel
Riccarton Gravel
amax (g)
rd
CSR
τmax (kPa)
P1M1
P1M2

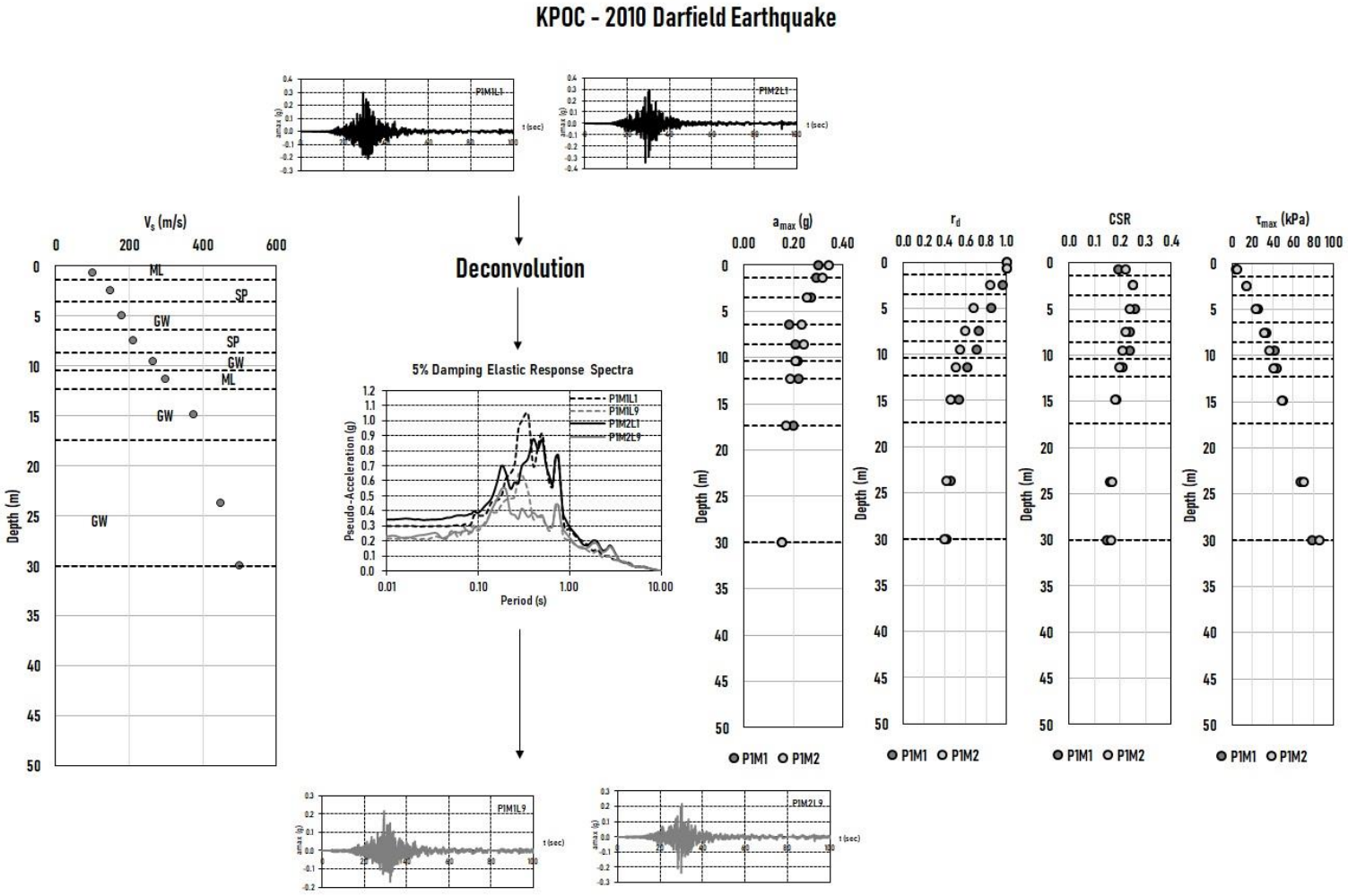

CCCC - 2011 Christchurch Earthquake
P1M3L1
P1M4L1
Forward Analysis with CACS
5% Damping Elastic Response Spectra
P1M4L1
P1M4L11
P1M3L1
P1M3L11
Pseudo-Acceleration (g)
Period (s)
V_s (m/s)
Depth (m)
Sandy Mixtures
Sand
Riccarton Gravel
a_{max} (g)
r_d
CSR
τ_{max} (kPa)
P1M4
P1M3
P1M3L11
P1M4L11

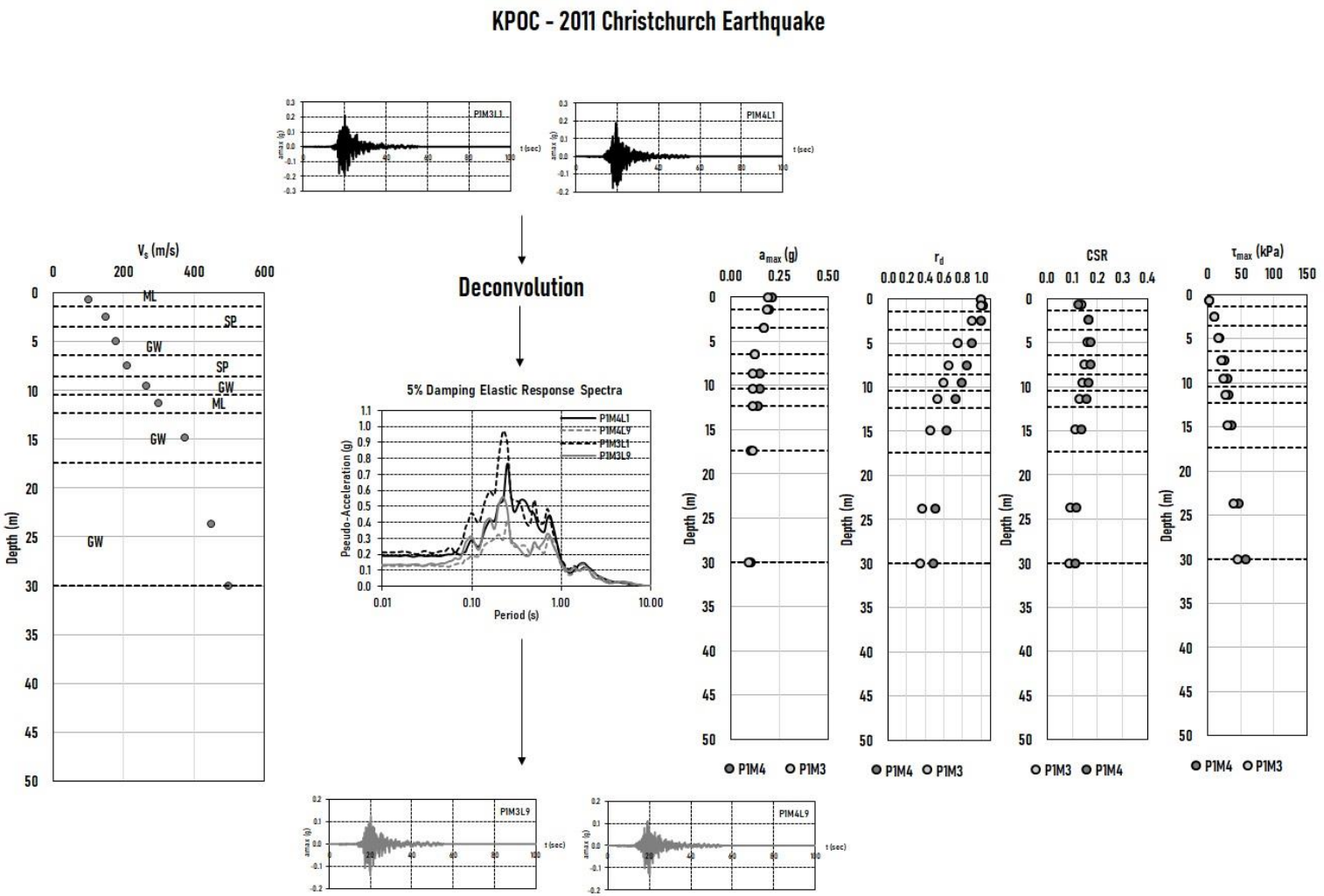

CHHC - 2010 Darfield Earthquake
P1M1L1
P1M2L1
t (sec)
Deconvolution
5% Damping Elastic Response Spectra
P1M1L1
P1M1L11
P1M2L1
P1M2L11
Pseudo-Acceleration (g)
Period (s)
0.01
0.10
1.00
10.00
P1M1L11
P1M2L11
V_s (m/s)
0
200
400
600
ML-GW
ML-GW
GW
GW
SP-SW
SP-SM
SP-SM
Riccarton Gravel
Riccarton Gravel
Riccarton Gravel
Depth (m)
a_{max} (g)
0.00
0.10
0.20
r_d
0.0 0.2 0.4 0.6 0.8 1.0
CSR
0.0
0.1
0.2
τ_{max} (kPa)
0 20 40 60 80 100
P1M1
P1M2

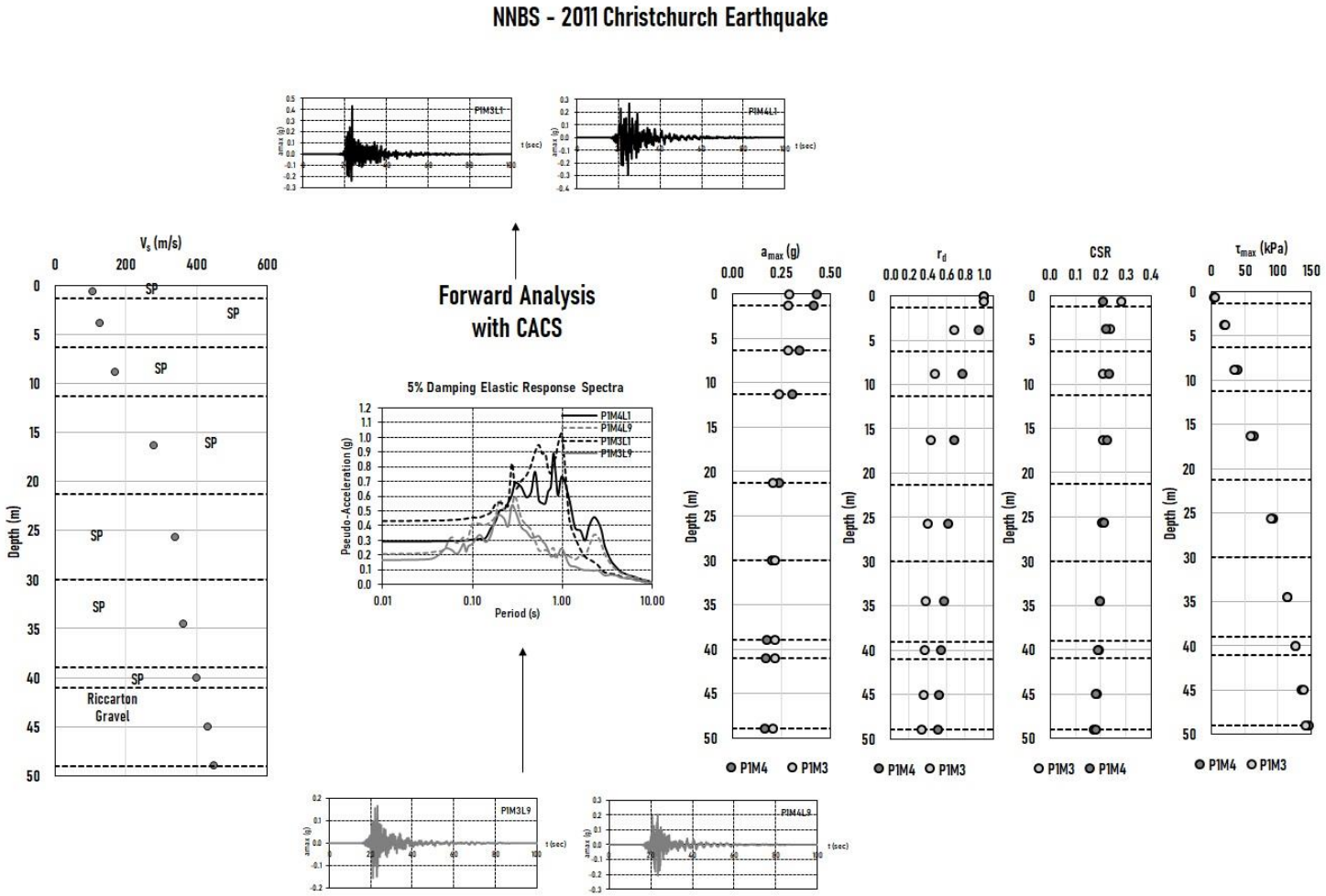

CHHC - 2011 Christchurch Earthquake
P1M3L1
P1M4L1
t (sec)
Forward Analysis with CACS
5% Damping Elastic Response Spectra
P1M4L1
P1M4L11
P1M3L1
P1M3L11
Pseudo-Acceleration (g)
Period (s)
V_s (m/s)
0 200 400 600
ML-GW
ML-GW
GW
GW
SP-SW
SP-SM
SP-SM
Riccarton Gravel
Riccarton Gravel
Riccarton Gravel
Depth (m)
a_{max} (g)
0.00 0.25 0.50
r_d
0.0 0.2 0.4 0.6 0.8 1.0
CSR
0.0 0.1 0.2 0.3 0.4
τ_{max} (kPa)
0 50 100 150
P1M4 P1M3
P1M4 P1M3
P1M3 P1M4
P1M4 P1M3
P1M3L11
P1M4L11

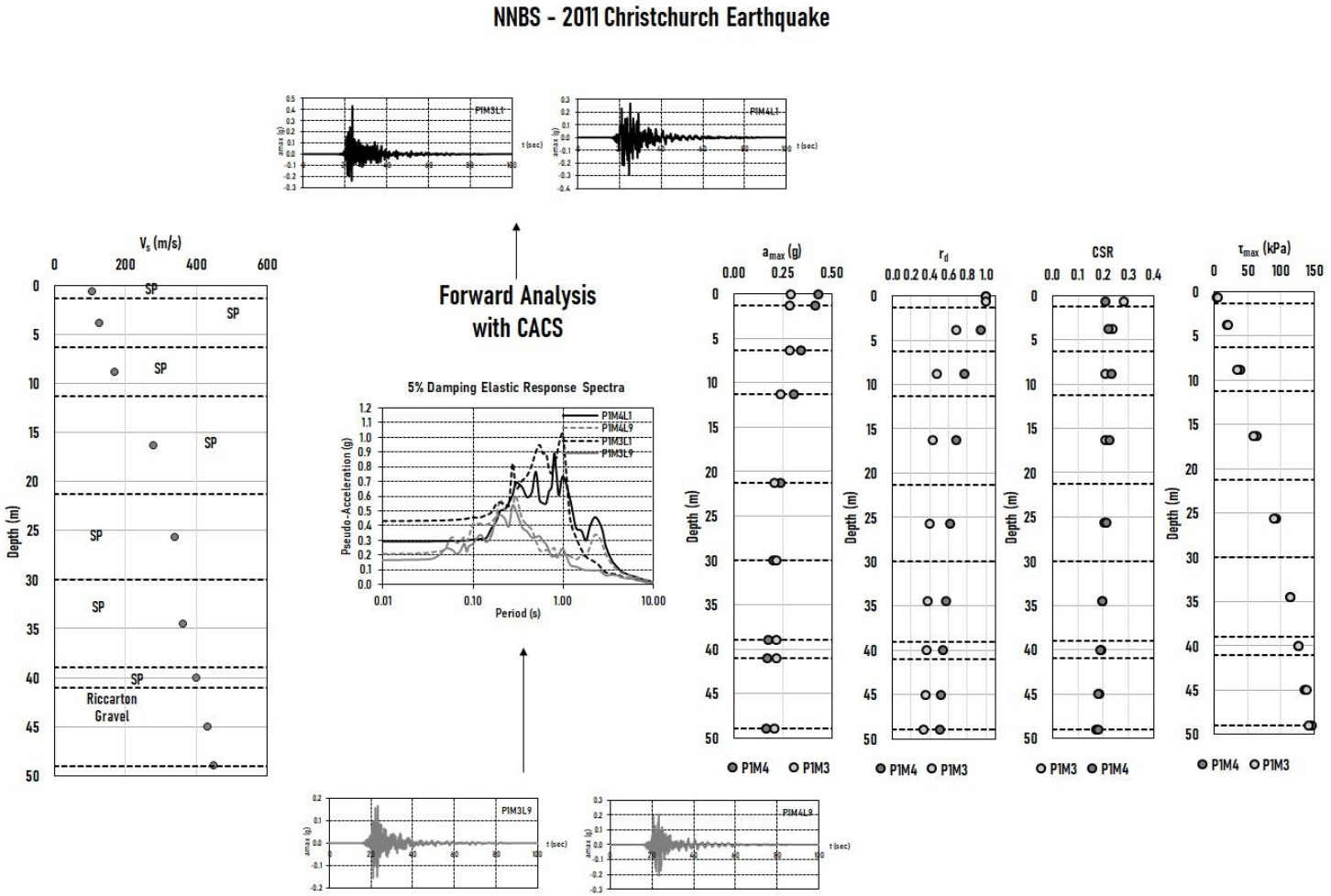

HPSC - 2010 Darfield Earthquake
P1M1L1
P1M2L1
Forward Analysis with CACS
5% Damping Elastic Response Spectra
P1M1L1
P1M1L13
P1M2L1
P1M2L13
Pseudo-Acceleration (g)
Period (s)
P1M1L13
P1M2L13
Vs (m/s)
Depth (m)
SM
SP
SW
Riccarton Gravel
Riccarton Gravel
amax (g)
rd
CSR
τmax (kPa)
P1M1
P1M2

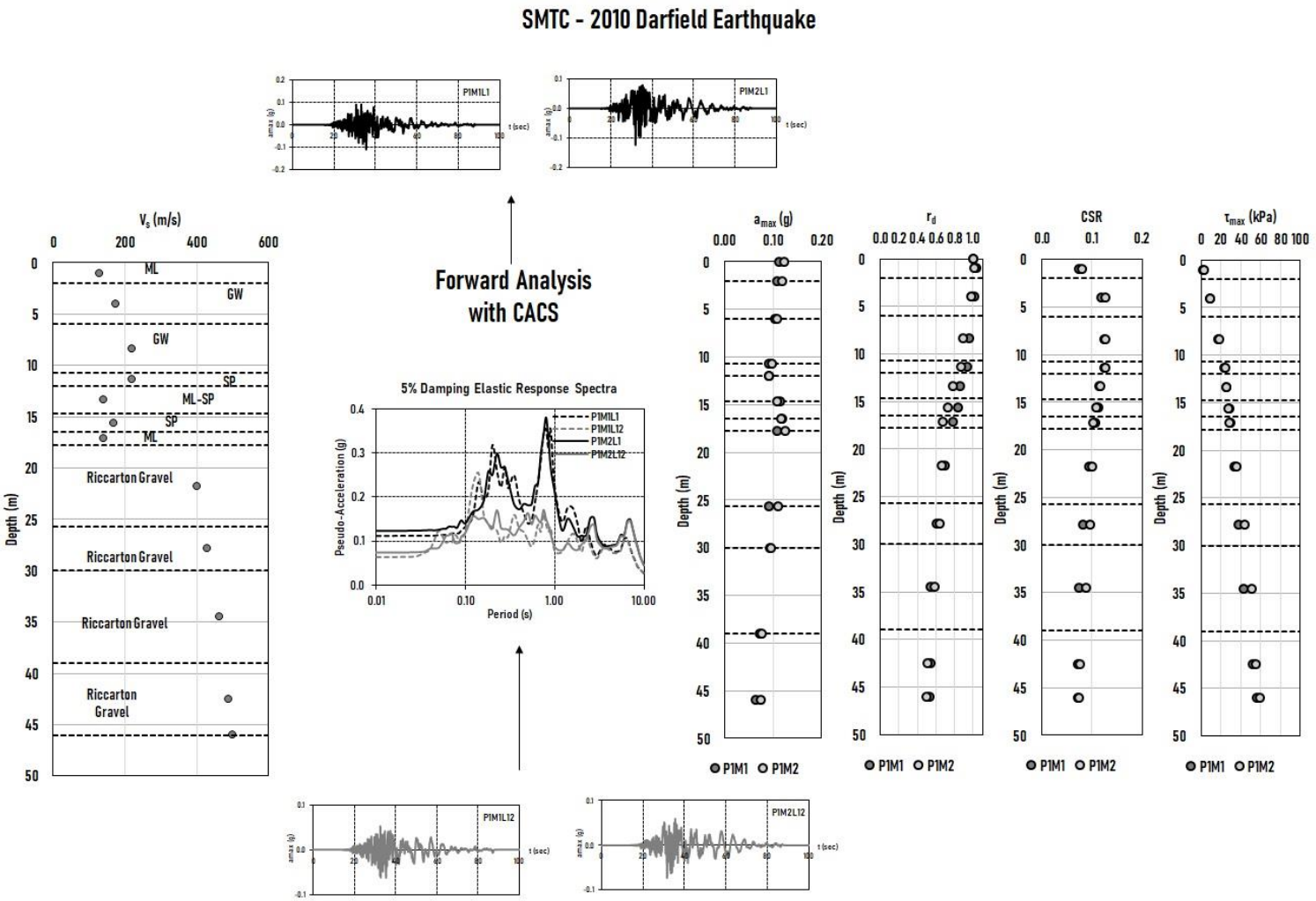

HPSC - 2011 Christchurch Earthquake
P1M3L1
P1M4L1
t (sec)
Forward Analysis with CACS
5% Damping Elastic Response Spectra
P1M4L1
P1M4LT3
P1M3L1
P1M3L13
Pseudo-Acceleration (g)
Period (s)
P1M3L13
P1M4L13
V_s (m/s)
SM
SP
SW
Riccarton Gravel
Depth (m)
a_max (g)
r_d
CSR
τ_max (kPa)
P1M4
P1M3


KPOC - 2010 Darfield Earthquake
P1M1L1
P1M2L1
Deconvolution
V_s (m/s)
ML
SP
GW
SP
GW
ML
GW
GW
Depth (m)
5% Damping Elastic Response Spectra
P1M1L1
P1M1L9
P1M2L1
P1M2L9
Pseudo-Acceleration (g)
Period (s)
a_{max} (g)
r_d
CSR
τ_{max} (kPa)
P1M1
P1M2
P1M1L9
P1M2L9

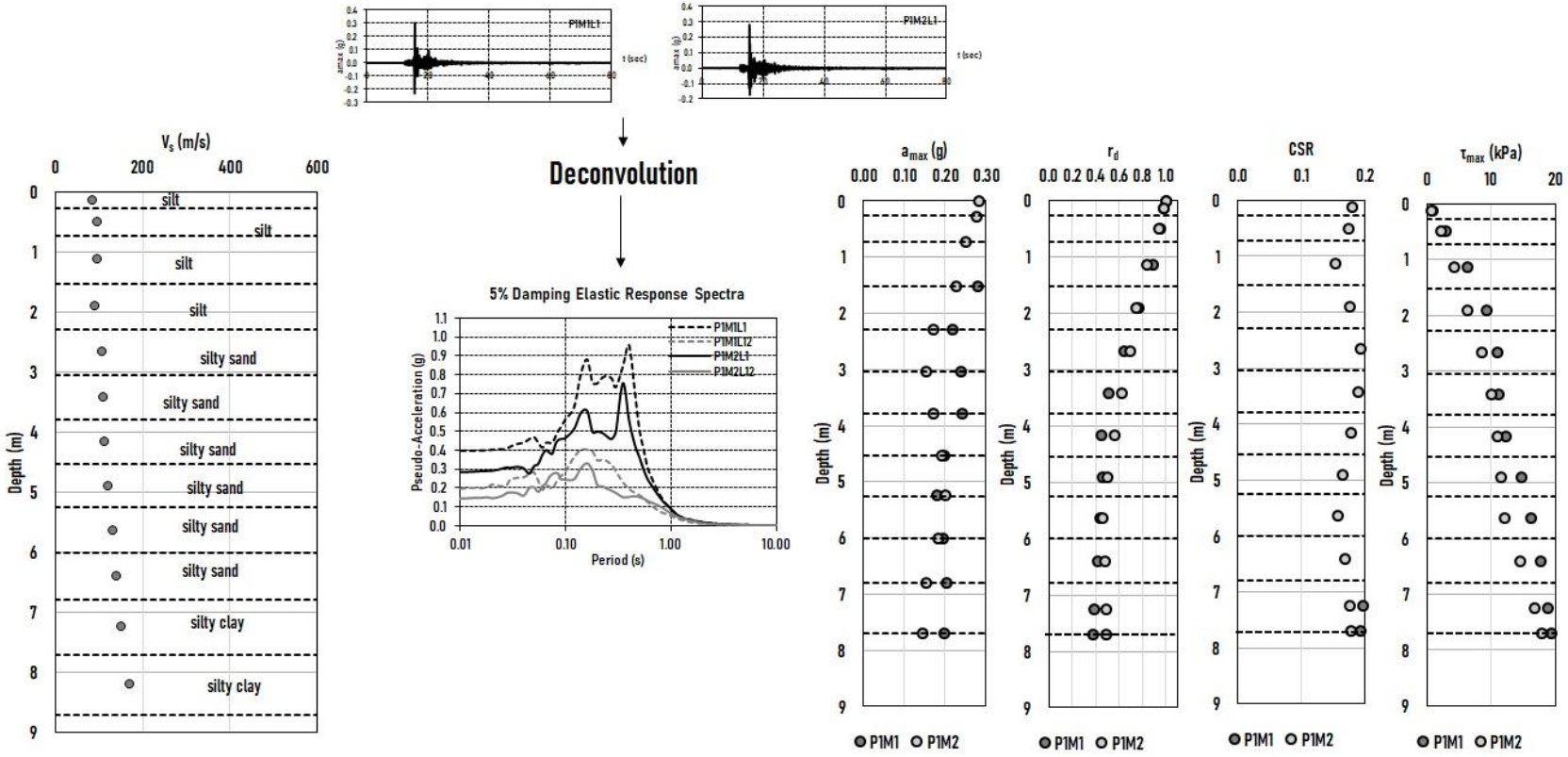

KPOC - 2011 Christchurch Earthquake
P1M3L1
P1M4L1
t (sec)
Deconvolution
V_s (m/s)
0 200 400 600
ML
SP
GW
SP
GW
ML
GW
GW
Depth (m)
5% Damping Elastic Response Spectra
P1M4L1
P1M4L9
P1M3L1
P1M3L9
Pseudo-Acceleration (g)
Period (s)
0.01 0.10 1.00 10.00
a_{max} (g)
0.00 0.25 0.50
r_d
0.0 0.2 0.4 0.6 0.8 1.0
CSR
0.0 0.1 0.2 0.3 0.4
τ_{max} (kPa)
0 50 100 150
P1M4 P1M3
P1M3L9
P1M4L9


NNBS - 2011 Christchurch Earthquake
P1M3L1
P1M4L1
t (sec)
Forward Analysis
with CACS
5% Damping Elastic Response Spectra
P1M4L1
P1M4L9
P1M3L1
P1M3L9
Pseudo-Acceleration (g)
Period (s)
V_s (m/s)
Depth (m)
SP
Riccarton
Gravel
a_{max} (g)
r_d
CSR
τ_{max} (kPa)
P1M4
P1M3
P1M3L9
P1M4L9

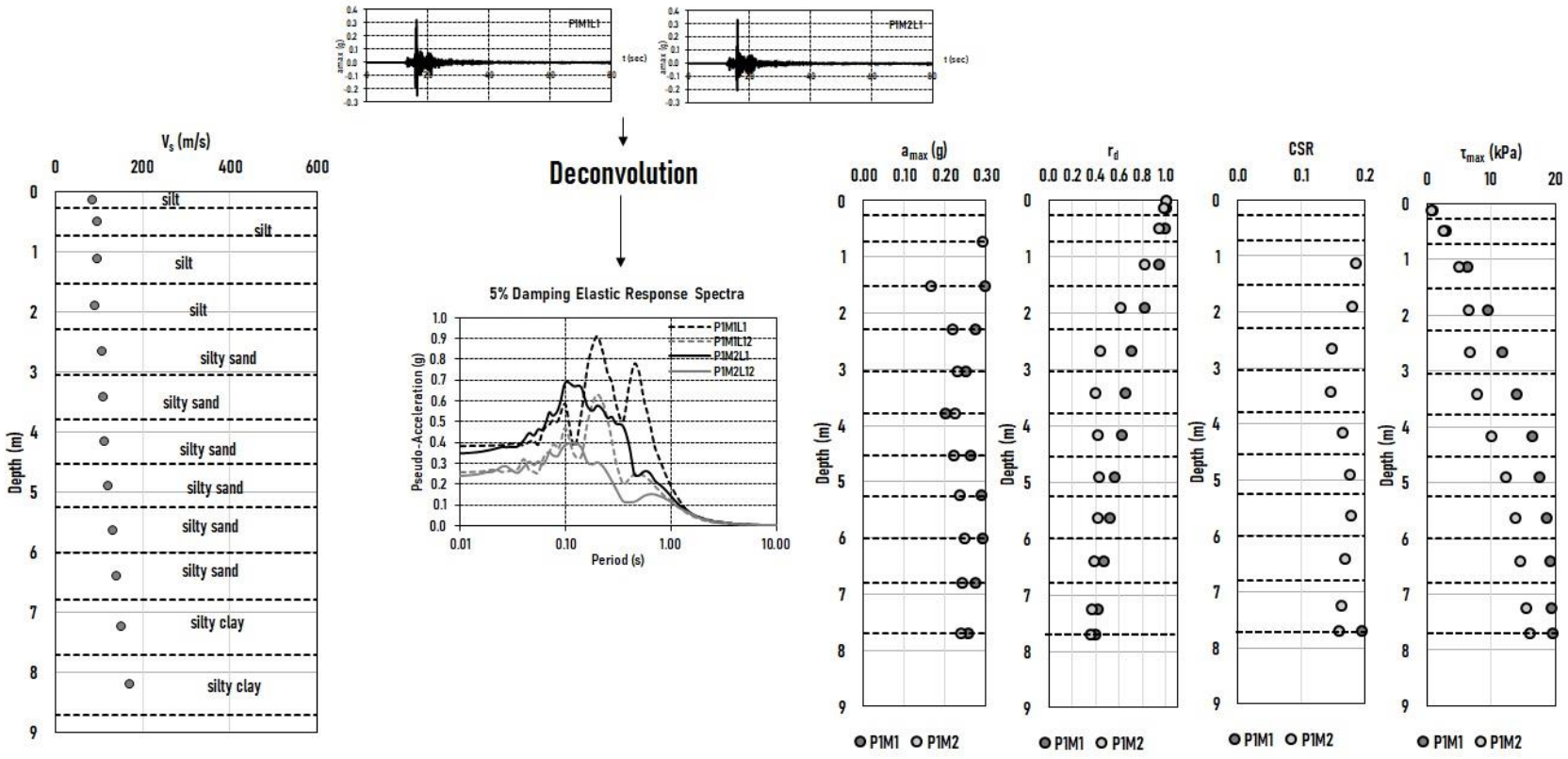

NNBS - 2011 Christchurch Earthquake
P1M3L1
P1M4L1
t (sec)
Forward Analysis
with CACS
5% Damping Elastic Response Spectra
P1M4L1
P1M4L9
P1M3L1
P1M3L9
Pseudo-Acceleration (g)
Period (s)
0.01
0.10
1.00
10.00
V_s (m/s)
0
200
400
600
SP
Riccarton
Gravel
Depth (m)
a_{max} (g)
0.00
0.25
0.50
r_d
0.0 0.2 0.4 0.6 0.8 1.0
CSR
0.0 0.1 0.2 0.3 0.4
τ_{max} (kPa)
0
50
100
150
P1M4
P1M3
P1M3L9
P1M4L9


SMTC - 2010 Darfield Earthquake
P1M1L1
P1M2L1
Forward Analysis with CACS
5% Damping Elastic Response Spectra
P1M1L1
P1M1L12
P1M2L1
P1M2L12
Pseudo-Acceleration (g)
Period (s)
P1M1L12
P1M2L12
V_s (m/s)
Depth (m)
ML
GW
GW
SP
ML-SP
SP
ML
Riccarton Gravel
Riccarton Gravel
Riccarton Gravel
Riccarton Gravel
a_{max} (g)
r_d
CSR
τ_{max} (kPa)
P1M1
P1M2

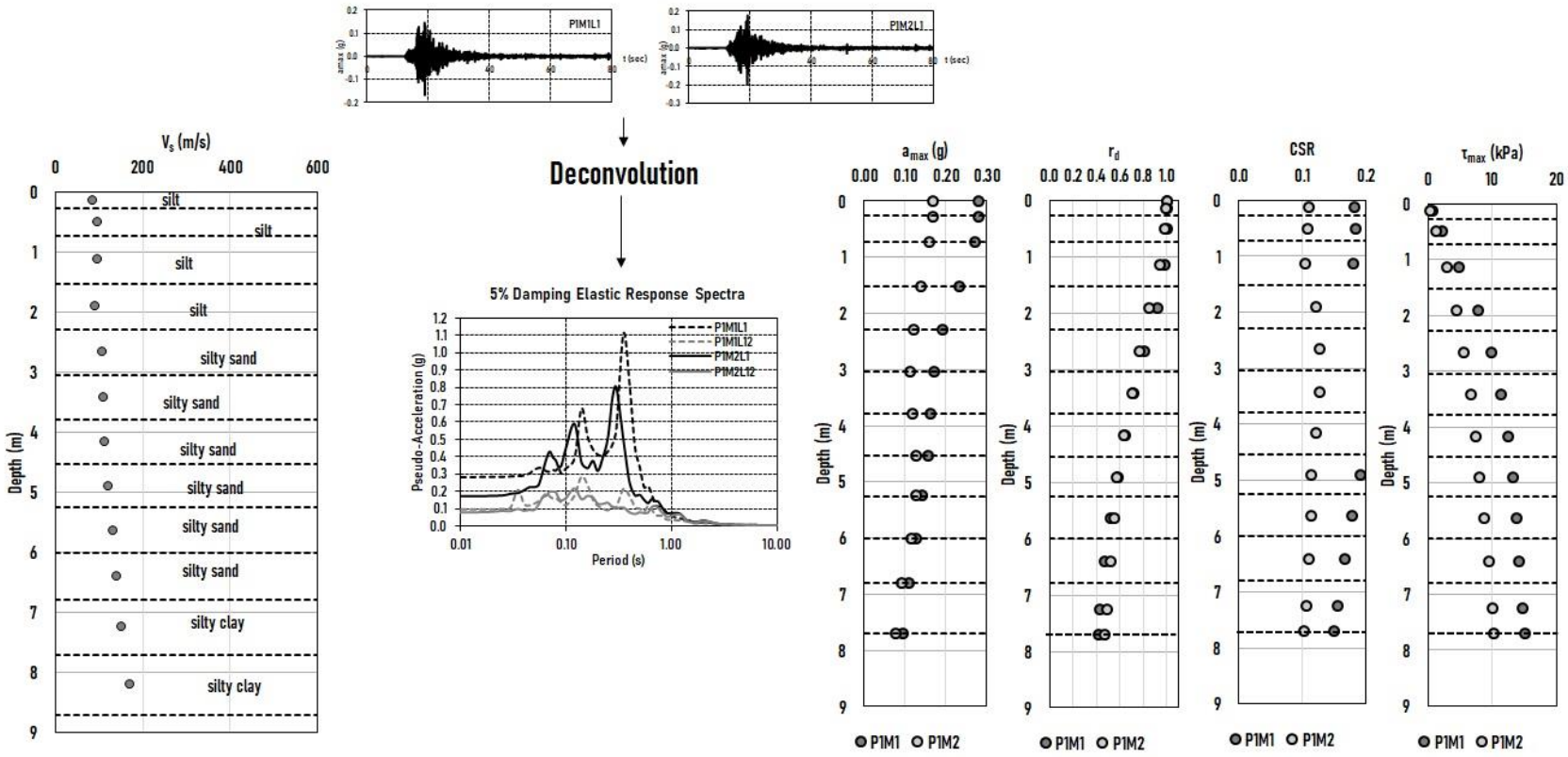
Wildlife B - 2012 Brawley Swarm_M=4.61



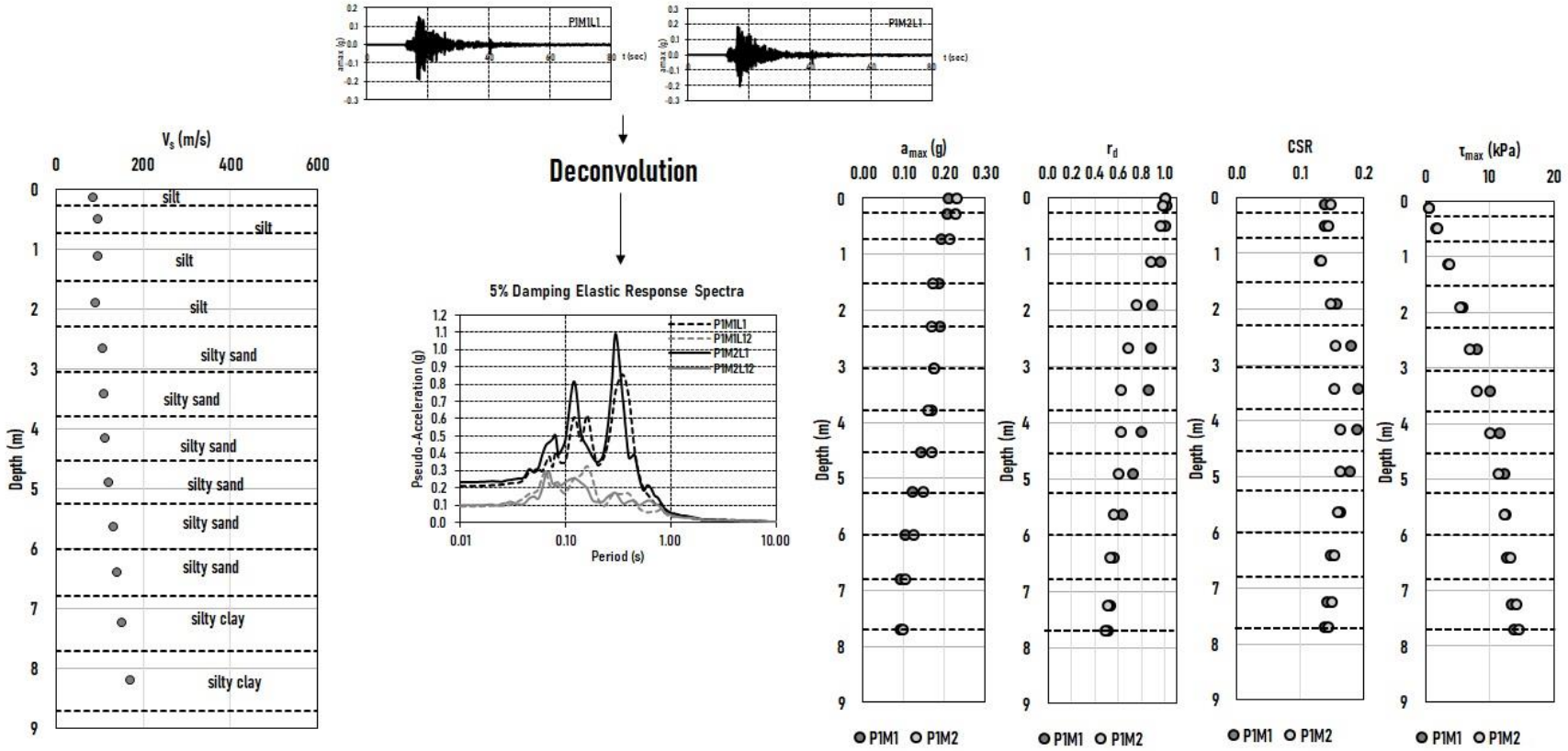
Wildlife B - 2012 Brawley Swarm_M=4.9



Wildlife B - 2012 Brawley Swarm_M=5.32



Wildlife B - 2012 Brawley Swarm_M=5.44



B. Liquefaction Case History Database

Case number:	6
Earthquake:	1964 Niigata Earthquake
Magnitude:	7.6 (Mw) http://ds.iris.edu/seismo-archives/quakes/1964niigata/
Location:	Aki City (Arayamotomachi)
References:	Yasuda and Tohno (1988), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Sand boils
GPS LAT	39.68427
GPS LONG	140.08464
Liq. layer consist of:	fine sand
Geological Unit:	Late Pleistocene to Holocene sand dune deposits/Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Cetin (2000) "The epicenter of the earthquake is located some 35 miles north of the city. At Arayamotomachi Town in Akita City, liquefaction was caused in a long and narrow area by Niigata Earthquake. The damage was concentrated in a small zone about 100 m in width and 500 m in length, in an area of land recently reclaimed over an old river by filling with sand from adjacent sand dunes. At a point near the center of the liquefied area, a layer of very loose fine sand, with SPT N values of 0-6, forms a deposit extending from the ground surface to about 6 m in depth. The water table is at 1 m depth. The maximum surface acceleration was assumed to be 0.09 g based on the value recorded at the Akita Prefectural Government building 4 km from Arayamotomachi Town." Bhattacharya et al. (2014) referred to two different fault plane solutions: 1) Shiba and Uetake (west-dipping) and 2) Hurukawa and Harada (east-dipping). SPT-N values are re-digitized hence N1,60 is slightly updated. Vs12m is updated based on SPT-N - Vs correlations.
	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en
Gravel Content (%):	0.00
CPT available:	No
Vs available:	No



Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	B	-	A	A
d_{crtc} range (m)	-	2.0 - 4.5		1.0 - 5.5	1.0 - 5.5
d_{crt} (m)	-	3.3	3.3	3.3	3.3
GWT (m)	-	1.0 ± 0.3	1	1.0 ± 0.1	1.0 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	15.7 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.1 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-	53.0 ± 7.1	63.2	56.5 ± 13.6	59.8 ± 14.2
σ_v' (kPa)	-	30.8 ± 4.2	41.1	34.4 ± 6.4	37.7 ± 6.9
a_{max} (g)	-	0.090 ± 0.018	0.09	0.090 ± 0.014	0.090 ± 0.014
r_d	-	0.90 ± 0.054	0.98	0.94 ± 0.054	0.98 ± 0.054
CSR	-	0.090 ± 0.021	0.089	0.090 ± 0.016	0.091 ± 0.016
M_w	-	7.50	7.60	7.60	7.60
D_{50}	-	0.150 ± 0.070	-	0.150 ± 0.050	0.150 ± 0.050
% Fines	-	5.0 ± 2.0	5	5.0 ± 2.0	5.0 ± 8.6
% PI	-	-	-	-	0
N	-	2.6 ± 1.4	2.6	4.4 ± 2.7	4.3 ± 1.9
C_R	-	0.86	0.85	0.86	0.91
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.76	1.70	1.72	1.64
$(N_1)_{60}$	-	4.8 ± 2.6	4.7	7.9 ± 4.8	8.8 ± 3.8
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	149.4	-	158.5	196.6

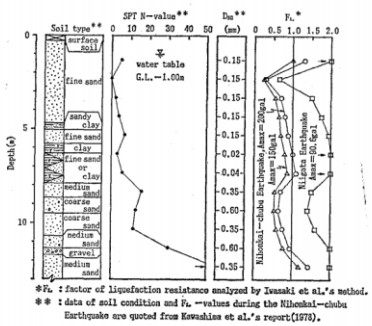
EVENT PARAMETERS

1964 Niigata Earthquake Hurukawa and Harada (2013)

Magnitude: 7.60 strike: N9◦E

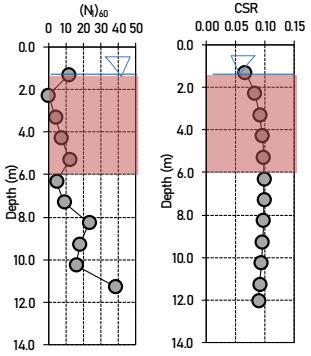
Fault Type: thrust earthqua Z_{tor} (km): 0 (USGS 15km) R_{rup} (km): 124-127

Dip: 60 or 34 Width (km): 14 or 27 R_{jb} (km): 124-127



*F_L : factor of liquefaction resistance analyzed by Iwasaki et al.'s method.
** : data of soil condition and F_L -values during the Niihonkai-chubu Earthquake are quoted from Kawashima et al.'s report(1978).

Fig. 3. Soil profile and results of liquefaction analysis at Arayamotomachi in Akita City



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	D50	
1.3	***4.2***	***0.066***	***5.0***	***2.00***	***0.86***	***11.8***	***0.15***	***fine sand***
2.3	7.4	0.083	0.0	1.88	0.89	0.0	0.15	fine sand outlier
3.3	***10.8***	***0.091***	***2.0***	***1.63***	***0.91***	***4.1***	***0.15***	***fine sand***
4.3	***14.0***	***0.096***	***4.0***	***1.47***	***0.93***	***7.4***	***0.15***	***fine sand***
5.3	***17.4***	***0.098***	***7.0***	***1.34***	***0.94***	***12.1***	***0.15***	***fine sand***
6.3	20.7	0.099	3.0	1.25	0.95	4.9	0.02	clay seam
7.3	24.0	0.099	6.0	1.17	0.96	9.2	0.04	fine sand or clay
8.3	27.1	0.097	16.0	1.10	0.97	23.4	0.35	medium sand
9.3	30.4	0.096	13.0	1.05	0.97	18.1	0.60	coarse sand
10.3	33.7	0.094	12.0	1.00	0.98	16.1	0.35	coarse sand
11.3	37.0	0.091	30.0	0.96	0.98	38.6	0.60	medium sand
12.1	39.6	0.089	50.0	0.93	0.99	62.6	0.35	medium sand
					Mean:	8.8	0.150	
					St. Dev.	3.8	0.050	assigned

Case number:	7
Earthquake:	1964 Niigata Earthquake
Magnitude:	7.6 (Mw)
Location:	Niigata Cc17-1
References:	Kishida (1966), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Seed and Idriss (1966)
GPS LAT	37.913699
GPS LONG	139.05883
Liq. layer consist of:	sand
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Niigata is located on the west coast of Japan where Shinano River enters the sea. The river has built up a considerable thickness of alluvial sand deposits, which along the coast have been overlain by deposits of dune sand. In general, the sand deposits underlying the city are relatively loose near the ground surface but get denser with increasing depths. The sand extends to a depth of ~100' and alluvial deposits to 200-300'. In the vicinity of the river, the ground is relatively flat. The epicenter of the earthquake is located 35 miles north of the city. From the seismograph, located in the basement of an apartment building it was estimated that the PGA at Niigata was in the order of 0.16 g. The soil below the seismograph liquefied during the earthquake. It is interesting to note the marked change in form of record from a predominantly short period motion to a long period motion which occurred after about 8 seconds. SPT values were taken both before and after the earthquake. N values before the earthquake were used for the analysis. SPT energy was estimated as 65 % by Seed et al. (84)". Cc17 (1) and (2) are located very close but show different SPT profiles hence we took two case histories. Bhattacharya et al. (2014) referred to two different fault plane solutions: 1) Shiba and Uetake (west-dipping) and 2) Hurukawa and Harada (east-dipping) SPT-N values are re-digitized hence N1,60 is slightly updated. PGA is updated based on the available digital recording as 0.169 g (geometric mean of 0.135 g and 0.213 g). Vs12m is updated based on SPT-N - Vs correlations.
	"Along Shinano River many buildings tilted or subsided constructed on reclaimed land. Sand particles at ~ 5-7 m depth came out; sand volcanoes at various places."
	http://ds.iris.edu/seismo-archives/quakes/1964niigata/
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	5.0 - 11.0		5.0 - 11.0	5.0 - 11.0
d_{crt} (m)	7.0	8.0	7.0	8.0	8.0
GWT (m)	0.91	0.9 ± 0.3	0.9	0.9 ± 0.1	0.9 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.9	-	15.7 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.9	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	132.5	130.8 ± 17.9	132.3	148.3 ± 19.2	149.7 ± 19.2
σ_v' (kPa)	72.5	61.2 ± 9.8	72.2	78.7 ± 9.7	80.1 ± 9.7
a_{max} (g)	0.16	0.160 ± 0.024	0.16	0.160 ± 0.024	0.169 ± 0.025
r_d	0.95	0.65 ± 0.116	0.94	0.80 ± 0.116	0.86 ± 0.116
CSR	0.18	0.145 ± 0.035	0.179	0.157 ± 0.033	0.176 ± 0.036
M_w	7.50	7.50	7.60	7.60	7.60
D_{50}	0.3	0.200 ± 0.035	-	0.200 ± 0.050	0.200 ± 0.050
% Fines	2	8.0 ± 2.0	2	2.0 ± 2.0	2.0 ± 8.6
% PI	-	-	-	-	0
N	8	8.8 ± 2.3	8	8.8 ± 2.3	10.0 ± 2.8
C_R	-	1.00	0.95	1.00	0.97
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.09	1.09	1.09	1.09	1.37
C_N	1.14	1.25	1.20	1.14	1.13
$(N_1)_{60}$	10	12.0 ± 3.1	9.9	10.9 ± 2.9	14.9 ± 4.1
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	155.4	-	167.6	182.9

EVENT PARAMETERS

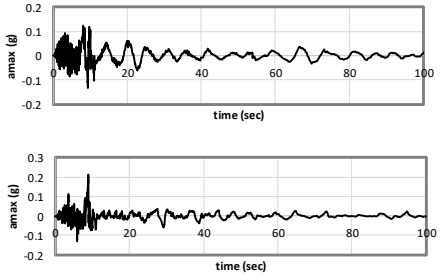
1964 Niigata Earthquake — Hurukawa and Harada 2013

Magnitude: 7.60 — strike: N9◦E

Fault Type: thrust earthqua — Z_{tor} (km): 0 (USGS 15km) — R_{rup} (km): 9--14

Dip: 60 or 34 — Width (km): 14 or 27 — R_{jb} (km): 9--14

H1	0.135
H2	0.213
GEO. MEAN	0.169



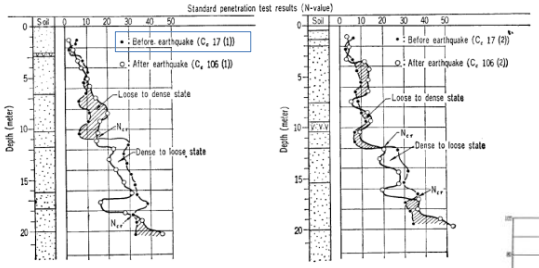
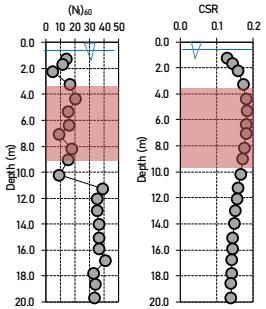
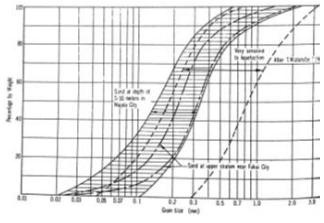


Fig. 5. Typical examples of standard penetration test results before and after Niigata earthquake (Location of boring is shown in Fig. 3)





5-10 m depth

D_{10} (mm)	0.08
D_{50} (mm)	0.23
D_{60} (mm)	0.27

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		
1.3	4.2	0.130	6	2.00	0.86	14.2	sand	
1.7	5.5	0.145	5	2.00	0.87	11.9	sand	
2.3	7.4	0.159	2	1.91	0.89	4.6	humus/sand	
3.3	10.7	0.173	8	1.66	0.91	16.5	sand	
4.4	***14.4***	***0.180***	***11***	***1.47***	***0.93***	***20.5***	sand	Kishida (1966)
5.3	***17.4***	***0.182***	***9***	***1.35***	***0.94***	***15.6***	sand	"because the
6.4	***20.9***	***0.182***	***10***	***1.25***	***0.95***	***16.2***	sand	liquefaction of sand
7.1	***23.3***	***0.180***	***6***	***1.19***	***0.96***	***9.4***	sand	stratum happens
8.2	***26.9***	***0.175***	***12***	***1.11***	***0.97***	***17.7***	sand	when loose sand"
9.0	***29.6***	***0.171***	***11***	***1.07***	***0.97***	***15.6***	sand	hence this layer is
10.2	***33.5***	***0.165***	***7***	***1.01***	***0.98***	***9.4***	sand	selected
11.3	37.0	0.159	30	0.96	0.98	38.8	sand	
12.1	39.6	0.155	28	0.93	0.99	35.1	sand	
13.0	42.6	0.151	29	0.90	0.99	35.3	sand	
14.0	45.9	0.148	31	0.87	0.99	36.5	sand	
15.1	49.4	0.145	32	0.84	0.99	36.4	sand	
15.9	52.3	0.143	33	0.82	0.99	36.6	sand	
16.8	55.1	0.141	38	0.80	0.99	41.2	sand	
17.8	58.4	0.140	31	0.78	1.00	32.7	sand	
18.6	61.1	0.140	33	0.76	1.00	34.1	sand	
19.7	64.7	0.139	33	0.74	1.00	33.2	sand	
					Mean:	14.9		
					St. Dev.	4.1		

Kishida (1966) "between sand stratum, there exist thin layers of silt and soft organic soil with very low permeability."

Case number:	8
Earthquake:	1964 Niigata Earthquake
Magnitude:	7.6 (Mw)
Location:	Niigata Cc17-2
References:	Kishida (1966), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Seed and Idriss (1966), "An analysis of soil liquefaction in the Niigata Eq."
GPS LAT	37.913699
GPS LONG	139.05883
Liq. layer consist of:	sand
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Niigata is located on the west coast of Japan where Shinano River enters the sea. The river has built up a considerable thickness of alluvial sand deposits, which along the coast have been overlain by deposits of dune sand. In general, the sand deposits underlying the city are relatively loose near the ground surface but get denser with increasing depth. The sand extends to a depth of ~100' and alluvial deposits to 200-300'. In the vicinity of river the ground is relatively flat. The epicenter of the earthquake is located some 35 miles north of the city. From the seismograph, located in the basement of the apartment building it was estimated that the PGA at Niigata was in the order of 0.16 g. The soil below the seismograph liquefied during the earthquake. It is interesting to note the marked change in form of record from a predominantly short period motion to a long period motion which occurred after about 8 seconds. SPT values were taken both before and after the earthquake. N values before the earthquake were used for the analysis. SPT energy was estimated as 65 % by Seed et al. (84)" Cc17 (1) and (2) are located very close but show different SPT profiles hence we took two case histories. Bhattacharya et al. (2014) referred to two different fault plane solutions: 1) Shiba and Uetake (west-dipping) and 2) Hurukawa and Harada (east-dipping). Depth of SPT-N values are re-digitized hence dcrt is slightly updated. PGA is updated based on the available digital recording as 0.169 g (geometric mean of 0.135 g and 0.213 g).
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

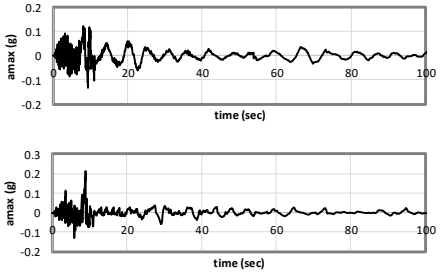
http://ds.iris.edu/seismo-archives/quakes/1964niigata/

In the Shinano River reclaimed land, many buildings tilted or subsided.

The sand particles at ~ 5-7 m depth came out; sand volcanoes at various places.



H1	0.135
H2	0.213
GEO. MEAN	0.169



Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	B	-	A	A
d_{crtc} range (m)	-	3.5 - 7.0	-	3.5 - 7.0	3.5 - 7.0
d_{crt} (m)	-	5.3	5.3	5.3	5.3
GWT (m)	-	0.9 ± 0.3	0.9	0.9 ± 0.1	0.9 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.9	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.9	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-	85.4 ± 10.5	85.2	96.3 ± 11.2	96.3 ± 11.2
σ_v' (kPa)	-	42.8 ± 6.3	43.1	53.7 ± 5.7	53.7 ± 5.7
a_{max} (g)	-	0.160 ± 0.024	0.16	0.160 ± 0.024	0.169 ± 0.025
r_d	-	0.78 ± 0.081	0.96	0.90 ± 0.081	0.90 ± 0.081
CSR	-	0.161 ± 0.032	0.199	0.168 ± 0.030	0.178 ± 0.031
M_w	-	7.50	7.60	7.60	7.60
D_{50}	-	0.200 ± 0.035	-	0.200 ± 0.050	0.200 ± 0.050
% Fines	-	8.0 ± 2.0	8	2.0 ± 2.0	2.0 ± 8.6
% PI	-	-	-	-	0
N	-	7.9 ± 1.4	7.9	8.0 ± 1.4	8.0 ± 1.3
C_R	-	0.93	0.95	0.93	0.94
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.09	1.09	1.09	1.37
C_N	-	1.50	1.55	1.37	1.38
$(N_1)_{60}$	-	12.0 ± 2.1	12.7	11.1 ± 1.9	14.1 ± 2.3
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	146.3	-	167.6	167.6

EVENT PARAMETERS

1964 Niigata Earthquake	Hurukawa and Harada 2013	
Magnitude: 7.60	strike: N9◦E	
Fault Type: thrust earthqua	Z_{tor} (km): 0 (USGS 15km)	R_{rup} (km): 124-127
Dip: 60 or 34	Width (km): 14 or 27	R_{jb} (km): 124-127

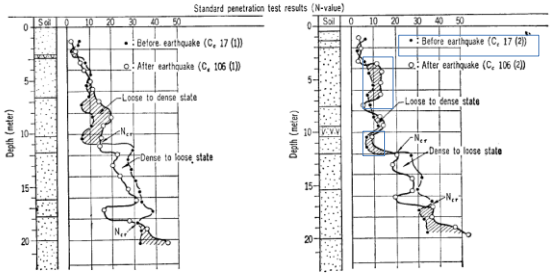
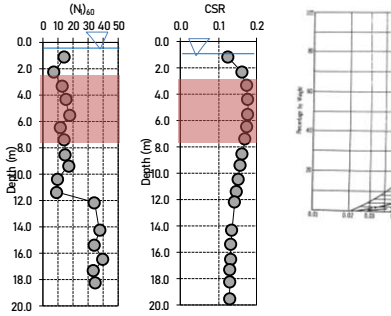
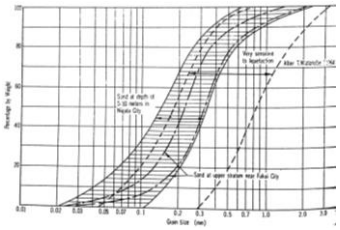


Fig. 5. Typical examples of standard penetration test results before and after Niigata earthquake (Location of boring is shown in Fig. 3)





5-10 m depth

D_{10} (mm)	0.08
D_{50} (mm)	0.23
D_{60} (mm)	0.27

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
1.2	3.8	0.124	6	2.00	0.86	14.1	sand
2.3	7.5	0.161	3	1.95	0.89	7.1	sand
3.3	***10.9***	***0.173***	***6***	***1.68***	***0.91***	***12.5***	sand
4.4	***14.4***	***0.178***	***8***	***1.49***	***0.93***	***15.1***	sand
5.5	***18.1***	***0.177***	***10***	***1.34***	***0.94***	***17.3***	sand
6.5	***21.2***	***0.174***	***7***	***1.25***	***0.95***	***11.4***	sand
7.4	***24.2***	***0.170***	***9***	***1.18***	***0.96***	***13.9***	sand
8.5	28.0	0.163	10	1.10	0.97	14.6	sand
9.4	30.7	0.158	12	1.06	0.97	16.9	sand
10.4	34.2	0.151	7	1.00	0.98	9.4	sand
11.4	37.4	0.146	7	0.96	0.98	9.1	sand
12.2	39.9	0.143	27	0.93	0.99	34.0	sand
14.3	46.9	0.136	32	0.87	0.99	37.5	sand
15.4	50.5	0.133	30	0.84	0.99	34.0	sand
16.5	54.1	0.132	36	0.81	0.99	39.5	sand
17.3	56.9	0.131	31	0.79	1.00	33.3	sand
18.2	59.8	0.130	33	0.77	1.00	34.6	sand
19.5	64.0	0.129	34	0.75	1.00	34.5	sand
					Mean:	14.1	
					St. Dev.	2.3	

Despite the fact that it is sligthly below the bottom of the critical depth range, due to consistent trend in N values, N=9 is used to characterize the critical layer

Case number:	9
Earthquake:	1964 Niigata Earthquake
Magnitude:	7.6 (Mw) http://ds.iris.edu/seismo-archives/quakes/1964niigata/
Location:	Old Town-1
References:	Koizumi (1964), Seed and Idriss (1966), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface evidence of liquefaction has been observed at Old Town section.
GPS LAT	37.920351
GPS LONG	139.043202
Liq. layer consist of:	sand
Geological Unit:	alluvial sand deposits/Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Niigata is located on the west coast of Japan where Shinano River enters the sea. The river has built up a considerable thickness of alluvial sand deposits, which along the coast have been overlain by deposits of dune sand. In general, the sand deposits underlying the city are relatively loose near the ground surface but get denser with increasing depth. The sand extends to a depth of ~100' and alluvial deposits to 200-300'. In the vicinity of the river, the ground is relatively flat. Niigata city was below sea level about a thousand years ago and the bay was ditted with several small islands. The EQ was the first large vibration the recent deposits had experienced. The epicenter of the earthquake was located some 35 miles north of the city. From the seismograph, located in the basement of an apartment building it was estimated that the PGA at Niigata was in the order of 0.16 g. The soil below the seismograph liquefied during the earthquake. It is interesting to note the marked change in form of record from a predominantly short period motion to a long period motion which occurred after about 8 seconds. Seed et al (84) estimated PGA not as 0.16 but 0.18 g probably due to the fact the site did not liquefy so no de-amplification. Seed et al (84) adopted rod energy of 73 % (average Japanese energy value) for non-liquefied sites and 65 % (Japanese lower bound) for liquefied sites. Water table was at 1-2 m except for dune sand. SPT values were taken before the earthquake. SPT energy was estimated as 73 % by Seed et al. (84)". Bhattacharya et al. (2014) referred to two different fault plane solutions: 1) Shiba and Uetake (west-dipping) and 2) Hurukawa and Harada (east-dipping). The borehole data provided represents many borehole data available in the old town. Hence taking two non-liquefied case histories is not against statistically independent assumptions. PGA is updated based on the available digital recording as 0.169 g (geometric mean of 0.135 g and 0.213 g) for the liquefied sites. Seed et al. (1984) estimated PGA for the site a little higher (0.18 g) than the recorded (0.16 g) one probably due to no de-amplification at non-liquefied sites. The ratio was 0.18/0.16=1.125. Hence 0.169*0.125=0.190 g is assigned to the site.

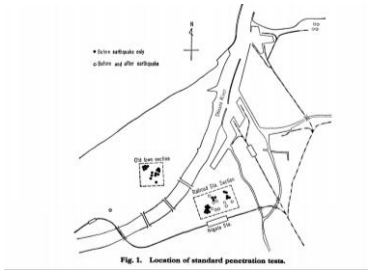


Fig. 1. Location of standard penetration tests.

Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	B	-	A	A
d_{crtc} range (m)	-	5.0 - 10.0		5.0 - 10.0	5.0 - 10.0
d_{crt} (m)	7.0	7.5	7.0	7.5	7.5
GWT (m)	1.8	1.8 ± 0.3	1.8	1.8 ± 0.1	1.8 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	18.9 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	132.5	136.0 ± 16.2	132.3	143.3 ± 16.6	148.7 ± 17.4
σ_v' (kPa)	81.6	80.2 ± 8.7	81.2	87.6 ± 8.7	92.9 ± 9.5
a_{max} (g)	0.18	0.180 ± 0.027	0.18	0.180 ± 0.027	0.190 ± 0.029
r_d	0.95	0.75 ± 0.110	0.94	0.87 ± 0.110	0.87 ± 0.110
CSR	0.18	0.149 ± 0.032	0.179	0.167 ± 0.033	0.172 ± 0.034
M_w	7.50	7.50	7.60	7.60	7.60
D_{50}	0.3	0.200 ± 0.035	-	0.200 ± 0.050	0.200 ± 0.050
% Fines	2	8.0 ± 2.0	2	2.0 ± 2.0	2.0 ± 8.6
% PI	-	-	-	-	0
N	18	17.4 ± 0.5	18	17.4 ± 0.5	17.5 ± 0.2
C_R	-	0.99	0.95	0.99	0.96
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.21	1.21	1.21	1.21	1.37
C_N	1.08	1.09	1.10	1.08	1.05
$(N_1)_{60}$	23.5	22.7 ± 0.7	22.7	22.3 ± 0.7	24.1 ± 0.3
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	170.7	-	182.9	182.9

EVENT PARAMETERS

1964 Niigata Earthquake — Hurukawa and Harada 2013

Magnitude: 7.60 — strike: N9◦E

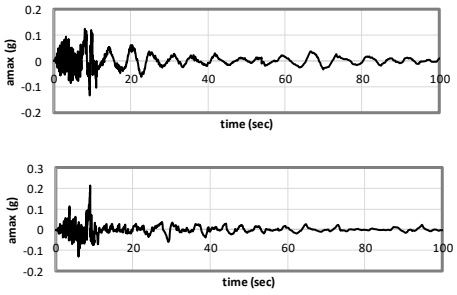
Fault Type: thrust earthqua — Z_{tor} (km): 0 (USGS 15km) — R_{rup} (km): 9--13

Dip: 60 or 34 — Width (km): 14 or 27 — R_{jb} (km): 9--13

H1 0.135

H2 0.213

GEO. MEAN 0.169



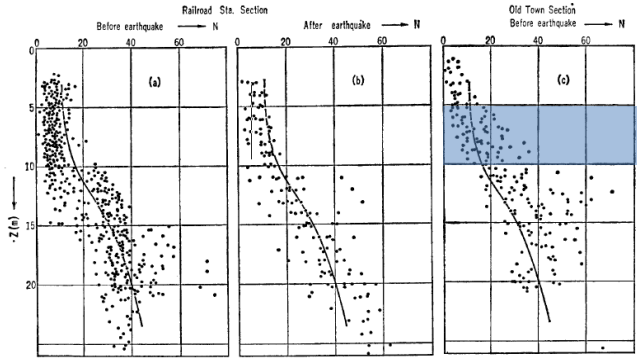
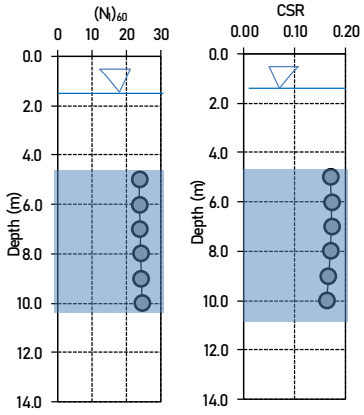


Fig. 2. N-values in two section in the city.



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
5.0	*16.4*	*0.171*	*15*	*1.24*	*0.94*	*23.8*
6.0	*19.7*	*0.173*	*16*	*1.15*	*0.95*	*23.9*
7.0	*23.0*	*0.173*	*17*	*1.08*	*0.96*	*24.0*
8.0	*26.2*	*0.171*	*18*	*1.02*	*0.97*	*24.1*
9.0	*29.5*	*0.167*	*19*	*0.96*	*0.97*	*24.4*
10.0	*32.8*	*0.163*	*20*	*0.92*	*0.98*	*24.6*
					Mean:	24.1
					St. Dev.	0.3

Case number:	10
Earthquake:	1964 Niigata Earthquake
Magnitude:	7.6 (Mw) http://ds.iris.edu/seismo-archives/quakes/1964niigata/
Location:	Old Town-2
References:	Koizumi (1964), Seed and Idriss (1966), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface evidence of liquefaction has been observed at Old Town section.
GPS LAT	37.920351
GPS LONG	139.043202
Liq. layer consist of:	sand
Geological Unit:	alluvial sand deposits/Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Niigata is located on the west coast of Japan where Shinano River enters the sea. The river has built up a considerable thickness of alluvial sand deposits, which along the coast have been overlain by deposits of dune sand. In general, the sand deposits underlying the city are relatively loose near the ground surface but get denser with increasing depth. The sand extends to a depth of ~100' and alluvial deposits to 200-300'. In the vicinity of the river, the ground is relatively flat. Niigata city was below sea level about a thousand years ago and the bay was ditted with several small islands. The EQ was the first large vibration the recent deposits had experienced. The epicenter of the earthquake was located some 35 miles north of the city. From the seismograph, located in the basement of an apartment building it was estimated that the PGA at Niigata was in the order of 0.16 g. The soil below the seismograph liquefied during the earthquake. It is interesting to note the marked change in form of record from a predominantly short period motion to a long period motion which occurred after about 8 seconds. Seed et al (84) estimated PGA not as 0.16 but 0.18 g probably due to the fact the site did not liquefy so no de-amplification. Seed et al (84) adopted rod energy of 73 % (average Japanese energy value) for non-liquefied sites and 65 % (Japanese lower bound) for liquefied sites. Water table was at 1-2 m except for dune sand. SPT values were taken before the earthquake. SPT energy was estimated as 73 % by Seed et al. (84)". Bhattacharya et al. (2014) referred to two different fault plane solutions: 1) Shiba and Uetake (west-dipping) and 2) Hurukawa and Harada (east-dipping). The borehole data provided represents many borehole data available in the old town. Hence taking two non-liquefied case histories is not against statistically independent assumptions. PGA is updated based on the available digital recording as 0.169 g (geometric mean of 0.135 g and 0.213 g) for the liquefied sites. Seed et al. (1984) estimated PGA for the site a little higher (0.18 g) than the recorded (0.16 g) one probably due to no de-amplification at non-liquefied sites. The ratio was 0.18/0.16=1.125. Hence 0.169*0.125=0.190 g is assigned to the site.

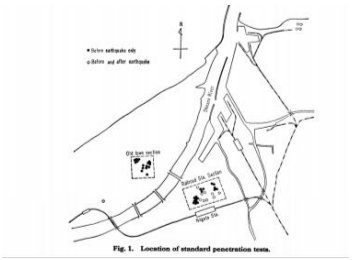


Fig. 1. Location of standard penetration tests.

Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	10.0 - 13.0		10.0 - 13.0	10.0 - 13.0
d_{crt} (m)	10.1	11.5	10.1	11.5	11.5
GWT (m)	1.8288	1.8 ± 0.3	1.8	1.8 ± 0.1	1.8 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	18.9 ± 0.6	-	19.6 ± 0.5	21.5 ± 0.5
σ_v (kPa)	190.1	211.6 ± 11.3	190.5	222.1 ± 10.9	240.3 ± 11.8
σ_v' (kPa)	109.0	116.5 ± 7.9	109.3	127.0 ± 6.8	145.3 ± 7.5
a_{max} (g)	0.18	0.180 ± 0.027	0.18	0.180 ± 0.027	0.190 ± 0.029
r_d	0.91	0.55 ± 0.158	0.9	0.74 ± 0.158	0.74 ± 0.158
CSR	0.185	0.116 ± 0.038	0.184	0.152 ± 0.040	0.152 ± 0.039
M_w	7.50	7.50	7.60	7.60	7.60
D_{50}	0.3	0.200 ± 0.035	-	0.200 ± 0.050	0.200 ± 0.050
% Fines	2	8.0 ± 2.0	2	2.0 ± 2.0	2.0 ± 8.6
% PI	-	-	-	-	0
N	20	24.7 ± 3.0	20	24.7 ± 3.0	24.7 ± 3.0
C_R	-	1.00	1.00	1.00	0.98
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.21	1.21	1.21	1.21	1.37
C_N	0.94	0.91	0.97	0.89	0.84
$(N_1)_{60}$	22.5	27.1 ± 3.3	23.5	26.7 ± 3.2	27.8 ± 3.4
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	170.7	-	182.9	182.9

EVENT PARAMETERS

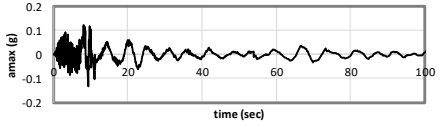
1964 Niigata Earthquake — Hurukawa and Harada 2013

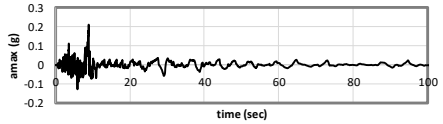
Magnitude: 7.60 — strike: N9◦E

Fault Type: thrust earthqua — Z_{tor} (km): 0 (USGS 15km) — R_{rup} (km): 9--13

Dip: 60 or 34 — Width (km): 14 or 27 — R_{jb} (km): 9--13

H1	0.135
H2	0.213
GEO. MEAN	0.169





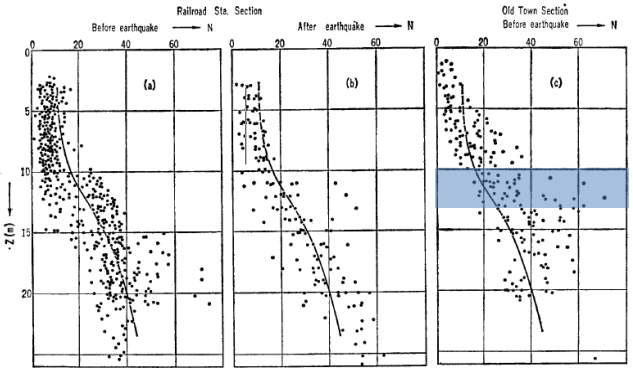
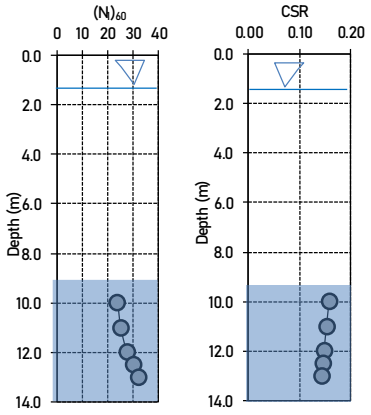


Fig. 2. N-values in two section in the city.



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
10.0	*32.8*	*0.159*	*20*	*0.89*	*0.98*	*23.8*
11.0	*36.1*	*0.154*	*22*	*0.85*	*0.98*	*25.2*
12.0	*39.4*	*0.149*	*25*	*0.82*	*0.99*	*27.6*
12.5	*41.0*	*0.147*	*28*	*0.80*	*0.99*	*30.4*
13.0	*42.7*	*0.145*	*30*	*0.79*	*0.99*	*32.0*
					Mean:	27.8
					St. Dev.	3.4

Case number:	12
Earthquake:	1964 Niigata Earthquake
Magnitude:	7.6 (Mw) http://ds.iris.edu/seismo-archives/quakes/1964niigata/
Location:	Rail Road-2
References:	Koizumi (1964), Seed and Idriss (1966), Cetin (2000), Cetin et al (2004, 2018), Fear and McRoberts (1993)
Nature of Failure:	The SPT measurements before and after the earthquake are used for predicting
GPS LAT	37.89553 liquefaction in conjunction with the surface evidence of it.
GPS LONG	139.01977
Liq. layer consist of:	sand
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Niigata is located on the west coast of Japan where Shinano River enters the sea. The river has built up a considerable thickness of alluvial sand deposits, which along the coast have been overlain by deposits of dune sand. In general, the sand deposits underlying the city are relatively loose near the ground surface but get denser with increasing depth. The sand extends to a depth of ~100' and alluvial deposits to 200-300'. In the vicinity of the river, the ground is relatively flat. Niigata city was below sea level about a thousand years ago and the bay was dotted with several small islands. The EQ was the first large vibration the recent deposits had experienced. The epicenter of the earthquake is located some 35 miles north of the city. From the seismograph, located in the basement of an apartment building it was estimated that the PGA at Niigata was of the order of 0.16 g. The soil below the seismograph liquefied during the earthquake. It is interesting to note the marked change in form of record from a predominantly short period motion to a long period motion which occurred after about 8 seconds. Seed et al (84) adopted rod energy of 73 % (average Japanese energy value) for non-liquefied sites and 65 % (Japanese lower bound) for liquefied sites. The water table was at 1-2 m except for dune sand. SPT values were taken before and after the earthquake. SPT energy % was estimated as 65 % by Seed et al. (1984)". PGA is updated based on the available digital recording as 0.169 g (geometric mean of 0.135 g and 0.213 g). The borehole data provided represents many borehole data available on the railroad site. Hence taking two case histories is not against statistically independent assumptions. (e.g. Rail road 1 and 2).

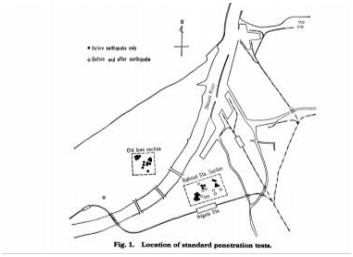


Fig. 1. Location of standard penetration tests.

Gravel Content (%):	0.00
CPT available:	No
Vs available:	No

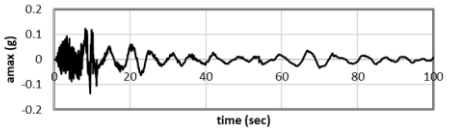
Summary of Input Data

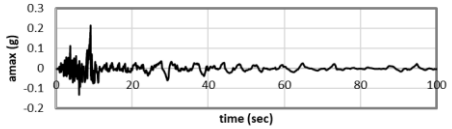
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No/Yes	No/Yes	Marginal	No/Yes	No/Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	9.0 - 11.0		9.0 - 11.0	9.0 - 11.0
d_{crt} (m)	10.1	10.0	10.1	10.0	10.0
GWT (m)	0.9144	0.9 ± 0.3	0.9	0.9 ± 0.3	0.9 ± 0.3
γ_{moist} (kN/m^3)	-	15.7 ± 0.9	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	17.3 ± 0.9	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	190.1	171.8 ± 10.4	190.5	194.7 ± 7.9	203.3 ± 8.2
σ_v' (kPa)	100.3	82.5 ± 9.3	100.3	105.4 ± 5.9	114.0 ± 6.0
a_{max} (g)	0.16	0.160 ± 0.024	0.16	0.160 ± 0.024	0.169 ± 0.025
r_d	0.91	0.65 ± 0.140	0.9	0.77 ± 0.140	0.77 ± 0.140
CSR	0.18	0.140 ± 0.038	0.178	0.147 ± 0.035	0.150 ± 0.036
M_w	7.50	7.50	7.60	7.60	7.60
D_{50}	0.3	0.200 ± 0.035	-	0.200 ± 0.050	0.200 ± 0.050
% Fines	2	2.0 ± 2.0	2	2.0 ± 2.0	2.0 ± 8.6
% PI	-	-	-	-	0
N	16	16.0 ± 2.1	16	16.0 ± 1.9	16.0 ± 1.6
C_R	-	1.00	1.00	1.00	0.98
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.09	1.09	1.09	1.09	1.37
C_N	0.98	1.08	1.01	0.98	0.94
$(N_1)_{60}$	17	18.8 ± 2.5	17.5	17.1 ± 2.0	20.2 ± 2.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	176.8	-	176.8	176.8

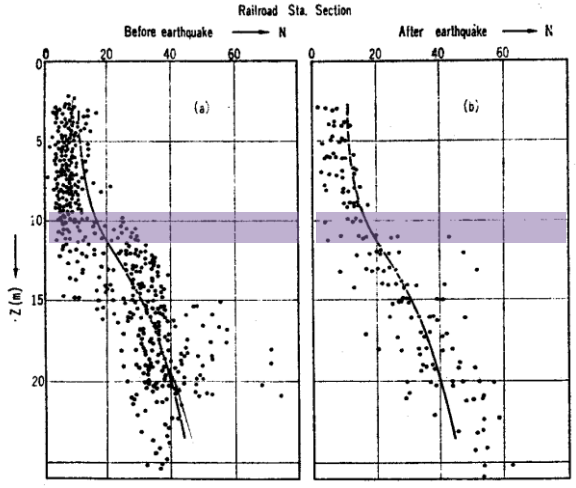
EVENT PARAMETERS

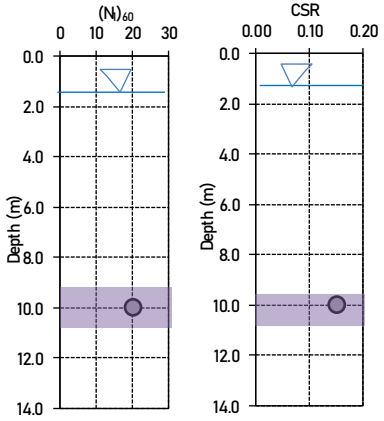
1964 Niigata Earthquake	Hurukawa and Harada 2013	
Magnitude: 7.60	strike: N9◦E	
Fault Type: thrust earthqua	Z_{tor} (km): 0 (USGS 15km)	R_{rup} (km): 12--16
Dip: 60 or 34	Width (km): 14 or 27	R_{jb} (km): 12--16

H1	0.135
H2	0.213
GEO. MEAN	0.169









Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
10.0	*32.8*	*0.150*	*16*	*0.94*	*0.98*	*20.2*
					Mean:	20.2
					St. Dev.	2.0

Case number:	11
Earthquake:	1964 Niigata Earthquake
Magnitude:	7.6 (Mw)
Location:	Rail Road-1
References:	Koizumi (1964), Seed and Idriss (1966), "An analysis of soil liquefaction in the Niigata Eq.", Cetin et al (2004, 2018)
Nature of Failure:	The SPT measurements before and after the earthquake are used for predicting
GPS LAT	37.89553
GPS LONG	139.01977
Liq. layer consist of:	sand
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Niigata is located on the west coast of Japan where Shinano River enters the sea. The river has built up a considerable thickness of alluvial sand deposits, which along the coast have been overlain by deposits of dune sand. In general, the sand deposits underlying the city are relatively loose near the ground surface but get denser with increasing depth. The sand extends to a depth of ~100' and alluvial deposits to 200-300'. In the vicinity of the river, the ground is relatively flat. Niigata city was below sea level about a thousand years ago and the bay was dotted with several small islands. The EQ was the first large vibration the recent deposits had experienced. The epicenter of the earthquake is located some 35 miles north of the city. From the seismograph, located in the basement of an apartment building it was estimated that the PGA at Niigata was of the order of 0.16 g. The soil below the seismograph liquefied during the earthquake. It is interesting to note the marked change in form of record from a predominantly short period motion to a long period motion which occurred after about 8 seconds. Seed et al (84) adopted rod energy of 73 % (average Japanese energy value) for non-liquefied sites and 65 % (Japanese lower bound) for liquefied sites. The water table was at 1-2 m except for dune sand. SPT values were taken before and after the earthquake. SPT energy % was estimated as 65 % by Seed et al. (1984)". PGA is updated based on the available digital recording as 0.169 g (geometric mean of 0.135 g and 0.213 g). The borehole data provided represents many borehole data available on the railroad site. Hence taking two case histories is not against statistically independent assumptions. (e.g. Rail road 1 and 2).

http://ds.iris.edu/seismo-archives/quakes/1964niigata/

liquefaction in conjunction with the surface evidence of it.

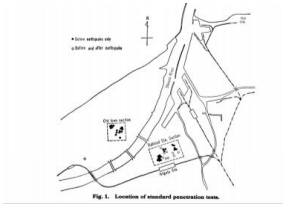


Fig. 1. Location of standard penetration tests.

Gravel Content (%):	0.00
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	A	A
d_{crtc} range (m)	-	5.0 - 10.0		5.0 - 10.0	5.0 - 10.0
d_{crt} (m)	10.1	7.5	10.1	7.5	7.5
GWT (m)	0.9	0.9 ± 0.3	0.9	0.9 ± 0.1	0.9 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.9	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.9	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	190.1	122.6 ± 15.2	190.5	145.5 ± 16.7	151.7 ± 17.5
σ_v' (kPa)	100.3	57.9 ± 8.8	100.3	80.8 ± 8.8	87.0 ± 9.6
a_{max} (g)	0.16	0.160 ± 0.024	0.16	0.160 ± 0.024	0.169 ± 0.025
r_d	0.91	0.78 ± 0.110	0.9	0.85 ± 0.110	0.85 ± 0.110
CSR	0.18	0.172 ± 0.038	0.178	0.160 ± 0.032	0.164 ± 0.032
M_w	7.50	7.50	7.60	7.60	7.60
D_{50}	0.3	0.200 ± 0.035	-	D10 (mm) ± 0.080	0.200 ± 0.050
% Fines	2	8.0 ± 2.0	2	0.0 ± 2.0	2.0 ± 8.6
% PI	-	-	-	-	0
N	10	9.4 ± 1.2	10	9.4 ± 1.1	9.5 ± 0.9
C_R	-	0.99	1.00	0.99	0.96
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.09	1.09	1.09	1.09	1.37
C_N	0.98	1.29	1.01	1.12	1.08
$(N_1)_{60}$	10.5	13.0 ± 1.6	11	11.3 ± 1.3	13.5 ± 1.3
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	176.8	-	176.8	176.8

EVENT PARAMETERS

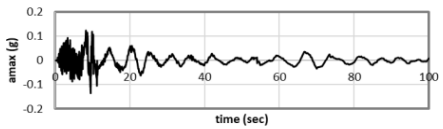
1964 Niigata Earthquake — Hurukawa and Harada 2013

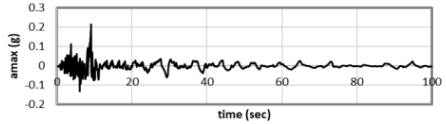
Magnitude: 7.60 — strike: N9◦E

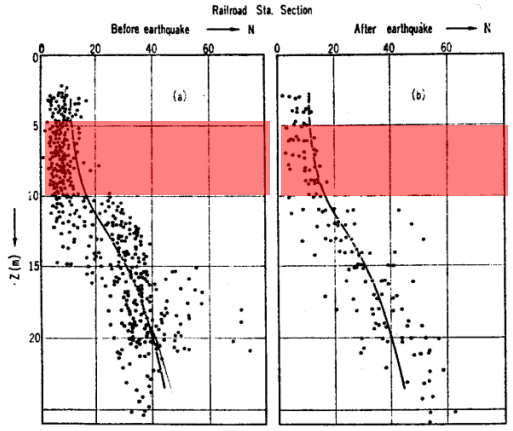
Fault Type: thrust earthqua — Z_{tor} (km): 0 (USGS 15km) — R_{rup} (km): 12--16

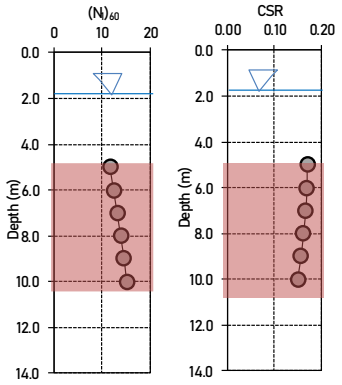
Dip: 60 or 34 — Width (km): 14 or 27 — R_{jb} (km): 12--16

H1	0.135
H2	0.213
GEO. MEAN	0.169









Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
5.0	*16.4*	*0.170*	*7*	*1.30*	*0.94*	*11.7*
6.0	*19.7*	*0.169*	*8*	*1.20*	*0.95*	*12.4*
7.0	*23.0*	*0.166*	*9*	*1.12*	*0.96*	*13.1*
8.0	*26.2*	*0.161*	*10*	*1.05*	*0.97*	*13.8*
9.0	*29.5*	*0.156*	*11*	*0.99*	*0.97*	*14.5*
10.0	*32.8*	*0.150*	*12*	*0.94*	*0.98*	*15.1*
					Mean:	13.5
					St. Dev.	1.3

Case number:	13
Earthquake:	1964 Niigata Earthquake
Magnitude:	7.6 (Mw)
Location:	River Site
References:	Ishihara et. al. (1979), Seed and Idriss (1966), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Surface cracking and ejection of sand and water; flooding of sand and water over the ground surface.
GPS LAT	37.896835
GPS LONG	139.015857
Liq. layer consist of:	sand
Geological Unit:	Uncompacted fill/alluvial deposits/Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

http://ds.iris.edu/seismo-archives/quakes/1964niigata/

Seed and Idriss (1966), "An analysis of soil liquefaction in the Niigata Eq."

Comments: Cetin (2000) "Niigata is located on the west coast of Japan where Shinano River enters the sea. The river has built up a considerable thickness of alluvial sand deposits, which along the coast have been overlain by deposits of dune sand. In general, the sand deposits underlying the city are relatively loose near the ground surface but get denser with increasing depth. The sand extends to a depth of ~100' and alluvial deposits to 200-300'. In the vicinity of river the ground is relatively flat. Niigata city was below sea level about thousand years ago and the bay was ditted with several small islands. The EQ was the first large vibration the recent deposits had experienced. The River Site was located ~ 10 m from the bank of the Shinano river. The site was reclaimed by in 1955 by constructing a dike along the river channel. The top 1 m consists of uncompacted fill dumped in the air. Undensified fine sand dumped through the water between a depth of 1-3m. From 3-5m overconsolidated medium sand deposits. Fluvial river deposits consisting of medium sand with occasional silt lenses. Below 15 m a silt layer is underlain by uniform coarse sand. The epicenter of the earthquake was located some 35 miles north of the city. From the seismograph, located in the basement of an apartment building it was estimated that the PGA at Niigata was of the order of 0.16 g. The soil below the seismograph liquefied during the earthquake. It is interesting to note the marked change in form of record from a predominantly short period motion to a long period motion which occurred after about 8 seconds. SPT values were taken before and after the earthquake." SPT energy was estimated as 65 % by Seed et al. (1984)



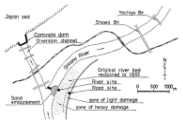


Fig. 1. Map showing location of the river sampling site and the road sampling site

Bhattacharya et al. (2014) referred two different fault plane solution: 1) Shiba and Uetake (west-dipping) and 2) Hurukawa and Harada (east dipping)

The River Site was located ~ 100 m from the bank of the Shinano river. Free field conditions satisfied.

PGA is updated based on the available digitial recording as 0.169 g (geometric mean of 0.135 g and 0.213 g).

SPT profile is redigitized and related depths slightly updated.

H1	0.135
H2	0.213
GEO. MEAN	0.169

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	A	A
d_{crtc} range (m)	-	4.0 - 13.0		2.0 - 6.0	2.0 - 6.0
d_{crt} (m)	4.6	8.5	4.6	4.0	4.0
GWT (m)	0.6096	0.6 ± 0.3	0.6	0.6 ± 0.1	0.6 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.9	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	17.3 ± 0.5	18.9 ± 0.5
σ_v (kPa)	86.4	139.6 ± 25.3	86.2	68.3 ± 11.7	73.7 ± 12.7
σ_v' (kPa)	47.5	62.0 ± 11.5	47.1	34.9 ± 5.3	40.3 ± 6.3
a_{max} (g)	0.16	0.160 ± 0.024	0.16	0.160 ± 0.024	0.169 ± 0.025
r_d	0.97	0.60 ± 0.122	0.97	0.93 ± 0.064	0.93 ± 0.064
CSR	0.185	0.140 ± 0.037	0.183	0.189 ± 0.032	0.187 ± 0.032
M_w	7.50	7.50	7.60	7.60	7.60
D_{50}	0.4	0.430 ± 0.040	-	0.400 ± 0.050	0.400 ± 0.050
% Fines	0	0.0 ± 0.0	0	0.0 ± 2.0	0.0 ± 8.6
% PI	-	-	-	-	0
N	6	8.2 ± 3.2	6	4.0 ± 1.2	4.1 ± 1.0
C_R	-	1.00	0.95	0.89	0.92
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.09	1.09	1.09	1.09	1.37
C_N	1.38	1.24	1.52	1.71	1.59
$(N_1)_{60}$	9	11.1 ± 4.3	9.4	6.6 ± 1.9	8.1 ± 2.1
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	149.4	-	164.6	164.6

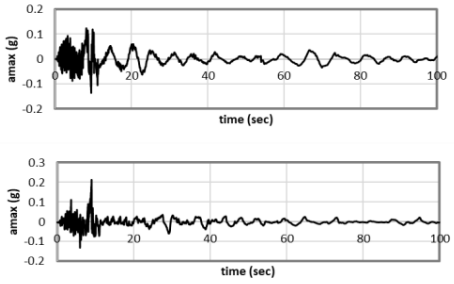
EVENT PARAMETERS

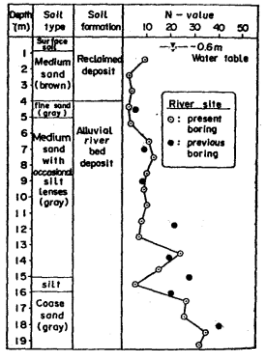
1964 Niigata Earthquake — Hurukawa and Harada 2013

Magnitude: 7.60 — strike: N9◦E

Fault Type: thrust earthqua — Z_{tor} (km): 0 (USGS 15km) — R_{rup} (km): 12--16

Dip: 60 or 34 — Width (km): 14 or 27 — R_{jb} (km): 12--16





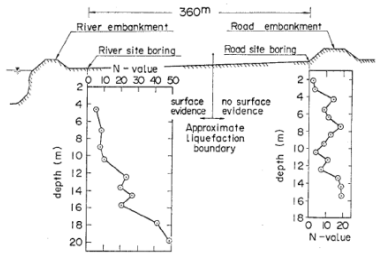


Fig. 3. Cross section between river and road boring sites Niigata, Japan

Ishihara et. al. (1979)

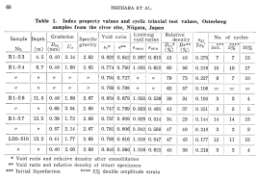
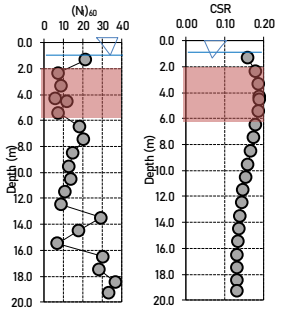


Table 1. Index property values and cyclic triaxial test values, Ostenfeld samples from the river site, Niigata, Japan

Sample No.	Depth (m)	Gradation D_{50} (mm)	Gradation U_c	Specific gravity	Void ratio e_0*	Void ratio e^{**}	Void ratio e_{max}	Void ratio e_{min}	Relative density D_r* (%)	Relative density D_r** (%)	G_d (kg/cm²)	No. of cycles one-way	No. of cycles DA***	No. of cycles SIG
B1-S3	4.5	0.40	3.34	2.62	0.856	0.842	0.997	0.631	63	63	0.276	7	7	13
B1-S4	6.7	0.40	1.83	2.65	0.774	0.760	1.035	0.623	69	66	0.276	10	10	17
〃	〃	〃	〃	〃	0.794	0.727	〃	〃	78	73	0.227	9	7	10
〃	〃	〃	〃	〃	0.766	0.736	〃	〃	82	97	0.106	∞	∞	∞
B1-S6	11.5	0.46	1.99	2.67	0.854	0.870	1.024	0.556	58	34	0.195	3	3	4
〃	〃	0.46	2.04	2.69	0.747	0.760	0.933	0.495	63	57	0.161	3	3	5
B1-S7	13.5	0.39	1.72	2.69	0.787	0.809	0.959	0.614	76	29	0.144	14	14	23
〃	〃	0.37	2.14	2.67	0.795	0.805	0.941	0.566	67	60	0.218	3	3	5
L30-S10	13.2	0.41	1.77	2.66	0.795	0.816	1.016	0.547	67	65	0.177	12	11	23
〃	〃	0.40	2.03	2.66	0.842	0.866	1.016	0.621	65	56	0.218	5	5	6

* Void ratio and relative density after consolidation
** Void ratio and relative density at thrust specimens
*** Initial liquefaction **** 5% double amplitude strain



d (m)	D_{50} (mm)
4.5	0.40
6.7	0.40
6.7	0.40
6.7	0.40
11.5	0.46
11.5	0.65
13.5	0.39
13.5	0.57
13.2	0.41
13.2	0.40

Depth (m)		
0	0.9	Surface Soil
0.9	4	Medium Sand (brown)
4	5	Fine Sand (gray)
5	15	Medium Sand with occasional Silt lenses (gray)
15	16	Silt
16	19.5	Coarse Sand (gray)

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
present boring	1.3	4.4	0.157	9	2.00	0.87	21.3	Medium Sand (brown)
present boring	***2.4***	***7.7***	***0.179***	***3***	***2.00***	***0.89***	***7.3***	Medium Sand (brown)
present boring	***3.3***	***10.9***	***0.186***	***4***	***1.73***	***0.91***	***8.6***	Medium Sand (brown)
present boring	***4.3***	***14.1***	***0.187***	***3***	***1.54***	***0.93***	***5.8***	Fine Sand (gray)
previous boring	***4.5***	***14.8***	***0.187***	***6***	***1.51***	***0.93***	***11.5***	Fine Sand (gray)
present boring	***5.4***	***17.7***	***0.184***	***4***	***1.38***	***0.94***	***7.1***	Medium Sand with occasional Silt lenses (gray)
present boring	6.5	21.3	0.179	11	1.27	0.95	*18.2*	Medium Sand with occasional Silt lenses (gray)
present boring	7.5	24.5	0.173	13	1.19	0.96	*20.3*	Medium Sand with occasional Silt lenses (gray)
present boring	8.5	27.9	0.166	10	1.12	0.97	*14.8*	Medium Sand with occasional Silt lenses (gray)
present boring	9.5	31.2	0.159	9	1.06	0.98	*12.7*	Medium Sand with occasional Silt lenses (gray)
present boring	10.5	34.5	0.152	10	1.01	0.98	*13.5*	Medium Sand with occasional Silt lenses (gray)
present boring	11.5	37.8	0.146	8	0.97	0.98	*10.4*	Medium Sand with occasional Silt lenses (gray)
present boring	12.5	40.9	0.142	7	0.93	0.99	*8.8*	Medium Sand with occasional Silt lenses (gray)
present boring	13.5	44.2	0.138	24	0.90	0.99	*29.1*	Medium Sand with occasional Silt lenses (gray)
present boring	14.5	47.6	0.135	15	0.87	0.99	*17.6*	Medium Sand with occasional Silt lenses (gray)
present boring	15.5	50.7	0.133	6	0.84	0.99	*6.8*	Silt
present boring	16.5	54.1	0.132	27	0.81	0.99	*29.8*	Coarse Sand (gray)
present boring	17.5	57.3	0.131	26	0.79	1.00	*28.0*	Coarse Sand (gray)
present boring	18.5	60.5	0.130	35	0.77	1.00	*36.7*	Coarse Sand (gray)
present boring	19.2	63.1	0.129	32	0.75	1.00	*32.9*	Coarse Sand (gray)
						Mean:	8.1	
						St. Dev.	2.1	

seems to belong the upper layer

Case number:	14
Earthquake:	1964 Niigata Earthquake
Magnitude:	7.6 (Mw) http://ds.iris.edu/seismo-archives/quakes/1964niigata/
Location:	Road Site
References:	Ishihara et. al. (1979), Seed and Idriss (1966), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface evidence of liquefaction
GPS LAT	37.89553
GPS LONG	139.01977
Liq. layer consist of:	Sand
Geological Unit:	Uncompacted fill/alluvial deposits/Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Niigata is located on the west coast of Japan where Shinano River enters the sea. The river has built up a considerable thickness of alluvial sand deposits, which along the coast have been overlain by deposits of dune sand. In general, the sand deposits underlying the city are relatively loose near the ground surface but get denser with increasing depth. The sand extends to a depth of ~100' and alluvial deposits to 200-300'. In the vicinity of the river, the ground is relatively flat. Niigata city was below sea level about a thousand years ago and the bay was ditted with several small islands. The EQ was the first large vibration the recent deposits had experienced. The Road Site was located on the level ground adjacent to the road ~ 350 m from the Shinano River bank. The top 1.5 m consists of surface soil which is underlain to a depth of 4 m by silt and sandy silt. Below 4 m the soil profile consists of alternate layers of medium sand and silt to a depth of 16 m. The epicenter of the earthquake was located some 35 miles north of the city. From the seismograph, located in the basement of an apartment building."



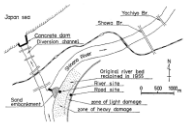


Fig. 1. Map showing location of the river sampling site and the road sampling site

Bhattacharya et al. (2014) referred two different fault plane solution: 1) Shiba and Uetake (west-dipping) and 2) Hurukawa and Harada (east dipping)

PGA is updated based on the available digitial recording as 0.169 g (geometric mean of 0.135 g and 0.213 g) for the liquefied sites. Seed et al. (1984) estimated PGA for the site a little higher (0.18 g) than the recorded (0.16 g) one probably due to no de-amplification at non-liquefied sites. The difference was 0.02 g. Hence 0.169+0.02=0.189 g is assigned to the site.

H1	0.135
H2	0.213
GEO. MEAN	0.169

Soil layers were digitized. Medium sand layer extends to 10 m hence critical layer is updated as 4-10 m.

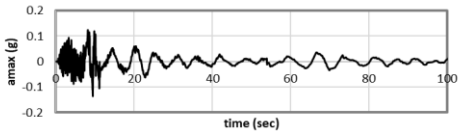
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

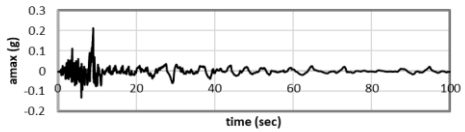
Summary of Input Data

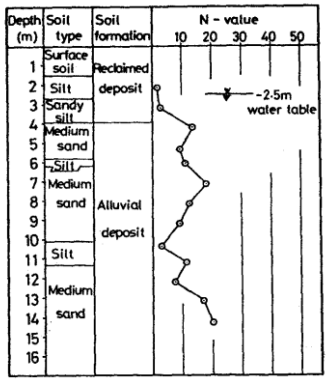
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	B	-	A	A
d_{crtc} range (m)	-	4.0 - 9.0		4.0 - 9.0	4.0 - 10.0
d_{crt} (m)	6.1	6.5	6.1	6.5	7.0
GWT (m)	2.4384	2.5 ± 0.3	2.4	2.5 ± 0.1	2.5 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.9	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	17.3 ± 0.9	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	115.2	106.7 ± 15.1	115.3	118.1 ± 16.6	132.2 ± 20.8
σ_v' (kPa)	79.2	67.4 ± 8.0	79.2	78.8 ± 8.5	88.0 ± 11.1
a_{max} (g)	0.18	0.180 ± 0.027	0.18	0.180 ± 0.027	0.189 ± 0.028
r_d	0.96	0.78 ± 0.097	0.95	0.88 ± 0.097	0.86 ± 0.103
CSR	0.165	0.144 ± 0.030	0.162	0.154 ± 0.029	0.159 ± 0.031
M_w	7.50	7.50	7.60	7.60	7.60
D_{50}	0.36	0.450 ± 0.040	-	0.360 ± 0.129	0.360 ± 0.129
% Fines	0	0.0 ± 0.0	0	0.0 ± 2.0	0.0 ± 8.6
% PI	-	-	-	-	0
N	12	12.0 ± 3.1	12	12.1 ± 3.2	12.5 ± 3.3
C_R	-	0.96	0.95	0.96	0.96
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.09	1.09	1.09	1.09	1.37
C_N	1.09	1.19	1.13	1.14	1.07
$(N_1)_{60}$	14.5	15.1 ± 3.9	14.1	14.4 ± 3.8	17.6 ± 4.7
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	164.6	-	173.7	173.7

EVENT PARAMETERS

1964 Niigata Earthquake	Hurukawa and Harada 2013	
Magnitude: 7.60	strike: N9°E	
Fault Type: thrust earthqua	Z_{tor} (km): 0 (USGS 15km)	R_{rup} (km): 12--16
Dip: 60 or 34	Width (km): 14 or 27	R_{jb} (km): 12--16







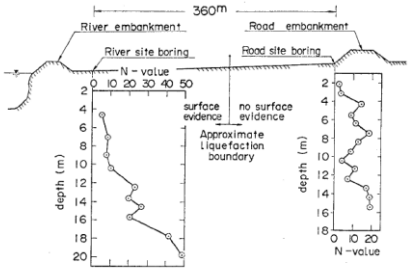
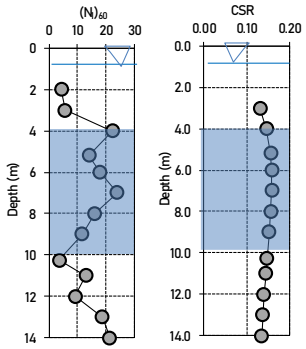


Fig. 3. Cross section between river and road boring sites Niigata, Japan



d(m)	D_{50} (mm)
4.2	0.63
4.2	0.34
5.1	0.23
6.9	0.36
6.9	0.38
8.4	0.3
8.4	0.28
9.2	0.34
9.2	0.3
11.7	0.36
11.7	0.35
12.8	0.48
12.8	0.48
13.8	0.39
13.8	0.45
D_{50} (mm)	0.36
d(m)	0.13

Depth (m)	
0	1.5 Surface soil
1.5	2.8 Silt
2.8	4 Sandy Silt
4	5.9 Medium Sand
5.9	6.2 Silt
6.2	10 Medium Sand
10	11.3 Silt
11.3	15 Medium Sand

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
2	6.6	NA	2	1.80	0.88	4.3	Silt
3.0	9.8	0.131	3	1.51	0.90	5.6	Sandy Silt
4.0	***13.1***	***0.147***	***13***	***1.35***	***0.92***	***22.2***	Medium Sand
5.2	***17.1***	***0.156***	***9***	***1.22***	***0.94***	***14.1***	Medium Sand
6.0	***19.7***	***0.158***	***12***	***1.15***	***0.95***	***17.8***	Silt
7.0	***23.0***	***0.159***	***17***	***1.07***	***0.96***	***23.9***	Medium Sand
8.0	***26.2***	***0.156***	***12***	***1.01***	***0.97***	***16.1***	Medium Sand
9.0	***29.5***	***0.153***	***9***	***0.96***	***0.97***	***11.5***	Medium Sand
10.3	33.6	0.148	3	0.91	0.98	3.6	Silt
11.0	36.1	0.145	11	0.88	0.98	13.0	Silt?
12.0	39.4	0.141	8	0.85	0.99	9.1	Medium Sand
13.0	42.7	0.137	17	0.82	0.99	18.7	Medium Sand
14.0	45.9	0.135	20	0.79	0.99	21.3	Medium Sand
					Mean:	17.6	
					St. Dev.	4.7	

Case number:	17
Earthquake:	1968 Tokachi-oki Earthquake
Magnitude:	8.2 (Mw)
Location:	Hachinohe-2
References:	Ohsaki (1970), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface evidence of liquefaction. Moderate densification after earthquake.
GPS LAT	40.65366 the map provided by Ohsaki (1970) was not clearly showing the area, hence the location
GPS LONG	141.440308 might not be acuurate
Liq. layer consist of:	sand
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Cetin (2000) "The sites are located in the city of Hachinohe ~560 km north of Tokyo. The site is a flat, sandy beach fronting the Pacific Ocean. The sites consist of sands almost entirely down to a depth of more than 20 m from the ground surface containing a large quantity of iron sand. However, the iron sand had been excavated and backfilled with waste sand except at P2 &5. The ground water table is not deeper than 1.5 m everywhere in the site. Site has been improved by vibrofloatation. It seems like the average Japanese estimated rod energy of 72.5 % has been used by Seed et al (1984). Same values will be adopted The epicenter was located ~180 km from the city of Hachinohe. The PGA was recorded as 0.225 g at the harbor of Hachinohe."

https://earthquake.usgs.gov/earthquakes/eventpage/iscgem821946/executive

FC=5% is assigned by Seed et al (1985) for the snad layer, hence PI is assigned as 0.

Ohsaki (1970)

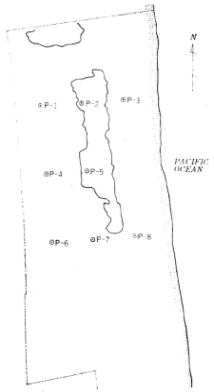


Fig. 2. Site and Locations of Exploratory Borings

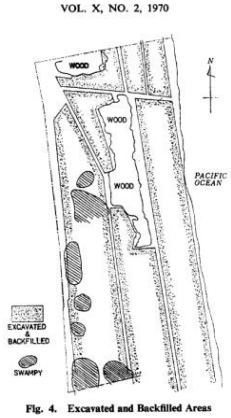


Fig. 4. Excavated and Backfilled Areas

Gravel Content (%):	0.00
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	A	-	B	B
d_{crtc} range (m)	-	3.0 - 7.9		3.0 - 7.9	3.0 - 7.9
d_{crt} (m)	6.1	5.5	6.1	5.5	5.5
GWT (m)	2.13	2.1 ± 0.3	2.1	2.1 ± 0.1	2.1 ± 0.1
γ_{moist} (kN/m^3)	-	18.1 ± 0.9	-	18.1 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	19.6 ± 0.5	-	19.6 ± 0.5	21.5 ± 0.5
σ_v (kPa)	115.2	104.6 ± 16.2	115.3	104.6 ± 16.1	112.7 ± 17.6
σ_v' (kPa)	76.3	71.7 ± 8.8	76.2	71.7 ± 8.3	79.7 ± 9.8
a_{max} (g)	0.23	0.225 ± 0.025	0.23	0.225 ± 0.068	0.225 ± 0.068
r_d	0.96	0.93 ± 0.084	0.98	0.99 ± 0.084	1.00 ± 0.084
CSR	0.215	0.199 ± 0.031	0.221	0.211 ± 0.066	0.206 ± 0.065
M_w	7.90	7.90	8.30	8.30	8.20
D_{50}	0.25	0.250 ± 0.025	-	0.250 ± 0.050	0.250 ± 0.050
% Fines	5	5.0 ± 2.0	5	5.0 ± 2.0	5.0 ± 8.6
% PI	-	-	-	-	0
N	28	28.6 ± 2.1	28	28.5 ± 2.2	29.6 ± 5.8
C_R	-	0.94	0.95	0.94	0.94
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.21	1.21	1.21	1.21	1.37
C_N	1.10	1.16	1.10	1.19	1.13
$(N_1)_{60}$	37.5	37.4 ± 2.8	35.3	38.4 ± 2.9	43.0 ± 8.4
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	201.2	-	231.6	259.1

EVENT PARAMETERS

1968 Tokachi-oki Earthquake

Magnitude: 8.20 No fault model was found

Fault Type: Subduction Z_{tor} (km): NAV R_{rup} (km): NAV

Dip: NAV Width (km): NAV R_{jb} (km): NAV

https://earthquake.usgs.gov/earthquakes/eventpage/iscgem821946/executive

May 16, 1968, 12:49 AM

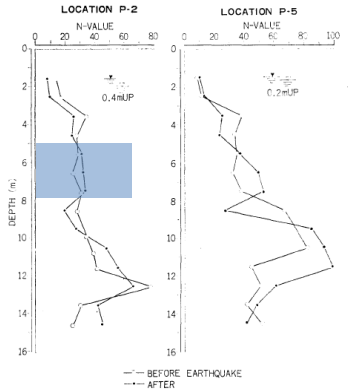
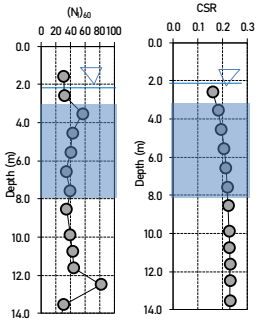


Fig. 15. Changes of N-Values at Locations P-2 and P-5



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
1.6	5.2	NA	14	1.84	0.87	30.9	sand
2.6	8.5	0.160	17	1.49	0.90	31.8	sand
3.5	***11.6***	***0.181***	***34***	***1.34***	***0.91***	***56.8***	sand
4.5	***14.9***	***0.196***	***28***	***1.22***	***0.93***	***43.3***	sand
5.6	***18.3***	***0.207***	***28***	***1.12***	***0.94***	***40.5***	sand
6.6	***21.6***	***0.214***	***25***	***1.05***	***0.95***	***34.2***	sand
7.6	***24.9***	***0.220***	***31***	***0.99***	***0.96***	***40.2***	sand
8.6	28.1	0.224	28	0.94	0.97	34.7	sand
9.9	32.4	0.227	34	0.88	0.98	39.9	sand
10.8	35.3	0.229	38	0.85	0.98	43.1	sand
11.6	38.1	0.230	41	0.82	0.98	45.1	sand
12.5	40.9	0.231	77	0.79	0.99	82.2	sand
13.5	44.4	0.230	30	0.76	0.99	31.0	sand
14.6	48.0	0.230	24	0.74	0.99	24.0	sand
					Mean:	43.0	
					St. Dev.	8.4	

At every location GWT has become shallower.

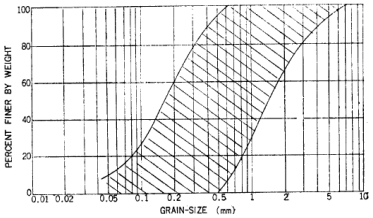


Fig. 5. Critical Zone for Grain-Size Distribution Curves

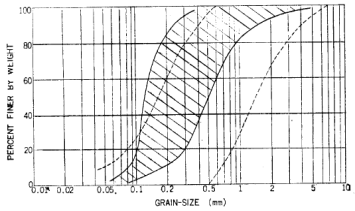


Fig. 6. Grain-Size Distribution of Loose Sands in the Site

Case number:	18
Earthquake:	1968 Tokachi-oki Earthquake
Magnitude:	8.2 (Mw)
Location:	Hachinohe-4
References:	Ohsaki (1970), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface manifestation of soil liquefaction.
GPS LAT	40.65366 the map provided by Ohsaki (1970) was not clearly showing the area, hence the location
GPS LONG	141.440308 might not be acuurate
Liq. layer consist of:	sand
Geological Unit:	Fill, sandy beach fronting on the Pacific Ocean
Site Response Anlaysis:	No
Comments:	Cetin (2000) "The sites are located in the city of Hachinohe ~560 km north of Tokyo. The site is a flat, sandy beach fronting the Pacific Ocean. The sites consist of sands almost entirely down to a depth of more than 20 m from the ground surface containing a large quantity of iron sand. However, the iron sand had been excavated and backfilled with waste sand except at P2 &5 The ground water table is not deeper than 1.5 m everywhere in the site. Site has been improved by vibrofloatation. It seems like the average Japanese estimated rod energy of 72.5 % has been used by Seed et al (1984). Same values will be adopted. The epicenter was located ~180 km from the city of Hachinohe. The PGA was recorded as 0.225 g at the harbor of Hachinohe."
	FC=5% is assigned by Seed et al (1985) for the snad layer, hence PI is assigned as 0.
	At every location GWT has become shallower. The GWT was 0.5 m up after the EQ. GWT=0.9 m by previous researchers is updated as it is the measurement after EQ.

Ohsaki (1970)

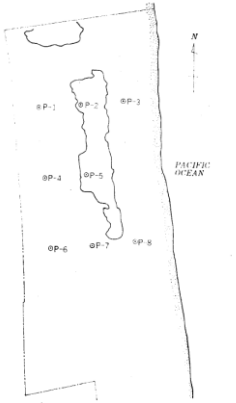


Fig. 2. Site and Locations of Exploratory Borings

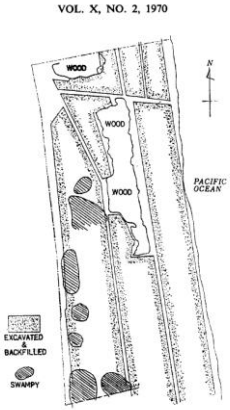


Fig. 4. Excavated and Backfilled Areas

Gravel Content (%):	0.00
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	A	-	B	B
d_{crt} range (m)	-	0.9 - 4.0		0.9 - 4.0	1.3 - 4.0
d_{crt} (m)	4.0	2.4	4.0	2.4	2.6
GWT (m)	0.91	0.9 ± 0.3	0.9	0.9 ± 0.1	1.3 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.9	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	18.1 ± 0.9	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	74.9	42.0 ± 9.4	75.2	45.8 ± 10.0	49.6 ± 9.4
σ_v' (kPa)	45.1	27.0 ± 5.1	45.1	30.9 ± 5.1	36.3 ± 5.0
a_{max} (g)	0.23	0.225 ± 0.025	0.23	0.225 ± 0.068	0.225 ± 0.068
r_d	0.97	0.96 ± 0.042	0.99	1.00 ± 0.042	1.00 ± 0.045
CSR	0.24	0.219 ± 0.037	0.246	0.217 ± 0.067	0.199 ± 0.062
M_w	7.90	7.90	8.30	8.30	8.20
D_{50}	0.25	0.250 ± 0.025	-	0.250 ± 0.050	0.250 ± 0.050
% Fines	5	5.0 ± 2.0	5	5.0 ± 2.0	5.0 ± 8.6
% PI	-	-	-	-	0
N	16	13.9 ± 1.4	16	14.0 ± 1.2	14.0 ± 0.9
C_R	-	0.82	0.85	0.82	0.90
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.21	1.21	1.21	1.21	1.37
C_N	1.41	1.88	1.40	1.81	1.67
$(N_1)_{60}$	27.5	26.0 ± 2.6	23	25.1 ± 2.2	28.7 ± 1.8
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	176.8	-	231.6	231.6

EVENT PARAMETERS

1968 Tokachi-oki Earthquake

Magnitude: 8.20 No fault model was found

Fault Type: Subduction Z_{tor} (km): NAV R_{rup} (km): NAV

Dip: NAV Width (km): NAV R_{jb} (km): NAV

https://earthquake.usgs.gov/earthquakes/eventpage/iscgem821946/executive

May 16, 1968, 12:49 AM

there exist 2 GWT (one after EQ, one before EQ)
At every location GWT has become shallower

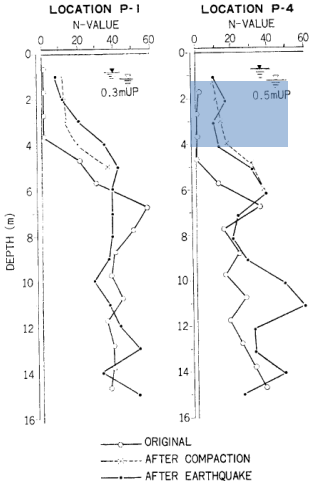
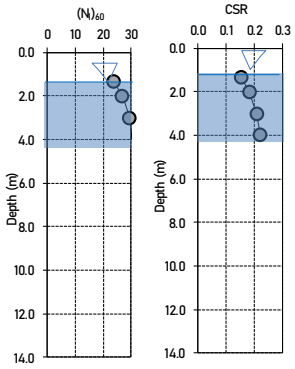


Fig. 14. Changes of N-Values at Locations P-1 and P-4



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
1.3	4.4	0.152	10	2.00	0.87	23.7	CN>2
2.0	*6.6*	*0.182*	*12*	*1.85*	*0.88*	*26.7*	
3.0	*9.8*	*0.207*	*15*	*1.58*	*0.90*	*29.3*	
4.0	*13.1*	*0.222*	*17*	*1.41*	*0.92*	*30.1*	
					Mean:	28.7	
					St. Dev.	1.8	

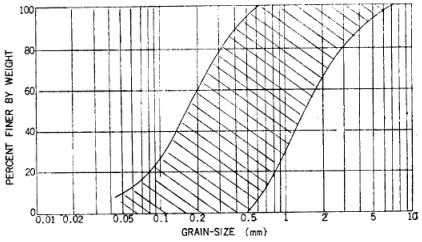


Fig. 5. Critical Zone for Grain-Size Distribution Curves

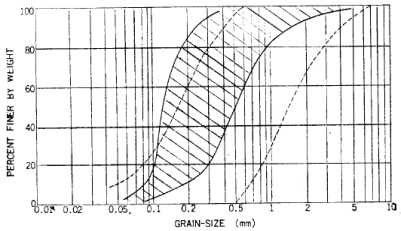


Fig. 6. Grain-Size Distribution of Loose Sands in the Site

Case number:	19
Earthquake:	1968 Tokachi-oki Earthquake
Magnitude:	7.8 (MR)
Location:	Hachinohe-6
References:	Ohsaki (1970), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Eruption of sand and water. Significant densification after earthquake
GPS LAT	40.65366 the map provided by Ohsaki (1970) was not clearly showing the area, hence the location
GPS LONG	141.440308 might not be accurate
Liq. layer consist of:	sand
Geological Unit:	Fill, sandy beach fronting on the Pacific Ocean.
Site Response Anlaysis:	No
Comments:	Cetin (2000) "The sites are located in the city of Hachinohe ~560 km north of Tokyo. The site is a flat, sandy beach fronting the Pacific Ocean. The sites consist of almost entirely sandy deposits down to a depth of 20 m from the ground surface containing a large quantity of iron sand. However, the iron sand had been excavated and backfilled with waste sand except at P2 &5 The ground water table is not deeper than 1.5 m everywhere in the site. Site has been improved by vibrofloatation. Estimated rod energy of 65 % has been used by Seed et al. (1984). Same value will be adopted for this study. The epicenter was located ~180 km from the city of Hachinohe. The PGA was recorded as 0.225 g at the harbor of Hachinohe."
	https://earthquake.usgs.gov/earthquakes/eventpage/iscgem821946/executive
	SPT-N values are redigitized.
	At every location GWT has become shallower. The GWT was 0.4 m up after the EQ. GWT=0.6 m by previous researchers is updated as it is the measurement after EQ.
	The sand has FC=5 by Seed et al (1985) hence PI is assigned as 0.
Gravel Content (%):	0.00
CPT available:	No
Vs available:	No

Ohsaki (1970)

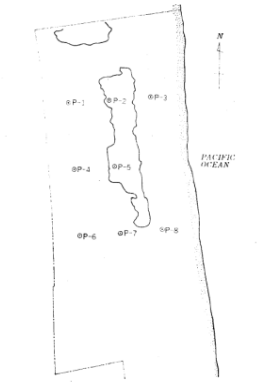


Fig. 2. Site and Locations of Exploratory Borings

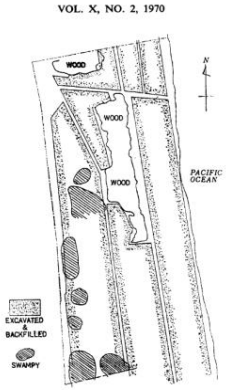


Fig. 4. Excavated and Backfilled Areas

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	A	-	B	B
d_{crtc} range (m)	-	2.0 - 6.1		2.0 - 6.1	2.0 - 6.1
d_{crt} (m)	4.0	4.1	4.0	4.1	4.1
GWT (m)	0.61	0.6 ± 0.3	0.6	0.6 ± 0.1	1.2 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.9	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 1.3	-	19.6 ± 0.5	19.6 ± 0.5
σ_v (kPa)	74.9	66.1 ± 12.1	75.2	78.4 ± 13.5	77.0 ± 13.5
σ_v' (kPa)	41.8	32.2 ± 6.8	42.1	44.5 ± 6.9	48.9 ± 6.9
a_{max} (g)	0.23	0.225 ± 0.025	0.23	0.225 ± 0.068	0.225 ± 0.068
r_d	0.97	0.89 ± 0.065	0.99	0.99 ± 0.065	0.99 ± 0.065
CSR	0.26	0.267 ± 0.047	0.265	0.254 ± 0.079	0.227 ± 0.070
M_w	7.90	7.90	8.30	8.30	8.20
D_{50}	0.25	0.250 ± 0.025	-	0.250 ± 0.050	0.250 ± 0.050
% Fines	5	5.0 ± 2.0	5	5.0 ± 2.0	5.0 ± 8.6
% PI	-	-	-	-	0
N	6	4.6 ± 0.5	6	4.7 ± 0.5	1.7 ± 1.0
C_R	-	0.89	0.85	0.89	0.92
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.09	1.09	1.09	1.09	1.37
C_N	1.47	1.73	1.63	1.51	1.44
$(N_1)_{60}$	9.5	7.6 ± 0.9	9.1	6.8 ± 0.7	3.1 ± 1.9
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	161.5	-	216.4	216.4

EVENT PARAMETERS

1968 Tokachi-oki Earthquake

Magnitude: 8.20 No fault model was found

Fault Type: Subduction Z_{tor} (km): NAV R_{rup} (km): NAV

Dip: NAV Width (km): NAV R_{jb} (km): NAV

https://earthquake.usgs.gov/earthquakes/eventpage/iscgem821946/executive

May 16, 1968, 12:49 AM

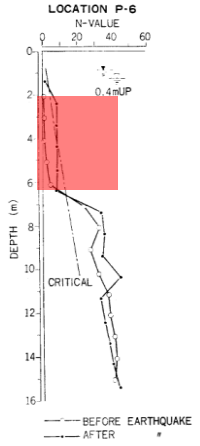


Fig. 13. Change of N-Values at Location P-6

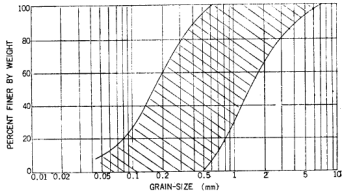


Fig. 5. Critical Zone for Grain-Size Distribution Curves

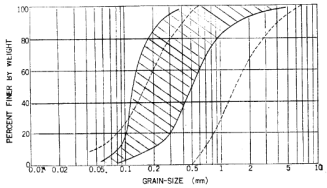
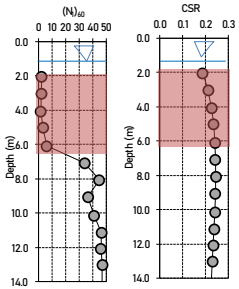


Fig. 6. Grain-Size Distribution of Loose Sands in the Site



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
2.0	*6.7*	*0.187*	*1*	*1.87*	*0.88*	*2.3*
3.0	*9.9*	*0.212*	*1*	*1.62*	*0.90*	*2.0*
4.1	*13.4*	*0.228*	*1*	*1.44*	*0.92*	*1.8*
5.0	*16.5*	*0.236*	*2*	*1.32*	*0.94*	*3.4*
6.1	*20.0*	*0.241*	*4*	*1.21*	*0.95*	*6.3*
7.1	23.3	0.244	23	1.13	0.96	34.2
8.1	26.5	0.245	32	1.07	0.97	45.3
9.1	29.8	0.244	27	1.02	0.97	36.5
10.2	33.4	0.241	32	0.96	0.98	41.2
11.1	36.5	0.238	38	0.92	0.98	46.8
12.1	39.6	0.234	39	0.89	0.99	46.2
13.1	42.8	0.230	41	0.86	0.99	47.4
14.1	46.2	0.226	42	0.83	0.99	47.0
15.1	49.4	0.222	41	0.80	0.99	44.5
					Mean:	3.1
					St. Dev.	1.9

Case number:	20
Earthquake:	1968 Tokachi-oki Earthquake
Magnitude:	7.8 (MR)
Location:	Nanaehama
References:	Kishida (1970), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	"complete liquefaction of level ground from the ground surface to some depth was observed",
GPS LAT	41.817314 coordinates shows the town not the boring
GPS LONG	140.708695
Liq. layer consist of:	sand
Geological Unit:	Hydraulic fill
Site Response Anlaysis:	No
Comments:	Cetin (2000) "So soft, hard to walk on even a week after the earthquake. The site is located at Nanaehama beach in Kamiiso Town on Hokkaido Island. Reclamation was made at the site by hydarulic fill about three years before the earthquake. The soil was coarse-grained sand in accordance with the unified classification system, having the 50% size of less than 2.0 mm and the uniformity coefficient of less than 10. The relative density was less than 75% No fine-grained strata above the saturated sand. 3 borings before the earthquake and 3 additional borings after the earthquake. SPT energy was estimated as 70 % by Seed et al. (1984)"
	"water and soil began to spout out from the ground surface soon after the beginning of the earthquake and continued for about an hour"
	https://earthquake.usgs.gov/earthquakes/eventpage/iscgem821946/executive
	Cetin (2000) adopted SPT-N values provided by Fear and McRoberts (1995) which is the average N values from BH1, 2 and 3 before EQ. This study digitize all the borehole data seperately and critical layer is characterized by using all of them. The upper SPT N values has CN>2 therefore even though the critical layer is 0.9 to 5 m these values were not used in the mean value. GWT is calculated as the average of BH1, 2 and 3 as 1.1 m as a result, critical layer has also updated to start from 1.1 m.
	Vs12m is updated based on VS-SPTN correlation.
Gravel Content (%):	0.00
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	0.9 - 5.0		0.9 - 5.0	1.1 - 5.0
d_{crt} (m)	4.0	3.0	4.0	3.0	3.1
GWT (m)	0.9	0.9 ± 0.3	0.9	0.8 ± 0.2	1.1 ± 0.2
γ_{moist} (kN/m^3)	-	14.9 ± 0.9	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	15.7 ± 0.9	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	74.9	45.9 ± 10.9	75.2	54.7 ± 12.9	55.9 ± 12.3
σ_v' (kPa)	45.1	25.8 ± 5.3	45.1	33.1 ± 6.4	36.8 ± 6.2
a_{max} (g)	0.2	0.200 ± 0.040	0.2	0.200 ± 0.060	0.200 ± 0.060
r_d	0.97	0.95 ± 0.050	0.99	0.97 ± 0.050	0.98 ± 0.051
CSR	0.21	0.219 ± 0.055	0.213	0.207 ± 0.065	0.194 ± 0.061
M_w	7.90	7.90	8.30	8.30	8.20
D_{50}	0.12	0.120 ± 0.020	-	0.121 ± 0.034	0.121 ± 0.034
% Fines	20	20.0 ± 3.0	20	21.7 ± 4.8	21.7 ± 4.8
% PI	-	-	-	-	NAV
N	5	5.5 ± 0.7	5	5.6 ± 0.9	5.5 ± 0.9
C_R	-	0.84	0.85	0.84	0.91
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.17	1.17	1.17	1.17	1.37
C_N	1.41	1.93	1.52	1.75	1.66
$(N_1)_{60}$	8	10.4 ± 1.4	7.6	9.6 ± 1.5	11.2 ± 1.8
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	170.7	-	170.7	192.0

EVENT PARAMETERS

1968 Tokachi-oki Earthquake

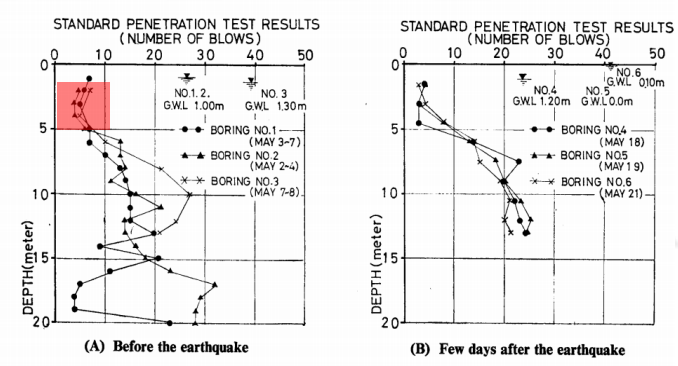
Magnitude: 8.20 — No fault model was found

Fault Type: Subduction — Z_{tor} (km): NAV — R_{rup} (km): NAV

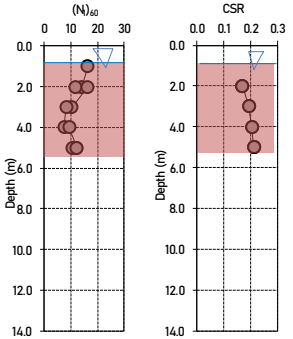
Dip: NAV — Width (km): NAV — R_{jb} (km): NAV

https://earthquake.usgs.gov/earthquakes/eventpage/iscgem821946/executive

May 16, 1968, 12:49 AM



NO:1	SPT-N	d (m)	GWT	
		7	1	1
		6	2	
		5	3	
		7	5	
NO:2	SPT-N			
		5	2	1
		4	3	
		4	4	
		6	5	
NO:3	SPT-N			
		7	2	1.3
		5	4	
		7	5	



3 different GWT measurements are available

i.	GWT 1	1.00 m
ii.	GWT 2	1.00 m
iii.	GWT 3	1.30 m
	Average	1.10
	Sdev	0.17 m

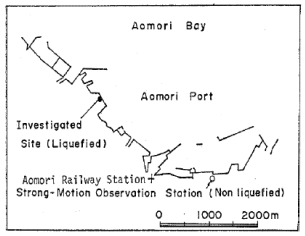
	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
NO:1	*1.0*	*3.3*	*NA*	*7*	*2.00*	*0.86*	*16.4*
NO:1	*2.0*	*6.6*	*0.170*	*6*	*1.93*	*0.88*	*14.0*
NO:2	*2.0*	*6.6*	*0.170*	*5*	*1.93*	*0.88*	*11.6*
NO:3	*2.0*	*6.6*	*0.170*	*7*	*1.93*	*0.88*	*16.3*
NO:1	*3.0*	*9.8*	*0.193*	*5*	*1.67*	*0.90*	*10.3*
NO:2	*3.0*	*9.8*	*0.193*	*4*	*1.67*	*0.90*	*8.3*
NO:2	*4.0*	*13.1*	*0.205*	*4*	*1.50*	*0.92*	*7.5*
NO:3	*4.0*	*13.1*	*0.205*	*5*	*1.50*	*0.92*	*9.4*
NO:1	*5.0*	*16.4*	*0.212*	*7*	*1.37*	*0.94*	*12.2*
NO:2	*5.0*	*16.4*	*0.212*	*6*	*1.37*	*0.94*	*10.5*
NO:3	*5.0*	*16.4*	*0.212*	*7*	*1.37*	*0.94*	*12.2*
						Mean:	11.2
						St. Dev.	1.8

NO:7	FC %	Silt	Clay	D_{50} (mm)
1	24.23	17.8	6.43	0.096
2	24.1	17.7	6.4	0.11
3	19.89	13.57	6.32	
4	19.47	13.04	6.43	0.12
5.2	24.67	15.23	9.44	0.11
NO:8				
1	48.34	40.69	7.65	0.09
2	48.38	40.66	7.72	0.074
3	15.12	8.19	6.93	
4	16.18	8.84	7.34	0.12
5	25.54	16.21	9.33	0.1
NO:9				
1	28.51	21.43	7.08	0.1
2	12.22	7	5.22	0.22
3	21.2	15.03	6.17	0.13
4	25.19	17.4	7.79	0.11
5	25.35	17.64	7.71	0.11
Mean:	21.7	14.5	7.1	0.12
St. Dev.	4.8	4.3	1.2	0.03

Case number: 21
Earthquake: 1968 Tokachi-Oki

Magnitude: 8.2 (Mw)
Location: AOM-RS (Aomori Railway Station) Dr. Greenfield named is as AOM-Station.
References: Yasuda and Tohno (1988), Iai et al (1989), Greenfield (2017, 2018), PARI
Nature of Failure: Observation at Aomori Railway Station during 1968 Tokachi-Oki earthquake: Yasuda and Tohno (1988) indicate sand boils and surficial damage in Aomori. Rails and buildings at Aomori Rail Station settled due to liquefaction.
GPS LAT 40.828947
GPS LONG 140.734833 Railway facility. Coordinates approximate
Liq. layer consist of: fine sand with medium sand, gravel
Geological Unit: Af, reclaimed land composed of sand and gravel fill, next to the sea
Site Response Anlaysis: No
Comments: Greenfield (2017, 2018) summarizes the site as follows: "The Port and Rail Station are founded on reclaimed land that was constructed around 1945. Yasuda and Tohno (1988) describe an investigation at the Aomori Railway Station about 1 km away from Aomori-S.The Mw = 8.2 Tokachi-Oki earthquake occurred on May 16, 1968. The interface between Pacific Plate and the Okhotsk Plate ruptured and produced a powerful subduction-zone earthquake. The nearest distance to the fault rupture, Rrup, was about 140 km. The strong motion recorder Aomori-S recorded ground motions during the 1968 Tokachi-Oki earthquake, which PARI has cataloged in their online database. The Mw = 7.4 Nihnokai-Chubu earthquake occurred on May 26, 1983. A reverse fault in the back-arc region of the Sea of Japan ruptured, producing a devastating earthquake and tsunami. The rupture is classified as a subduction zone earthquake. The nearest distance to the fault rupture, Rrup, was about 120 km." Aomori railway station is located 1 km away from the strong ground motin station Aomori-S which recorded 1968 Tokachi-Oki. PARI provided NS and EW components of 207.7 gals (0.212 g) and 179.9 gals (0.183 g). Geometric mean of the two component is assigend as 0.197 g. Greenfield (2018) reported Peak ground acceleration as 0.170g.

https://earthquake.usgs.gov/earthquakes/eventpage/iscgem821946/executive



Cetin (2000) "Sand boils, settled structures. The station faces the sea and the north part of the station is used as a landing place for ferryboats. The north part was built on reclaimed land constructed around 1945, but the sout part was built on natural land. Liquefaction was induced at the north part of the station during the Tokachi-Oki and the main shock of Nihonakai-chubu EQ's. Many sand volcanoes, settlement of rails and buildings and uplift of buried tanks were observed. The maximum surface acceleration at Aomari Port, about 1 km north of Aomori Station was recorded as 0.213 g." Critical layer is updated as to be the fill layer.



Gravel Content (%): has gravel content
CPT available: No
Vs available: No

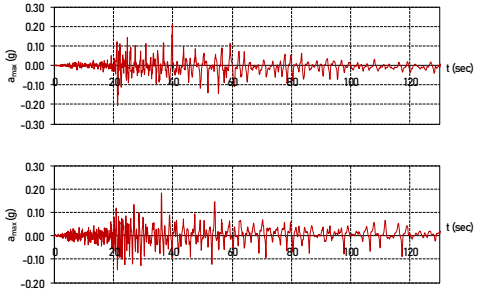
Summary of Input Data

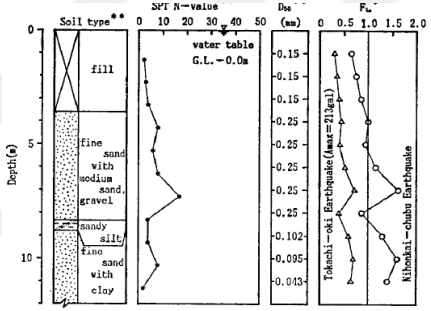
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	A	-	A	A
d_{crtc} range (m)	-	4.0 - 7.5		4.0 - 7.5	4.0 - 7.5
d_{crt} (m)	-	5.8	5.7	5.8	5.8
GWT (m)	-	0.0 ± 0.1	0	0.0 ± 0.1	0.0 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.5	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	18.9 ± 0.5	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-	108.7 ± 11.4	95.2	108.7 ± 11.4	108.7 ± 11.4
σ_v' (kPa)	-	52.2 ± 6.0	38.1	52.2 ± 6.0	52.2 ± 6.0
a_{max} (g)	-	0.213 ± 0.011	0.213	0.213 ± 0.011	0.197 ± 0.010
r_d	-	0.87 ± 0.087	0.98	0.87 ± 0.087	0.87 ± 0.087
CSR	-	0.250 ± 0.029	0.335	0.250 ± 0.029	0.231 ± 0.027
M_w	-	8.30	8.30	8.30	8.20
D_{50}	-	0.250 ± 0.050	-	0.250 ± 0.050	0.250 ± 0.050
% Fines	-	3.0 ± 2.0	3	3.0 ± 2.0	<5 ± 8.6
% PI	-	-	-	-	0
N	-	9.0 ± 0.9	9	9.0 ± 0.9	7.8 ± 1.4
C_R	-	0.94	0.95	0.94	0.95
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.40	1.58	1.40	1.40
$(N_1)_{60}$	-	14.4 ± 1.4	16.5	14.4 ± 1.4	14.0 ± 2.6
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	158.5	-	158.5	161.3

EVENT PARAMETERS

1968 Tokachi-Oki USGS No fault model was found
Magnitude: 8.20 Depth (km): 29.9
Fault Type: Subduction Z_{tor} (km): NAV R_{rup} (km): 140.0
Dip: NAV Width (km): NAV R_{jb} (km): NAV

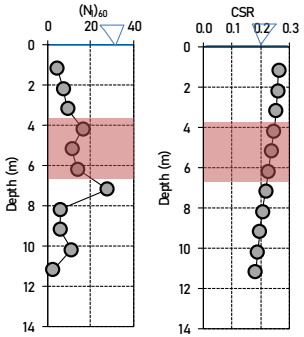
ACCELERATION TIME HISTORY





*F_L : foctor of liquefaction resistance analyzed by Iwasaki et al.'s method.
** : data of soil condition and F_L -values during the Nihonkai-chubu Earthquake are quoted from the Railway Technical Research Institute, J N R (1984)

Fig. 12. Soil profile and results of liquefaction analysis at Aomori Station



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		D_{50}
1.15	3.8	0.263	2	2.00	0.86	4.7	Fill	0.150
2.15	7.1	0.258	3	2.00	0.89	7.3	Fill	0.150
3.15	10.3	0.252	4	1.89	0.91	9.4	Fill	0.150
4.15	***13.6***	***0.245***	***8***	***1.64***	***0.92***	***16.6***	***fine sand with medium sand, grave***	***0.250***
5.15	***16.9***	***0.237***	***6***	***1.47***	***0.94***	***11.3***	***fine sand with medium sand, grave***	***0.250***
6.15	***20.2***	***0.227***	***8***	***1.35***	***0.95***	***14.0***	***fine sand with medium sand, grave***	***0.250***
7.15	23.5	0.217	17	1.25	0.96	27.9	fine sand with medium sand, gravel	0.250
8.15	26.7	0.207	4	1.17	0.97	6.2	fine sand with medium sand, gravel	0.250
9.15	30.0	0.197	4	1.11	0.97	5.9	fine sand with clay	0.102
10.15	33.3	0.189	8	1.05	0.98	11.2	fine sand with clay	0.095
11.15	36.6	0.181	2	1.00	0.98	2.7	fine sand with clay	0.043
					Mean:	14.0	Mean:	0.250
					St. Dev.	2.6	St. Dev.	0.050

assigned

BH data is from Yasuda and Tohno (1988)

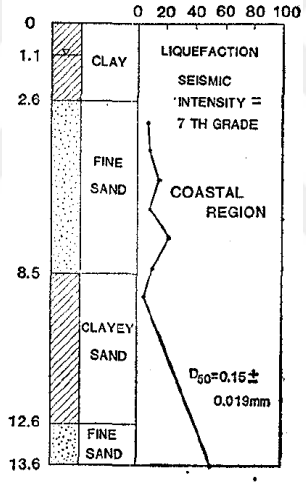
Case number:	30
Earthquake:	1976 Tangshan
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Coastal Region
References:	Shengcong et al (1983), Fear and McRobert (1993), Cetin (2000), Cetin et al (2004, 2018), Liu (1985)
Nature of Failure:	Liquefied
GPS LAT	39.377713 very approximate location.
GPS LONG	118.906102
Liq. layer consist of:	fine sand
Geological Unit:	flood plains including plains of marine and continental sediments
Site Response Anlaysis:	No
Comments:	Cetin (2000) "This site is located in the south-east of Tangshan City, south of Jing Shan Railway, in the zone of liquefaction (Source document, Fig. 11, Qian Jian Yeng?). The site was identified as in the area of 7th grade on the Chinese intensity scale. Consisted essentially of flood plains formed by flooding from Luan and Dou Rivers. Luan river changed its river course frequently. Therefore, loose sand deposits were very common in the region. The Tangshan Earthquake had a focal depth of 12-16 km and epicenter in Tangshan City. The area based on seismic intensity may be divided into two regions by the Jing-Shan railway. The north of the railway is mainly of hill areas and experienced relatively lower seismic intensity. The south of the railway is mainly of flood plains including plains of marine and continental sediments. PGA was estimated as >0.1 g SPT energy was estimated as 60 % by Seed et al. (1984)"
	SPT-N values are taken from Fear and McRoberts (1993) catalogue
	There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS).
	Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
Gravel Content (%):	0.00
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
$d_{crtc.}$ range (m)	-	3.0 - 6.0		3.0 - 6.0	2.6 - 6.5
$d_{crt.}$ (m)	6.1	4.5	4.5	4.5	4.6
GWT (m)	1.22	1.2 ± 0.3	1.1	1.1 ± 0.1	1.1 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	117.1	72.5 ± 8.6	87.2	83.3 ± 9.6	84.3 ± 12.4
σ_v' (kPa)	69.1	40.3 ± 4.7	54.1	49.9 ± 4.9	50.3 ± 6.2
a_{max} (g)	0.13	0.130 ± 0.026	0.13	0.130 ± 0.039	0.158 ± 0.032
r_d	0.96	0.92 ± 0.064	0.97	0.95 ± 0.064	0.94 ± 0.065
CSR	0.14	0.140 ± 0.032	0.13	0.133 ± 0.041	0.162 ± 0.035
M_w	0.97	8.00	7.60	7.60	7.50
D_{50}	0.14	0.140 ± 0.030	-	0.140 ± 0.050	0.140 ± 0.050
% Fines	12	12.0 ± 3.0	12	12.0 ± 2.0	12.0 ± 8.6
% PI	-	-	-	-	NAV
N	10	9.5 ± 2.3	9	9.5 ± 2.2	9.5 ± 2.1
C_R	-	0.90	0.95	0.90	0.93
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.00	1.00	1.00	1.00	1.23
C_N	1.16	1.54	1.37	1.43	1.42
$(N_1)_{60}$	11.5	13.2 ± 3.2	11.7	12.2 ± 2.9	15.5 ± 3.4
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	179.8	-	179.8	179.8

EVENT PARAMETERS

1976 Tangshan		Chen et al. (1979)	Bulter et al. (1979)
Magnitude: 7.50		Yong-Ge et al (2017)	Huang and Yeh (1997)
Fault Type: right lateral str	Z_{tor} (km): 0		R_{rup} (km): 67.5
Dip: 67-89.1	Width (km): 15		R_{jb} (km): 67.5



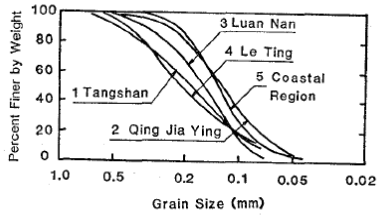
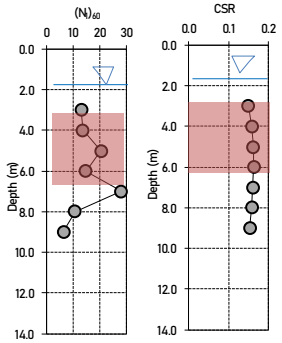


Fig. 16. Representative grain siz distribution curves of sands a sites along section I–I′ indicate in Fig. 11 (depth<10 m)



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
3.0	*9.8*	*0.151*	*7.0*	*1.67*	*0.90*	*13.1*	*fine sand*
4.0	*13.1*	*0.159*	*8.0*	*1.50*	*0.92*	*13.6*	*fine sand*
5.0	*16.4*	*0.163*	*13.0*	*1.37*	*0.94*	*20.5*	*fine sand*
6.0	*19.7*	*0.163*	*10.0*	*1.26*	*0.95*	*14.8*	*fine sand*
7.0	23.0	0.162	20.0	1.18	0.96	28.0	fine sand
8.0	26.2	0.158	8.0	1.12	0.97	10.6	fine sand clayey sand transion?
9.0	29.5	0.154	5.0	1.06	0.97	6.3	clayey sand
					Mean:	15.5	
					St. Dev.	3.4	

Case number:	31
Earthquake:	1976 Tangshan
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Le Ting L8-14
References:	Shengcong et al (1983), Fear and McRoberts (1993), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefied
GPS LAT	39.464916 very approximate location.
GPS LONG	118.679678
Liq. layer consist of:	fine sand
Geological Unit:	flood plains including plains of marine and continental sediments, alluvial (Holocene) plain deposits
Site Response Anlaysis:	No
Comments:	Cetin (2000) "This site is located in the south-east of Tangshan City, south of Jing Shan Railway, in the zone of severe liquefaction (Source doc., Fig. 11, Qian Jian Yeng?). The site was identified as in the area of 7th grade on the Chinese intensity scale. Alluvial (Holocene) deposits. Manifestations of liquefaction were observed in the coastal region, south of Le Ting County. The Tangshan Earthquake had a focal depth of 12-16 km and epicenter in Tangshan City. The area based on seismic intensity may be divided into two regions by the Jing-Shan railway. The north of the railway is mainly of hill areas, and experienced relatively lower seismic intensity. The south of the railway is mainly of flood plains including plains of marine and continental sediments. New borelogs were obtained in addition to the typical borelog (Fear et al, 1995) PGA was estimated as >0.1 g SPT energy was estimated as 60 % by Seed et al. (1984)"
	SPT-N values are redigitized
	Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
	The additional boreholes that were presented by Fear and McRoberts (1993) catologue were used.
	Seed et al (1984) used the BH given by Shengcong et al (1983). Cetin (2000) used Fear and McRoberts (1993) study which compiled 26 BH from the area.
	There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS).
Gravel Content (%):	0.00
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
$d_{crtc.}$ range (m)	-	3.5 - 6.0		3.5 - 6.0	3.5 - 6.0
$d_{crt.}$ (m)	2.0	4.8	4.4	4.8	4.8
GWT (m)	1.52	1.1 ± 0.3	1.5	1.0 ± 0.2	1.1 ± 0.2
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	17.3 ± 0.5	17.4 ± 0.5
γ_{sat} (kN/m^3)	-	18.1 ± 0.6	-	18.9 ± 0.5	20.6 ± 0.5
σ_v (kPa)	36.5	83.5 ± 8.0	81.2	88.2 ± 8.1	94.7 ± 8.8
σ_v' (kPa)	31.4	47.3 ± 4.8	53.1	51.3 ± 4.4	58.3 ± 5.0
a_{max} (g)	0.2	0.200 ± 0.040	0.2	0.200 ± 0.060	0.217 ± 0.043
r_d	0.99	0.94 ± 0.067	0.97	0.98 ± 0.067	0.98 ± 0.067
CSR	0.155	0.217 ± 0.048	0.194	0.219 ± 0.068	0.223 ± 0.048
M_w	0.97	8.00	7.60	7.60	7.50
D_{50}	0.22	0.100 ± 0.030	-	0.185 ± 0.040	0.185 ± 0.040
% Fines	12	12.0 ± 3.0	12	12.0 ± 2.0	12.0 ± 8.6
% PI	-	-	-	-	NAV
N	10	9.9 ± 2.0	9.7	9.9 ± 2.0	10.0 ± 2.0
C_R	-	0.91	0.85	0.91	0.93
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.00	1.00	1.00	1.00	1.23
C_N	1.65	1.42	1.39	1.41	1.32
$(N_1)_{60}$	12.5	12.8 ± 2.6	11.5	12.7 ± 2.6	15.2 ± 3.0
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	198.1	-	213.4	213.4

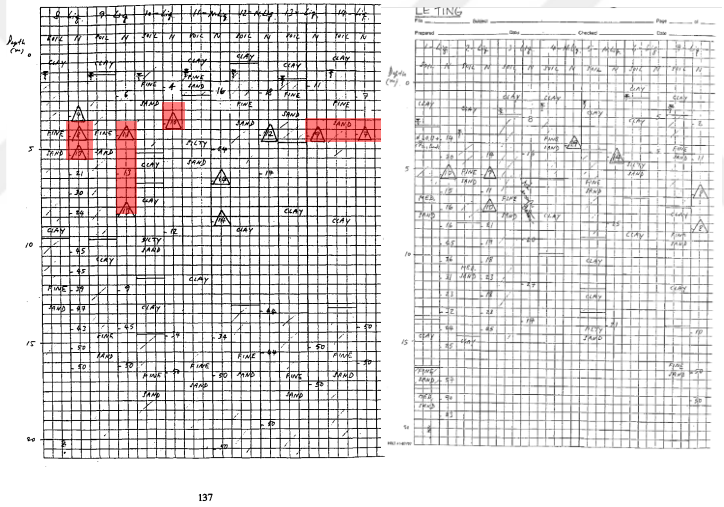
EVENT PARAMETERS

1976 Tangshan — Chen et al. (1979) Bulter et al. (1979)

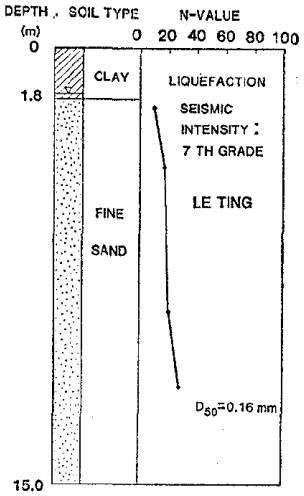
Magnitude: 7.50 — Yong-Ge et al (2017) Huang and Yeh (1997)

Fault Type: right lateral str — Z_{tor} (km): 0 — R_{rup} (km): 47.0

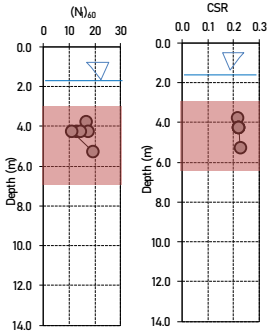
Dip: 67-89.1 — Width (km): 15 — R_{jb} (km): 47.0



137



Shengcong et al (1983), Fear and McRoberts (1993)



	GWT	
L8	*1.00*	m
L9	*1.11*	m
L10	*1.11*	m
L11	0.89	m
L12	0.84	m
L13	*1.26*	m
L14	*0.78*	m
mean	1.05	m
sdev	0.18	m

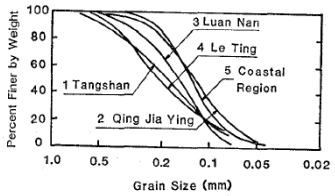


Fig. 16. Representative grain size distribution curves of sands at sites along section I-I′ indicated in Fig. 11 (depth<10 m)

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		
3.8	*12.3*	*0.216*	*10.0*	*1.46*	*0.92*	*16.6*	*L10*	fine sand
4.3	*13.9*	*0.220*	*8.0*	*1.39*	*0.93*	*12.7*	*L8*	fine sand
4.3	*13.9*	*0.220*	*11.0*	*1.39*	*0.93*	*17.4*	*L9*	fine sand
4.3	*13.9*	*0.220*	*9.0*	*1.39*	*0.93*	*14.2*	*L13*	fine sand
4.3	*13.9*	*0.220*	*7.0*	*1.39*	*0.93*	*11.1*	*L14*	fine sand
5.3	*17.2*	*0.226*	*13.0*	*1.26*	*0.94*	*19.0*	*L8*	fine sand
					Mean:	15.2		
					St. Dev.	3.0		

Case number:	32
Earthquake:	1976 Tangshan
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Luan Nan-L1
References:	Shengcong et al (1983), Fear and McRobert (1993), Cetin (2000), Cetin et al (2004, 2018), Liu (1985)
Nature of Failure:	No surface evidence of liquefaction
GPS LAT	39.840916 very approximate location.
GPS LONG	118.635184
Liq. layer consist of:	fine sand
Geological Unit:	flood plains including plains of marine and continental sediments
Site Response Anlaysis:	No
Comments:	Cetin (2000) "This site was classified as in the area of 8th grade on the Chinese intensity scale. It is located just south of the Jing Shan Railway, and southeast of Tangshan City, in the zone of liquefaction (Source document, fig.11). The Tangshan Earthquake had a focal depth of 12-16 km, the epicenter was located in Tangshan City. The area based on seismic intensity may be divided into two regions by the Jing-Shan railway. The north of the railway is mainly of hill area, and experienced relatively lower seismic intensity. The south of the railway is mainly of flood plains including plains of marine and continental sediments. Additional borelogs for this site were obtained from a report by the Beijing Municipal Bureau of City Planning (1982) (Fear et al., 1995). Based on newly available borelogs, it became apparent that representative N value selection by Seed et al (84) can be further improved. Borelog L2 is thought to be a better representative borelog. Probably the medium-fine sand layer liquefied at L2 liquefied first and excess pore pressure dissipated to the neighboring layers causing them to liquefy as well. Seed et al (84) used borelog L3 (probably the rest were not available) PGA was estimated as >0.1 g SPT energy was estimated as 60 % by Seed et al. (1984)" SPT-N values are taken from Fear and McRoberts (1993) catalog. Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study. Critical layer is updated to start from the GWT table level. PI is assigned as 0 as FC=5%. There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS).
Gravel Content (%):	0.00
CPT available:	No
Vs available:	No

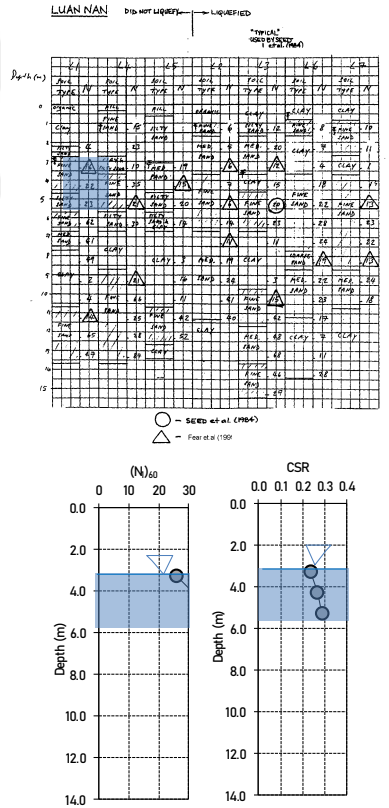
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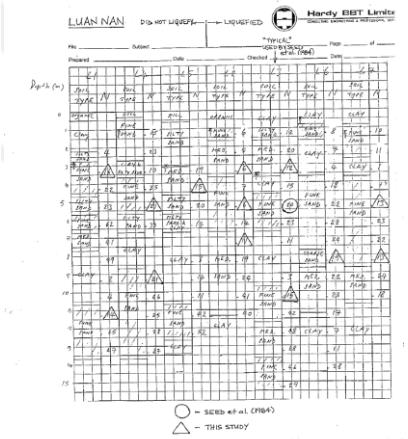
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?		No	No	No	No
Data Class		B	-	B	B
d_{crtc} range (m)		1.5 - 5.5		1.5 - 5.5	2.9 - 5.5
d_{crt} (m)		3.5	3.5	3.5	4.2
GWT (m)		1.1 ± 0.3	1.1	2.9 ± 0.1	2.9 ± 0.1
γ_{moist} (kN/m^3)		14.9 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)		18.9 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)		61.8 ± 12.8	62.2	57.7 ± 13.2	72.2 ± 9.2
σ_v' (kPa)		38.2 ± 6.5	38.1	51.3 ± 6.7	59.2 ± 5.0
a_{max} (g)		0.220 ± 0.044	0.22	0.220 ± 0.066	0.340 ± 0.068
r_d		0.96 ± 0.052	0.98	0.99 ± 0.052	0.98 ± 0.060
CSR		0.223 ± 0.050	0.226	0.159 ± 0.051	0.265 ± 0.057
M_w		8.00	7.60	7.60	7.50
D_{50}		0.170 ± 0.060	-	0.170 ± 0.050	0.170 ± 0.050
% Fines		5.0 ± 3.0	5	5.0 ± 2.0	5.0 ± 8.6
% PI		-	-	-	0
N		19.3 ± 2.6	19.3	19.6 ± 2.9	20.2 ± 2.5
C_R		0.87	0.85	0.87	0.92
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.00	1.00	1.00	1.23
C_N		1.58	1.49	1.41	1.31
$(N_1)_{60}$		26.5 ± 3.6	24.4	23.9 ± 3.6	30.1 ± 3.8
V_{s30m} (m/s)		-	-	-	NAV
V_{s12m} (m/s)		195.1	-	216.4	216.4

EVENT PARAMETERS

1976 Tangshan — Chen et al. (1979) Bulter et al. (1979)
Magnitude: 7.50 — Yong-Ge et al (2017) Huang and Yeh (1997)
Fault Type: right lateral str — Z_{tor} (km): 0 — R_{rup} (km): 24.4
Dip: 67-89.1 — Width (km): 15 — R_{jb} (km): 24.4

References: Shengcong et al (1983), Fear and McRobert (1993), Cetin (2000), Cetin et al (2004, 2018), Liu (1985)





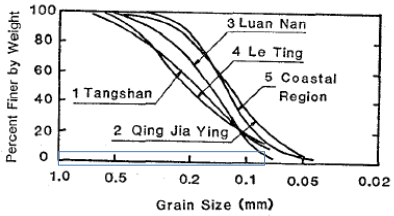


Fig. 16. Representative grain size distribution curves of sands at sites along section I–I′ indicated in Fig. 11 (depth<10 m)

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
3.3	*10.7*	*0.236*	*16.0*	*1.44*	*0.91*	*25.8*	fine sand
4.3	*13.9*	*0.267*	*22.0*	*1.30*	*0.93*	*32.7*	fine sand
5.3	*17.2*	*0.287*	*23.0*	*1.20*	*0.94*	*31.9*	fine sand
					Mean:	30.1	
					St. Dev.	3.8	

Case number:	33
Earthquake:	1976 Tangshan
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Luan Nan-L2
References:	Shengcong et al (1983), Fear and McRobert (1993), Cetin (2000), Cetin et al (2004, 2018), Liu (1985)
Nature of Failure:	Liquefied
GPS LAT	39.840916 very approximate location.
GPS LONG	118.635184
Liq. layer consist of:	fine sand
Geological Unit:	flood plains including plains of marine and continental sediments
Site Response Anlaysis:	No
Comments:	Cetin (2000) "This site was classified as in the area of 8th grade on the Chinese intensity scale. It is located just south of the Jing Shan Railway, and south-east of Tangshan City in the zone of liquefaction (Source document, fig.11) The Tangshan Earthquake had a focal depth of 12-16 km and the epicenter was located in Tangshan City. The area based on seismic intensity may be divided into two regions by the Jing-Shan railway. The north of the railway is mainly of hill areas and experienced relatively lower seismic intensity. The south of the railway is mainly of flood plains including plains of marine and continental sediments. Additional borelogs for this site were obtained from a report by the Beijing Municipal Bureau of City Planning (1982) (Fear et al., 1995). Based on newly available borelogs, it became apparent that representative N value selection by Seed et al (84) can be further improved. Borelog L2 is thought to be a better representative borelog. Probably the medium-fine sand layer liquefied at L2 liquefied first and excess pore pressure dissipated to the neighboring layers causing them to liquefy as well. Seed et al (84) used borelog L3 (probably the rest were not available) PGA was estimated as >0.1 g. SPT energy was estimated as 60 % by Seed et al. (1984)"
	SPT-N values are taken from Fear and McRoberts (1993) catalog. Seed et al. (1984) used the BH given by Shengcıong et al. (1983). Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study. PI is assigned as 0 as FC=3%. There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS).
Gravel Content (%):	0.00
CPT available:	No
Vs available:	No

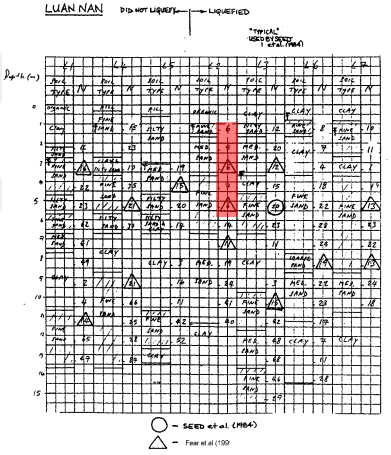
Summary of Input Data

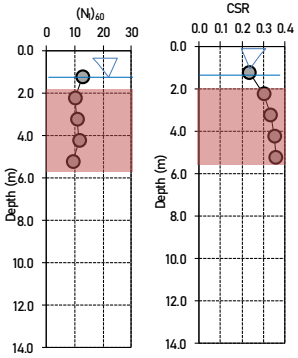
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	used another BH which is not comparable.	Yes	Yes	Yes	Yes
Data Class		B	-	B	B
d_{crtc} range (m)		1.5 - 5.5		1.5 - 5.5	1.5 - 5.5
d_{crt} (m)		3.5	3.5	3.5	3.5
GWT (m)		1.1 ± 0.3	1.1	1.1 ± 0.1	1.1 ± 0.1
γ_{moist} (kN/m^3)		14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)		16.5 ± 0.6	-	19.6 ± 0.5	18.9 ± 0.5
σ_v (kPa)		56.1 ± 11.2	56.1	66.3 ± 13.2	64.4 ± 12.7
σ_v' (kPa)		32.6 ± 5.4	32.1	42.7 ± 6.7	40.8 ± 6.2
a_{max} (g)		0.220 ± 0.044	0.22	0.220 ± 0.066	0.340 ± 0.068
r_d		0.96 ± 0.052	0.98	0.98 ± 0.052	0.97 ± 0.052
CSR		0.238 ± 0.055	0.241	0.217 ± 0.067	0.340 ± 0.073
M_w		8.00	7.60	7.60	7.50
D_{50}		0.170 ± 0.060	-	0.170 ± 0.050	0.170 ± 0.050
% Fines		3.0 ± 2.0	3	3.0 ± 2.0	3.0 ± 8.6
% PI		-	-	-	0
N		5.9 ± 0.6	5.9	5.9 ± 0.6	5.9 ± 0.6
C_R		0.87	0.85	0.87	0.91
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.00	1.00	1.00	1.23
C_N		1.72	1.70	1.54	1.58
$(N_1)_{60}$		8.8 ± 0.9	8.5	7.9 ± 0.8	10.5 ± 1.0
V_{s30m} (m/s)		-	-	-	NAV
V_{s12m} (m/s)		195.1	-	195.1	195.1

EVENT PARAMETERS

1976 Tangshan		Chen et al. (1979) Bulter et al. (1979)	
Magnitude: 7.50		Yong-Ge et al (2017) Huang and Yeh (1997)	
Fault Type: right lateral str	Z_{tor} (km): 0		R_{rup} (km): 24.4
Dip: 67-89.1	Width (km): 15		R_{jb} (km): 24.4

References: Shengcong et al (1983), Fear and McRobert (1993), Cetin (2000), Cetin et al (2004, 2018), Liu (1985)





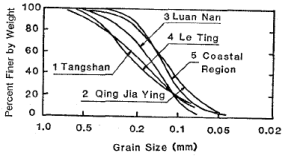


Fig. 16. Representative grain size distribution curves of sands at sites along section I–I′ indicated in Fig. 11 (depth<10 m)

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
1.3	4.1	0.236	6.0	2.00	0.86	12.8	fine sand too close to surface CN>2
2.3	*7.4*	*0.302*	*5.0*	*1.86*	*0.89*	*10.2*	medium sand
3.3	*10.7*	*0.334*	*6.0*	*1.62*	*0.91*	*10.9*	medium sand
4.3	*13.9*	*0.352*	*7.0*	*1.46*	*0.93*	*11.7*	fine sand
5.3	*17.2*	*0.361*	*6.0*	*1.34*	*0.94*	*9.3*	fine sand
					Mean:	10.5	
					St. Dev.	1.0	

Case number:	34
Earthquake:	1976 Tangshan
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Qing Jia Ying
References:	Shengcong et al (1983), Fear and McRobert (1993), Cetin (2000), Cetin et al (2004, 2018), Liu (1985)
Nature of Failure:	Liquefied
GPS LAT	39.548792 very approximate location.
GPS LONG	118.367673
Liq. layer consist of:	fine sand
Geological Unit:	flood plains including plains of marine and continental sediments
Site Response Anlaysis:	No
Comments:	Cetin (2000) "This site was classified as in the area of 9th grade on the Chinese intensity scale. It is located in just south of the Jing Shan Railway, and south-east of Tangshan City in the zone of liquefaction (Source document, fig.11., Qian Jia Yeng?) The Tangshan Earthquake had a focal depth of 12-16 km and the epicenter was located in Tangshan City. The area based on seismic intensity may be divided into two regions by the Jing-Shan railway. The north of the railway is mainly of hill areas, and experienced relatively lower seismic intensity. The south of the railway is mainly of flood plains including plains of marine and continental sediments. PGA was estimated as >0.1 g SPT energy was estimated as 60 % by Seed et al. (84)"
	There is two susceptible layers for this site: silt and fine sand layer. Seed et al. (1985) selected the SPT-N value of 17 at 5.3 m (fine sand layer) and Cetin (2000) also selected the fine sand layer by averaging the SPT –N values falling in the layer. The SPT-N value at 6 m seems to follow the same trend of fine sand SPT values hence it is also included in the average of N1,60. SPT-N values are re-digitized for this study. Soil layers were also digitized and the critical layer which is also the same layer (fine sand) with previous studies extends from 3.75 m to 6.5 m hence critical layer range is updated. No information regarding the plasticity index of the upper silt layer exists which has lesser SPT than fine sand. Late Prof. Seed selected the fine sand layer and he might have had some information that we might not access today. As a result, the fine sand layer is kept as the critical stratum. Fear and McRoberts (1995) averaged SPT N value of 10 (silt) and the below fine sand layer together. GWT is re-digitized from the BH and updated as 1 m. 7 SMS recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS). Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
Gravel Content (%):	0.00
CPT available:	No
Vs available:	No

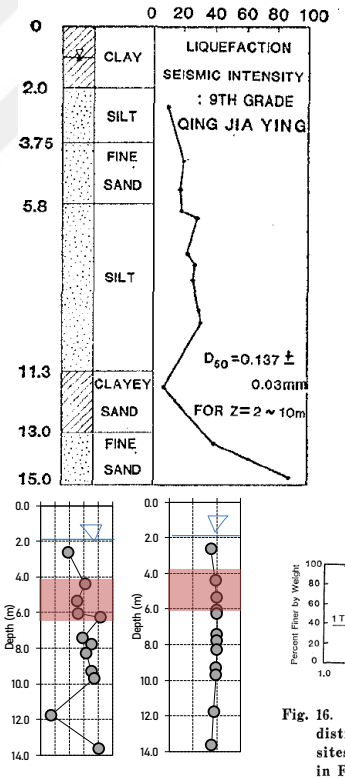
Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	4.5 - 6.5		4.5 - 6.5	3.8 - 6.5
d_{crt} (m)	5.3	5.5	5.3	5.5	5.1
GWT (m)	0.91	0.9 ± 0.3	0.9	0.9 ± 0.1	1.0 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	18.1 ± 0.6	-	19.6 ± 0.5	19.6 ± 0.5
σ_v (kPa)	102.2	97.5 ± 6.8	102.3	106.1 ± 6.9	98.5 ± 9.2
σ_v' (kPa)	59.0	52.3 ± 4.6	59.1	60.9 ± 4.1	58.0 ± 5.0
a_{max} (g)	0.35	0.350 ± 0.070	0.35	0.350 ± 0.105	0.367 ± 0.073
r_d	0.96	0.92 ± 0.076	0.96	0.97 ± 0.076	0.98 ± 0.071
CSR	0.38	0.389 ± 0.087	0.378	0.385 ± 0.120	0.395 ± 0.085
M_w	0.96	8.00	7.60	7.60	7.50
D_{50}	0.137	0.137 ± 0.030	-	0.137 ± 0.050	0.137 ± 0.050
% Fines	20	20.0 ± 3.0	20	20.0 ± 2.0	20.0 ± 8.6
% PI	-	-	-	-	NAV
N	17	18.3 ± 2.0	17	18.3 ± 2.1	18.0 ± 1.9
C_R	-	0.94	0.95	0.94	0.94
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.00	1.00	1.00	1.00	1.23
C_N	1.25	1.36	1.24	1.29	1.32
$(N_1)_{60}$	21.5	23.2 ± 2.6	20.1	22.1 ± 2.5	27.5 ± 2.9
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	195.1	-	216.4	216.4

EVENT PARAMETERS

1976 Tangshan		Chen et al. (1979)	Bulter et al. (1979)
Magnitude: 7.50		Yong-Ge et al (2017)	Huang and Yeh (1997)
Fault Type: right lateral str	Z_{tor} (km): 0		R_{rup} (km): 21.4
Dip: 67-89.1	Width (km): 15		R_{jb} (km): 21.4

References: Shengcong et al (1983), Fear and McRobert (1993), Cetin (2000), Cetin et al (2004, 2018), Liu (1985)



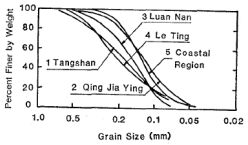


Fig. 16. Representative grain size distribution curves of sands at sites along section I-I′ indicated in Fig. 11 (depth<10m)

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		
2.6	8.6	0.350	10.0	1.74	0.90	19.3	silt	clayey?
4.4	*14.4*	*0.388*	*19.0*	*1.41*	*0.93*	*30.7*	*fine sand*	
5.3	*17.5*	*0.397*	*17.0*	*1.30*	*0.94*	*25.6*	*fine sand*	
6.0	*19.8*	*0.400*	*18.0*	*1.23*	*0.95*	*26.0*	*silt*	fine sand?
6.3	20.5	0.401	29.0	1.21	0.95	41.2	silt	
7.4	24.4	0.402	22.0	1.12	0.96	29.3	silt	
7.8	25.6	0.401	27.0	1.10	0.96	35.3	silt	
8.3	27.2	0.400	25.0	1.07	0.97	31.8	silt	
9.3	30.4	0.395	29.0	1.01	0.97	35.3	silt	
9.7	31.9	0.392	31.0	0.99	0.98	37.0	silt	
11.8	38.6	0.374	7.0	0.91	0.98	7.7	clayey sand	
13.6	44.7	0.355	39.0	0.85	0.99	40.3	fine sand	
					Mean:	27.5		
					St. Dev.	2.9		

Case number:	35
Earthquake:	1976 Tangshan
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Tangshan City
References:	Shengcong et al (1983), Fear and McRobert (1993), Cetin (2000), Cetin et al (2004, 2018), Liu (1985)
Nature of Failure:	Non-liquefied site
GPS LAT	39.533882 very approximate location.
GPS LONG	118.211659
Liq. layer consist of:	fine sand
Geological Unit:	flood plains including plains of marine and continental sediments
Site Response Anlaysis:	No
Comments:	Cetin (2000) "This site was classified as in the area of 11th grade on the Chinese intensity scale. It is located in just north of the Jing Shan Railway, and northwest of the epicentral area. Sandy layers are generally dense with the relative density values of 80 to 90 % and the ground water level was low, at ~ 5-10 m. below the ground surface. The Tangshan Earthquake had a focal depth of 12-16 km and the epicenter was located in Tangshan City. The area based on seismic intensity may be divided into two regions by the Jing-Shan railway. The north of the railway is mainly of hill areas, and experienced relatively lower seismic intensity. The south of the railway is mainly of flood plains including plains of marine and continental sediments. PGA was estimated as >0.1 g. SPT energy was estimated as 60 % by Seed et al. (1984)"
	SPT-N values are taken from Fear and McRoberts (1993) catalogue
	Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
	Critical layer is fine sand and the layer extends from 3 to 5.5 m. Hence critical layer range is updated.
	There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS).
Gravel Content (%):	0.00
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	3.5 - 5.5		3.5 - 5.5	3.0 - 5.5
d_{crt} (m)	5.3	4.5	5.3	4.5	4.3
GWT (m)	3.05	3.0 ± 0.3	3.1	3.0 ± 0.1	3.0 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	18.9 ± 0.6	-	19.6 ± 0.5	21.5 ± 0.5
σ_v (kPa)	97.9	75.6 ± 6.7	98.2	81.5 ± 6.8	78.9 ± 9.1
σ_v' (kPa)	75.4	60.9 ± 4.2	75.2	66.8 ± 3.7	66.7 ± 5.2
a_{max} (g)	0.5	0.500 ± 0.100	0.5	0.500 ± 0.150	0.550 ± 0.110
r_d	0.96	0.96 ± 0.064	0.96	1.00 ± 0.064	1.00 ± 0.061
CSR	0.405	0.386 ± 0.084	0.405	0.395 ± 0.122	0.422 ± 0.090
M_w	0.96	8.00	7.60	7.60	7.50
D_{50}	0.196	0.196 ± 0.024	-	0.196 ± 0.050	0.196 ± 0.050
% Fines	10	10.0 ± 2.0	10	10.0 ± 2.0	10.0 ± 8.6
% PI	-	-	-	-	NAV
N	30	29.7 ± 5.1	30	29.7 ± 5.0	29.4 ± 6.4
C_R	-	0.90	0.95	0.90	0.93
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.00	1.00	1.00	1.00	1.23
C_N	1.12	1.26	1.11	1.23	1.23
$(N_1)_{60}$	33.5	33.7 ± 5.8	31.6	33.1 ± 5.6	41.4 ± 9.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	205.7	-	259.1	259.1

EVENT PARAMETERS

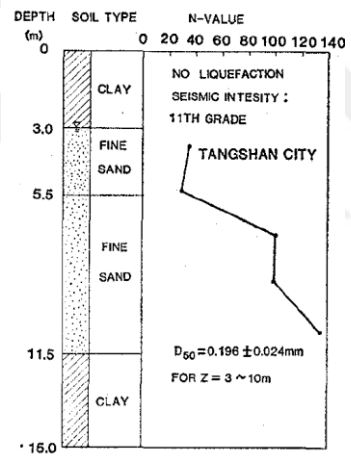
1976 Tangshan — Chen et al. (1979) Bulter et al. (1979)

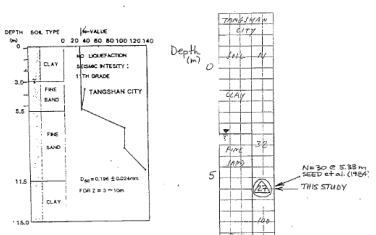
Magnitude: 7.50 — Yong-Ge et al (2017) Huang and Yeh (1997)

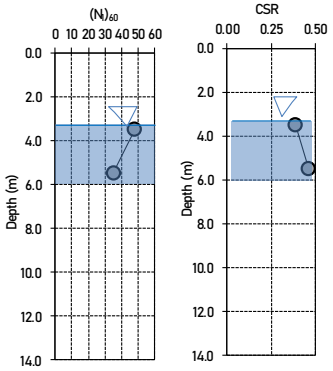
Fault Type: right lateral str — Z_{tor} (km): 0 — R_{rup} (km): 8.9

Dip: 67-89.1 — Width (km): 15 — R_{jb} (km): 8.9

References: Shengcong et al (1983), Fear and McRobert (1993), Cetin (2000), Cetin et al (2004, 2018), Liu (1985)







Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
3.5	*11.5*	*0.387*	*32.0*	*1.33*	*0.91*	*47.8*	fine sand
5.5	*18.0*	*0.463*	*27.0*	*1.12*	*0.94*	*35.1*	fine sand
					Mean:	41.4	
					St. Dev.	9.0	

Depth (m)	Soil Layer
0-3	Clay
3-5.5	Fine Sand
5.5-11.5	Fine Sand
11.5-15	Clay

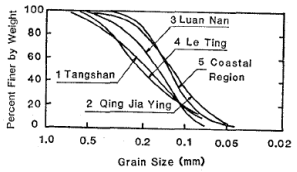


Fig. 16. Representative grain size distribution curves of sands at sites along section I–I′ indicated in Fig. 11 (depth<10m)

Case number:	36
Earthquake:	1976 Tangshan
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Yao Yuan Village
References:	Shengcong et al (1983), Fear et al. (1995), Cetin (2000)
Nature of Failure:	Sand swept in the canal; depression due to liquefaction.
GPS LAT	39.464916 A map showing the location of this case history could not be found. In the text it was mentioned that this
GPS LONG	118.679678 case history in Le Ting so the coordinate of Le Ting is used.
Liq. layer consist of:	silt with sand
Geological Unit:	flood plains including plains of marine and continental sediments
Site Response Anlaysis:	No
Comments:	Cetin (2000) "An extraordinary level of damage to one-story house due to soil liquefaction was observed in Yao Yuan Village, near Wang Tan, Le Ting County. A big sand boil into a canal due to soil liquefaction was observed. Correspondingly, a big depression appeared. The length of the depression was around 30m, the width and depth were around 10 m and 4m respectively. Assuming that the groundwater level was the same with the water level in the canal (at 1 m depth from the ground surface), the maximum pore pressure in the liquefied sand layer at depth of 2 m was estimated as ~ 30kN/m2 which was 3 times as large as the water pressure in the canal. It seems that this pressure gradient induced the horizontal migration of pore water, which was easier to occur than the vertical migration due to "impermeable" top clay layer. PGA was estimated as >0.1 g . SPT energy was estimated as 60 % by Seed et al. (1984)"
	Soil layers are digitized.
	Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
	The additional boreholes that were presented by Fear and McRoberts (1993) catologue were used.
	There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS).
Gravel Content (%):	0.00
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	3.5 - 5.0		3.5 - 5.0	3.5 - 5.0
d_{crt} (m)	6.1	4.3	6.1	4.3	4.3
GWT (m)	0.91	1.0 ± 0.3	0.9	1.0 ± 0.1	1.0 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	17.3 ± 0.6	-	19.6 ± 0.5	19.6 ± 0.5
σ_v (kPa)	117.8	72.0 ± 4.9	118.3	81.3 ± 5.2	81.3 ± 5.2
σ_v' (kPa)	67.0	40.1 ± 3.8	67.2	49.4 ± 3.0	49.4 ± 3.0
a_{max} (g)	0.2	0.200 ± 0.040	0.2	0.200 ± 0.060	0.215 ± 0.043
r_d	0.96	0.92 ± 0.061	0.95	0.97 ± 0.061	0.97 ± 0.061
CSR	0.22	0.214 ± 0.048	0.218	0.208 ± 0.064	0.224 ± 0.047
M_w	0.96	8.00	7.60	7.60	7.50
D_{50}	Silt and sand	0.150 ± 0.050	-	0.150 ± 0.050	0.150 ± 0.050
% Fines	Silt and sand	5.0 ± 3.0	20	20.0 ± 2.0	20.0 ± 8.6
% PI	-	-	-	-	NAV
N	9	8.6 ± 3.8	9	8.7 ± 3.8	8.7 ± 4.0
C_R	-	0.90	0.95	0.90	0.93
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.00	1.00	1.00	1.00	1.23
C_N	1.19	1.55	1.22	1.43	1.43
$(N_1)_{60}$	11	11.9 ± 5.3	10.5	11.1 ± 4.9	14.2 ± 6.5
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	175.3	-	198.1	198.1

EVENT PARAMETERS

1976 Tangshan — Chen et al. (1979) Bulter et al. (1979)
Magnitude: 7.50 — Yong-Ge et al (2017) Huang and Yeh (1997)
Fault Type: right lateral str — Z_{tor} (km): 0 — R_{rup} (km): 47.3
Dip: 67-89.1 — Width (km): 15 — R_{jb} (km): 47.3

References: Shengcong et al (1983), Fear et al. (1995), Cetin (2000)

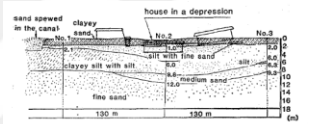


Fig. 19. House sunk into ground, Yao Yuan village, Le Ting county, induced during Tangshan earthquake (reproduced from Fang et al, 1981)

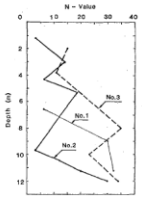
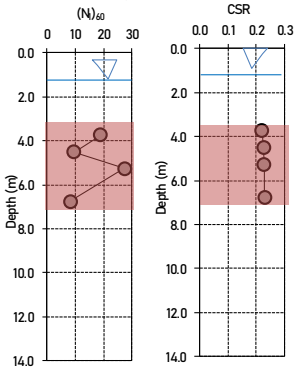


Fig. 20. N-values measured at Yao Yuan village, Le Ting county (reproduced from Fang et al, 1981)



No:2

Depth (m)	Soil Layer
0-1	Clayey Sand
1--6	silt with fine sand
6-9.8	silt
9.8-12	medium sand
12--18	fine sand

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
3.8	***12.3***	***0.220***	***11.0***	***1.51***	***0.92***	***18.8***	No:3 Silt
4.5	***14.8***	***0.225***	***6.0***	***1.40***	***0.93***	***9.6***	No:2 Silt with fine sand
5.3	17.2	0.228	18.0	1.31	0.94	27.3	No:2 Silt with fine sand
6.8	22.1	0.229	6.0	1.17	0.96	8.3	No:1 Clayey silt
					Mean:	14.2	
					St. Dev.	6.5	

Case number:	T2
Earthquake:	1976 Tangshan Earthquake
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Tangshan_Wali
References:	Liu (1985), Moss et al. (2011), NGL Project
Nature of Failure:	Surface evidence of liquefaction documented by Zhou and Zhang (1979)
GPS LAT	39.6986
GPS LONG	118.34025
Liq. layer consist of:	Sand
Geological Unit:	Stone River watershed (Quaternary) (Moss et al 2011)
Site Response Anlaysis:	No
Comments:	BORH_TYPE Mud rotary
	BORH_CREW Liu (1985)
	BORH_MECH semi-automatic
	BORH_STAR 28338
	SAMP_TYPE Split-barrel
	Single bridge, push rods, thrust mechanism and reaction frame
	CPT available
	Zhou and Zhang (1979); Moss et al. (2009, 2011). From translation of the Zhou and Zhang (1979) report: "Generally one borehole was used to secure samples for determination of properties. Two to three holes were used for standard penetration tests. One to three holes were used for static cone penetration tests. Spacings between two neighboring boreholes were about 2 m." There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS).
	Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
	Shear wave velocity for the upper 8 m layer is very high
	SPT values are up tp depth of 7 m.
	Vs12m is assigned as 200 m/s
	PI is assigned as 0 since FC<5.
	Mw is updated as 7.5 (USGS).
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crc} range (m)	-	-	-	-	2.3 - 4.4
d_{cr1} (m)	-	-	-	-	3.4
GWT (m)	-	-	-	-	1.3 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	19.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	19.8 ± 0.5
σ_v (kPa)	-	-	-	-	65.9 ± 7.0
σ_v' (kPa)	-	-	-	-	45.3 ± 3.8
a_{max} (g)	-	-	-	-	0.564 ± 0.113
r_d	-	-	-	-	0.98 ± 0.050
CSR	-	-	-	-	0.523 ± 0.109
M_w	-	-	-	-	7.50
D_{50}	-	-	-	-	0.275 ± 0.106
% Fines	-	-	-	-	4.9 ± 6.5
% PI	-	-	-	-	0
N	-	-	-	-	10.1 ± 0.7
C_R	-	-	-	-	0.91
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.23
C_N	-	-	-	-	1.50
$(N_1)_{60}$	-	-	-	-	17.0 ± 1.1
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	202.4

EVENT PARAMETERS

1976 Tangshan Earthquake — Chen et al. (1979) Bulter et al. (1979)
Magnitude: 7.50 — Yong-Ge et al (2017) Huang and Yeh (1997)
Fault Type: right lateral str — Z_{tor} (km): 0 — R_{rup} (km): 8.3
Dip: 67-89.1 — Width (km): 15 — R_{jb} (km): 8.3

ACCELERATION TIME HISTORY

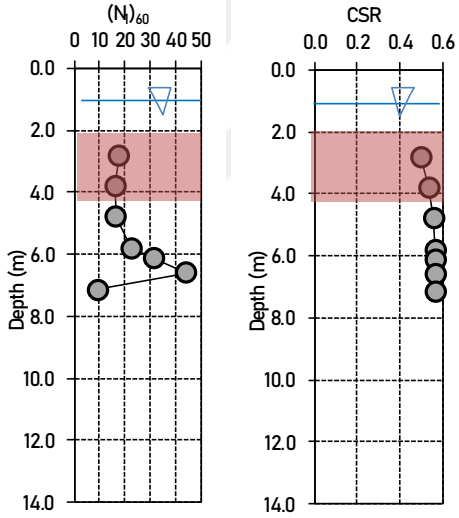


Table 4. Exploration data of Borehole 2.

(Wali, Tangshan city; area of intensity X; water table: 1.25 m; soil liquefied; date: Aug. 1977)

		Type of soil	Static cone penetration			Standard penetration test		Sampling data								
			100	200	300						Particle analysis					
						Depth	# of blow	Sampling depth	Water content	Vol. wt.	10–2	2-0.5	0.5-0.25	0.25-0.1	<0.1	0.1-0.05
		Clayey soil				2.8	10	2.0	26.3	1.97						
		Fine sand				3.8	10	2.8	21.2	2.06		1.5	27	62	9.5	
		Medium sand														
		Silty clayey sand				4.8	11									
		Silty sand														
		Clayey soil				5.8	16									
						6.15	23	3.8	21.0	2.04		4.2	81.0	14.5	0.3	
		Clay				6.6	33	5.6	18.8	2.12		3.5	15.5	33.5	47.5	
						7.15	7	6.2	19.1	2.04		4.5	26.5	30.5	38.5	

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
Fine Sand	***2.8***	***9.2***	***0.499***	***10***	***1.60***	***0.90***	***17.7***
Medium Sand	***3.8***	***12.5***	***0.537***	***10***	***1.43***	***0.92***	***16.2***
Silty clayey sand	4.8	15.7	0.558	11	1.30	0.93	16.5
SM	5.8	19.0	0.569	16	1.21	0.95	22.5
Silty sand	6.15	20.2	0.570	23	1.18	0.95	31.7
Clayey soil	6.6	21.7	0.571	33	1.14	0.95	44.4
Clayey soil	7.15	23.5	0.570	7	1.10	0.96	9.1
						Mean:	17.0
						St. Dev.	1.1

Depth (m)	FC	D_{50}	D_{10}	
2.8	***9.5***	***0.20***	***0.10***	SMALLER
3.8	***0.3***	***0.35***	***0.25***	SMALLER
	SC?			
5.6	47.5			
6.2	38.5			
	4.9	0.28	0.18	
	6.5	0.11	0.11	

Case number:	T3
Earthquake:	1976 Tangshan Earthquake
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Fengnan_Xugezhuang
References:	Liu (1985), Moss et al. (2011), NGL Project
Nature of Failure:	No liquefaction manifestation
GPS LAT	39.54396
GPS LONG	118.11207
Liq. layer consist of:	Sand
Geological Unit:	Stone River watershed (Quaternary) (Moss et al 2011)
Site Response Anlaysis:	No
Comments:	BORH_TYPE Mud rotary
	BORH_CREW Liu (1985)
	BORH_MECH semi-automatic
	BORH_STAR 28764
	SAMP_TYPE Split-barrel
	Single bridge, push rods, thrust mechanism and reaction frame
	CPT available
	Energy of the hammer was assumed 60 % by the author.
	There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS).
	Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{mtc} range (m)	-	-	-	-	1.8 - 4.6
d_{crt} (m)	-	-	-	-	3.2
GWT (m)	-	-	-	-	1.5 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	19.6 ± 0.5
σ_v (kPa)	-	-	-	-	61.8 ± 9.2
σ_v' (kPa)	-	-	-	-	45.1 ± 4.8
a_{max} (g)	-	-	-	-	0.770 ± 0.154
r_d	-	-	-	-	0.94 ± 0.048
CSR	-	-	-	-	0.648 ± 0.138
M_w	-	-	-	-	7.50
D_{50}	-	-	-	-	0.157 ± 0.075
% Fines	-	-	-	-	24.7 ± 19.4
% PI	-	-	-	-	NAV
N	-	-	-	-	21.9 ± 5.9
C_R	-	-	-	-	0.91
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.23
C_N	-	-	-	-	1.50
$(N_1)_{60}$	-	-	-	-	36.7 ± 10.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	169.6

EVENT PARAMETERS

1976 Tangshan Earthquake	Chen et al. (1979) Bulter et al. (1979)	
Magnitude: 7.50	Yong-Ge et al (2017) Huang and Yeh (1997)	
Fault Type: right lateral str	Z_{tor} (km): 0	R_{rup} (km): 0.3
Dip: 67-89.1	Width (km): 15	R_{jb} (km): 0.3

ACCELERATION TIME HISTORY

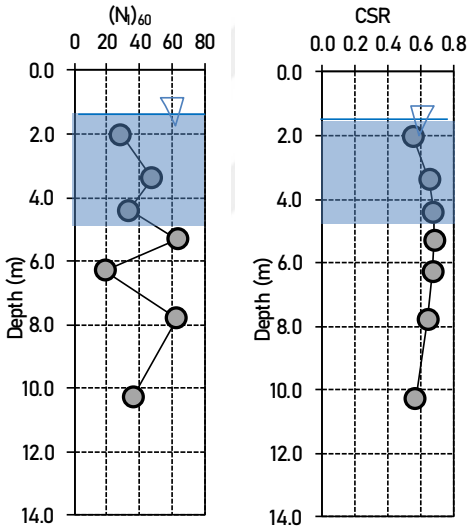


Table 5. Exploration data of Borehole 3.

(Xugezhuang, Fengnan County; area of intensity X; water table: 1.5 m; soil unliquefied; date: Oct. 1978)

Type of soil	Static cone penetration			Standard penetration test		Sampling data			Particle analysis					
	100	200	300	Depth	# of blow	Sampling depth	Water content	Vol. wt.	10–2	2-0.5	0.5-0.25	0.25-0.1	0.1-0.05	<0.05
Surface soil Clayey soil				2.0	15	1.7				1	6	19	54	20
Silty sand				3.4	29	3.1			1	18	26	36	14	5
Fine sand				4.4	22	4.1				4	27	46	16	7
Light loam Silt				5.3	44	5.1				1	30	52	13	4
Light loam				6.3	14	6.0				3	11	15	45	26
Silty sand				7.8	50	7.6					1	9	77	13
				10.3	32	10				1	3	7	55	34

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
silty sand	***2***	***6.6***	***0.56***	***15***	***1.75***	***0.88***	***28.5***
fine sand	***3.4***	***11.2***	***0.66***	***29***	***1.47***	***0.91***	***47.9***
fine sand	***4.4***	***14.4***	***0.68***	***22***	***1.34***	***0.93***	***33.6***
fine sand	5.3	17.4	0.69	44	1.24	0.94	63.4
SC	6.3	20.7	0.68	14	1.16	0.95	19.0
silty sand	7.8	25.6	0.65	50	1.06	0.96	63.0
silty sand	10.3	33.8	0.57	32	0.94	0.98	36.3
						Mean:	36.7
						St. Dev.	10.0

read from the graphs

Depth (m)	FC (%)	D50	D10	0.1-0.05	<0.05
1.7	***47.0***	***0.07***	***-***	***54***	***20***
3.1	***12.0***	***0.20***	***0.07***	***14***	***5***
4.1	***15.0***	***0.20***	***0.07***	***16***	***7***
5.1				13	4
6				45	26
7.6				77	13
10				55	34
	24.7	0.16	0.07		
	19.4	0.08	0.00		

Case number:	T6
Earthquake:	1976 Tangshan Earthquake
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Tangshan_Xidafutuo
References:	Liu (1985), Moss et al. (2011), NGL Project
Nature of Failure:	Liquefaction documented by Zhou and Zhang (1979)
GPS LAT	39.56293
GPS LONG	118.18641
Liq. layer consist of:	Sand
Geological Unit:	Stone River watershed (Quaternary) (Moss et al 2011)
Site Response Anlaysis:	No
Comments:	BORH_TYPE Mud rotary BORH_CREW Liu (1985) BORH_MECH semi-automatic BORH_STAR 28338 SAMP_TYPE Split-barrel Single bridge, push rods, thrust mechanism and reaction frame CPT available Approximately 130 m from intersection where 78/79 measurements and SASW measurements were performed. Zhou and Zhang (1979); Moss et al. (2009, 2011). From translation of the Zhou and Zhang (1979) report: "Generally one borehole was used to secure samples for determination of properties. Two to three holes were used for standard penetration tests. One to three holes were used for static cone penetration tests. Spacings between two neighboring boreholes were about 2 m." There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS). PI is assigned as 0 since FC<5. Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{rtc} range (m)	-	-	-	-	4.4 - 5.5
d_{rt} (m)	-	-	-	-	5.0
GWT (m)	-	-	-	-	1.5 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.1 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.2 ± 0.5
σ_v (kPa)	-	-	-	-	97.2 ± 4.1
σ_v' (kPa)	-	-	-	-	63.3 ± 2.7
a_{max} (g)	-	-	-	-	0.599 ± 0.120
r_d	-	-	-	-	0.89 ± 0.069
CSR	-	-	-	-	0.529 ± 0.114
M_w	-	-	-	-	7.50
D_{50}	-	-	-	-	0.300 ± 0.050
% Fines	-	-	-	-	4.4 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	15.3 ± 1.4
C_R	-	-	-	-	0.94
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.23
C_N	-	-	-	-	1.27
$(N_1)_{60}$	-	-	-	-	22.4 ± 2.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	165.7

EVENT PARAMETERS

1976 Tangshan Earthquake — Chen et al. (1979) Bulter et al. (1979)
Magnitude: 7.50 — Yong-Ge et al (2017) Huang and Yeh (1997)
Fault Type: right lateral str — Z_{tor} (km): 0 — R_{rup} (km): 6.9
Dip: 67-89.1 — Width (km): 15 — R_{jb} (km): 6.9

ACCELERATION TIME HISTORY

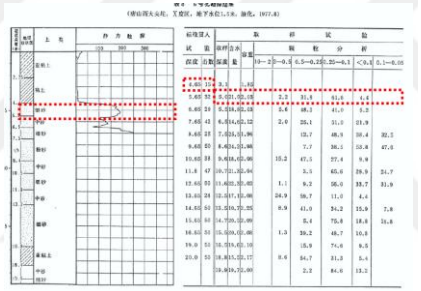
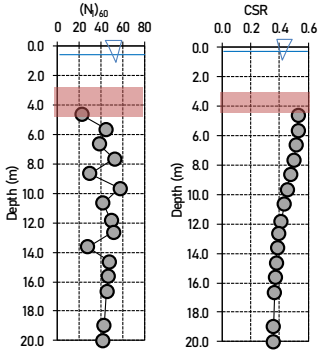


Table 8. Exploration data of Borehole 6.

(Dasifutuo, west of Tangshan; area of intensity X; water table: 1.5 m; soil liquefied; date: Aug. 1977)

Type of soil	Static cone penetration			Standard penetration test	Sampling data									
	100	200	300	Depth	Sampling depth	Water content	Vol. wt.	Particle analysis						
								10–2	2–0.5	0.5–0.25	0.25–0.1	<0.1	0.1–0.05	
Clayey soil				4.65	3.1		1.85							
Clay				5.65	5.0	21.0	2.03		2.2	31.8	61.0	4.4		
Fine sand				6.65	5.5	18.8	2.03		5.6	48.2	41.0	5.2		
				7.65	6.5	14.6	2.12		2.0	25.1	51.0	21.9		
Medium sand				8.65	7.5	25.5	1.96			12.7	48.9	38.4	32.5	
Fine sand				9.65	8.6	24.2	1.98			7.7	38.5	53.8	47.6	
Silty sand				10.65	9.6	18.6	2.06		15.2	47.5	27.4	9.9		
				11.8	10.7	21.3	2.04			3.5	65.6	29.9	24.7	
Medium sand				12.65	11.6	22.3	2.02		1.1	9.2	56.0	33.7	31.9	
				13.65	12.5	17.1	2.08		24.9	59.7	11.0	4.4		
Fine sand				14.65	13.5	10.7	2.25		8.9	41.0	34.2	15.9	7.8	
Medium sand				15.65	14.7	20.5	2.09			5.4	75.8	18.8	16.8	
				16.65	15.5	20.0	2.08		1.3	39.2	48.7	10.8		
Clayey soil				19.0	16.5	19.6	2.10			15.9	74.6	9.5		
				20.0	18.8	15.5	2.17		8.6	54.7	31.3	5.4		
					19.9	19.7	2.00			2.2	84.6	13.2		
Clayey soil														
Medium sand														
Fine sand														



	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
Fine Sand	***4.65***	***15.3***	***0.529***	***15***	***1.30***	***0.93***	***22.4***
Medium Sand	5.65	18.5	0.527	32	1.20	0.94	44.7
Fine Sand	6.65	21.8	0.516	29	1.12	0.95	38.3
Silty Sand	7.65	25.1	0.497	42	1.05	0.96	52.6
Silty Sand	8.65	28.4	0.475	25	1.00	0.97	29.9
Medium Sand	9.65	31.7	0.453	50	0.95	0.98	57.2
Fine Sand	10.65	34.9	0.431	38	0.91	0.98	41.8
Fine Sand	11.8	38.7	0.410	47	0.87	0.98	49.6
Medium Sand	12.65	41.5	0.396	50	0.84	0.99	51.2
Fine Sand	13.65	44.8	0.384	28	0.81	0.99	27.8
Clayey soil	14.65	48.1	0.374	50	0.79	0.99	48.1
Clayey soil	15.65	51.3	0.367	50	0.76	0.99	46.7
Clayey soil	16.65	54.6	0.362	50	0.74	0.99	45.4
Medium Sand	19	62.3	0.356	50	0.70	1.00	42.8
Fine Sand	20	65.6	0.355	50	0.68	1.00	41.8
						Mean:	22.4
						St. Dev.	2.0

assigned

Depth (m)	<0.1	0.1-0.05	D50
3.1	-		
5	4.4		0.3
5.5	5.2		
6.5	21.9		
7.5	38.4	32.5	
8.6	53.8	47.6	
9.6	9.9		
10.7	29.9	24.7	
11.6	33.7	31.9	
12.5	4.4		
13.5	15.9	7.8	
14.7	18.8	16.8	
15.5	10.8		
16.5	9.5		
18.8	5.4		
19.7	13.2		
Mean:	4.4		0.3
St. Dev.	8.6	assigned	0.05

Case number:	T8
Earthquake:	1976 Tangshan Earthquake
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Tangshan_Laobianzhuang
References:	Liu (1985), Moss et al. (2011), NGL Project
Nature of Failure:	Liquefaction documented by Zhou and Zhang (1979). "Survivors reported wide spread liquefaction with
GPS LAT	39.54255 sand blows issuing white sand ejecta" (Moss et al 2009).
GPS LONG	118.20538
Liq. layer consist of:	Medium Sand
Geological Unit:	Stone River watershed (Quaternary) (Moss et al 2011)
Site Response Anlaysis:	No
Comments:	BORH_TYPE Mud rotary
	BORH_CREW Liu (1985)
	BORH_MECH semi-automatic
	BORH_STAR 28338
	SAMP_TYPE Split-barrel
	Single bridge, push rods, thrust mechanism and reaction frame
	CPT available
	Zhou and Zhang (1979); Moss et al. (2009, 2011). From translation of the Zhou and Zhang (1979) report: "Generally one borehole was used to secure samples for determination of properties. Two to three holes were used for standard penetration tests. One to three holes were used for static cone penetration tests. Spacings between two neighboring boreholes were about 2 m." There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS).
	Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes

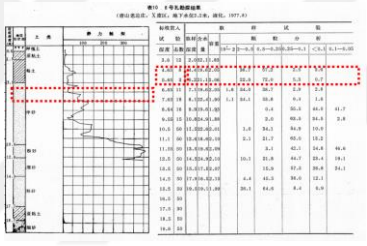
Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this sudy
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{rtr} range (m)	-	-	-	-	4.0 - 6.7
d_{rtr} (m)	-	-	-	-	5.3
GWT (m)	-	-	-	-	2.2 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	19.6 ± 0.5
σ_v (kPa)	-	-	-	-	101.0 ± 9.2
σ_v' (kPa)	-	-	-	-	70.3 ± 4.9
a_{max} (g)	-	-	-	-	0.569 ± 0.114
r_d	-	-	-	-	0.93 ± 0.074
CSR	-	-	-	-	0.491 ± 0.107
M_w	-	-	-	-	7.50
D_{50}	-	-	-	-	0.467 ± 0.115
% Fines	-	-	-	-	2.4 ± 1.5
% PI	-	-	-	-	0
N	-	-	-	-	9.3 ± 1.4
C_R	-	-	-	-	0.94
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.23
C_N	-	-	-	-	1.20
$(N_1)_{60}$	-	-	-	-	13.0 ± 1.9
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	186.0

EVENT PARAMETERS

1976 Tangshan Earthquake	Chen et al. (1979)	Bulter et al. (1979)	
Magnitude: 7.50	Yong-Ge et al (2017)	Huang and Yeh (1997)	
Fault Type: right lateral str	Z_{tor} (km): 0	R_{rup} (km): 8.1	
Dip: 67-89.1	Width (km): 15	R_{jb} (km): 8.1	

ACCELERATION TIME HISTORY



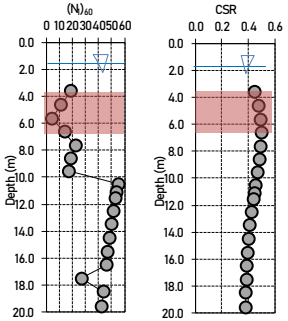


Table 10. Exploration data of Borehole 8.

(Laobianzhuang, Tangshan; area of intensity X; water table: 3.2 m; soil liquefied; date: Aug. 1977)

Type of soil	Static cone penetration 100	200	300	Standard penetration test Depth	# of blow	Sampling data: Sampling depth	Water content	Vol. wt.	Particle analysis: 10–2	2-0.5	0.5-0.25	0.25-0.1	<0.1	0.1-0.05
Cultiv. Soil				3.6	12	2.0	32.1	1.83						
Clayey soil				4.65	8	4.4	19.6	2.05		36.7	57.2	2.5	3.6	
Clay				5.65	3	6.2	21.1	2.06		22.0	72.0	5.3	0.7	
				6.65	11	7.1	19.6	2.05	1.6	54.0	38.7	2.9	2.8	
				7.65	18	8.1	22.4	1.90	1.1	34.1	53.8	9.4	1.6	
Medium sand				8.64	16	9.9	19.6	1.93			0.4	55.5	44.0	41.7
				9.55	15	10.8	24.9	1.88			2.0	63.5	34.5	2.8
				10.5	50	11.5	22.6	2.01		1.0	34.1	54.9	10.0	
				11.1	50	12.6	18.6	2.10		2.1	21.7	63.0	13.2	
				11.55	50	13.5	19.6	2.09			3.1	42.1	54.8	46.6
Silty sand				12.5	50	14.5	24.9	2.10		10.1	21.8	44.7	23.4	19.1
				13.5	50	15.5	17.5	2.07			15.9	57.3	26.8	24.1
Fine sand				14.5	50	17.9	16.5	2.15		4.4	45.5	38.0	12.1	
				15.5	50	19.5	19.1	1.99		26.1	64.6	8.4	0.9	
Silty sand				16.5	50									
				17.5	30									
				18.5	50									
Clayey soil				19.6	50									
Fine sand														

CPT indicates 0-3 m surfical soils are cohesive and plastic which confirmes the critical layer was selected based on SPT hence the case history is included in the database

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
Clay	3.6	11.8	0.45	12	1.38	0.92	18.7
Medium Sand	***4.65***	***15.3***	***0.48***	***8***	***1.26***	***0.93***	***11.6***
Medium Sand	***5.65***	***18.5***	***0.50***	***3***	***1.18***	***0.94***	***4.1***
Medium Sand	***6.65***	***21.8***	***0.50***	***11***	***1.10***	***0.95***	***14.3***
Medium Sand	***7.65***	***25.1***	***0.50***	***18***	***1.04***	***0.96***	***22.3***
Medium Sand	***8.64***	***28.3***	***0.49***	***16***	***0.99***	***0.97***	***19.0***
Medium Sand	***9.55***	***31.3***	***0.47***	***15***	***0.95***	***0.98***	***17.2***
Medium Sand	10.5	34.4	0.46	50	0.92	0.98	55.3
Silty Sand	11.1	36.4	0.45	50	0.89	0.98	54.1
Silty Sand	11.55	37.9	0.44	50	0.88	0.98	53.3
Fine Sand	12.5	41.0	0.43	50	0.85	0.99	51.7
Fine Sand	13.5	44.3	0.41	50	0.82	0.99	50.1
Silty Sand	14.5	47.6	0.40	50	0.80	0.99	48.6
Silty Sand	15.5	50.9	0.40	50	0.77	0.99	47.3
Silty Sand	16.5	54.1	0.39	50	0.75	0.99	46.0
Clayey Soil	17.5	57.4	0.39	30	0.73	1.00	26.9
Clayey Soil	18.5	60.7	0.38	50	0.71	1.00	43.8
Fine Sand	19.6	64.3	0.38	50	0.69	1.00	42.7
						Mean:	13.0
						St. Dev.	1.9

read from the graphs

	Depth (m)	<0.1	0.1-0.05	D50
	2			
	4.4	3.6		0.4
outlier clayey??	6.2	0.7		0.4
	7.1	2.8		0.6
another sublayer	8.1	1.6		
	9.9	44	41.7	
	10.8	34.5	2.8	
	11.5	10		
	12.6	13.2		
	13.5	54.8	46.6	
	14.5	23.4	19.1	
	15.5	26.8	24.1	
	17.9	12.1		
	19.5	0.9		
	Mean:	2.4		0.467
	St. Dev.	1.5		0.115

Case number:	T9
Earthquake:	1976 Tangshan Earthquake
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Fengnan_Rice field
References:	Liu (1985), Moss et al. (2011), NGL Project
Nature of Failure:	Non-liquefaction documented by Zhou and Zhang (1979).
GPS LAT	39.52287
GPS LONG	118.213560
Liq. layer consist of:	Silty Sand
Geological Unit:	Stone River watershed (Quaternary) (Moss et al 2011)
Site Response Anlaysis:	No
Comments:	BORH_TYPE Mud rotary
	BORH_CREW Liu (1985)
	BORH_MECH semi-automatic
	BORH_STAR 28734
	SAMP_TYPE Split-barrel
	Single bridge, push rods, thrust mechanism and reaction frame
	CPT available
	Zhou and Zhang (1979); Moss et al. (2009, 2011). From translation of the Zhou and Zhang (1979) report: "Generally one borehole was used to secure samples for determination of properties. Two to three holes were used for standard penetration tests. One to three holes were used for static cone penetration tests. Spacings between two neighboring boreholes were about 2 m." There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS).
	Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes

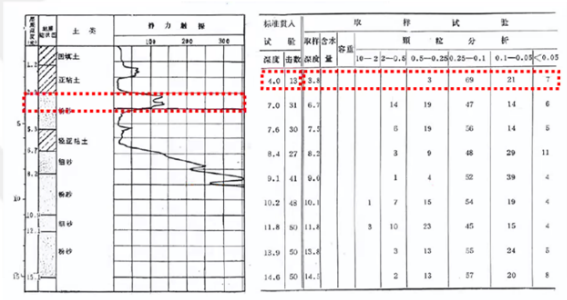
Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.9 - 5.3
d_{crt} (m)	-	-	-	-	4.1
GWT (m)	-	-	-	-	1.1 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	21.2 ± 0.5
σ_v (kPa)	-	-	-	-	84.6 ± 8.6
σ_v' (kPa)	-	-	-	-	55.1 ± 4.9
a_{max} (g)	-	-	-	-	0.539 ± 0.108
r_d	-	-	-	-	0.96 ± 0.059
CSR	-	-	-	-	0.516 ± 0.109
M_w	-	-	-	-	7.50
D_{50}	-	-	-	-	0.150 ± 0.050
% Fines	-	-	-	-	17.5 ± 8.9
% PI	-	-	-	-	NAV
N	-	-	-	-	13.2 ± 1.3
C_R	-	-	-	-	0.92
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_F	-	-	-	-	1.23
C_N	-	-	-	-	1.36
$(N_1)_{60}$	-	-	-	-	20.3 ± 2.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	190.1

EVENT PARAMETERS

1976 Tangshan Earthquake — Chen et al. (1979) Bulter et al. (1979)
Magnitude: 7.50 — Yong-Ge et al (2017) Huang and Yeh (1997)
Fault Type: right lateral str — Z_{tor} (km): 0 — R_{rup} (km): 9.4
Dip: 67-89.1 — Width (km): 15 — R_{jb} (km): 9.4

ACCELERATION TIME HISTORY



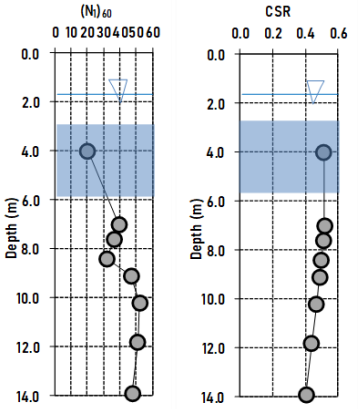


Table 11. Exploration data of Borehole 9.

(Daodi, Fengnan County; area of intensity X; water table: 1.1 m; soil unliquefied; date: Sept. 1978)

Type of soil	Static cone penetration 100	200	300	Standard penetration test Depth	# of blow	Sampling data: Sampling depth	Water content	Vol. wt.	Particle analysis 10–2	2-0.5	0.5-0.25	0.25-0.1	0.1-0.05	<0.05
Filled land														
Clayey soil				4.0	13	3.8					3	69	21	7
Silty sand				7.0	31	6.7				14	19	47	14	6
Light loam				7.6	30	7.5				6	19	56	14	5
Fine sand				8.4	27	8.2				3	9	48	29	11
Silty sand				9.1	41	9.0				1	4	52	39	4
Fine sand				10.2	48	10.1			1	7	15	54	19	4
Silty sand				11.8	50	11.8			3	10	23	45	15	4
				13.9	50	13.8				3	13	55	24	5
				14.6	50	14.5				2	13	57	20	8

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
Silty Sand	***4***	***13.1***	***0.51***	***13***	***1.37***	***0.92***	***20.3***	
Fine Sand	7	23.0	0.52	31	1.07	0.96	39.3	
Fine Sand	7.6	24.9	0.51	30	1.03	0.96	36.8	
Silty Sand	8.4	27.6	0.50	27	0.99	0.97	31.8	
Silty Sand	9.1	29.9	0.49	41	0.95	0.97	46.8	
Silty Sand	10.2	33.5	0.47	48	0.90	0.98	52.2	
Fine Sand	11.8	38.7	0.44	50	0.84	0.98	51.1	
Silty Sand	13.9	45.6	0.40	50	0.78	0.99	47.6	
Silty Sand	14.6	47.9	0.40	50	0.76	0.99	46.6	
						Mean:	20.3	
						St. Dev.	2.0	assigned

	read from the graphs			read from the graphs	
Depth (m)	**FC (%)**	**0.1-0.05**	**<0.05**	**D50**	
3.8	***17.5***	***21***	***7***	***0.15***	
6.7		14.0	6.0		
7.5		14.0	5.0		
8.2		29.0	11.0		
9.0		39.0	4.0		
10.1		19.0	4.0		
11.8		15.0	4.0		
13.8		24.0	5.0		
14.5		20.0	8.0		
	17.5			0.2	
	8.9	assigned		0.05	assigned

CPT also confirm this selection. Although there is no SPT within 3.9-6.9 m.

Case number:	T10
Earthquake:	1976 Tangshan Earthquake
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Fengnan_Jingzhuang
References:	Liu (1985), Moss et al. (2011), NGL Project
Nature of Failure:	Liquefaction documented by Zhou and Zhang (1979).
GPS LAT	39.53253
GPS LONG	118.20206
Liq. layer consist of:	Sand
Geological Unit:	Stone River watershed (Quaternary) (Moss et al 2011)
Site Response Anlaysis:	No
Comments:	BORH_TYPE Mud rotary
	BORH_CREW Liu (1985)
	BORH_MECH semi-automatic
	BORH_STAR Sep-78
	SAMP_TYPE Split-barrel
	Single bridge, push rods, thrust mechanism and reaction frame
	CPT available
	Zhou and Zhang (1979); Moss et al. (2009, 2011). From translation of the Zhou and Zhang (1979) report: "Generally one borehole was used to secure samples for determination of properties. Two to three holes were used for standard penetration tests. One to three holes were used for static cone penetration tests. Spacings between two neighboring boreholes were about 2 m." There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS).
	PI is assigned as 0 since FC<5.
	Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
Gravel Content (%):	0
CPT available:	Yes
Vs available:	Yes

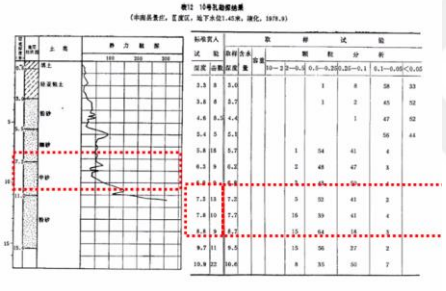
Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{cr1c} range (m)	-	-	-	-	6.0 - 9.5
d_{cr1} (m)	-	-	-	-	7.8
GWT (m)	-	-	-	-	1.5 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.1 ± 0.5
σ_v (kPa)	-	-	-	-	152.1 ± 12.2
σ_v' (kPa)	-	-	-	-	90.2 ± 6.8
a_{max} (g)	-	-	-	-	0.566 ± 0.113
r_d	-	-	-	-	0.81 ± 0.101
CSR	-	-	-	-	0.505 ± 0.120
M_w	-	-	-	-	7.50
D_{50}	-	-	-	-	0.287 ± 0.029
% Fines	-	-	-	-	3.0 ± 0.9
% PI	-	-	-	-	0
N	-	-	-	-	10.2 ± 1.7
C_R	-	-	-	-	0.96
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.23
C_N	-	-	-	-	1.06
$(N_1)_{60}$	-	-	-	-	12.9 ± 2.1
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	176.8

EVENT PARAMETERS

1976 Tangshan Earthquake — Chen et al. (1979) Bulter et al. (1979)
Magnitude: 7.50 — Yong-Ge et al (2017) Huang and Yeh (1997)
Fault Type: right lateral str — Z_{tor} (km): 0 — R_{rup} (km): 2.4
Dip: 67-89.1 — Width (km): 15 — R_{jb} (km): 2.4

ACCELERATION TIME HISTORY



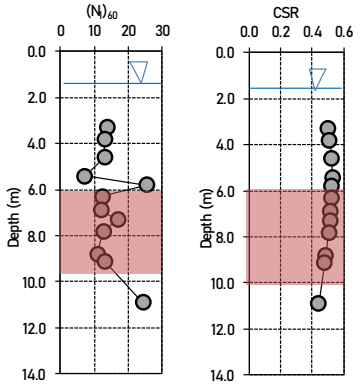


Table 12. Exploration data of Borehole 10.

(Jingzhuang, Fengnan County; area of intensity IX; water table: 1.45 m; soil liquefied; date: Sept. 1978)

Type of soil	Static cone penetration 100	200	300	Standard penetration test Depth	# of blow	Sampling data: Sampling depth	Water content	Vol. wt.	Particle analysis 10–2	2-0.5	0.5-0.25	0.25-0.1	0.1-0.05	<0.05
Filled land														
Light Loam				3.3	8	3.0					1	8	58	33
				3.8	8	3.7					1	2	45	52
Silty sand				4.6	8.5	4.4						1	47	52
				5.4	5	5.1							56	44
				5.8	18	5.7				1	54	41	4	
Fine sand				6.3	9	6.2				2	48	47	3	
				6.9	9	6.8				3	43	50	4	
				7.3	13	7.2				5	52	41	2	
Medium sand				7.8	10	7.7				16	39	41	4	
				8.8	9	8.7				15	64	18	3	
Silty sand				9.7	11	9.5				15	56	27	2	
				10.9	22	10.6				8	35	50	7	

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
Silty Sand	3.3	10.8	0.50	8	1.52	0.91	13.6
Silty Sand	3.8	12.5	0.51	8	1.43	0.92	13.0
Silty Sand	4.6	15.1	0.52	8.5	1.33	0.93	13.0
Silty Sand	5.4	17.7	0.53	5	1.24	0.94	7.2
Fine Sand	5.8	19.0	0.53	18	1.20	0.95	25.3
Fine Sand	***6.3***	***20.7***	***0.52***	***9***	***1.16***	***0.95***	***12.3***
Fine Sand	***6.90***	***22.6***	***0.52***	***9***	***1.12***	***0.96***	***11.9***
Fine Sand	***7.30***	***24.0***	***0.51***	***13***	***1.09***	***0.96***	***16.8***
Medium Sand	***7.8***	***25.6***	***0.50***	***10***	***1.06***	***0.96***	***12.6***
Medium Sand	***8.8***	***28.9***	***0.49***	***9***	***1.00***	***0.97***	***10.8***
Medium Sand	***9.1***	***29.9***	***0.48***	***11***	***0.99***	***0.97***	***13.0***
Medium Sand	10.90	35.8	0.44	22	0.91	0.98	24.2
						Mean:	12.9
						St. Dev.	2.1

read from the graphs

Depth (m)	FC (%)	
3.0	62.0	
3.7	74.5	
4.4	75.5	
5.1	72.0	
5.7	4.0	smaller
6.2	***3.0***	smaller
6.8	***4.0***	smaller
7.2	***2.0***	smaller
7.7	***4.0***	smaller
8.7	***3.0***	smaller
9.5	***2.0***	smaller
10.6	7.0	smaller
	3.0	smaller
	0.9	

read from the graphs — table — table

D50	D10	0.1-0.05	<0.05
		58	33
		45	52
		47	52
		56	44
		4	
0.250	***0.150***	***3***	
0.250	***0.150***	***4***	
0.300	***0.150***	***2***	
0.300	0.150	4	
0.320	0.180	3	
0.300	0.150	2	
		7	
0.29	0.16		
0.03	0.01		

Joint evaluatin of CPT suggested that upper Silty sand layer is plastic 3<RF<4

Case number:	T11
Earthquake:	1976 Tangshan Earthquake
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Fengnan_Fanzhuang
References:	Liu (1985), Moss et al. (2011), NGL Project
Nature of Failure:	Liquefaction documented by Zhou and Zhang (1979).
GPS LAT	39.51628
GPS LONG	118.20302
Liq. layer consist of:	Sand (S_fine)
Geological Unit:	Stone River watershed (Quaternary) (Moss et al 2011)
Site Response Anlaysis:	No
Comments:	BORH_TYPE Mud rotary
	BORH_CREW Liu (1985)
	BORH_MECH semi-automatic
	BORH_STAR Sep-78
	SAMP_TYPE Split-barrel
	Single bridge, push rods, thrust mechanism and reaction frame
	CPT available
	Zhou and Zhang (1979); Moss et al. (2009, 2011). From translation of the Zhou and Zhang (1979) report: "Generally one borehole was used to secure samples for determination of properties. Two to three holes were used for standard penetration tests. One to three holes were used for static cone penetration tests. Spacings between two neighboring boreholes were about 2 m." There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS).
	Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
Gravel Content (%):	0
CPT available:	Yes
Vs available:	Yes

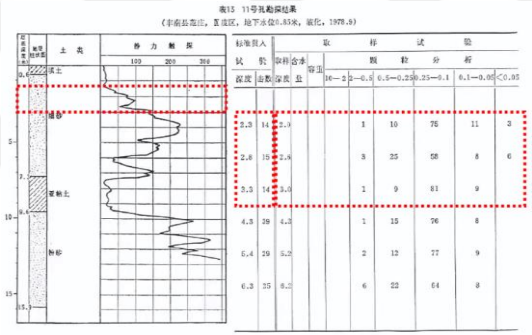
Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.0 - 3.5
d_{crt} (m)	-	-	-	-	2.8
GWT (m)	-	-	-	-	0.9 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	55.3 ± 5.3
σ_v' (kPa)	-	-	-	-	36.6 ± 3.0
a_{max} (g)	-	-	-	-	0.555 ± 0.111
r_d	-	-	-	-	0.97 ± 0.042
CSR	-	-	-	-	0.527 ± 0.109
M_w	-	-	-	-	7.50
D_{50}	-	-	-	-	0.160 ± 0.017
% Fines	-	-	-	-	9.2 ± 0.8
% PI	-	-	-	-	NAV
N	-	-	-	-	14.3 ± 1.0
C_R	-	-	-	-	0.90
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.23
C_N	-	-	-	-	1.67
$(N_1)_{60}$	-	-	-	-	26.4 ± 1.9
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	178.9

EVENT PARAMETERS

1976 Tangshan Earthquake — Chen et al. (1979) Bulter et al. (1979)
Magnitude: 7.50 — Yong-Ge et al (2017) Huang and Yeh (1997)
Fault Type: right lateral str — Z_{tor} (km): 0 — R_{rup} (km): 8.7
Dip: 67-89.1 — Width (km): 15 — R_{jb} (km): 8.7

ACCELERATION TIME HISTORY



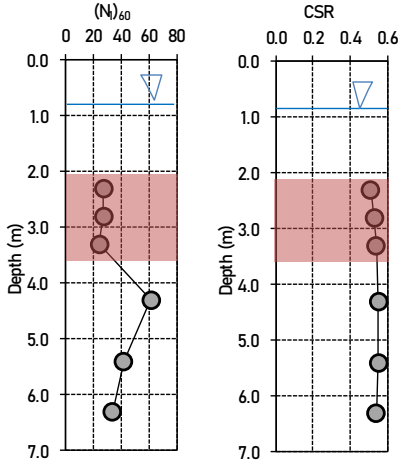


Table 13. Exploration data of Borehole 11.

(Fanzhuang, Fengnan County; area of intensity IX; water table: 0.85 m; soil liquefied; date: Sept. 1978

Type of soil	Static cone penetration 100	200	300	Standard penetration test Depth	# of blow	Sampling data: Sampling depth	Water content	Vol. wt.	Particle analysis 10–2	2-0.5	0.5-0.25	0.25-0.1	0.1-0.05	<0.05
Filled land														
Fine sand				2.3	14	2.0				1	10	75	11	3
				2.8	15	2.6				3	25	58	8	6
				3/3	14	3.0				1	9	81	9	
Clayey soil				4.3	39	4.3				1	15	76	8	
				5.4	29	5.2				2	12	77	9	
Silty sand				6.3	25	6.2				6	22	64		

Fine Sand (particle diameter:0.075mm-0.25mm)

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
2.3	***7.5***	***0.51***	***14***	***1.79***	***0.89***	***27.5***
2.8	***9.2***	***0.53***	***15***	***1.65***	***0.90***	***27.5***
3.3	***10.8***	***0.54***	***14***	***1.55***	***0.91***	***24.3***
4.3	14.1	0.55	39	1.38	0.93	61.5
5.4	17.7	0.55	29	1.25	0.94	42.0
6.3	20.7	0.54	25	1.16	0.95	34.2
					Mean:	26.4
					St. Dev.	1.9

read from the graphs

Depth (m)	FC (%)	D50	D10	0.1-0.05	<0.05
2	***8.5***	***0.150***	***0.100***	***11***	***3***
2.6	***10.0***	***0.180***	***0.100***	***8***	***6***
3	***9.0***	***0.150***	***0.100***	***9***	***-***
4.3				8	-
5.2				9	-
6.2				-	-
	9.2	0.2	0.1		
	0.8	0.02	0.00		

Case number:	T12
Earthquake:	1976 Tangshan Earthquake
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Fengnan_Xuanzhuang
References:	Liu (1985), Moss et al. (2011), NGL Project
Nature of Failure:	Liquefaction documented by Zhou and Zhang (1979).
GPS LAT	39.50315
GPS LONG	118.13576
Liq. layer consist of:	Fine Sand (particle diameter:0.075mm-0.25mm)
Geological Unit:	Stone River watershed (Quaternary) (Moss et al 2011)
Site Response Anlaysis:	No
Comments:	BORH_TYPE Mud rotary
	BORH_CREW Liu (1985)
	BORH_MECH semi-automatic
	BORH_STAR Sep-78
	SAMP_TYPE Split-barrel
	Single bridge, push rods, thrust mechanism and reaction frame
	CPT available
	Zhou and Zhang (1979); Moss et al. (2009, 2011). From translation of the Zhou and Zhang (1979) report: "Generally one borehole was used to secure samples for determination of properties. Two to three holes were used for standard penetration tests. One to three holes were used for static cone penetration tests. Spacings between two neighboring boreholes were about 2 m." There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS).
	Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
	Vs12 is based on measured Vs values
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	1.8 - 10.2
d_{crt} (m)	-	-	-	-	6.0
GWT (m)	-	-	-	-	1.6 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	110.9 ± 26.6
σ_v' (kPa)	-	-	-	-	67.2 ± 12.9
a_{max} (g)	-	-	-	-	0.696 ± 0.139
r_d	-	-	-	-	0.88 ± 0.082
CSR	-	-	-	-	0.656 ± 0.149
M_w	-	-	-	-	7.50
D_{50}	-	-	-	-	0.178 ± 0.037
% Fines	-	-	-	-	8.0 ± 5.1
% PI	-	-	-	-	NAV
N	-	-	-	-	8.2 ± 2.4
C_R	-	-	-	-	0.95
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.23
C_N	-	-	-	-	1.23
$(N_1)_{60}$	-	-	-	-	11.7 ± 3.4
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	177.9

EVENT PARAMETERS

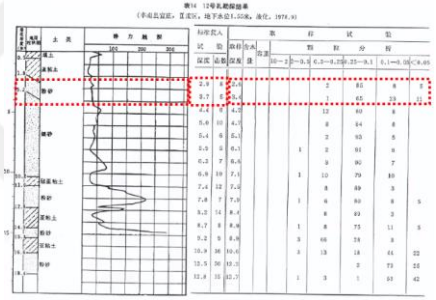
1976 Tangshan Earthquake — Chen et al. (1979) Bulter et al. (1979)

Magnitude: 7.50 — Yong-Ge et al (2017) Huang and Yeh (1997)

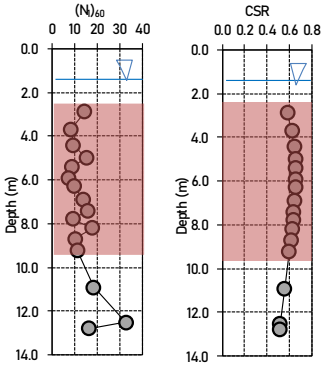
Fault Type: right lateral str — Z_{tor} (km): 0 — R_{rup} (km): 3.6

Dip: 67-89.1 — Width (km): 15 — R_{jb} (km): 3.6

ACCELERATION TIME HISTORY



(Xuanzhuang, Fengnan County; area of intensity IX; water table: 1.55 m; soil liquefied; date: Sept. 1978)



Type of soil	Static cone penetration 100	200	300	Standard penetration test Depth	# of blow	Sampling data: Sampling depth	Water content	Vol. wt.	Particle analysis: 10~2	2-0.5	0.5-0.25	0.25-0.1	0.1-0.05	<0.05
Filled land														
Clayey soil														
Silty sand				2.9	8	2.6					2	85	8	5
				3.7	5	3.4					1	65	23	11
				4.4	6	4.2					12	80	8	
				5.0	10	4.7					8	84	8	
				5.4	6	5.1					2	93	5	
Fine sand				5.9	5	6.1				1	2	91	6	
				6.3	7	6.6					3	90	7	
				6.9	10	7.1				1	10	79	10	
				7.4	12	7.5					8	89	3	
Light loam				7.8	7	7.9				1	6	80	8	5
				8.2	14	8.4					8	89	3	
Silty sand				8.7	8	8.9				1	8	75	11	5
				9.2	9	8.9				3	66	28	3	
Clayey soil				10.9	16	10.6				3	13	18	44	22
Silty sand				12.5	30	12.2						2	73	25
Clayey soil				12.8	15	12.7				1	3	1	53	42
Silty sand														

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
Silty Sand	***2.9***	***9.5***	***0.58***	***8***	***1.61***	***0.90***	***14.4***
S_fine	***3.7***	***12.1***	***0.62***	***5***	***1.48***	***0.92***	***8.4***
S_fine	***4.4***	***14.4***	***0.64***	***6***	***1.39***	***0.93***	***9.5***
S_fine	***5***	***16.4***	***0.65***	***10***	***1.32***	***0.94***	***15.3***
S_fine	***5.4***	***17.7***	***0.66***	***6***	***1.28***	***0.94***	***8.9***
S_fine	***5.9***	***19.4***	***0.66***	***5***	***1.24***	***0.95***	***7.2***
S_fine	***6.3***	***20.7***	***0.65***	***7***	***1.21***	***0.95***	***9.9***
S_fine	***6.9***	***22.6***	***0.65***	***10***	***1.16***	***0.96***	***13.7***
S_fine	***7.4***	***24.3***	***0.64***	***12***	***1.13***	***0.96***	***16.0***
S_fine	***7.8***	***25.6***	***0.63***	***7***	***1.10***	***0.96***	***9.2***
S_fine	***8.2***	***26.9***	***0.63***	***14***	***1.08***	***0.97***	***18.0***
S_fine	***8.7***	***28.5***	***0.61***	***8***	***1.05***	***0.97***	***10.1***
S_fine	***9.2***	***30.2***	***0.60***	***9***	***1.03***	***0.97***	***11.1***
SC	10.9	35.8	0.56	16	0.95	0.98	18.5
SM	12.5	41.0	0.52	30	0.90	0.99	32.8
SM	12.8	42.0	0.51	15	0.89	0.99	16.2
						Mean:	11.7
						St. Dev.	3.4

read from the graphs — table

Depth (m)	FC (%)	D50	D10	0.1-0.05	<0.05
2.6	***9.0***	***0.170***	***0.100***	***8***	
3.4	***22.5***	***0.150***	***0.040***	***23***	
4.2	***8.0***	***0.170***	***0.100***	***8***	
4.7	***8.0***	***0.170***	***0.100***	***8***	
5.1	***5.0***	***0.170***	***0.100***	***5***	
6.1	***6.0***	***0.170***	***0.100***	***6***	
6.6	***7.0***	***0.170***	***0.100***	***7***	
7.1	***10.0***	***0.170***	***0.100***	***10***	
7.5	***3.0***	***0.170***	***0.100***	***3***	
7.9	***9.0***	***0.170***	***0.090***	***8***	***5***
8.4	***3.0***	***0.170***	***0.100***	***3***	
8.9	***10.5***	***0.170***	***0.080***	***11***	***5***
8.9	***3.0***	***0.300***	***0.140***	***3***	
10.6				44	22
12.2				73	25
12.7				53	42
Mean:	8.0	0.178	0.096		
St. Dev.	5.1	0.037	0.021		

Case number:	T13
Earthquake:	1976 Tangshan Earthquake
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Fengnan_Caogezhuang
References:	Liu (1985), Moss et al. (2011), NGL Project
Nature of Failure:	Liquefaction documented by Zhou and Zhang (1979).
GPS LAT	39.58128
GPS LONG	118.32427
Liq. layer consist of:	Fine Sand (particle diameter:0.075mm-0.25mm)
Geological Unit:	Stone River watershed (Quaternary) (Moss et al 2011)
Site Response Anlaysis:	No
Comments:	BORH_TYPE Mud rotary
	BORH_CREW Liu (1985)
	BORH_MECH semi-automatic
	BORH_STAR Sep-78
	SAMP_TYPE Split-barrel
	Single bridge, push rods, thrust mechanism and reaction frame
	CPT available
	Zhou and Zhang (1979); Moss et al. (2009, 2011). From translation of the Zhou and Zhang (1979) report: "Generally one borehole was used to secure samples for determination of properties. Two to three holes were used for standard penetration tests. One to three holes were used for static cone penetration tests. Spacings between two neighboring boreholes were about 2 m." There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS).
	Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

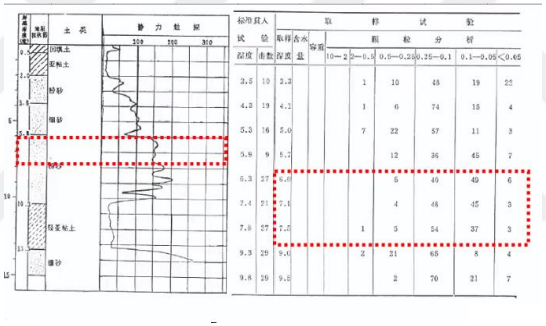
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crit} range (m)	-	-	-	-	2.0 - 5.8
d_{cr1} (m)	-	-	-	-	3.9
GWT (m)	-	-	-	-	1.1 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	77.0 ± 13.1
σ_v' (kPa)	-	-	-	-	49.0 ± 7.0
a_{max} (g)	-	-	-	-	0.416 ± 0.083
r_d	-	-	-	-	0.97 ± 0.057
CSR	-	-	-	-	0.413 ± 0.087
M_w	-	-	-	-	7.50
D_{50}	-	-	-	-	0.158 ± 0.043
% Fines	-	-	-	-	20.3 ± 7.3
% PI	-	-	-	-	NAV
N	-	-	-	-	13.0 ± 4.5
C_R	-	-	-	-	0.92
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.23
C_N	-	-	-	-	1.44
$(N_1)_{60}$	-	-	-	-	21.3 ± 7.3
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	197.6

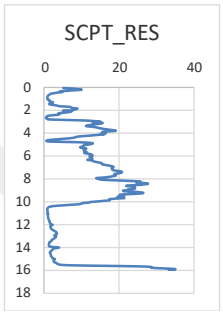
EVENT PARAMETERS

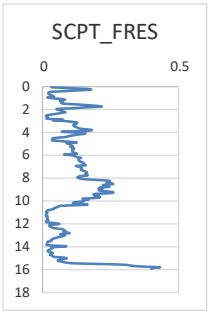
1976 Tangshan Earthquake
Magnitude: 7.50
Fault Type: right lateral str
Dip: 67-89.1

Chen et al. (1979) Bulter et al. (1979)
Yong-Ge et al (2017) Huang and Yeh (1997)
Z_{tor} (km): 0
Width (km): 15
R_{rup} (km): 16.9
R_{jb} (km): 16.9

ACCELERATION TIME HISTORY







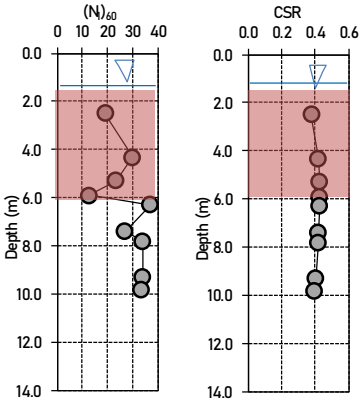


Table 15. Exploration data of Borehole 13.

(Caogezhuang, Fengnan County; area of intensity IX; water table: 1.05 m; soil liquefied; date: Sept. 1978)

Type of soil	Static cone penetration	Standard penetration test		Sampling data								
							Particle analysis					
		Depth	# of blow	Sampling depth	Water content	Vol. wt.	10–2	2-0.5	0.5-0.25	0.25-0.1	0.1-0.05	<0.05
Filled land		2.5	10	2.3				1	10	48	19	22
Clayey soil		4.3	19	4.1				1	6	74	15	4
Silty sand		5.3	16	5.0				7	22	57	11	3
Fine sand		5.9	9	5.7					12	36	45	7
Silty sand		6.3	27	6.0					5	40	49	6
Light loam		7.4	21	7.1					4	48	45	3
Fine sand		7.8	27	7.5				1	5	54	37	3
		9.3	29	9.0				2	21	65	8	4
		9.8	29	9.5					2	70	21	7

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
Silty Sand	*2.5*	*8.2*	*0.38*	*10*	*1.73*	*0.89*	*19.1*
Fine Sand (	*4.3*	*14.1*	*0.42*	*19*	*1.38*	*0.93*	*30.0*
Fine Sand (	*5.3*	*17.4*	*0.42*	*16*	*1.26*	*0.94*	*23.4*
Fine Sand (	*5.9*	*19.4*	*0.43*	*9*	*1.20*	*0.95*	*12.6*
Silty Sand	6.3	20.7	0.42	27	1.16	0.95	36.9
Silty Sand	7.4	24.3	0.42	21	1.08	0.96	26.9
Silty Sand	7.8	25.6	0.42	27	1.06	0.96	33.9
Silty Sand	9.3	30.5	0.40	29	0.97	0.97	33.9
Silty Sand	9.8	32.2	0.40	29	0.95	0.98	33.2
						Mean:	21.3
						St. Dev.	7.3

more critic layer

	read from graphs			table	
Depth (m)	**FC**	**D50**	**D10**	**0.1-0.05**	**<0.05**
2.3	*31.5*	*0.150*	*-*	*19.0*	*22.0*
4.1	*11.5*	*0.180*	*0.070*	*15.0*	*4.0*
5	*8.5*	*0.200*	*0.085*	*11.0*	*3.0*
5.7	*29.5*	*0.100*	*0.055*	*45.0*	*7.0*
6				49.0	6.0
7.1					3.0
7.5					3.0
9					4.0
9.5					7.0
	20.3	0.158	0.070		
	11.9	0.043	0.015		

Case number:	T17
Earthquake:	1976 Tangshan Earthquake
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Luannan_Zhuanglizhuang
References:	Liu (1985), Moss et al. (2009, 2011), NGL Project, Shibata and Teparasaka (1988), Zhou and Zhang (1979)
Nature of Failure:	No indication of surface evidence.
GPS LAT	39.5309
GPS LONG	118.614475
Liq. layer consist of:	Sand and SIty Sand
Geological Unit:	watershed of the Li Yun River (Quaternary) (Moss et al 2011)
Site Response Anlaysis:	No
Comments:	BORH_TYPE Mud rotary BORH_CREW Liu (1985) BORH_MECH semi-automatic BORH_STAR Aug-77 SAMP_TYPE Split-barrel Single bridge, push rods, thrust mechanism and reaction frame CPT available Energy of the hammer was assumed 60 % by the author. Zhou and Zhang (1979); Moss et al. (2009, 2011). From translation of the Zhou and Zhang (1979) report: "Generally one borehole was used to secure samples for determination of properties. Two to three holes were used for standard penetration tests. One to three holes were used for static cone penetration tests. Spacings between two neighboring boreholes were about 2 m." There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS). Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{rtr} range (m)	-	-	-	-	2.8 - 5.7
d_{rt} (m)	-	-	-	-	4.3
GWT (m)	-	-	-	-	2.8 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.5 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	19.9 ± 0.5
σ_v (kPa)	-	-	-	-	81.0 ± 9.8
σ_v' (kPa)	-	-	-	-	66.7 ± 5.2
a_{max} (g)	-	-	-	-	0.255 ± 0.051
r_d	-	-	-	-	0.99 ± 0.061
CSR	-	-	-	-	0.200 ± 0.043
M_w	-	-	-	-	7.50
D_{50}	-	-	-	-	0.197 ± 0.045
% Fines	-	-	-	-	10.7 ± 2.1
% PI	-	-	-	-	NAV
N	-	-	-	-	20.2 ± 2.8
C_R	-	-	-	-	0.93
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.23
C_N	-	-	-	-	1.23
$(N_1)_{60}$	-	-	-	-	28.5 ± 3.9
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	233.9

EVENT PARAMETERS

1976 Tangshan Earthquake — Chen et al. (1979) Bulter et al. (1979)
Magnitude: 7.50 — Yong-Ge et al (2017) Huang and Yeh (1997)
Fault Type: right lateral str — Z_{tor} (km): 0 — R_{rup} (km): 37.8
Dip: 67-89.1 — Width (km): 15 — R_{jb} (km): 37.8

ACCELERATION TIME HISTORY

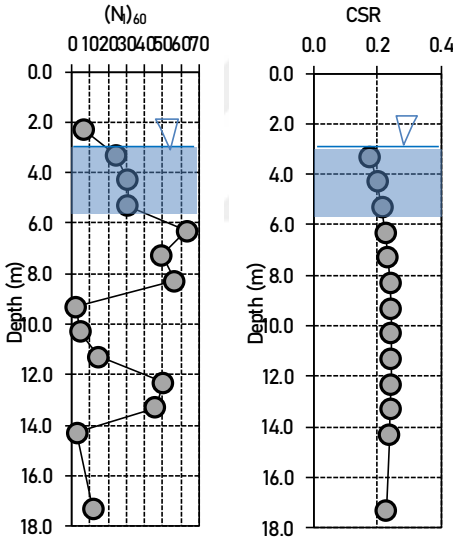


Table 19. Exploration data of Borehole 17.

(Zhuanglizhuang, Luan County; area of intensity VIII ; water table: 2.8 m; soil unliquefied; date: Aug. 1977)

Type of soil	Static cone penetration	Standard penetration test		Sampling data								
							Particle analysis					
	Depth	# of blow	Sampling depth	Water content	Vol. wt.	10–2	2-0.5	0.5-0.25	0.25-0.1	<0.1	0.1-0.05
Cultiv. soil											
Clayey soil											
	2.3	4	2.2	18.4	1.89			13.0	34.5	52.5	42.3
Fine sand	3.3	16	3.2	13.8	2.13		7.2	41.8	23.4	18.6	17.3
	4.3	22	4.1	18.3	2.10		3.6	28.2	57.4	10.8	
Silty sand	5.3	23	5.1	21.9	1.99			0.8	74.1	25.1	24.2
	6.3	50	6.1	20.4	2.09			10.5	67.4	22.1	21.1
Fine sand	7.25	41	7.1	20.0	2.09		15.1	73.8	8.0	3.1	
	8.3	49	8.1	23.2	2.02			0.6	35.4	64.0	40.0
Medium sand	9.3	2	11.1	21.4	2.01			0.8	63.2	36.0	30.1
	10.3	4	13.0	23.6	1.96			1.5	68.5	30.0	28.3
Silty sand	11.3	14									
	12.3	50									
Clayey soil	13.3	47									
	14.3	3									
Silty sand	17.3	13									
Clayey soil											

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
SC	2.3	7.5	NA	4	1.54	0.89	6.8	
S_fine	***3.3***	***10.8***	***0.179***	***16***	***1.33***	***0.91***	***24.0***	
SM	***4.3***	***14.1***	***0.201***	***22***	***1.23***	***0.93***	***30.9***	
SM	***5.3***	***17.4***	***0.216***	***23***	***1.15***	***0.94***	***30.6***	
S_fine	6.3	20.7	0.227	50	1.08	0.95	63.2	
S_medium	7.25	23.8	0.235	41	1.02	0.96	49.7	
SM	8.3	27.2	0.240	49	0.97	0.97	56.8	
SC	9.3	30.5	0.243	2	0.93	0.97	2.2	clayey
SC	10.3	33.8	0.245	4	0.89	0.98	4.3	clayey
SM	11.3	37.1	0.245	14	0.86	0.98	14.6	
SM	12.3	40.4	0.243	50	0.83	0.99	50.3	
SM	13.3	43.6	0.241	47	0.80	0.99	45.9	
SC	14.3	46.9	0.238	3	0.78	0.99	2.8	clayey
SC	17.3	56.8	0.230	13	0.71	0.99	11.4	clayey
						Mean:	28.5	
						St. Dev.	3.9	

read from graph

Depth (m)	FC	D50	D10	<0.1	0.1-0.05
2.2				52.5	42.3
3.2	***10.0***	***0.240***	***0.075***	***18.6***	***17.3***
4.1	***9.0***	***0.200***	***-***	***10.8***	
5.1	***13.0***	***0.150***	***0.070***	***25.1***	***24.2***
6.1				22.1	21.1
7.1				3.1	
8.1				64.0	40.0
11.1				36.0	30.1
13.0				30.0	28.3
	10.7	0.197	0.073		
	2.1	0.045	0.004		

Case number:	T18
Earthquake:	1976 Tangshan Earthquake
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Luannan_Wangguanzhai
References:	Liu (1985), Moss et al. (2009, 2011), NGL Project, Shibata and Teparasaka (1988), Zhou and Zhang (1979)
Nature of Failure:	Indication of surface evidence noted as exist.
GPS LAT	39.515177
GPS LONG	118.640152
Liq. layer consist of:	Sand
Geological Unit:	watershed of the Li Yun River (Quaternary) (Moss et al 2011)
Site Response Anlaysis:	No
Comments:	BORH_TYPE Mud rotary
	BORH_CREW Liu (1985)
	BORH_MECH semi-automatic
	BORH_STAR Aug-77
	SAMP_TYPE Split-barrel
	Single bridge, push rods, thrust mechanism and reaction frame
	CPT available
	Energy of the hammer was assumed 60 % by the author.
	There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS).
	Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crit} range (m)	-	-	-	-	9.7 - 10.5
d_{crt} (m)	-	-	-	-	10.1
GWT (m)	-	-	-	-	3.6 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.6 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	19.5 ± 0.5
σ_v (kPa)	-	-	-	-	190.2 ± 4.4
σ_v' (kPa)	-	-	-	-	126.3 ± 3.8
a_{max} (g)	-	-	-	-	0.242 ± 0.048
r_d	-	-	-	-	0.90 ± 0.127
CSR	-	-	-	-	0.213 ± 0.052
M_w	-	-	-	-	7.50
D_{50}	-	-	-	-	0.200 ± 0.050
% Fines	-	-	-	-	10.0 ± 8.6
% PI	-	-	-	-	NAV
N	-	-	-	-	14.9 ± 1.8
C_R	-	-	-	-	0.98
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_F	-	-	-	-	1.23
C_N	-	-	-	-	0.90
$(N_1)_{60}$	-	-	-	-	16.1 ± 2.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	217.2

EVENT PARAMETERS

1976 Tangshan Earthquake — Chen et al. (1979) Bulter et al. (1979)
Magnitude: 7.50 — Yong-Ge et al (2017) Huang and Yeh (1997)
Fault Type: right lateral str — Z_{tor} (km): 0 — R_{rup} (km): 40.6
Dip: 67-89.1 — Width (km): 15 — R_{jb} (km): 40.6

ACCELERATION TIME HISTORY

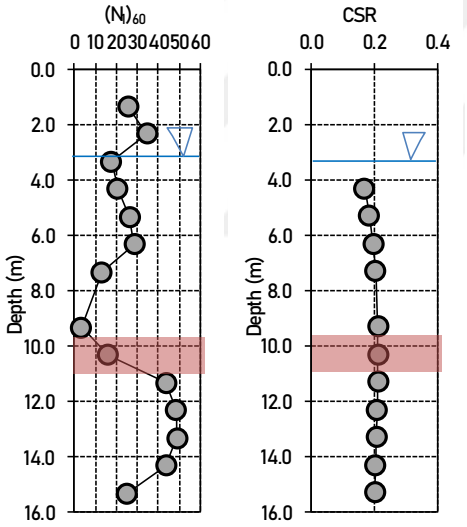


Table 20. Exploration data of Borehole 18.

(Wangguanzhai, Luannan County; area of intensity VIII; water table: 3.6 m; soil liquefied; date: Aug. 1977)

Type of soil	Static cone penetration	Standard penetration test		Sampling data									
							Particle analysis						
		Depth	# of blow	Sampling depth	Water content	Vol. wt.	10–2	2-0.5	0.5-0.25	0.25-0.1	<0.1	0.1-0.05
Light loam													
Silty sand		1.3	12	1.1	11.5	1.79		1.0	17.0	51.4	30.6	27.5
		2.3	20	2.1	6.1	1.77		4.8	59.5	33.0	2.7	
Medium sand		3.3	12	3.1	15.7	1.99		6.5	44.7	40.2	8.6	
		4.3	15	4.0	32.8	1.81						
Clayey soil		5.3	20	5.1	16.1	2.10		10.1	25.0	38.7	26.2	15.4
		6.3	23	6.1	16.0	2.10		8.0	33.0	44.0	15.0	12.8
Fine sand		7.3	11	7.0	21.4	2.04						
		9.3	3	8.0	26.8	1.95						
Light loam		10.3	15	10.1	20.9	2.00		2.0	18.4	62.6	7.0	12.6
		11.3	42	11.1	21.8	2.03			32.1	60.2	7.7	
Fine sand		12.3	48	12.1	18.9	2.01		13.2	43.0	34.7	9.1	
		13.3	50	13.1	22.7	2.00		51.7	45.9	2.8		
Medium sand		14.3	46	14.0	20.9	2.02		3.6	67.4	29.0	26.2	
		15.3	27	15.0				10.1	67.3	22.6		
Silty sand													

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		read from graph / table					
									Depth (m)	FC	D50	D10	<0.1	0.1-0.05
SM	1.3	4.3	NA	12	2.00	0.86	25.6	above GWT	1.1				30.6	27.5
S_medium	2.3	7.5	NA	20	1.58	0.89	34.8	above GWT	2.1				2.7	
S_medium	3.3	10.8	NA	12	1.32	0.91	17.8	above GWT	3.1				8.6	
SC	4.3	14.1	0.17	15	1.20	0.93	20.6	plastic?	4.0					
S_fine	***5.3***	***17.4***	***0.19***	***20***	***1.13***	***0.94***	***26.2***		***5.1***	***18.5***	***0.180***	***0.048***	***26.2***	***15.4***
S_fine	***6.3***	***20.7***	***0.20***	***23***	***1.07***	***0.95***	***28.8***		***6.1***	***8.6***	***0.200***	***0.080***	***15.0***	***12.8***
SC	7.3	24.0	0.21	11	1.01	0.96	13.2	plastic?	7.0					
SC	9.3	30.5	0.21	3	0.93	0.97	3.3	plastic?	8.0					
S_fine	10.3	33.8	0.21	15	0.89	0.98	16.1	more critical	***10.1***	***10.0***	***0.200***	***0.075***	***7.0***	***12.6***
S_fine	11.3	37.1	0.21	42	0.86	0.98	43.7		11.1				7.7	
S_medium	12.3	40.4	0.21	48	0.83	0.99	48.4		12.1				9.1	
S_medium	13.3	43.6	0.21	50	0.80	0.99	49.0		13.1					
SM	14.3	46.9	0.20	46	0.78	0.99	43.8		14.0				26.2	
SM	15.3	50.2	0.20	27	0.76	0.99	25.1		15.0					
						Mean:	16.1			10.0	0.20	0.08		
						St. Dev.	2.0	assigned		8.6	0.05	0.05		

Case number:	T19
Earthquake:	1976 Tangshan Earthquake
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Luannan_Jiangpao
References:	Liu (1985), Moss et al. (2009, 2011), NGL Project, Shibata and Teparasaka (1988), Zhou and Zhang (1979)
Nature of Failure:	Liquefaction documented by Zhou and Zhang (1979).
GPS LAT	39.54545
GPS LONG	118.70051
Liq. layer consist of:	Medium Sand (particle diameter:0.25mm-0.5mm), Fine Sand (particle diameter:0.075mm-0.25mm)
Geological Unit:	watershed of the Li Yun River (Quaternary) (Moss et al 2011)
Site Response Anlaysis:	No
Comments:	BORH_TYPE Mud rotary
	BORH_CREW Liu (1985)
	BORH_MECH semi-automatic
	BORH_STAR Aug-77
	SAMP_TYPE Split-barrel
	Single bridge, push rods, thrust mechanism and reaction frame
	CPT available
	Zhou and Zhang (1979); Moss et al. (2009, 2011). From translation of the Zhou and Zhang (1979) report: "Generally one borehole was used to secure samples for determination of properties. Two to three holes were used for standard penetration tests. One to three holes were used for static cone penetration tests. Spacings between two neighboring boreholes were about 2 m." There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS).
	Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{cr1c} range (m)	-	-	-	-	1.1 - 5.5
d_{cr1} (m)	-	-	-	-	3.3
GWT (m)	-	-	-	-	1.1 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.8 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	61.3 ± 13.9
σ_v' (kPa)	-	-	-	-	39.7 ± 6.8
a_{max} (g)	-	-	-	-	0.238 ± 0.048
r_d	-	-	-	-	0.94 ± 0.049
CSR	-	-	-	-	0.225 ± 0.049
M_w	-	-	-	-	7.50
D_{50}	-	-	-	-	0.232 ± 0.063
% Fines	-	-	-	-	3.9 ± 6.3
% PI	-	-	-	-	0
N	-	-	-	-	6.1 ± 0.8
C_R	-	-	-	-	0.91
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_F	-	-	-	-	1.23
C_N	-	-	-	-	1.60
$(N_1)_{60}$	-	-	-	-	10.9 ± 1.4
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	161.9

EVENT PARAMETERS

1976 Tangshan Earthquake — Chen et al. (1979) Bulter et al. (1979)
Magnitude: 7.50 — Yong-Ge et al (2017) Huang and Yeh (1997)
Fault Type: right lateral str — Z_{tor} (km): 0 — R_{rup} (km): 41.5
Dip: 67-89.1 — Width (km): 15 — R_{jb} (km): 41.5

ACCELERATION TIME HISTORY

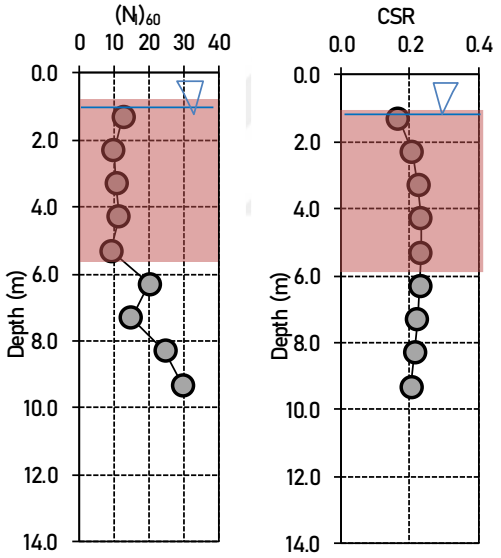


Table 21. Exploration data of Borehole 19.

(Jianpao, Luannan County; area of intensity VIII; water table: 1.1 m; soil liquefied; date: ug. 1977)

Type of soil	Static cone penetration	Standard penetration test		Sampling data								
							Particle analysis					
		Depth	# of blow	Sampling depth	Water content	Vol. wt.	10–2	2–0.5	0.5–0.25	0.25–0.1	<0.1	0.1–0.05
Cultiv. soil												
Fine sand		1.3	6	1.2	25.1	1.82			28.5	68.3	3.0	
		2.3	5	2.2	24.7	1.85		3.0	64.3	31.2	1.5	
Medium sand		3.3	6	3.1	25.4	1.89		1.9	70.0	27.1	1.0	
Fine sand		4.3	7	4.1	26.3	1.93			20.6	73.0	6.4	
Medium sand		5.3	6	5.2	30.0	1.89			23.6	51.8	24.6	20.3
with a small amount of gravel		6.3	14	6.0					37.1	60.5	2.4	
		7.3	11	7.2	23.2	1.98		3.6	72.5	21.6	2.3	
Clayey soil		8.3	19	8.0			7.5	12.9	52.8	19.4	7.4	
		9.3	24	9.0	22.7	2.01	3.7	21.4	59.4	14.0	1.5	

read from graph

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	Depth (m)	FC	D50	D10
S_fine	***1.3***	***4.3***	***0.166***	***6***	***2.00***	***0.86***	***12.8***	***1.2***	***0.0***	***0.200***	***0.120***
S_medium	***2.3***	***7.5***	***0.207***	***5***	***1.82***	***0.89***	***10.0***	***2.3***	***0.0***	***0.300***	***0.150***
S_medium	***3.3***	***10.8***	***0.225***	***6***	***1.60***	***0.91***	***10.8***	***3.3***	***0.0***	***0.300***	***0.150***
S_fine	***4.3***	***14.1***	***0.232***	***7***	***1.44***	***0.93***	***11.5***	***4.3***	***5.0***	***0.180***	***0.120***
S_fine	***5.3***	***17.4***	***0.233***	***6***	***1.32***	***0.94***	***9.2***	***5.3***	***14.5***	***0.180***	***0.070***
S_fine	6.3	20.7	0.229	14	1.23	0.95	20.2	6.3			
S_medium	7.3	24.0	0.223	11	1.16	0.96	15.1	7.3			
S_medium	8.3	27.2	0.214	19	1.09	0.97	24.8	8.3			
S_medium	9.3	30.5	0.206	24	1.04	0.97	29.9	9.3			
						Mean:	10.9		3.9	0.232	0.122
						St. Dev.	1.4		6.3	0.063	0.033

Case number:	T20
Earthquake:	1976 Tangshan Earthquake
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Luannan_Gaocaozhuang
References:	Liu (1985), Moss et al. (2009, 2011), NGL Project, Shibata and Teparasaka (1988), Zhou and Zhang (1979)
Nature of Failure:	No indication of surface evidence noted.
GPS LAT	39.472828
GPS LONG	118.62542
Liq. layer consist of:	SM/S_fine, Interaction Layer of fine sand and silty sand
Geological Unit:	watershed of the Li Yun River (Quaternary) (Moss et al 2011)
Site Response Anlaysis:	No
Comments:	BORH_TYPE Mud rotary
	BORH_CREW Liu (1985)
	BORH_MECH semi-automatic
	BORH_STAR Aug-77
	SAMP_TYPE Split-barrel
	Single bridge, push rods, thrust mechanism and reaction frame
	CPT available
	Energy of the hammer was assumed 60 % by the author.
	There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS).
	Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
Gravel Content (%):	5.9
CPT available:	Yes
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crit} range (m)	-	-	-	-	8.7 - 12.5
d_{cr1} (m)	-	-	-	-	10.6
GWT (m)	-	-	-	-	1.1 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	19.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.3 ± 0.5
σ_v (kPa)	-	-	-	-	215.3 ± 13.7
σ_v' (kPa)	-	-	-	-	121.9 ± 8.1
a_{max} (g)	-	-	-	-	0.231 ± 0.046
r_d	-	-	-	-	0.91 ± 0.132
CSR	-	-	-	-	0.241 ± 0.060
M_w	-	-	-	-	7.50
D_{50}	-	-	-	-	NAV
% Fines	-	-	-	-	31.0 ± 10.0
% PI	-	-	-	-	NAV
N	-	-	-	-	24.3 ± 2.1
C_R	-	-	-	-	0.98
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.23
C_N	-	-	-	-	0.91
$(N_1)_{60}$	-	-	-	-	26.8 ± 2.3
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	224.2

EVENT PARAMETERS

1976 Tangshan Earthquake — Chen et al. (1979) Bulter et al. (1979)

Magnitude: 7.50 — Yong-Ge et al (2017) Huang and Yeh (1997)

Fault Type: right lateral str — Z_{tor} (km): 0 — R_{rup} (km): 43.3

Dip: 67-89.1 — Width (km): 15 — R_{jb} (km): 43.3

ACCELERATION TIME HISTORY

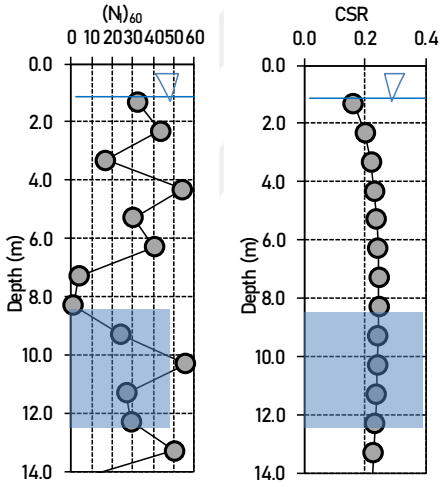
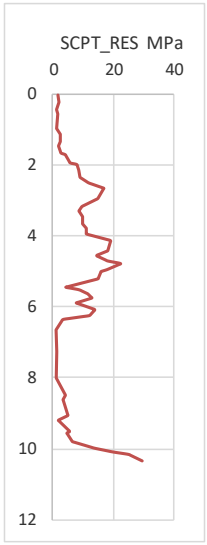


Table 22. Exploration data of Borehole 20.

(Gaocaozhuang, Luannan County; area of intensity VIII; water table: 1.1 m; soil unliquefied; date: Aug . 1977)

Type of soil	Static cone penetration	Standard penetration test		Sampling data									
							Particle analysis						
		Depth	# of blow	Sampling depth	Water content	Vol. wt.	10–2	2–0.5	0.5–0.25	0.25–0.1	<0.1	0.1–0.05
Cultiv. soil		1.3	15									
Fine sand		2.3	23	2.1	17.8	2.03		0.9	26.5	53.5	19.1	17.2
Clayey soil with silty sand interca-lation		3.3	10	4.1	18.6	2.09		3.1	29.0	52.9	15.0	13.7
Fine sand		4.3	35	5.1	18.8	2.07	2.07		36.0	56.3	7.7	
Silty sand		5.3	21	6.1	20.7	2.12			1.7	20.8	77.5	58.1
Clayey soil		6.3	30									
Silty and fine sand intercal.		7.3	3									
Clayey soil		8.3	1									
		9.3	21									
		10.3	50									
		11.3	25									
		12.3	28									
		13.3	50									
		14.3	3									



**depths of the soil type are wrong in this table. The original data given by the author is used.*

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
S_fine	1.3	4.3	0.16	15	2.00	0.86	32.0	CN>2
S_fine	2.3	7.5	0.20	23	1.71	0.89	43.2	
SM/SC	3.3	10.8	0.22	10	1.50	0.91	16.8	clayey
S_fine	4.3	14.1	0.23	35	1.35	0.93	54.1	
S_fine	5.3	17.4	0.24	21	1.24	0.94	30.2	
SM	6.3	20.7	0.24	30	1.15	0.95	40.5	
SC	7.3	24.0	0.25	3	1.08	0.96	3.8	clayey
SC	8.3	27.2	0.25	1	1.02	0.97	1.2	clayey
SM/S_fine	***9.3***	***30.5***	***0.24***	***21***	***0.97***	***0.97***	***24.4***	
SM/S_fine	***10.3***	***33.8***	***0.24***	***50***	***0.92***	***0.98***	***55.8***	outlier
SM/S_fine	***11.3***	***37.1***	***0.24***	***25***	***0.89***	***0.98***	***26.9***	more critical when
SM/S_fine	***12.3***	***40.4***	***0.23***	***28***	***0.85***	***0.99***	***29.0***	compared to upper
SM/S_fine	13.3	43.6	0.23	50	0.82	0.99	50.1	layers
C	14.3	46.9	0.22	3	0.79	0.99	2.9	
						Mean:	26.8	
						St. Dev.	2.3	

	Depth (m)	D50	D10	<0.1	0.1-0.05
S_fine	2.1			19.1	17.2
S_fine	4.1			15	13.7
S_fine	5.3			7.7	
SM	6.1			77.5	58.1
		-	-		
		-	-		
		-	-		
		-	-		
		-	-		
		-	-		

FC of the upper SM layer is about 50% and upper Fine sand layer is about 13 %. No FC info for the below layer.
The average FC of the upper layers 31% is used.

Case number:	T21
Earthquake:	1976 Tangshan Earthquake
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Luannan_Crematory
References:	Liu (1985), Moss et al. (2009, 2011), NGL Project, Shibata and Teparasaka (1988), Zhou and Zhang (1979)
Nature of Failure:	Non-liquefaction documented by Zhou and Zhang (1979).
GPS LAT	39.48637
GPS LONG	118.67279
Liq. layer consist of:	Sand and Silty Sand
Geological Unit:	watershed of the Li Yun River (Quaternary) (Moss et al 2011)
Site Response Anlaysis:	No
Comments:	BORH_TYPE Mud rotary BORH_CREW Liu (1985) BORH_MECH semi-automatic BORH_STAR Aug-77 SAMP_TYPE Split-barrel Single bridge, push rods, thrust mechanism and reaction frame CPT available Zhou and Zhang (1979); Moss et al. (2009, 2011). From translation of the Zhou and Zhang (1979) report: "Generally one borehole was used to secure samples for determination of properties. Two to three holes were used for standard penetration tests. One to three holes were used for static cone penetration tests. Spacings between two neighboring boreholes were about 2 m." There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS). Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
Gravel Content (%):	0
CPT available:	Yes
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	3.1 - 5.7
d_{crt} (m)	-	-	-	-	4.4
GWT (m)	-	-	-	-	3.1 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.5 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.3 ± 0.5
σ_v (kPa)	-	-	-	-	84.1 ± 9.0
σ_v' (kPa)	-	-	-	-	71.3 ± 4.9
a_{max} (g)	-	-	-	-	0.224 ± 0.045
r_d	-	-	-	-	0.99 ± 0.063
CSR	-	-	-	-	0.169 ± 0.036
M_w	-	-	-	-	7.50
D_{50}	-	-	-	-	0.233 ± 0.076
% Fines	-	-	-	-	13.0 ± 11.8
% PI	-	-	-	-	NAV
N	-	-	-	-	18.2 ± 2.7
C_R	-	-	-	-	0.93
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.23
C_N	-	-	-	-	1.19
$(N_1)_{60}$	-	-	-	-	24.8 ± 3.7
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	220.7

EVENT PARAMETERS

1976 Tangshan Earthquake — Chen et al. (1979) Bulter et al. (1979)
Magnitude: 7.50 — Yong-Ge et al (2017) Huang and Yeh (1997)
Fault Type: right lateral str — Z_{tor} (km): 0 — R_{rup} (km): 45.0
Dip: 67-89.1 — Width (km): 15 — R_{jb} (km): 45.0

ACCELERATION TIME HISTORY

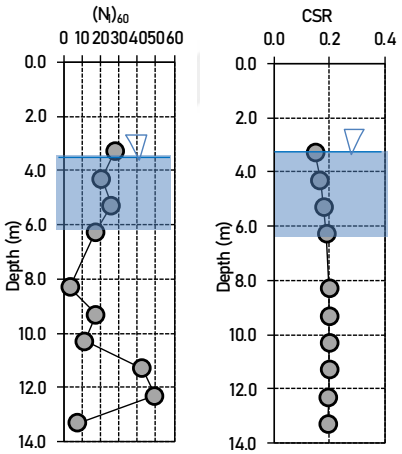


Table 23. Exploration data of Borehole 21.

(Crematorivum, Luannan County; area of intensity VIII; water table: 3.1 m; soil unliquefied; date: Aug. 1977)

Type of soil	Static cone penetration	Standard penetration test		Sampling data									
							Particle analysis						
		Depth	# of blow	Sampling depth	Water content	Vol. wt.	10–2	2-0.5	0.5-0.25	0.25-0.1	<0.1	0.1-0.05
Filled land												
Silty sand		3.3	19	2.1	13.4			4.7	24.8	43.5	27.0	17.1
		4.3	15	3.1	17.6	1.89		2.8	52.7	38.7	5.8	
Medium sand		5.3	20	4.1	19.1	2.06		0.4	49.6	43.4	6.6	
		6.3	14	5.1	16.4	2.08			8.4	46.9	44.7	36.3
Silty sand		8.3	3	6.1	22.0	2.01			0.6	36.0	63.4	52.6
		9.3	16	8.1	20.2	2.08						
Clayey soil and silty sand intercalation		10.3	11	10.1	16.5	2.15						
		11.3	42	11.1	18.8	2.03		7.1	31.2	45.5	16.2	12.8
		12.3	50	12.1	16.6	2.11		13.1	42.3	35.4	9.2	
Clayey soil		13.3	8									
Fine sand												
Clayey soil												

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
S_medium	***3.3***	***10.8***	***0.15***	***19***	***1.30***	***0.91***	***27.8***	
S_medium	***4.3***	***14.1***	***0.17***	***15***	***1.20***	***0.93***	***20.6***	
SM	***5.3***	***17.4***	***0.18***	***20***	***1.12***	***0.94***	***26.0***	
SM/SC	6.3	20.7	0.19	14	1.05	0.95	17.3	Interaction layer of silty sand and slight clay
S_fine	8.3	27.2	0.20	3	0.95	0.97	3.4	Clayey Soil
S_fine	9.3	30.5	0.20	16	0.91	0.97	17.5	Clayey Soil
S_fine	10.3	33.8	0.20	11	0.87	0.98	11.6	Clayey Soil
SC	11.3	37.1	0.20	42	0.84	0.98	42.8	
SC	12.3	40.4	0.20	50	0.81	0.99	49.3	
Clayey Soil	13.3	43.6	0.20	8	0.78	0.99	7.7	
						Mean:	24.8	
						St. Dev.	3.7	

	from table	from graph		
Depth (m)	**<0.1**	**FC**	**D50**	**D10**
2.1	27	20		
3.1	***5.8***	***5.8***	***0.300***	***0.120***
4.1	***6.6***	***6.6***	***0.250***	***0.110***
5.1	***44.7***	***26.6***	***0.150***	***0.550***
6.1	63.4	37.1	0.090	0.048
8.1		7.0		
10.1		5.0	-	-
11.1	16.2			
12.1	9.2			
		13.0	0.233	0.207
		11.8	0.076	0.251

Case number:	T22
Earthquake:	1976 Tangshan Earthquake
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Luannan_Xinzhuangzi
References:	Liu (1985), Moss et al. (2011), NGL Project
Nature of Failure:	Liquefaction documented by Zhou and Zhang (1979).
GPS LAT	39.46351
GPS LONG	118.65812
Liq. layer consist of:	Medium Sand (particle diameter:0.25mm-0.5mm)
Geological Unit:	watershed of the Li Yun River (Quaternary) (Moss et al 2011)
Site Response Anlaysis:	No
Comments:	BORH_TYPE Mud rotary
	BORH_CREW Liu (1985)
	BORH_MECH semi-automatic
	BORH_STAR Aug-77
	SAMP_TYPE Split-barrel
	Single bridge, push rods, thrust mechanism and reaction frame
	CPT available
	Zhou and Zhang (1979); Moss et al. (2009, 2011). From translation of the Zhou and Zhang (1979) report: "Generally one borehole was used to secure samples for determination of properties. Two to three holes were used for standard penetration tests. One to three holes were used for static cone penetration tests. Spacings between two neighboring boreholes were about 2 m." There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS).
	Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
Gravel Content (%):	0
CPT available:	Yes
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	7.7 - 11.2
d_{crt} (m)	-	-	-	-	9.5
GWT (m)	-	-	-	-	0.8 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.8 ± 0.5
σ_v (kPa)	-	-	-	-	178.5 ± 11.8
σ_v' (kPa)	-	-	-	-	93.5 ± 6.7
a_{max} (g)	-	-	-	-	0.220 ± 0.044
r_d	-	-	-	-	0.87 ± 0.120
CSR	-	-	-	-	0.238 ± 0.058
M_w	-	-	-	-	7.50
D_{50}	-	-	-	-	0.209 ± 0.061
% Fines	-	-	-	-	6.1 ± 4.1
% PI	-	-	-	-	0
N	-	-	-	-	19.6 ± 2.9
C_R	-	-	-	-	0.97
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.23
C_N	-	-	-	-	1.04
$(N_1)_{60}$	-	-	-	-	24.5 ± 3.6
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	201.6

EVENT PARAMETERS

1976 Tangshan Earthquake — Chen et al. (1979) Bulter et al. (1979)
Magnitude: 7.50 — Yong-Ge et al (2017) Huang and Yeh (1997)
Fault Type: right lateral str — Z_{tor} (km): 0 — R_{rup} (km): 46.0
Dip: 67-89.1 — Width (km): 15 — R_{jb} (km): 46.0

ACCELERATION TIME HISTORY

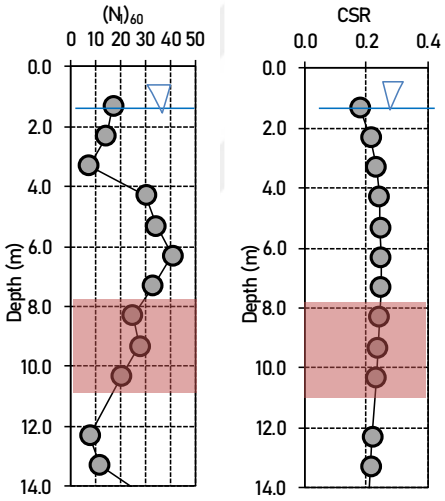


Table 24. Exploration data of Borehole 22.

(Xinzhuangzhi, Luannan County; area of intensity VIII; water table: 0.8 m; soil liquefied; date: Aug. 1977)

Type of soil	Static cone penetration	Standard penetration test		Sampling data								
							Particle analysis					
		Depth	# of blow	Sampling depth	Water content	Vol. wt.	>10	10–2	2-0.5	0.5-0.25	0.25-0.1	<0.1
Sandy clay		1.3	8	1.1	26.0	1.93				26.4	63.2	10.4
Fine sand		2.3	7	2.1	29.0	1.86						
		3.3	4	4.1	27.9	1.93				11.0	83.5	5.5
Clayey sand		4.3	18	5.1	27.5	1.90				8.7	84.3	7.0
		5.3	22	7.1	29.7	1.86				8.8	84.4	6.8
Fine sand		6.3	28	8.1	20.6	1.99		3.5	52.0	43.5	0.8	0.2
		7.3	24	9.1	24.4	1.93			13.5	72.9	10.8	2.8
		8.3	19	10.1	24.2	1.98	3.5	3.4	8.4	70.0	13.1	1.6
Coarse and		9.3	22	11.0					16.3	69.0	13.1	1.6
		10.3	17									
		12.3	7									
Medium sand		13.3	11									
		14.3	28									
Light loam												

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
S_fine	***1.3***	***4.3***	***0.178***	***8***	***2.00***	***0.86***	***17.1***	CN>2
SC	***2.3***	***7.5***	***0.214***	***7***	***1.88***	***0.89***	***14.4***	clayey
SC	3.3	10.8	0.232	4	1.64	0.91	7.4	clayey
S_fine	4.3	14.1	0.242	18	1.47	0.93	30.3	
S_fine	5.3	17.4	0.246	22	1.35	0.94	34.4	
S_fine	6.3	20.7	0.248	28	1.25	0.95	41.1	
S_fine	7.3	24.0	0.247	24	1.17	0.96	33.3	
S_coarse	***8.3***	***27.2***	***0.243***	***19***	***1.11***	***0.97***	***25.1***	
S_medium	***9.3***	***30.5***	***0.239***	***22***	***1.05***	***0.97***	***27.8***	
S_medium	***10.3***	***33.8***	***0.233***	***17***	***1.00***	***0.98***	***20.6***	
SC	12.3	40.4	0.220	7	0.92	0.99	7.9	clayey
SC	13.3	43.6	0.214	11	0.89	0.99	11.9	clayey
SC	14.3	46.9	0.208	28	0.86	0.99	29.4	clayey
						Mean:	24.5	
						St. Dev.	3.6	

	from graph			from table
Depth (m)	**FC**	**D50**	**D10**	**<0.1**
1.1				***10.4***
2.1				
4.1				5.5
5.1				7.0
7.1				6.8
8.1	***0.0***	***0.30***	***0.15***	***0.20***
9.1	***8.2***	***0.18***	***0.10***	***2.80***
10.1	***8.2***	***0.18***	***0.10***	***1.60***
11	***8.2***	***0.18***	***0.10***	***1.60***
	6.1	0.209	0.113	
	4.1	0.061	0.025	

Case number:	T23
Earthquake:	1976 Tangshan Earthquake
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Luannan_Weigezhuang
References:	Liu (1985), Moss et al. (2009, 2011), NGL Project, Shibata and Teparasaka (1988), Zhou and Zhang (1979)
Nature of Failure:	Indication of surface evidence noted as exist.
GPS LAT	39.420761
GPS LONG	118.652168
Liq. layer consist of:	Sand
Geological Unit:	watershed of the Li Yun River (Quaternary) (Moss et al 2011)
Site Response Anlaysis:	No
Comments:	BORH_TYPE Mud rotary
	BORH_CREW Liu (1985)
	BORH_MECH semi-automatic
	BORH_STAR Aug-77
	SAMP_TYPE Split-barrel
	Single bridge, push rods, thrust mechanism and reaction frame
	CPT available
	Energy of the hammer was assumed 60 % by the author.
	PI is assigned as 0 since FC=9 for the sand layer..
	There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS).
	Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
Gravel Content (%):	0
CPT available:	Yes
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	1.4 - 2.7
d_{crt} (m)	-	-	-	-	2.0
GWT (m)	-	-	-	-	1.4 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.0 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	37.2 ± 4.3
σ_v' (kPa)	-	-	-	-	30.6 ± 2.3
a_{max} (g)	-	-	-	-	0.209 ± 0.042
r_d	-	-	-	-	0.99 ± 0.032
CSR	-	-	-	-	0.163 ± 0.034
M_w	-	-	-	-	7.50
D_{50}	-	-	-	-	0.150 ± 0.050
% Fines	-	-	-	-	9.0 ± 2.1
% PI	-	-	-	-	NAV
N	-	-	-	-	10.7 ± 0.1
C_R	-	-	-	-	0.88
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.23
C_N	-	-	-	-	1.82
$(N_1)_{60}$	-	-	-	-	21.2 ± 0.1
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	188.1

EVENT PARAMETERS

1976 Tangshan Earthquake — Chen et al. (1979) Bulter et al. (1979)

Magnitude: 7.50 — Yong-Ge et al (2017) Huang and Yeh (1997)

Fault Type: right lateral str — Z_{tor} (km): 0 — R_{rup} (km): 49.2

Dip: 67-89.1 — Width (km): 15 — R_{jb} (km): 49.2

ACCELERATION TIME HISTORY

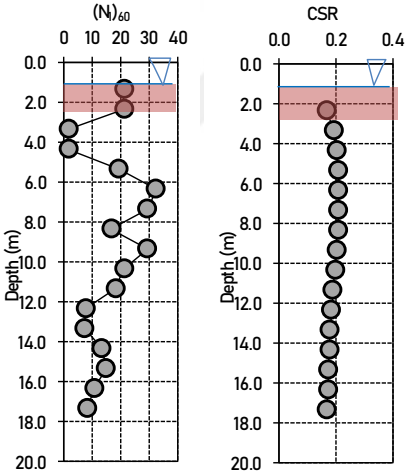


Table 25. Exploration data of Borehole 23.

(Weigezhuang, Luannan County; area of intensity VIII; water table: 1.35 m; soil liquefied; date: Aug. 1977)

Type of soil	Static cone penetration	Standard penetration test		Sampling data								
							Particle analysis					
		Depth	# of blow	Sampling depth	Water content	Vol. wt.	10–2	2-0.5	0.5-0.25	0.25-0.1	<0.1	0.1-0.05
Clayey soil												
		1.3	10	1.1	27.2	1.84			0.8	91.7	7.5	
Fine sand		2.3	11	2.1	27.8	1.91			5.1	84.5	10.4	
		3.3	1	3.1	38.7	1.87						
Clayey soil		4.3	1	4.1	30.5	1.89			0.3	79.5	20.2	15.8
		5.3	13	5.1	26.4	1.92				81.8	18.2	17.0
		6.3	23	6.1	24.2	1.97			45.9	51.8	2.3	
Fine sand		7.3	22	7.1	24.7	1.95			49.8	46.5	3.7	
		8.3	13	8.1	26.0	1.96			29.6	66.1	4.3	
		9.3	24	9.1	21.7	1.97		14.2	70.8	14.0	1.0	
		10.3	18	10.1	24.1	1.97		3.4	60.7	31.5	4.4	
Medium sand		11.3	16									
		12.3	7									
		13.3	7									
Clayey soil		14.3	13									
		15.3	15									
		16.3	11									
		17.3	9									

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
S_fine	***1.3***	***4.3***	***NA***	***10***	***2.00***	***0.86***	***21.3***	CN>2 but most likely same SPTN with the below on
S_fine	***2.3***	***7.5***	***0.17***	***11***	***1.75***	***0.89***	***21.1***	
SC	3.3	10.8	0.19	1	1.55	0.91	1.7	clayey
S_fine	4.3	14.1	0.20	1	1.41	0.93	1.6	clayey?
S_fine	***5.3***	***17.4***	***0.21***	***13***	***1.30***	***0.94***	***19.5***	
S_fine	***6.3***	***20.7***	***0.21***	***23***	***1.21***	***0.95***	***32.6***	
S_fine	***7.3***	***24.0***	***0.21***	***22***	***1.13***	***0.96***	***29.6***	
S_fine	***8.3***	***27.2***	***0.21***	***13***	***1.07***	***0.97***	***16.7***	denser layer when compared to upper shallow layer
S_medium	***9.3***	***30.5***	***0.20***	***24***	***1.02***	***0.97***	***29.5***	
S_medium	***10.3***	***33.8***	***0.20***	***18***	***0.98***	***0.98***	***21.2***	
SC	11.3	37.1	0.19	16	0.94	0.98	18.2	clayey
SC	12.3	40.4	0.19	7	0.90	0.99	7.7	clayey
SC	13.3	43.6	0.18	7	0.87	0.99	7.4	clayey
SC	14.3	46.9	0.18	13	0.84	0.99	13.4	clayey
SC	15.3	50.2	0.17	15	0.82	0.99	15.0	clayey
SC	16.3	53.5	0.17	11	0.79	0.99	10.7	clayey
SC	17.3	56.8	0.17	9	0.77	0.99	8.5	clayey
						Mean:	21.2	
						St. Dev.	0.1	

	from graph			from table
Depth (m)	**FC**	**D50**	**D10**	**<0.1**
1.1	***7.50***	***0.15***	***0.12***	***7.50***
2.1	***10.40***	***0.15***	***0.12***	***10.40***
3.1				-
4.1				20.2
5.1				18.2
6.1				2.3
7.1				3.7
8.1				4.3
9.1				1
10.1				4.4
	9.0	0.150	0.120	
	2.1	0.050	0.050	
	Smaller than 9%		assigned	

Case number:	T24
Earthquake:	1976 Tangshan Earthquake
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Baigezhuang_Farm6
References:	Liu (1985), Moss et al. (2009, 2011), NGL Project, Shibata and Teparasaka (1988), Zhou and Zhang (1979)
Nature of Failure:	Indication of surface evidence noted as exist.
GPS LAT	39.36771
GPS LONG	118.434506
Liq. layer consist of:	Silty Sand (SM)
Geological Unit:	watershed of the Li Yun River (Quaternary) (Moss et al 2011)
Site Response Anlaysis:	No
Comments:	BORH_TYPE Mud rotary
	BORH_CREW Liu (1985)
	BORH_MECH semi-automatic
	BORH_STAR Oct-78
	SAMP_TYPE Split-barrel
	Single bridge, push rods, thrust mechanism and reaction frame
	CPT available
	Energy of the hammer was assumed 60 % by the author.
	There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS).
	Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
$d_{crit.}$ range (m)	-	-	-	-	1.0 - 3.3
d_{crit} (m)	-	-	-	-	2.2
GWT (m)	-	-	-	-	1.0 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	42.6 ± 7.9
σ_v' (kPa)	-	-	-	-	31.3 ± 4.3
a_{max} (g)	-	-	-	-	0.287 ± 0.057
r_d	-	-	-	-	0.99 ± 0.034
CSR	-	-	-	-	0.251 ± 0.053
M_w	-	-	-	-	7.50
D_{50}	-	-	-	-	0.170 ± 0.050
% Fines	-	-	-	-	11.0 ± 8.9
% PI	-	-	-	-	NAV
N	-	-	-	-	11.3 ± 5.7
C_R	-	-	-	-	0.89
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_F	-	-	-	-	1.23
C_N	-	-	-	-	1.80
$(N_1)_{60}$	-	-	-	-	22.2 ± 11.2
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	201.6

EVENT PARAMETERS

1976 Tangshan Earthquake	Chen et al. (1979)	Bulter et al. (1979)
Magnitude: 7.50	Yong-Ge et al (2017)	Huang and Yeh (1997)
Fault Type: right lateral str	Z_{tor} (km): 0	R_{rup} (km): 32.0
Dip: 67-89.1	Width (km): 15	R_{jb} (km): 32.0

ACCELERATION TIME HISTORY

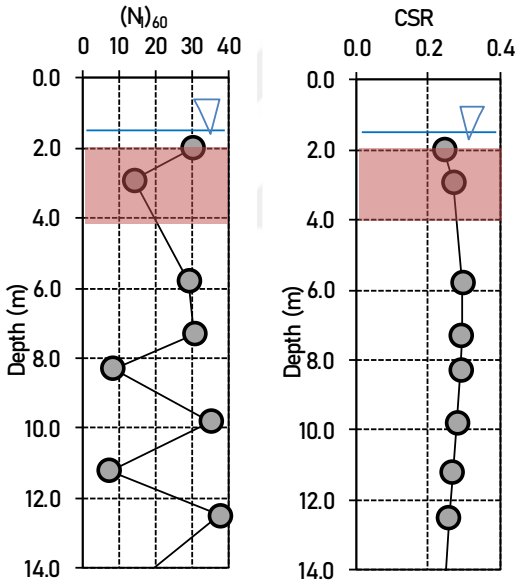


Table 26. Exploration data of Borehole 24.

(Baigezhuang Ranch, Branch No. 6; area of intensity VIII; water table: 1.0 m; soil liquefied; date: Oct. 1978)

Type of soil	Static cone penetration	Standard penetration test		Sampling data								
							Particle analysis					
		Depth	# of blow	Sampling depth	Water content	Vol. wt.	10–2	2-0.5	0.5-0.25	0.25-0.1	0.1-0.05	<0.05
Silty sand		2.0	15	2.6					10	79	11	
Silty clayey soil		2.9	8	5.5					35	59	6	
Silty sand		5.8	21	7.0					50	44	6	
Silty clayey soil		7.3	24	12.2					2	85	13	
Silty sand		8.3	7									
Silty clayey soil		9.8	31									
Silty sand		11.2	7									
Silty clayey soil		12.5	37									
		14.9	9									

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	Depth (m)	FC	D50	D10	0.05-0.1
SM	***2***	***6.6***	***0.25***	***15***	***1.85***	***0.88***	***30.2***	***2.6***	***-***			***11***
SM	***2.9***	***9.5***	***0.27***	***8***	***1.61***	***0.90***	***14.3***	***5.5***	***11.0***	***0.170***	***0.090***	***6***
SM	5.8	19.0	0.30	21	1.20	0.95	29.4	7	6.0	0.200	0.090	6
SM	7.3	24.0	0.29	24	1.08	0.96	30.7	12.2	6.0	0.240	0.100	13
SC	8.3	27.2	0.29	7	1.02	0.97	8.5					
SM	9.8	32.2	0.28	31	0.94	0.98	35.2					
SC	11.2	36.7	0.27	7	0.89	0.98	7.5					
SM	12.5	41.0	0.26	37	0.84	0.99	37.9					
SC	14.9	48.9	0.24	9	0.78	0.99	8.5					
						Mean:	22.2		11.0	0.2	0.1	
						St. Dev.	11.2		8.9	0.1	0.1	
									assigned			

Case number:	T30
Earthquake:	1976 Tangshan Earthquake
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Leting_Magezhuang
References:	Liu (1985), Moss et al. (2009, 2011), NGL Project, Shibata and Teparasaka (1988), Zhou and Zhang (1979)
Nature of Failure:	Non-liquefaction documented by Zhou and Zhang (1979).
GPS LAT	39.40985
GPS LONG	118.81973
Liq. layer consist of:	Fine Sand (particle diameter:0.075mm-0.25mm)
Geological Unit:	watershed of the Li Yun River (Quaternary) (Moss et al 2011)
Site Response Anlaysis:	No
Comments:	BORH_TYPE Mud rotary
	BORH_CREW Liu (1985)
	BORH_MECH semi-automatic
	BORH_STAR Aug-77
	SAMP_TYPE Split-barrel
	Single bridge, push rods, thrust mechanism and reaction frame
	CPT available
	Zhou and Zhang (1979); Moss et al. (2009, 2011). From translation of the Zhou and Zhang (1979) report: "Generally one borehole was used to secure samples for determination of properties. Two to three holes were used for standard penetration tests. One to three holes were used for static cone penetration tests. Spacings between two neighboring boreholes were about 2 m." There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS).
	Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
Gravel Content (%):	0
CPT available:	Yes
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	4.7 - 7.7
d_{crt} (m)	-	-	-	-	6.2
GWT (m)	-	-	-	-	2.5 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	19.0 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.7 ± 0.5
σ_v (kPa)	-	-	-	-	117.2 ± 9.6
σ_v' (kPa)	-	-	-	-	80.8 ± 5.0
a_{max} (g)	-	-	-	-	0.177 ± 0.035
r_d	-	-	-	-	0.97 ± 0.084
CSR	-	-	-	-	0.162 ± 0.036
M_w	-	-	-	-	7.50
D_{50}	-	-	-	-	0.267 ± 0.058
% Fines	-	-	-	-	2.0 ± 0.8
% PI	-	-	-	-	0
N	-	-	-	-	18.3 ± 1.6
C_R	-	-	-	-	0.95
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.23
C_N	-	-	-	-	1.12
$(N_1)_{60}$	-	-	-	-	24.0 ± 2.1
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	215.7

EVENT PARAMETERS

1976 Tangshan Earthquake — Chen et al. (1979) Bulter et al. (1979)

Magnitude: 7.50 — Yong-Ge et al (2017) Huang and Yeh (1997)

Fault Type: right lateral str — Z_{tor} (km): 0 — R_{rup} (km): 59.5

Dip: 67-89.1 — Width (km): 15 — R_{jb} (km): 59.5

ACCELERATION TIME HISTORY

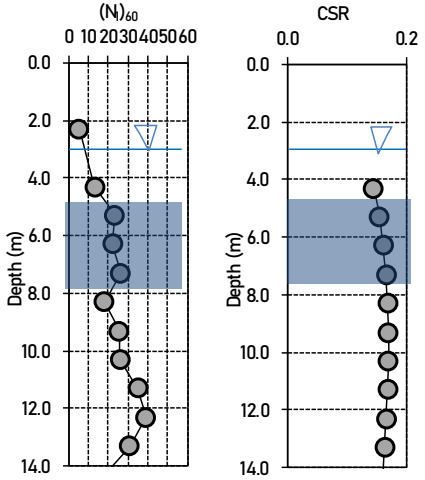


Table 32. Exploration data of Borehole 30.

(Magezhuang, Laoting County; area of intensity VII; water table: 2.5 m; soil unliquefied; date: Aug.. 1977)

		Type of soil	Static cone penetration	Standard penetration test		Sampling data								
									Particle analysis					
				Depth	# of blow	Sampling depth	Water content	Vol. wt.	10–2	2-0.5	0.5-0.25	0.25-0.1	<0.1	0.1-0.05
		Clayey soil		2.3	3									
				4.3	9									
		Fine sand		5.3	17	4.0		1.94			36.7	60.4	2.9	
		with inter-		6.3	17	5.0		1.91		0.2	61.6	35.8	2.4	
		calation		7.3	21	6.0		1.92		0.5	64.9	33.6	1.0	
				8.3	15	7.0		1.89			33.0	64.5	2.5	
				9.3	22	8.0				1.1	65.5	30.5	2.9	
		Medium sand		10.3	23	9.0		1.97		7.2	43.8	41.7	7.3	
				11.3	32	10		1.86		2.2	66.7	28.7	2.4	
		Medium sand		12.3	37	11.0		1.91			87.5	12.0	0.5	
		Light loam		13.3	30	12.4				14.9	75.8	8.5	0.8	
		with inter-		14.3	18	13.0			7.4	29.4	49.2	11.2	2.8	
		calation of		15.3	50	16.0						48.5	51.5	37.0
		silty sand		16.3	50	18.0					10.6	59.6	29.8	14.9
				17.3	28									
		Fine sand		18.3	31									

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
SC	2.3	7.5	NA	3	1.52	0.89	5.0
S_fine	4.3	14.1	0.14	9	1.26	0.93	13.0
S_fine	***5.3***	***17.4***	***0.15***	***17***	***1.18***	***0.94***	***23.3***
S_fine	***6.3***	***20.7***	***0.16***	***17***	***1.12***	***0.95***	***22.2***
S_fine	***7.3***	***24.0***	***0.17***	***21***	***1.06***	***0.96***	***26.3***
S_medium	8.3	27.2	0.17	15	1.01	0.97	18.1
S_medium	*9.3*	*30.5*	*0.17*	*22*	*0.97*	*0.97*	*25.6*
S_medium	10.3	*33.8*	*0.17*	*23*	*0.93*	*0.98*	*25.8*
S_medium	*11.3*	*37.1*	*0.17*	*32*	*0.90*	*0.98*	*34.8*
S_medium	12.3	*40.4*	*0.17*	*37*	*0.87*	*0.99*	*39.0*
S_medium	*13.3*	*43.6*	*0.16*	*30*	*0.84*	*0.99*	*30.7*
SC	14.3	46.9	0.16	18	0.81	0.99	17.9
SC	*15.3*	50.2	0.16	50	0.79	0.99	48.4
SC	16.3	53.5	0.16	50	0.77	0.99	47.2
SC	*17.3*	56.8	0.16	28	0.75	0.99	25.8
S_fine	18.3	60.0	0.16	31	0.73	1.00	27.9
						Mean:	24.0
						St. Dev.	2.1

outlier SC above has effect??

Depth (m)	FC (%)	D50	D10
4.0	2.9		
5.0	***2.4***	***0.300***	***0.120***
6.0	***1.0***	***0.300***	***0.140***
7.0	***2.5***	***0.200***	***0.140***
8.0	2.9		
9.0			
10.0			
11.0			
12.4			
13.0			
16.0			
18.0			
	1.967	0.267	0.133
	0.8	0.058	0.012

Case number:	T32
Earthquake:	1976 Tangshan Earthquake
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Leting_Caigezhuang
References:	Liu (1985), Moss et al. (2009, 2011), NGL Project, Shibata and Teparasaka (1988), Zhou and Zhang (1979)
Nature of Failure:	Liquefaction documented by Zhou and Zhang (1979).
GPS LAT	39.40454
GPS LONG	118.8913
Liq. layer consist of:	Medium Sand (particle diameter:0.25mm-0.5mm)
Geological Unit:	watershed of the Li Yun River (Quaternary) (Moss et al 2011)
Site Response Anlaysis:	No
Comments:	BORH_TYPE Mud rotary BORH_CREW Liu (1985) BORH_MECH semi-automatic BORH_STAR Aug-77 SAMP_TYPE Split-barrel Single bridge, push rods, thrust mechanism and reaction frame CPT available Zhou and Zhang (1979); Moss et al. (2009, 2011). From translation of the Zhou and Zhang (1979) report: "Generally one borehole was used to secure samples for determination of properties. Two to three holes were used for standard penetration tests. One to three holes were used for static cone penetration tests. Spacings between two neighboring boreholes were about 2 m." There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS). Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
Gravel Content (%):	0
CPT available:	Yes
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.6 - 8.5
d_{crt} (m)	-	-	-	-	5.6
GWT (m)	-	-	-	-	2.3 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	19.5 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	19.1 ± 0.5
σ_v (kPa)	-	-	-	-	107.3 ± 18.9
σ_v' (kPa)	-	-	-	-	75.4 ± 9.4
a_{max} (g)	-	-	-	-	0.165 ± 0.033
r_d	-	-	-	-	0.98 ± 0.076
CSR	-	-	-	-	0.150 ± 0.033
M_w	-	-	-	-	7.50
D_{50}	-	-	-	-	0.320 ± 0.142
% Fines	-	-	-	-	1.6 ± 0.5
% PI	-	-	-	-	0
N	-	-	-	-	15.0 ± 3.7
C_R	-	-	-	-	0.94
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.23
C_N	-	-	-	-	1.16
$(N_1)_{60}$	-	-	-	-	20.2 ± 5.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	225.8

EVENT PARAMETERS

1976 Tangshan Earthquake — Chen et al. (1979) Bulter et al. (1979)
Magnitude: 7.50 — Yong-Ge et al (2017) Huang and Yeh (1997)
Fault Type: right lateral str — Z_{tor} (km): 0 — R_{rup} (km): 64.2
Dip: 67-89.1 — Width (km): 15 — R_{jb} (km): 64.2

ACCELERATION TIME HISTORY

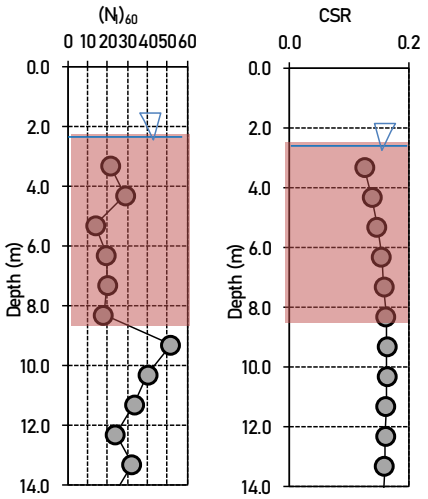
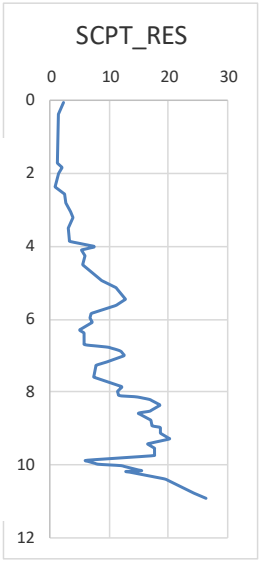


Table 34. Exploration data of Borehole 32.

(Caigezhuang, Laoting County; area of intensity VIII; water table: 2.3 m; soil liquefied; date: Aug. 1977)

Type of soil	Static cone penetration	Standard penetration test		Sampling data								
							Particle analysis					
		Depth	# of blow	Sampling depth	Water content	Vol. wt.	10~2	2-0.5	0.5-0.25	0.25-0.1	<0.1	0.1-0.05
Clayey soil		3.3	14	2.1	30.6	1.99			1.7	63.2	35.1	26.0
		4.3	20	3.1	29.5	1.89			52.4	45.4	2.2	
		5.3	10	4.1	26.3	1.95			38.4	59.7	1.9	
		6.3	15	5.2	25.2	1.96			51.0	47.1	1.9	
		7.3	16	6.1	26.4	1.97		0.2	71.5	27.1	1.2	
Medium sand		8.3	15	7.1	28.7	1.93		1.7	62.0	35.4	0.9	
		9.3	45	8.2	27.9	1.93		59.5	39.3	1.2		
		10.3	36	9.1	24.0	2.00			62.0	37.1	0.9	
		11.3	31	10.1	23.9	1.96		1.0	64.4	33.6	1.0	
Clayey soil		12.3	23	11.1	26.3	2.0		1.6	68.9	29.1	0.4	
		13.3	32	12.1	26.5	1.94		0.4	58.0	40.4	1.2	
		14.3	24	17.2					0.6	88.8	10.6	
Fine sand		15.3	25	18.2				4.5	50.9	36.8	7.8	
		17.3	50	19.2			2.9	26.5	44.2	21.2	5.2	
Medium sand		18.3	50									
		19.3	50									



	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
S_medium	*3.3*	*10.8*	*0.13*	*14*	*1.37*	*0.91*	*21.5*
S_medium	*4.3*	*14.1*	*0.14*	*20*	*1.26*	*0.93*	*28.9*
S_medium	*5.3*	*17.4*	*0.15*	*10*	*1.18*	*0.94*	*13.7*
S_medium	*6.3*	*20.7*	*0.15*	*15*	*1.11*	*0.95*	*19.5*
S_medium	*7.3*	*24.0*	*0.16*	*16*	*1.05*	*0.96*	*19.9*
S_medium	*8.3*	*27.2*	*0.16*	*15*	*1.00*	*0.97*	*18.0*
S_medium	9.3	30.5	0.16	45	0.96	0.97	51.8
S_medium	10.3	33.8	0.16	36	0.92	0.98	40.0
S_medium	11.3	37.1	0.16	31	0.89	0.98	33.3
S_medium	12.3	40.4	0.16	23	0.86	0.99	24.0
S_medium	13.3	43.6	0.16	32	0.83	0.99	32.3
	14.3	46.9	0.16	24	0.80	0.99	23.6
	15.3	50.2	0.16	25	0.78	0.99	23.9
	17.3	56.8	0.15	50	0.74	0.99	45.4
	18.3	60.0	0.15	50	0.72	1.00	44.4
	19.3	63.3	0.15	50	0.71	1.00	43.4
						Mean:	20.2
						St. Dev.	5.0

Depth (m)	FC (%)	D50	D10	<0.1
2.1	20.0	0.150		35.1
3.1	*2.2*	*0.250*		*2.2*
4.1	*1.9*	*0.210*		*1.9*
5.2	*1.9*	*0.250*		*1.9*
6.1	*1.2*	*0.320*		*1.2*
7.1	*0.9*	*0.290*		*0.9*
8.2	*1.2*	*0.600*		
9.1				0.9
10.1				1.0
11.1				0.4
12.1				1.2
17.2				10.6
18.2				7.8
19.2				5.2
	1.6	0.320		
	0.5	0.142		

Case number:	T33
Earthquake:	1976 Tangshan Earthquake
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Leting_Liubianzhuang
References:	Liu (1985), Moss et al. (2009, 2011), NGL Project, Shibata and Teparasaka (1988), Zhou and Zhang (1979)
Nature of Failure:	Indication of surface evidence noted as exist.
GPS LAT	39.421007
GPS LONG	118.924505
Liq. layer consist of:	Sand medium, particle diameter:0.25mm-0.5mm
Geological Unit:	watershed of the Li Yun River (Quaternary) (Moss et al 2011)
Site Response Anlaysis:	No
Comments:	BORH_TYPE Mud rotary
	BORH_CREW Liu (1985)
	BORH_MECH semi-automatic
	BORH_STAR Aug-77
	SAMP_TYPE Split-barrel
	Single bridge, push rods, thrust mechanism and reaction frame
	CPT available
	Energy of the hammer was assumed 60 % by the author.
	PI is assigned as 0 since FC<5.
	There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS).
	Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crit} range (m)	-	-	-	-	4.7 - 13.7
d_{rel} (m)	-	-	-	-	9.2
GWT (m)	-	-	-	-	2.3 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.5 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	19.0 ± 0.5
σ_v (kPa)	-	-	-	-	174.3 ± 28.8
σ_v' (kPa)	-	-	-	-	106.5 ± 14.3
a_{max} (g)	-	-	-	-	0.163 ± 0.033
r_d	-	-	-	-	0.88 ± 0.117
CSR	-	-	-	-	0.152 ± 0.037
M_w	-	-	-	-	7.50
D_{50}	-	-	-	-	0.313 ± 0.026
% Fines	-	-	-	-	3.6 ± 2.1
% PI	-	-	-	-	0
N	-	-	-	-	17.8 ± 2.5
C_R	-	-	-	-	0.97
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.23
C_N	-	-	-	-	0.98
$(N_1)_{60}$	-	-	-	-	20.8 ± 2.9
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	200.7

EVENT PARAMETERS

1976 Tangshan Earthquake		Chen et al. (1979)	Bulter et al. (1979)
Magnitude: 7.50		Yong-Ge et al (2017)	Huang and Yeh (1997)
Fault Type: right lateral str	Z_{tor} (km): 0		R_{rup} (km): 65.3
Dip: 67-89.1	Width (km): 15		R_{jb} (km): 65.3

ACCELERATION TIME HISTORY

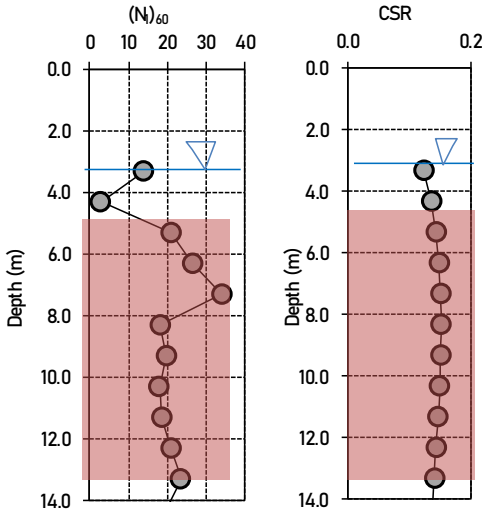
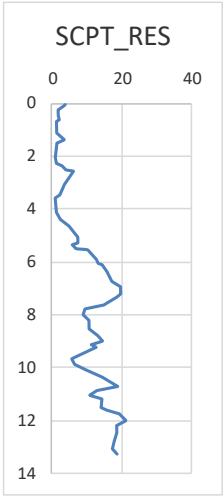


Table 35. Exploration data of Borehole 33.

(Liubianzhuang, Laoting County; area of intensity VIII; water table: 2.3 m; soil liquefied; date: Aug. 1977)

Type of soil	Static cone penetration	Standard penetration test		Sampling data								
							Particle analysis					
		Depth	# of blow	Sampling depth	Water content	Vol. wt	10–2	2-0.5	0.5-0.25	0.25-0.1	<0.1	0.1-0.05
Clayey soil		3.3	9	2.1	32.6	1.89						
		4.3	2	3.1	30.6	1.89			1.3	80.5	18.2	
Fine sand		5.3	15	4.3	32.6	1.87			0.6	25.0	74.4	
Clayey soil		6.3	20	5.2	25.2	1.93		1.1	66.5	31.7	0.7	
with an		7.3	27	6.1	24.1	2.01		1.0	79.0	19.5	0.5	
intercalation		8.3	15	7.1	19.7	2.04	4.8	15.3	65.7	12.2	2.0	
of fine sand		9.3	17	8.1				11.7	46.8	36.7	4.8	
		10.3	16	9.1	23.3			2.5	46.7	46.7	4.1	
		11.3	17	10.2	22.5		7.2	18.5	57.7	11.2	5.5	
		12.3	20	11.0				18.2	61.3	16.1	4.4	
Medium sand		13.3	23	12.0				15.8	56.2	22.0	5.5	
		14.3	20									
Clayey soil												



	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
S_fine	3.3	10.8	0.12	9	1.40	0.91	14.1	
SC/S	4.3	14.1	0.14	2	1.29	0.93	2.9	
S_medium	***5.3***	***17.4***	***0.14***	***15***	***1.20***	***0.94***	***20.9***	
S_medium	***6.3***	***20.7***	***0.15***	***20***	***1.13***	***0.95***	***26.5***	
S_medium	7.3	24.0	0.15	27	1.07	0.96	34.2	outlier
S_medium	***8.3***	***27.2***	***0.15***	***15***	***1.02***	***0.97***	***18.2***	
S_medium	***9.3***	***30.5***	***0.15***	***17***	***0.97***	***0.97***	***19.9***	
S_medium	***10.3***	***33.8***	***0.15***	***16***	***0.93***	***0.98***	***18.0***	
S_medium	***11.3***	***37.1***	***0.15***	***17***	***0.90***	***0.98***	***18.5***	
S_medium	***12.3***	***40.4***	***0.14***	***20***	***0.87***	***0.99***	***21.1***	
S_medium	***13.3***	***43.6***	***0.14***	***23***	***0.84***	***0.99***	***23.5***	
SC	14.3	46.9	0.14	20	0.81	0.99	19.9	
						Mean:	20.8	
						St. Dev.	2.9	

Depth (m)	FC (%)	D50	D10	GRAT_ID	<0.1
3.1					18.2
4.3					74.4
5.2	***0.7***	***0.300***		***3.0***	***0.7***
6.1	***0.5***	***0.330***		***4.0***	***0.5***
7.1	2.0	0.400		5.0	2.0
8.1	***4.8***	***0.300***		***6.0***	***4.8***
9.1	***4.1***	***0.270***		***7.0***	***4.1***
10.2	***5.5***	***0.350***		***8.0***	***5.5***
11	***4.4***	***0.320***		***9.0***	***4.4***
12	***5.5***	***0.320***		***10.0***	***5.5***
	3.6	0.313			
	2.1	0.026			

Case number:	T36
Earthquake:	1976 Tangshan Earthquake
Magnitude:	7.6 (Mw) USGS Centennial Earthquake Catalog
Location:	Leting_Maozhuang
References:	Liu (1985), Moss et al. (2009, 2011), NGL Project, Shibata and Teparasaka (1988), Zhou and Zhang (1979)
Nature of Failure:	Non-liquefaction documented by Zhou and Zhang (1979).
GPS LAT	39.42161
GPS LONG	118.97049
Liq. layer consist of:	Fine Sand (particle diameter: 0.075mm-0.25mm)
Geological Unit:	watershed of the Li Yun River (Quaternary) (Moss et al 2011)
Site Response Anlaysis:	No
Comments:	BORH_TYPE Mud rotary
	BORH_CREW Liu (1985)
	BORH_MECH semi-automatic
	BORH_STAR Aug-77
	SAMP_TYPE Split-barrel
	Single bridge, push rods, thrust mechanism and reaction frame
	CPT available
	Zhou and Zhang (1979); Moss et al. (2009, 2011). From translation of the Zhou and Zhang (1979) report: "Generally one borehole was used to secure samples for determination of properties. Two to three holes were used for standard penetration tests. One to three holes were used for static cone penetration tests. Spacings between two neighboring boreholes were about 2 m." There are 7 SMS that recorded the 1976 Tangshan EQ. SMS located at Beijing Hotel Basement (Rjb=148 km) recorded 0.059 g (Geo. mean of the two comp.) is used to estimate PGA at the site. A scale factor is calculated by considering Rjb and Vs30m of the SMS and site using ASK 2014. PGA is determined by multiplying the PGA of the SMS by the scale factor. Mw is updated as 7.5 (USGS).
	Liu (1985) described a semi-automatic system for the SPT performed at sites T1-T36. Hammer energy is taken as 74% which is calculated as the average value of the safety (66%) and automatic (82%) hammers adopted in this study.
Gravel Content (%):	0
CPT available:	Yes
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	5.5 - 7.5
d_{crt} (m)	-	-	-	-	6.5
GWT (m)	-	-	-	-	2.3 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.8 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.7 ± 0.5
σ_v (kPa)	-	-	-	-	119.8 ± 6.7
σ_v' (kPa)	-	-	-	-	78.5 ± 3.8
a_{max} (g)	-	-	-	-	0.156 ± 0.031
r_d	-	-	-	-	0.93 ± 0.087
CSR	-	-	-	-	0.144 ± 0.032
M_w	-	-	-	-	7.50
D_{50}	-	-	-	-	0.225 ± 0.021
% Fines	-	-	-	-	2.5 ± 0.5
% PI	-	-	-	-	0
N	-	-	-	-	10.4 ± 1.0
C_R	-	-	-	-	0.95
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.23
C_N	-	-	-	-	1.14
$(N_1)_{60}$	-	-	-	-	13.9 ± 1.4
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	194.6

EVENT PARAMETERS

1976 Tangshan Earthquake — Chen et al. (1979) Bulter et al. (1979)
Magnitude: 7.50 — Yong-Ge et al (2017) Huang and Yeh (1997)
Fault Type: right lateral str — Z_{tor} (km): 0 — R_{rup} (km): 68.1
Dip: 67-89.1 — Width (km): 15 — R_{jb} (km): 68.1

ACCELERATION TIME HISTORY

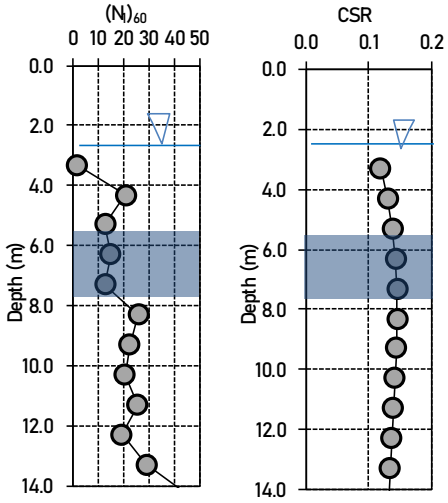
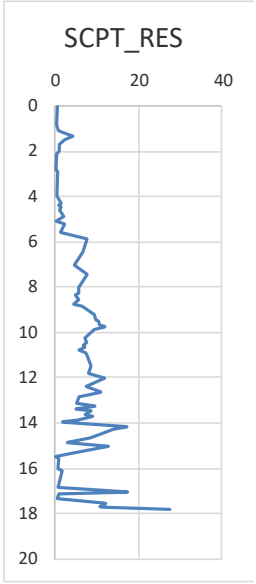


Table 38. Exploration data of Borehole 36.

(Maozhuang Commune, Laoting County; area of intensity VIII; water table: 2.3 m; soil unliquefied; date: Aug. 1977)

Type of soil	Static cone penetration	Standard penetration test		Sampling data								
							Particle analysis					
		Depth	# of blow	Sampling depth	Water content	Vol. wt.	10–2	2–0.5	0.5–0.25	0.25–0.1	<0.1	0.1–0.05
		3.3	1	2.0		1.81						
		4.3	14	4.1	26.0	2.00		0.1	19.6	78.0	2.3	
Clayey soil		5.3	9	5.1	28.6	1.91			33.7	60.7	5.6	
		6.3	11	6.1	28.8	1.93		0.1	47.6	49.5	2.8	
		7.3	10	7.1	26.0	1.82		0.4	40.5	57.0	2.1	
Fine sand		8.3	21	8.1	27.4	1.89		0.5	61.6	36.5	1.4	
		9.3	19	9.0				23.1	38.4	32.5	6.0	1
Medium sand		10.3	18	10				16.8	33.6	43.2	6.4	
		11.3	23	12.0					2.9	60.5	28.1	8.5
		12.3	18	13.0			4.9	16.2	40.7	36.0	2.2	
Clayey soil with a thin intercalation of silty sand		13.3	28	14.0				13.8	47.7	31.4	7.1	
		14.3	45									
		15.3	7									
Fine sand												



	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		Depth (m)	FC (%)	D50	D10
SC	3.3	10.8	0.12	1	1.43	0.91	1.6	Clayey soil	2.0			
SC	4.3	14.1	0.13	14	1.31	0.93	21.0	Clayey soil	4.1			
SC	5.3	17.4	0.14	9	1.22	0.94	12.8	Clayey soil	5.1			
S_fine	6.3	20.7	0.14	11	1.15	0.95	14.9		6.1	2.8	0.240	0.120
S_fine	7.3	24.0	0.15	10	1.09	0.96	12.9		7.1	2.1	0.210	0.120
S_fine	8.3	27.2	0.15	21	1.04	0.97	26.0		8.1			
S_fine	9.3	30.5	0.14	19	0.99	0.97	22.6		9.0			
S_medium	10.3	33.8	0.14	18	0.95	0.98	20.6		10.0			
S_medium	11.3	37.1	0.14	23	0.91	0.98	25.5		12.0			
SC	12.3	40.4	0.14	18	0.88	0.99	19.3	Clayey soil	13.0			
SC	13.3	43.6	0.13	28	0.85	0.99	29.1	Clayey soil	14.0			
SC	14.3	46.9	0.13	45	0.83	0.99	45.5	Clayey soil				
SC	15.3	50.2	0.13	7	0.80	0.99	6.9	Clayey soil				
						Mean:	13.9			2.5	0.225	0.120
						St. Dev.	1.4			0.5	0.021	0.000

Case number:	37
Earthquake:	1977 Argentina
Magnitude:	7.4 (Mw) USGS Centennial Earthquake Catalog
Location:	San Juan B-1
References:	Idriss et al. (1979), Fear et al. (1995), Youd and Keefer (1994), Cetin (2000), Cetin et al (2004, 2018), NGL Project
Nature of Failure:	At several locations, the surface manifestation of liquefaction has been
GPS LAT	-31.6466 observed in association with abandoned fluvial deposits
GPS LONG	-68.2886
Liq. layer consist of:	med. dense silty sand
Geological Unit:	Alluvial deposits in the Rio San Juan floodplain, evidence of buried paleochannels in the area
Site Response Anlaysis:	No
Comments:	Cetin (2000) "The boreholes were drilled at Dept. of Caucete in the Barrio Justo P. Castro, newly constructed single family stucco homes. The borehole is located northeast of Crevasse. Ground response analyses were performed based on generalized soil profile: 0-700 ft : sand with lenses of silt and clay 700-1400 ft : gravel >1400 ft : limestone, claystone and sand stone Shear moduli values were estimated from SPT values; Borehole1,3&6 and 2,4&5 were grouped for the analyses. The drainage was prevented at the surface by the clay layer. PGA record was made available by INPRES in San Juan and corrected by USGS. A PGA of 0.187 g was recorded at the seismographic station which was located within 10 km of the study area. Average unit weight of soil was estimated as 110 pcf. Dry Unit weight was reported in the range of 86-93 pcf for silty clay (CL) layer in Table B-1. Estimated rod energy was 45%."
	N values were back calculated from N_1 plots by using above summarized info."
	The orginial reference of Idriss et al (1979) could not be obtained. Youd and Keefer (1994) has provided limited SPT-N values and these values were already corrected for overburden stress hence they are N1. Cetin et al (2004, 2018) has used this limited data and back calculated raw SPT-N values from N1. NGL Project has acessed Idriss et al (1979) and provided the full borehole data. Critical layer and corresponding SPT-N values were found to be the same. But this study has used the entire data provided by NGL. Vs12m is updated based on Vs-SPTN correlations since the entire borehole data is now obtained.
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	7.9 - 8.5		7.9 - 8.5	7.9 - 8.5
d_{crt} (m)	8.2	8.2	8.2	8.2	8.2
GWT (m)	4.57	4.6 ± 0.3	4.6	4.6 ± 0.1	4.6 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	17.3 ± 0.5	18.1 ± 0.5
γ_{sat} (kN/m^3)	-	17.3 ± 0.6	-	19.6 ± 0.5	18.9 ± 0.5
σ_v (kPa)	142.6	131.8 ± 4.1	142.4	151.2 ± 3.4	151.9 ± 3.4
σ_v' (kPa)	106.6	95.8 ± 4.4	106.3	115.3 ± 3.1	116.0 ± 3.1
a_{max} (g)	0.2	0.200 ± 0.015	0.2	0.200 ± 0.030	0.200 ± 0.040
r_d	0.94	0.78 ± 0.107	0.92	0.86 ± 0.107	0.81 ± 0.107
CSR	0.165	0.139 ± 0.022	0.16	0.146 ± 0.029	0.139 ± 0.033
M_w	7.40	7.40	7.50	7.50	7.40
D_{50}	0.15	0.140 ± 0.050	-	0.140 ± 0.050	0.140 ± 0.050
% Fines	20	20.0 ± 3.0	20	20.0 ± 2.0	20.0 ± 8.6
% PI	-	-	-	-	NAV
N	9	9.0 ± 2.0	9	9.0 ± 2.9	9.0 ± 2.7
C_R	-	0.98	0.95	0.98	0.96
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	0.75	0.75	0.75	0.75	0.82
C_N	0.95	1.00	0.97	0.94	0.94
$(N_1)_{60}$	6	6.7 ± 1.5	6.3	6.2 ± 2.0	6.6 ± 2.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	185.9	-	185.9	175.3

EVENT PARAMETERS

1977 Argentina — foot wall site

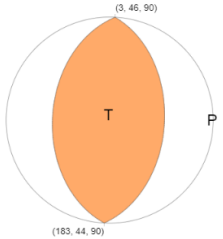
Magnitude: 7.40 — Langer and Hartzell 1996, USGS — dip moderately to the east

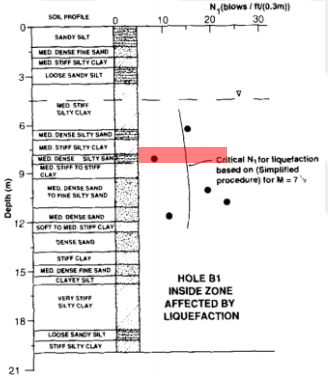
Fault Type: reverse faults — Z_{tor} (km): 1 — R_{rup} (km): 24.8

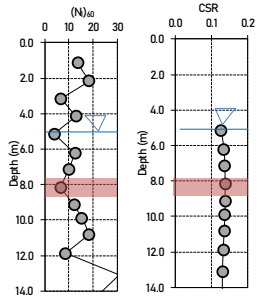
Dip: 44 — Width (km): 50 — R_{jb} (km): 24.8

https://earthquake.usgs.gov/earthquakes/eventpage/usp0000rp1/executive

https://earthquake.usgs.gov/earthquakes/eventpage/usp0000rp1/map







NGL database has another borehole data from the log given in Appendix A of Idriss et al. (1979). That paper could not be found. The data from NGL is used since the data at 8.2 m matches what was presented by Cetin (2000)

Depth (m)		
0	*1.2*	*sandy silt*
1.2	*1.8*	*med. dense fine sand*
1.8	*2.5*	*med. stiff silty clay*
2.5	*3.5*	*loose sandy silt*
3.5	*6.4*	*med. Stiff silty clay*
6.4	*7*	*med. dense silty sand*
7	*7.9*	*med. Stiff silty clay*
7.9	*8.5*	*med. dense silty sand*
8.5	*9.5*	*med. stiff to stiff clay*
9.5	*11.2*	*med. dense sand to fine silty sand*
11.2	*12.2*	*med. dense sand*
12.2	*12.8*	*soft to med. Stiff clay*
12.8	*14*	*dense sand*
14	*14.8*	*stiff clay*
14.8	*15.5*	*med. dense fine sand*
15.5	*15.9*	*clayey silt*
15.9	*18.8*	*very stiff silty clay*
18.8	*19.5*	*loose sandy silt*
19.5	*20.2*	*stiff silty clay*

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
1.2	3.8	NA	10	2.00	0.83	13.6	sandy silt
2.2	7.1	NA	16	1.62	0.86	18.2	med. stiff silty clay
3.2	10.3	NA	7	1.33	0.89	6.8	loose sandy silt
4.2	13.6	NA	15	1.16	0.91	12.9	med. Stiff silty clay
5.2	16.9	0.127	5	1.07	0.93	4.1	med. Stiff silty clay
6.3	20.5	0.134	16	1.02	0.94	12.5	med. Stiff silty clay
7.2	23.5	0.137	13	0.98	0.95	9.9	med. Stiff silty clay
8.2	***26.7***	***0.139***	***9***	***0.94***	***0.96***	***6.6***	***med. dense silty sand***
9.2	30.0	0.138	17	0.90	0.97	12.1	med. stiff to stiff clay
9.9	32.5	0.137	22	0.88	0.97	15.4	med. dense sand to fine silty sand
10.8	35.5	0.135	27	0.85	0.98	18.4	med. dense sand to fine silty sand
11.9	39.0	0.133	13	0.83	0.98	8.6	med. dense sand
13.1	43.0	0.131	48	0.80	0.99	30.8	dense sand
14.2	46.4	0.129	36	0.77	0.99	22.5	stiff clay
15.2	49.7	0.129	15	0.75	0.99	9.1	med. dense fine sand
16.2	53.0	0.128	35	0.74	0.99	20.9	very stiff silty clay
17.3	56.6	0.128	14	0.72	0.99	8.1	very stiff silty clay
18.3	60.0	0.129	15	0.70	1.00	8.5	very stiff silty clay
19.4	63.5	0.129	8	0.68	1.00	4.5	loose sandy silt
20.0	65.5	0.129	23	0.68	1.00	12.7	stiff silty clay
					Mean:	6.6	
					St. Dev.	2.0	assigned

Case number:	38
Earthquake:	1977 Argentina
Magnitude:	7.4 (Mw) USGS Centennial Earthquake Catalog
Location:	San Juan B-3
References:	Idriss et al. (1979), Fear et al. (1995), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	At several locations, the surface manifestation of liquefaction has been observed
GPS LAT	-31.6516 in association with abandoned fluvial deposits.
GPS LONG	-68.27928
Liq. layer consist of:	SP
Geological Unit:	Alluvial deposits in the Rio San Juan floodplain, evidence of buried paleochannels in the area
Site Response Anlaysis:	No
Comments:	Cetin (2000) "The borehole was located in north of downtown Caucete on private property which suffered substantial damage during the earthquake. Ground response analyses were performed based on generalized soil profile: 0-700 ft : sand with lenses of silt and clay 700-1400 ft : gravel >1400 ft : limestone, claystone and sand stone Shear moduli values were estimated from SPT values; Borehole1,3&6 and 2,4&5 were grouped for the analyses. The drainage was prevented at the surface by the clay layer. PGA record was made available by INPRES in San Juan and corrected by USGS. A PGA of 0.187 g was recorded at the subject seismographic station which was located within 10 km of the study area. Average unit weight of soil was estimated as 110 pcf. Dry Unit weight was reported in the range of 86-93 pcf in Table B-1. Estimated rod energy was 45% N values are back calculated from N1 plots by using above summarized info."
	"Near B-3: a large sand boil at the intersection of Coronel Dupuy and Aberastain streets" (Idriss et al. 1979)
	"Differential settlement to the east of the crevasse that appeared south of the intersection of Coronel Dupuy and Aberastain streets" (Idriss et al. 1979).
	The orginial reference of Idriss et al (1979) could not be obtained. Youd and Keefer (1994) has provided limited SPT-N values and these values were already corrected for overburden stress hence they are N1. Cetin et al (2004, 2018) has used this limited data and back calculated raw SPT-N values from N1. NGL Project has acessed Idriss et al (1979) and provided the full borehole data. Critical layer and corresponding SPT-N values were found to be the same. But this study has used the entire data provided by NGL. Vs12m is updated based on Vs-SPTN correlations since the entire borehole data is now obtained.
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

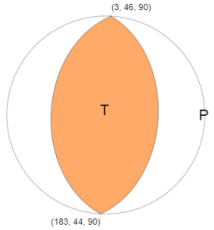
Summary of Input Data

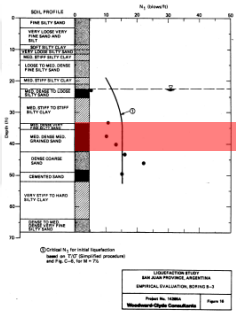
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	10.2 - 13.1		10.2 - 13.1	10.2 - 13.1
d_{crt} (m)	11.9	11.7	11.1	11.7	11.7
GWT (m)	6.71	6.7 ± 0.3	6.7	6.7 ± 0.1	6.7 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	17.3 ± 0.5	17.4 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.9 ± 0.5	19.0 ± 0.5
σ_v (kPa)	153.1	182.2 ± 9.6	199.5	209.8 ± 9.9	211.4 ± 10.0
σ_v' (kPa)	102.2	133.5 ± 6.7	156.4	161.1 ± 5.9	162.8 ± 6.0
a_{max} (g)	0.2	0.200 ± 0.015	0.2	0.200 ± 0.030	0.200 ± 0.040
r_d	0.86	0.56 ± 0.144	0.87	0.71 ± 0.144	0.60 ± 0.144
CSR	0.165	0.099 ± 0.027	0.169	0.120 ± 0.030	0.102 ± 0.032
M_w	7.40	7.40	7.50	7.50	7.40
D_{50}	SP	0.140 ± 0.050	-	0.140 ± 0.050	0.140 ± 0.050
% Fines	0	20.0 ± 3.0	5	20.0 ± 2.0	<5 ± 8.6
% PI	-	-	-	-	NAV
N	12	11.5 ± 1.6	13	14.1 ± 2.5	15.5 ± 3.3
C_R	-	1.00	1.00	1.00	0.98
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	0.75	0.75	0.75	0.75	0.82
C_N	0.97	0.85	0.78	0.79	0.79
$(N_1)_{60}$	8.5	7.3 ± 1.0	7.6	8.4 ± 1.5	9.8 ± 2.1
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	176.8	-	176.8	152.4

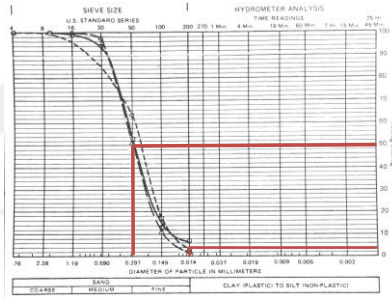
EVENT PARAMETERS

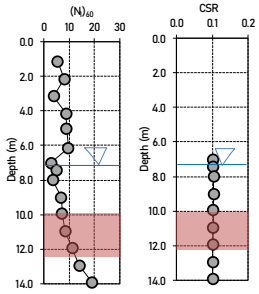
1977 Argentina		foot wall site
Magnitude: 7.40	Langer and Hartzell 1996, USGS	dip moderately to the east
Fault Type: reverse faults	Z_{tor} (km): 1	R_{rup} (km): 24.0
Dip: 44	Width (km): 50	R_{jb} (km): 24.0

https://earthquake.usgs.gov/earthquakes/eventpage/usp0000rp1/executive
https://earthquake.usgs.gov/earthquakes/eventpage/usp0000rp1/map









Borehole given in Appendix A of Idriss et al. (1979) as digitized by the NGL group
The original document could not be found.

Depth (m)			
0	*2.26*	ML-SM	Very loose, moist to very moist, yellowish brown sandy SILT to silty sand (ML-SM) very fine grained
2.26	*3.66*	CL	Soft, moist to very moist, brown, silty CLAY (CL) with very fine grained sand, and some veinlets of white mineral gypsum
3.66	*4.11*	CL	Medium stiff, very moist, dark yellowish brown silty CLAY (CL) traces of gravel
4.11	*5.64*	SM	Very loose to medium dense, moist, dark yellowish brown, silty SAND (SM) fine grained
5.64	*6.4*	CL	Medium stiff, moist, brown, silty CLAY (CL)
6.4	*7.74*	SM	Medium dense, very moist to wet, dark brown, silty SAND (SM) fine to medium grained, traces of clay
7.74	*10.21*	CL	Medium stiff to stiff, very moist, brown, silty CLAY (CL) traces of organics, veinlets of crystallized gypsum
10.21	*10.79*	SM	Medium dense, very moist to wet, brown, silty SAND (SM) very fine grained
10.79	*15.85*	SP	Medium dense, wet, dark brown, SAND (SP) medium grained, witht traces of silt
15.85	*19.51*	CL	Very stiff to hard, moist, brown, silty CLAY (CL) traces of organics and veinlets of gypsum
19.51	*20.7*	SM	Dense, moist, brown, silty SAND (SM) very fine grained

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		
1.2	3.8	NA	4	2.00	0.83	5.4		
2.2	7.1	NA	7	1.64	0.86	8.1		
3.2	10.3	NA	4	1.36	0.89	3.9		
4.2	13.6	NA	10	1.18	0.91	8.8		
5.1	16.6	NA	11	1.07	0.92	8.9		
6.2	20.2	NA	13	0.97	0.94	9.7		
7.0	23.0	0.103	4	0.92	0.95	2.9	SM	clayey?
7.5	24.4	0.103	7	0.90	0.95	4.9	SM	clayey?
8.0	26.2	0.104	5	0.89	0.96	3.5	CL	
9.0	***29.5***	***0.104***	***10***	***0.86***	***0.97***	***6.8***	***CL***	***SP?***
10.0	***32.6***	***0.103***	***11***	***0.83***	***0.97***	***7.3***	***CL***	***SP?***
11.0	***35.9***	***0.102***	***13***	***0.81***	***0.98***	***8.4***	***SP***	
12.0	***39.2***	***0.102***	***18***	***0.78***	***0.98***	***11.3***	***SP***	
13.0	42.5	0.101	23	0.76	0.99	14.1	SP	
14.0	45.8	0.101	32	0.74	0.99	19.2	SP	
15.0	49.0	0.102	23	0.72	0.99	13.5	SP	
15.9	52.0	0.102	32	0.71	0.99	18.4	SP	
16.9	55.4	0.103	28	0.69	0.99	15.8	CL	
17.9	58.6	0.104	19	0.68	0.99	10.5	CL	
19.3	63.2	0.105	33	0.66	1.00	17.7	CL	
20.3	66.4	0.106	24	0.65	1.00	12.7	SM	
					Mean:	9.8		
					St. Dev.	2.1		

Case number:	39
Earthquake:	1977 Argentina
Magnitude:	7.5 (Mw) USGS Centennial Earthquake Catalog
Location:	San Juan B-4
References:	Idriss et al. (1979), Fear et al. (1995), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	There is no surface evidence of liquefaction
GPS LAT	-31.6516
GPS LONG	-68.39514
Liq. layer consist of:	sand SP
Geological Unit:	Alluvial deposits in the Rio San Juan floodplain, evidence of buried paleochannels in the area
Site Response Anlaysis:	No
Comments:	Cetin (2000) "The borehole is located in the Dept. of 9 de Julio in the Finca Delta; It is at the corner of vineyard. Ground response analyses were performed based on generalized soil profile: 0-700 ft : sand with lenses of silt and clay 700-1400 ft : gravel >1400 ft : limestone, claystone and sand stone Shear moduli values were estimated from SPT values; Borehole1,3&6 and 2,4&5 were grouped for the analyses. PGA record was made available by INPRES in San Juan and corrected by USGS. A PGA of 0.187 g was recorded at the seismographic station which was located within 10 km of the study area. Average unit weight of soil was estimated as 110 pcf. Dry Unit weight was reported in the range of 86-93 pcf in Table B-1. Estimated rod energy was 45% N values were back calculated from N1 plots by using above summarized info."
	PI is assigned as 0 since FC=4%.
	The orginial reference of Idriss et al (1979) could not be obtained. Youd and Keefer (1994) has provided limited SPT-N values and these values were already corrected for overburden stress hence they are N1. Cetin et al (2004, 2018) has used this limited data and back calculated raw SPT-N values from N1. NGL Project has acessed Idriss et al (1979) and provided the full borehole data. Critical layer were found to be the same but corresponding SPT-N values are slightly changed. But this study has used the entire data provided by NGL. Vs12m is updated based on Vs-SPTN correlations since the entire borehole data is now obtained.
	Slightly different site (BH4 and BH5). Decided to include them as the soil profiles are different.
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	1.2 - 3.7		1.2 - 3.7	1.2 - 3.7
d_{crt} (m)	3.7	2.4	3.7	2.4	2.4
GWT (m)	1.22	1.2 ± 0.3	1.2	1.2 ± 0.1	1.2 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	17.3 ± 0.6	-	19.6 ± 0.5	19.6 ± 0.5
σ_v (kPa)	63.4	39.4 ± 7.2	63.2	45.1 ± 8.0	45.1 ± 8.0
σ_v' (kPa)	39.4	27.4 ± 4.0	39.1	33.1 ± 4.1	33.1 ± 4.1
a_{max} (g)	0.2	0.200 ± 0.015	0.2	0.200 ± 0.030	0.200 ± 0.040
r_d	0.97	0.97 ± 0.038	0.98	0.98 ± 0.038	0.98 ± 0.038
CSR	0.2	0.181 ± 0.027	0.204	0.173 ± 0.029	0.173 ± 0.037
M_w	7.40	7.40	7.50	7.50	7.40
D_{50}	0.29	0.290 ± 0.025	-	0.290 ± 0.050	0.290 ± 0.050
% Fines	4	4.0 ± 1.5	4	4.0 ± 2.0	4.0 ± 8.6
% PI	-	-	-	-	0
N	14	13.7 ± 0.6	14	13.6 ± 0.7	12.9 ± 2.4
C_R	-	0.77	0.85	0.77	0.87
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	0.75	0.75	0.75	0.75	0.82
C_N	1.50	1.87	1.60	1.75	1.75
$(N_1)_{60}$	16	14.8 ± 0.6	14.3	13.8 ± 0.7	16.0 ± 3.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	179.8	-	179.8	179.8

EVENT PARAMETERS

1977 Argentina

Magnitude: 7.40 | Langer and Hartzell 1996, USGS | foot wall site

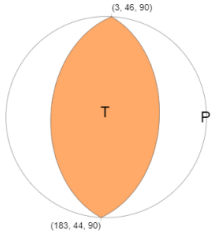
Fault Type: reverse faults | Z_{tor} (km): 1 | dip moderately to the east

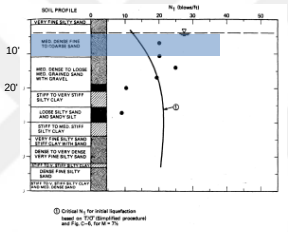
Dip: 44 | Width (km): 50 | R_{rup} (km): 34.6

R_{jb} (km): 34.6

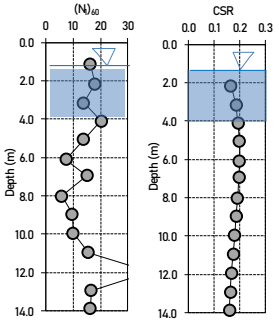
https://earthquake.usgs.gov/earthquakes/eventpage/usp0000rp1/executive

https://earthquake.usgs.gov/earthquakes/eventpage/usp0000rp1/map





Borehole given in Appendix A of Idriss et al. (1979) as digitized by the NGL group
The original document could not be found



Depth (m)			
0	*0.46*	SM-ML	Dry to damp, pale brown, silty SAND (SM-ML) very fine grained with traces of clay, some roots
0.46	*3.41*	SP	Medium dense, moist, very dark grayish brown SAND (SP) medium grained
3.41	*3.57*	CL	Medium dense, moist to very moist, yellowish brown sandy CLAY (CL) traces of gravel
3.57	*6.25*	SP	Medium dense, very moist, very dark grayish brown SAND (SP) medium grained, traces of gravel
6.25	*7.77*	CL	Stiff to very stiff, moist, brown, silty CLAY (CL) with traces of organics and veinlets of gypsum
7.77	*9.24*	SM-ML	Loose, wet, brown, silty SAND sandy silt (SM-ML)
9.24	*10.15*	CL	Stiff to medium stiff, wet, dark yellowish brown silty CLAY (CL) with traces of organics and some fine bedding
10.15	*10.3*	SM	Medium dense, very moist to wet, brown, silty SAND (SM) very fine grained
10.3	*11.43*	CH	Stiff, very moist, brown, CLAY (CH) with coarse grains of sand with veinlets of gypsum
11.43	*12.04*	SM	Dense, very moist, brown, silty SAND (SM) very fine grained with traces of organics
12.04	*12.8*	SP-SM	Very dense, moist to very moist, dark brown SAND (SP-SM) fine to medium grained, traces of silt
12.8	*13.08*	CL	Stiff to very stiff, very moist, yellowish brown, silty CLAY (CL)
13.08	*14.33*	SM-SP	Dense, very moist, dark brown, silty SAND to SAND (SM-SP) fine grained
14.33	*13.56*	CL	Stiff to very stiff, very moist, dark yellowish brown, stily CLAY (CL) with traces of organics
13.56	*15.24*	SM	Medium dense, very moist to wet, brown, silty SAND (SM) very fine grained

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
1.2	3.8	NA	12	2.00	0.83	16.3	SP
2.2	***7.1***	***0.166***	***14***	***1.83***	***0.86***	***18.1***	SP
3.2	***10.3***	***0.185***	***12***	***1.59***	***0.89***	***13.8***	SP
4.1	13.5	0.194	19	1.43	0.91	20.2	SP
5.1	16.6	0.198	14	1.31	0.92	13.9	SP
6.1	20.0	0.198	8	1.21	0.94	7.4	SP
7.0	22.8	0.196	17	1.14	0.95	15.1	CL
8.0	26.2	0.192	7	1.07	0.96	5.9	
9.0	29.4	0.186	12	1.02	0.97	9.7	
10.0	32.6	0.180	13	0.97	0.97	10.1	
11.0	35.9	0.174	21	0.93	0.98	15.6	
12.0	39.2	0.168	53	0.89	0.98	38.0	
13.0	42.5	0.163	24	0.86	0.99	16.6	
13.9	45.4	0.160	24	0.84	0.99	16.2	
14.9	48.9	0.156	18	0.81	0.99	11.7	
					Mean:	16.0	
					St. Dev.	3.0	

Case number:	40
Earthquake:	1977 Argentina
Magnitude:	7.5 (Mw) USGS Centennial Earthquake Catalog
Location:	San Juan B-5
References:	Idriss et al. (1979), Fear et al. (1995), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No apparent damage at nearby structures; no sand boils or other surface
GPS LAT	-31.651743 evidence of liquefaction.
GPS LONG	-68.380258
Liq. layer consist of:	sand (SP-SM)
Geological Unit:	Alluvial deposits in the Rio San Juan floodplain, evidence of buried paleochannels in the area
Site Response Anlaysis:	No
Comments:	Cetin (2000) "The borehole was located in the Dept. of 9 de Julio in the Finca La Porfia about 1.5 km east of route 20. It was drilled near the center of an old filled-in tributary channel. Ground response analyses were performed based on generalized soil profile: 0-700 ft : sand with lenses of silt and clay 700-1400 ft : gravel >1400 ft : limestone, claystone and sand stone. Shear moduli values were estimated from SPT values; Borehole1,3&6 and 2,4&5 were grouped for the analyses. PGA record was made available by INPRES in San Juan and corrected by USGS. A PGA of 0.187 g was recorded at the subject seismographic station which was located within 10 km of the study area. Average unit weight of soil was estimated as 110 pcf. Dry Unit weight was reported in the range of 86-93 pcf in Table B-1. Estimated rod energy was 45% N values were back calculated from N1 plots by using above summarized info."
	PI is assigned as 0 since FC=3%.
	The orginial reference of Idriss et al (1979) could not be obtained. Youd and Keefer (1994) has provided limited SPT-N values and these values were already corrected for overburden stress hence they are N1. Cetin et al (2004, 2018) has used this limited data and back calculated raw SPT-N values from N1. NGL Project has acessed Idriss et al (1979) and provided the full borehole data. Critical layer was updated as to include all the SPTN values in the sand layer. Vs12m is updated based on Vs-SPTN correlations since the entire borehole data is now obtained.
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	2.1 - 3.7		2.1 - 3.7	2.1 - 4.7
d_{crt} (m)	3.0	2.9	3.1	2.9	3.4
GWT (m)	2.13	2.1 ± 0.3	2.1	2.1 ± 0.1	2.1 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	18.1 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	52.8	45.7 ± 4.9	53.1	52.0 ± 5.1	63.4 ± 8.9
σ_v' (kPa)	43.7	38.2 ± 3.3	44.1	44.5 ± 2.8	50.8 ± 4.8
a_{max} (g)	0.2	0.200 ± 0.015	0.2	0.200 ± 0.030	0.200 ± 0.040
r_d	0.98	0.98 ± 0.044	0.98	0.99 ± 0.044	0.97 ± 0.051
CSR	0.155	0.152 ± 0.019	0.154	0.150 ± 0.024	0.157 ± 0.033
M_w	7.40	7.40	7.50	7.50	7.40
D_{50}	0.24	0.240 ± 0.025	-	0.240 ± 0.050	0.240 ± 0.050
% Fines	3	3.0 ± 1.0	3	3.0 ± 2.0	6-27.5 ± 5.0
% PI	-	-	-	-	NAV
N	14	15.3 ± 0.1	14	15.3 ± 0.1	17.7 ± 0.8
C_R	-	0.80	0.85	0.80	0.89
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	0.75	0.75	0.75	0.75	0.82
C_N	1.44	1.58	1.53	1.51	1.41
$(N_1)_{60}$	14.5	14.5 ± 0.1	13.6	13.8 ± 0.1	18.3 ± 0.8
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	204.2	-	204.2	184.4

EVENT PARAMETERS

1977 Argentina — foot wall site

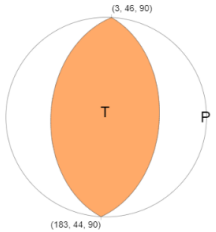
Magnitude: 7.40 — Langer and Hartzell 1996, USGS — dip moderately to the east

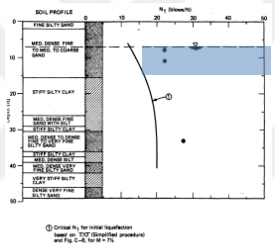
Fault Type: reverse faults — Z_{tor} (km): 1 — R_{rup} (km): 33.3

Dip: 44 — Width (km): 50 — R_{jb} (km): 33.3

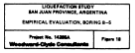
https://earthquake.usgs.gov/earthquakes/eventpage/usp0000rp1/executive

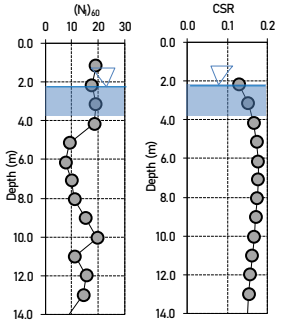
https://earthquake.usgs.gov/earthquakes/eventpage/usp0000rp1/map





Borehole given in Appendix A of Idriss et al. (1979) as digitized by the NGL group
The original document could not be obtained.





Depth (m)			
0	*0.61*	SM	Moist, dark brown, silty SAND (SM) fine grained, traces of hairlike roots
0.61	*4.72*	SP-SM	Medium dense, moist, dark grayish brown SAND (SP-SM) fine to medium grained with traces of silt
4.72	*8.08*	CL	Stiff, moist to very moist, brown, silty CLAY (CL) traces of very fine sand and roots
8.08	*8.69*	SP-SM	Medium dense, wet, dark brown, SAND (SP-SM) fine grained with traces of silt
8.69	*9.14*	CL	Stiff, very moist, brown, silty CLAY (CL) with gypsum veinlets
9.14	*10.82*	SM	
10.82	*11.28*	CL	Medium stiff to stiff, very moist, brown, silty CLAY (CL) traces of organics, traces of gypsum
11.28	*11.73*	ML	Medium dense, wet, dark brown, SILT (ML)
11.73	*12.65*	SM	
12.65	*14.02*	CL	Very stiff, moist, brown, (varigated) silty CLAY (CL) with traces of organics and veinlets of gypsum
14.02	*14.78*	SM	Dense, moist to very moist, brown, silty SAND (SM) very fine grained, traces of clay, veinlet of clay

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
1.2	3.8	NA	14	2.00	0.83	19.0	SP-SM
2.2	***7.1***	***0.128***	***15***	***1.65***	***0.86***	***17.5***	SP-SM
3.2	***10.3***	***0.153***	***18***	***1.46***	***0.89***	***19.0***	SP-SM
4.2	***13.6***	***0.166***	***19***	***1.31***	***0.91***	***18.6***	SP-SM
5.2	16.9	0.174	10	1.21	0.93	9.1	CL
6.2	20.2	0.177	9	1.12	0.94	7.8	CL
7.1	23.1	0.177	12	1.06	0.95	9.9	CL
8.1	26.4	0.175	14	1.00	0.96	11.0	CL
9.0	29.5	0.172	20	0.96	0.97	15.1	CL
10.1	33.0	0.167	27	0.91	0.97	19.5	SM
11.0	36.1	0.162	16	0.87	0.98	11.2	CL
12.0	39.4	0.158	23	0.84	0.98	15.5	SM
13.0	42.7	0.154	22	0.81	0.99	14.4	CL
14.1	46.1	0.150	14	0.78	0.99	8.8	SM
14.6	47.7	0.149	45	0.77	0.99	28.0	SM
					Mean:	18.3	
					St. Dev.	0.8	

Case number:	41
Earthquake:	1977 Argentina
Magnitude:	7.5 (Mw) USGS Centennial Earthquake Catalog
Location:	San Juan B-6
References:	Idriss et al. (1979), Fear et al. (1995), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Nearby structures were damaged; sand boils; stairway collapsed, concrete
GPS LAT	-31.73277 posts were sheared off.
GPS LONG	-68.33553
Liq. layer consist of:	MH-CL, SM-ML
Geological Unit:	Alluvial deposits in the Rio San Juan floodplain, evidence of buried paleochannels in the area
Site Response Anlaysis:	No
Comments:	Cetin (2000) "The borehole is located in the Dept. of 25 de Mayo at the Finca Santiago adjacent to La Plata Highway. Ground response analyses were performed based on generalized soil profile: 0-700 ft : sand with lenses of silt and clay 700-1400 ft : gravel >1400 ft : limestone, claystone and sand stone Shear moduli values were estimated from SPT values; Borehole1,3&6 and 2,4&5 were grouped for the anayses. PGA record was made available by INPRES in San Juan and corrected by USGS. A PGA of 0.187 g was recorded at the seismographic station which was located within 10 km of the study area. Average unit weight of soil was estimated as 110 pcf. Dry Unit weight was reported in the range of 86-93 pcf in Table B-1. Estimated rod energy was 45%"
	N values were back calculated from N_1 plots by using above summarized info."
	The orginial reference of Idriss et al (1979) could not be obtained. Youd and Keefer (1994) has provided limited SPT-N values and these values were already corrected for overburden stress hence they are N1. Cetin et al (2004, 2018) has used this limited data and back calculated raw SPT-N values from N1. NGL Project has acessed Idriss et al (1979) and provided the full borehole data. Critical layer and corresponding SPT-N values were found to be the same. But this study has used the entire data provided by NGL. Vs12m is updated based on Vs-SPTN correlations since the entire borehole data is now obtained.
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

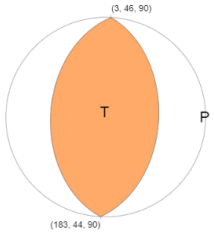
Summary of Input Data

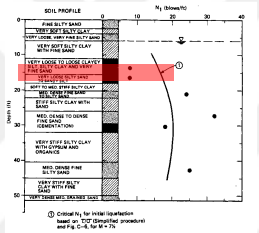
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	3.7 - 5.5		3.7 - 5.5	3.7 - 5.5
d_{crt} (m)	5.2	4.6	5.2	4.6	4.6
GWT (m)	1.83	1.8 ± 0.3	1.8	1.8 ± 0.1	1.8 ± 0.1
γ_{moist} (kN/m^3)	-	14.1 ± 0.6	-	17.3 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	17.3 ± 0.6	-	18.9 ± 0.5	17.3 ± 0.5
σ_v (kPa)	89.8	73.4 ± 5.8	90.2	83.5 ± 6.0	76.3 ± 5.5
σ_v' (kPa)	56.6	46.5 ± 3.7	56.1	56.6 ± 3.3	49.4 ± 2.9
a_{max} (g)	0.2	0.200 ± 0.015	0.2	0.200 ± 0.030	0.200 ± 0.040
r_d	0.96	0.94 ± 0.065	0.96	0.96 ± 0.065	0.96 ± 0.065
CSR	0.195	0.192 ± 0.023	0.198	0.184 ± 0.031	0.193 ± 0.041
M_w	7.40	7.40	7.50	7.50	7.40
D_{50}	SM-ML	0.100 ± 0.025	-	0.100 ± 0.050	0.100 ± 0.050
% Fines	50	50.0 ± 5.0	50	50.0 ± 2.0	50.0 ± 8.6
% PI	-	-	-	-	NAV
N	6	6.0 ± 0.2	6	6.0 ± 0.2	6.0 ± 0.2
C_R	-	0.87	0.95	0.87	0.92
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	0.75	0.75	0.75	0.75	0.82
C_N	1.28	1.44	1.36	1.34	1.43
$(N_1)_{60}$	6	5.7 ± 0.2	5.8	5.3 ± 0.2	6.4 ± 0.2
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	192.0	-	192.0	192.0

EVENT PARAMETERS

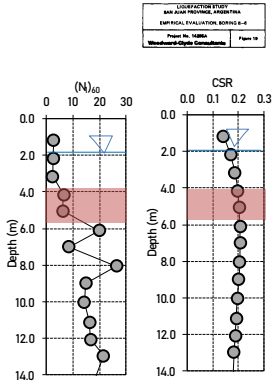
1977 Argentina		foot wall site
Magnitude: 7.40	Langer and Hartzell 1996, USGS	dip moderately to the east
Fault Type: reverse faults	Z_{tor} (km): 1	R_{rup} (km): 27.3
Dip: 44	Width (km): 50	R_{jb} (km): 27.3

https://earthquake.usgs.gov/earthquakes/eventpage/usp0000rp1/executive
https://earthquake.usgs.gov/earthquakes/eventpage/usp0000rp1/map





NGL database has another borehole data from the log given in Appendix A of Idriss et al. (1979). That paper could not be found. The data from NGL is used since the data at 4-5 m matches what was presented by Cetin (2000) (slight change in the depth, it is also confirmed by digitizing the figure on the left.

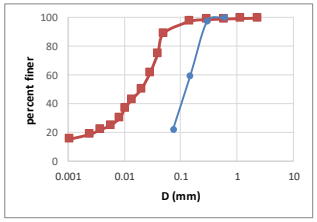


Depth (m)		
0	1.22	Very soft, wet, brown, silty CLAY (CL)
1.22	1.83	Very loose, wet, brown, silty SAND (SM) very fine grained
1.83	3.35	Very soft, wet, brown, silty CLAY (CL) with some fine grained sand
3.35	4.72	Very loose to loose, wet, brown, clayey to silty CLAY (MH-CL) with some very fine grained sand
4.72	5.49	Very loose, wet, brown, silty SAND to sandy silt (SM-ML)
5.49	6.25	Soft to medium stiff, moist, brown, silty CLAY (CL) with veinlets of gypsum
6.25	6.71	Medium dense, moist to very moist, dark yellowish brown, sand to silty SAND (SP-SM) fine grained
6.71	7.92	Stiff, moist, brown, silty CLAY (CL) with veinlet of sand
7.92	9.75	Medium dense to dense, moist to very moist, dark yellowish brown, SAND (SP) fine grained
9.75	12.34	Very stiff, wet, yellowish brown, silty CLAY (CL) some small root holes
12.34	13.72	Medium dense, moist to very moist, brown, silty SAND (SM) fine grained
13.72	15.24	Very stiff, very moist, brown, silty CLAY (CL) with very fine SAND and organics, veinlets gypsum
15.24	15.36	Very dense, saturated, brown, SAND (SP) medium grained

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
1.2	3.8	NA	2	2.00	0.83	2.7	CL
2.2	7.1	0.141	2	1.80	0.86	2.5	CL
3.2	10.3	0.170	2	1.62	0.89	2.4	CL
4.2	***13.6***	***0.187***	***6***	***1.48***	***0.91***	***6.6***	MH-CL
5.1	***16.6***	***0.198***	***6***	***1.39***	***0.92***	***6.3***	SM-ML
6.1	20.0	0.204	20	1.29	0.94	19.8	CL
7.0	23.0	0.207	9	1.23	0.95	8.6	CL
8.1	26.4	0.207	29	1.16	0.96	26.4	SP
9.0	29.5	0.205	17	1.11	0.97	14.9	SP
10.1	33.0	0.201	17	1.06	0.97	14.3	CL
11.1	36.4	0.196	20	1.02	0.98	16.2	CL
12.1	39.5	0.192	21	0.98	0.98	16.5	CL
13.0	42.5	0.188	28	0.95	0.99	21.4	SM
14.1	46.1	0.183	25	0.92	0.99	18.5	CL
15.1	49.4	0.180	26	0.89	0.99	18.7	CL
					Mean:	6.4	
					St. Dev.	0.2	

transion zone partially in clay and partially in sand, decided to include

	GRAT_SIZE	GRAT_PERP
	2.38	*99.5*
	1.19	*99.3*
	0.59	*98.9*
	0.297	*98.5*
	0.149	*97.3*
	0.051	*89.1*
	0.04	*75*
depth 1.7 m-2 m	*0.029*	*61.3*
	0.0204	*50.3*
	0.0137	*42.7*
	0.0104	*36.7*
	0.0085	*30.2*
	0.00585	*25.1*
	0.00387	*22*
	0.00248	*18.7*
	0.00111	*15.5*
	0.59	*99.9*
depth 3.7-2m	*0.297*	*97.4*
	0.149	*59.3*
	0.074	*22.2*



Case number:	42
Earthquake:	1978 Miyagiken-Oki
Magnitude:	6.5
Location:	Arahama
References:	Tohno and Yasuda (1981), Fear et al. (1995), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No apparent evidence of liquefaction
GPS LAT	38.04258
GPS LONG	140.919003
Liq. layer consist of:	coarse sand with silt and gravel
Geological Unit:	Fill, Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Cetin (2000) "The site is located in Watari Town, district of Arahama. Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. Only the Nakamura site liquefied during this earthquake. The subject zone is seismically very active and had been shaken in 1897 and 1936 by earthquakes of Magnitudes 7.3 and 7.7 Arahama area is covered with very soft sandy deposits; about 9 m in thickness, N values generally less than 10. SPT values were taken before main earthquake (M=7.4) in 1974 SPT energy is estimated as 65 % by Seed et al. (84)"
	The hatched zone is reclaimed land. Arahama sewage treatment tank remained intact due to its strong foundation. However the area has liquefied and surrounding ground settled about 20 cm. Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.
	PI is assigned as 0 as FC=0.
	V12m is updated based on Vs-SPTN correlations.
	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en
	https://earthquake.usgs.gov/earthquakes/eventpage/usp0000v0f/executive
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Shiogama-kojyo-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	103.1	62
FS	61.1		0.062		0.062	50	
Ishinomaki	293		0.299		0.299	80	24

Summary of Input Data

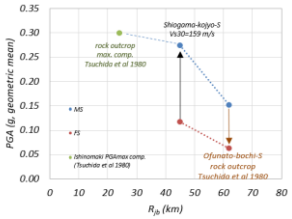
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	2.0 - 8.0		2.0 - 8.0	2.0 - 8.6
d_{crt} (m)	6.4	5.0	6.4	5.0	5.3
GWT (m)	0.91	0.9 ± 0.3	0.9	0.9 ± 0.1	0.9 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	17.3 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	121.0	85.2 ± 17.5	121.3	93.0 ± 19.0	98.7 ± 20.9
σ_v' (kPa)	67.2	45.0 ± 8.3	67.2	52.9 ± 9.3	55.6 ± 10.2
a_{max} (g)	0.1	0.100 ± 0.020	0.1	0.100 ± 0.030	0.100 ± 0.020
r_d	0.95	0.91 ± 0.070	0.9	0.94 ± 0.070	0.98 ± 0.073
CSR	0.11	0.112 ± 0.025	0.105	0.107 ± 0.033	0.113 ± 0.024
M_w	6.70	6.70	6.50	6.50	6.50
D_{50}	0.6	0.450 ± 0.080	-	0.450 ± 0.050	0.450 ± 0.050
% Fines	0	0.0 ± 0.0	0	0.0 ± 2.0	0.0 ± 8.6
% PI	-	-	-	-	0
N	10	9.6 ± 1.8	10	8.9 ± 2.4	9.0 ± 2.2
C_R	-	0.92	0.95	0.92	0.94
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.09	1.09	1.09	1.09	1.37
C_N	1.18	1.46	1.23	1.39	1.35
$(N_1)_{60}$	13	14.1 ± 2.7	12.8	12.4 ± 3.3	15.6 ± 3.8
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	185.9	-	185.9	222.5

EVENT PARAMETERS

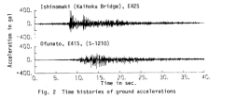
1978 Miyagiken-Oki
Magnitude: 6.50
Fault Type: thrust
Dip: 20

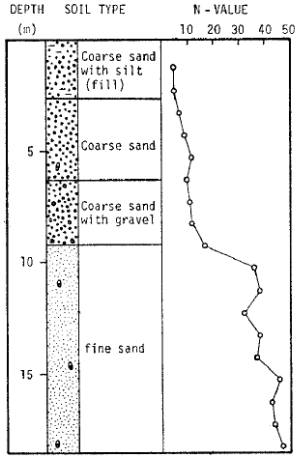
Seno et al (1980)
Length (km): 30
Z_{tor} (km): 0
Width (km): 80

Foreshock parameters were assumed to be same with mainshock
R_{rup} (km): -
R_{jb} (km): 55-65 ± 30



Mainshock record by Tsuchida et al (1980)





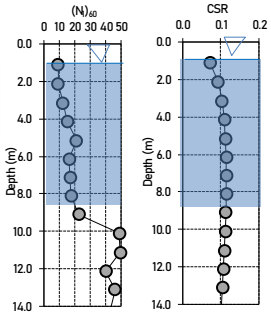


Fig. 10. Soil profile at the Arahama Gesuiro Sewage Plant (Site A-9). Data from Watari Town

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
1.1	3.6	0.072	4	2.00	0.86	9.4	coarse sand with silt (fill)
2.2	***7.1***	***0.094***	***4***	***1.93***	***0.89***	***9.4***	coarse sand with silt (fill)
3.2	***10.3***	***0.104***	***6***	***1.68***	***0.91***	***12.5***	coarse sand
4.1	***13.6***	***0.109***	***8***	***1.50***	***0.92***	***15.2***	coarse sand
5.2	***16.9***	***0.112***	***12***	***1.37***	***0.94***	***21.1***	coarse sand
6.1	***20.1***	***0.114***	***10***	***1.27***	***0.95***	***16.5***	coarse sand
7.1	***23.4***	***0.115***	***11***	***1.19***	***0.96***	***17.1***	coarse sand with gravel
8.1	***26.5***	***0.115***	***12***	***1.12***	***0.97***	***17.8***	coarse sand with gravel
9.1	29.8	0.114	16	1.06	0.97	22.6	coarse sand with gravel
10.1	33.1	0.112	36	1.01	0.98	48.7	fine sand
11.1	36.5	0.110	38	0.97	0.98	49.4	fine sand
12.1	39.8	0.107	32	0.93	0.99	40.1	fine sand
13.1	43.0	0.104	38	0.90	0.99	46.0	fine sand
14.1	46.4	0.102	37	0.87	0.99	43.3	fine sand
15.1	49.5	0.099	45	0.84	0.99	51.2	fine sand
16.1	52.9	0.097	42	0.81	0.99	46.3	fine sand
17.1	56.1	0.095	43	0.79	0.99	46.2	fine sand
18.1	59.3	0.094	47	0.77	1.00	49.2	fine sand
					Mean:	15.6	
					St. Dev.	3.8	

Depth (m)

0	2.62	coarse sand with silt (fill)
2.62	6.3	coarse sand
6.3	9.2	coarse sand with gravel
9.2	18.52	fine sand

Case number:	43
Earthquake:	1978 Miyagiken-Oki
Magnitude:	6.5
Location:	Hiyori-18
References:	Tsuchida et al (1979, 1980), Fear et al. (1995), Tohno et al. (1981), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface evidence of liquefaction
GPS LAT	38.419355
GPS LONG	141.27366
Liq. layer consist of:	Sand
Geological Unit:	Artifically filled sand next to the ocean
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. Only the Nakamura site liquefied during this earthquake. The subject zone is seismically very active and had been shaken in 1897 and 1936 by earthquakes of Magnitudes 7.3 and 7.7. The original Tsuchida (1979) paper (in Japanese) could not be accessed. However the same author's paper of 1980 in English was used to obtain borelogs. Hiyori-18 site was claimed by Tokimatsu (1993) to be by Site C. SPT energy was estimated as 65 % by Seed et al. (84)"

The borehole data is redigitized and the soil classification was noted.

Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.

https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Shiogama-kojyo-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	103.1	62
FS	61.1		0.062		0.062	50	
Ishinomaki	293		0.299		0.299	80	24

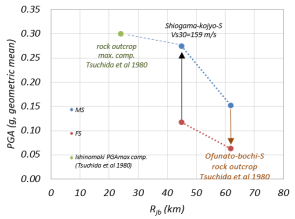
Gravel Content (%):	0.00
CPT available:	No
Vs available:	No

Summary of Input Data

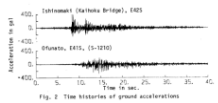
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	2.5 - 4.0		2.5 - 4.0	2.5 - 4.0
d_{crt} (m)	5.2	3.3	5.2	3.3	3.3
GWT (m)	2.44	2.4 ± 0.3	2.4	2.4 ± 0.1	2.4 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	17.3 ± 0.9	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	97.9	52.5 ± 4.7	98.2	57.6 ± 4.9	57.6 ± 4.9
σ_v' (kPa)	71.0	44.5 ± 3.6	71.2	49.6 ± 2.7	49.6 ± 2.7
a_{max} (g)	0.14	0.140 ± 0.028	0.14	0.140 ± 0.042	0.140 ± 0.028
r_d	0.96	0.96 ± 0.048	0.93	0.98 ± 0.048	0.98 ± 0.048
CSR	0.12	0.103 ± 0.023	0.116	0.103 ± 0.032	0.103 ± 0.022
M_w	1.14	6.70	6.50	6.50	6.50
D_{50}	0.15	0.150 ± 0.030	-	0.150 ± 0.050	0.150 ± 0.050
% Fines	20	20.0 ± 3.0	20	20.0 ± 2.0	20.0 ± 8.6
% PI	-	-	-	-	NAV
N	9	9.1 ± 1.8	9	9.1 ± 1.5	9.2 ± 1.1
C_R	-	0.86	0.95	0.86	0.91
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.09	1.09	1.09	1.09	1.37
C_N	1.15	1.47	1.19	1.43	1.43
$(N_1)_{60}$	11.5	12.5 ± 2.5	11.1	12.2 ± 2.0	16.3 ± 2.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	195.1	-	195.1	195.1

EVENT PARAMETERS

1978 Miyagiken-Oki	Seno et al (1980)	Foreshock parameters were assumed to be same with mainshock
Magnitude: 6.50	Length (km): 30	R_{rup} (km): -
Fault Type: thrust	Z_{tor} (km): 0	R_{jb} (km): 22-30 ± 30
Dip: 20	Width (km): 80	



Mainshock record by Tsuchida et al (1980)



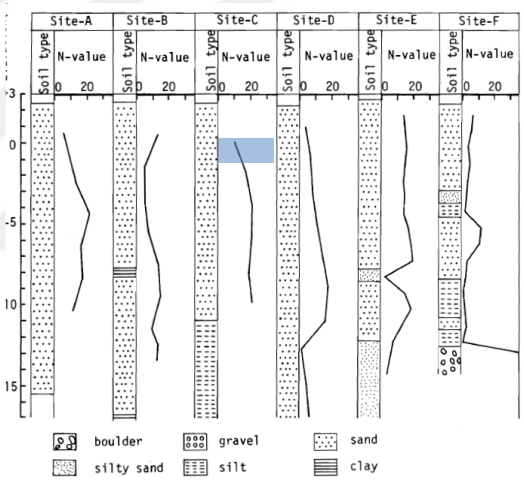
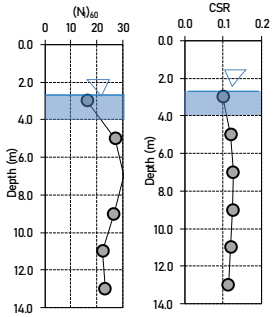


Fig. 3 Soil types and N-values of standard penetration test



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
3.0	***9.8***	***0.099***	***9.0***	***1.46***	***0.90***	***16.3***	sand
5.0	16.4	0.120	17.0	1.25	0.94	27.1	sand
7.0	23.0	0.127	21.0	1.10	0.96	30.3	sand
9.0	29.5	0.125	20.0	1.00	0.97	26.6	sand
11.0	36.1	0.120	18.0	0.92	0.98	22.2	sand
13.0	42.7	0.113	20.0	0.86	0.99	23.2	sand
					Mean:	16.3	
					St. Dev.	2.0	assigned

Case number:	45
Earthquake:	1978 Miyagiken-Oki
Magnitude:	6.5
Location:	Kitawabuchi 2
References:	Iwasaki et al. (1981), Fear et al. (1995), Tohno et al. (1981), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface evidence of liquefaction
GPS LAT	38.53346
GPS LONG	141.2157
Liq. layer consist of:	sand with gravel
Geological Unit:	old river bed
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. Only the Nakamura site liquefied during this earthquake. The subject zone is seismically very active and had been shaken in 1897 and 1936 by the earthquakes of Magnitudes 7.3 and 7.7. SPT values were taken after main earthquake (M=7.4) SPT energy was estimated as 60 % by Seed et al. (84)"

A better resolution burehole data is obtained from Iwasaki (1986)

Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.

Shiogama-kojyo-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	103.1	62
FS	61.1		0.062		0.062	50	
Ishinomaki	293		0.299		0.299	80	24

Gravel Content (%):	silty sand with gravel (content unknown)
CPT available:	No
Vs available:	No

Summary of Input Data

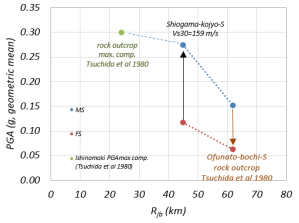
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	3.0 - 4.0		3.0 - 4.0	2.8 - 4.1
d_{crt} (m)	3.4	3.5	3.4	3.5	3.5
GWT (m)	3.05	3.0 ± 0.2	3.1	3.0 ± 0.1	2.5 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	15.7 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	17.3 ± 0.9	-	18.9 ± 0.5	20.6 ± 0.5
σ_v (kPa)	62.4	53.5 ± 3.5	62.2	56.7 ± 3.5	63.1 ± 4.7
σ_v' (kPa)	59.5	48.6 ± 2.6	59.1	51.8 ± 2.2	53.2 ± 2.7
a_{max} (g)	0.14	0.140 ± 0.028	0.14	0.140 ± 0.042	0.140 ± 0.028
r_d	0.98	0.85 ± 0.052	0.96	0.88 ± 0.052	0.97 ± 0.051
CSR	0.095	0.085 ± 0.018	0.092	0.087 ± 0.027	0.105 ± 0.022
M_w	6.70	6.70	6.50	6.50	6.50
D_{50}	0.53	0.530 ± 0.100	-	0.530 ± 0.050	0.530 ± 0.050
% Fines	5	5.0 ± 2.0	5	5.0 ± 2.0	5.0 ± 8.6
% PI	-	-	-	-	NAV
N	11	11.1 ± 2.1	11	11.1 ± 1.6	11.2 ± 1.2
C_R	-	0.87	0.85	0.87	0.91
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.00	1.00	1.00	1.00	1.37
C_N	1.24	1.41	1.32	1.40	1.38
$(N_1)_{60}$	13.5	13.5 ± 2.5	12.3	13.5 ± 2.0	19.3 ± 2.0
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	140.2	-	140.2	195.1

EVENT PARAMETERS

1978 Miyagiken-Oki
Magnitude: 6.50
Fault Type: thrust
Dip: 20

Seno et al (1980)
Length (km): 30
Z_{tor} (km): 0
Width (km): 80

Foreshock parameters were assumed to be same with mainshock
R_{rup} (km): -
R_{jb} (km): 32-38 ± 30



Mainshock record by Tsuchida et al (1980)

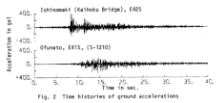
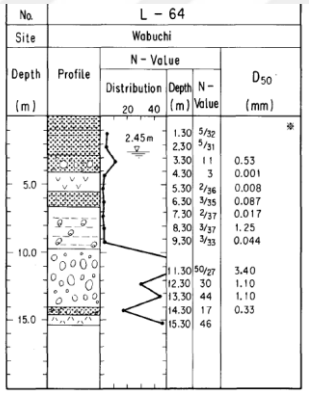
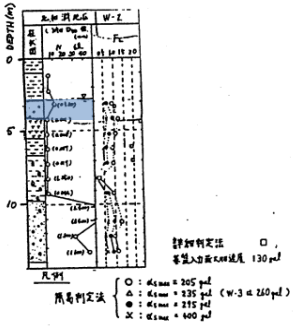


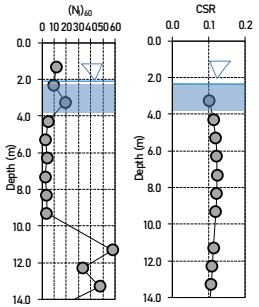
Fig. 2 Time histories of ground accelerations





Ds : Nothing (Eye Measurement)

Appendix 22



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	D50	
1.3	4.3	NA	5.0	2.00	0.86	11.8		sandy silt
2.3	7.5	NA	5.0	1.60	0.89	9.7		sandy silt
3.3	***10.7***	***0.103***	***11.0***	***1.41***	***0.91***	***19.3***	***0.530***	*sand with gravel*
4.3	14.1	0.113	3.0	1.28	0.93	4.8	0.001	humus
5.3	17.4	0.119	2.0	1.18	0.94	3.0	0.008	humus
6.3	20.7	0.122	3.0	1.10	0.95	4.3	0.087	sandy silt
7.3	24.0	0.123	2.0	1.03	0.96	2.7	0.017	silt with shells
8.3	27.2	0.122	3.0	0.98	0.97	3.9	1.250	silt with shells
9.3	30.5	0.120	3.0	0.93	0.97	3.7	0.044	silt with shells
11.3	37.1	0.113	50.0	0.86	0.98	57.6	3.400	gravel
12.3	40.4	0.110	30.0	0.83	0.99	33.4	1.100	gravel
13.3	43.6	0.107	44.0	0.80	0.99	47.4	1.100	gravel
14.3	46.9	0.104	17.0	0.77	0.99	17.8	0.330	silty sand with gravel
15.3	50.2	0.102	46.0	0.75	0.99	46.7		Rock
					Mean:	19.3	0.530	
					St. Dev.	2.0	0.050	assigned

Depth (m)		
0	*2.8*	*sandy silt*
2.8	*4.1*	*sand with gravel*
4.1	*5.6*	*humus*
5.6	*6.7*	*sandy silt*
6.7	*9.8*	*silt with shells*
9.8	*14*	*gravel*
14	*14.7*	*silty sand with gravel*
14.7	*15.4*	*Rock*

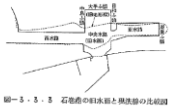
Case number:	46
Earthquake:	1978 Miyagiken-Oki
Magnitude:	6.5
Location:	Nakajima-18
References:	Tsuchida et al (1979, 1980), Fear et al. (1995), Tohno et al (1981), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface evidence of liquefaction
GPS LAT	38.415014
GPS LONG	141.26592
Liq. layer consist of:	sand
Geological Unit:	Artificially filled sand next to the ocean
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. Only the Nakamura site liquefied during this earthquake. The subject zone is seismically very active and had been shaken in 1897 and 1936 by the earthquakes of Magnitudes 7.3 and 7.7. The original Tsuchida (1979) paper (in Japanese) could not be accessed. However the same author's paper of 1980 in English was used to obtain borelogs. Nakajima 18 site was claimed by Tokimatsu (1993) to be by Site A. SPT energy was estimated as 65 % by Seed et al. (84)"

The original Tsuchida (1979) paper (in Japanese) is accessed. CB-15 seems to fit the data of Site A. The SPT values are redigitized. All the sites are artificially filled sand

Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.

PI is assigned as 0 since FC=3%.



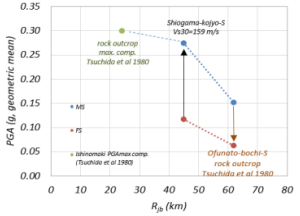


かどうかは不明である。地盤特の砂の液状化判定の資料となる砂の粒径加積曲線を図－３．３．７に示す。土層の全体構成には局部的な変化がなく，全体的に成層状態が均一である。各土層ごとの土質の性状はおおよそ次のようである。

a）中粒土層

表面から約－１３mまでにN値１０前後から２０程度が多所があり，その下には－２５m程度までN値５程度の軟弱土が続いている。更にその下には－４０m程度ま

図－３．３．８ 石巻港の氷水層と県漁船の北岸図



Mainshock record by Tsuchida et al (1980)

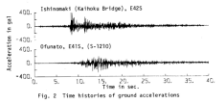


Fig. 2 Time histories of ground accelerations

Gravel Content (%):	0.00
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	2.4 - 6.1		2.4 - 6.1	2.4 - 6.1
d_{crt} (m)	6.1	4.3	6.1	4.3	4.3
GWT (m)	2.44	2.4 ± 0.3	2.4	2.4 ± 0.1	2.4 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	18.1 ± 0.9	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	115.2	71.5 ± 11.3	115.3	78.2 ± 12.1	80.0 ± 12.7
σ_v' (kPa)	79.2	53.5 ± 6.0	79.2	60.3 ± 6.2	62.0 ± 6.8
a_{max} (g)	0.14	0.140 ± 0.028	0.14	0.140 ± 0.042	0.140 ± 0.028
r_d	0.96	0.92 ± 0.061	0.91	0.97 ± 0.061	0.97 ± 0.061
CSR	0.125	0.111 ± 0.025	0.12	0.114 ± 0.036	0.113 ± 0.025
M_w	6.70	6.70	6.50	6.50	6.50
D_{50}	0.35	0.350 ± 0.050	-	0.350 ± 0.050	0.350 ± 0.050
% Fines	3	3.0 ± 1.0	3	3.0 ± 2.0	3.0 ± 8.6
% PI	-	-	-	-	0
N	12	9.6 ± 4.0	12	9.6 ± 3.9	10.0 ± 4.3
C_R	-	0.90	0.95	0.90	0.93
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.09	1.09	1.09	1.09	1.37
C_N	1.09	1.34	1.13	1.30	1.28
$(N_1)_{60}$	14.5	12.6 ± 5.3	14.1	12.2 ± 5.0	16.2 ± 6.9
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	179.8	-	198.1	198.1

EVENT PARAMETERS

1978 Miyagiken-Oki	Seno et al (1980)	Foreshock parameters were assumed to be same with mainshock
Magnitude: 6.50	Length (km): 30	R_{rup} (km): -
Fault Type: thrust	Z_{tor} (km): 0	R_{jb} (km): 25-30 ± 30
Dip: 20	Width (km): 80	

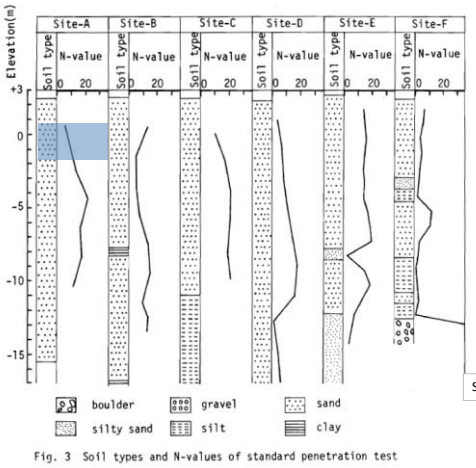
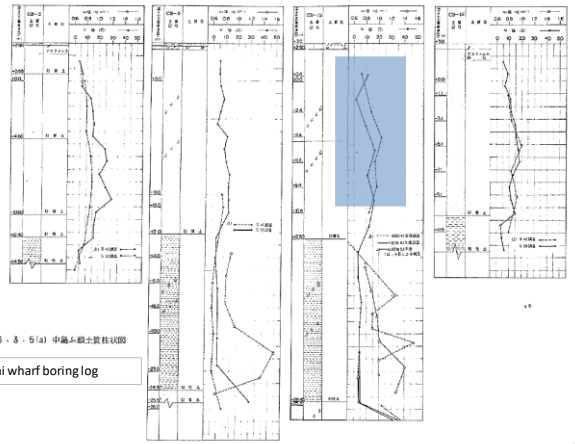
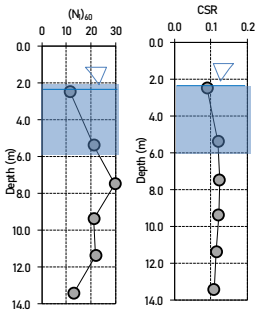


Fig. 3 Soil types and N-values of standard penetration test



Shiomi wharf boring log



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
2.4	***8.0***	***0.090***	***6***	***1.55***	***0.89***	***11.3***	sand
5.4	***17.6***	***0.120***	***14***	***1.17***	***0.94***	***21.1***	sand
7.5	24.5	0.124	22	1.03	0.96	29.7	sand
9.4	30.7	0.121	17	0.93	0.97	21.1	sand
11.4	37.3	0.115	19	0.86	0.98	21.8	sand
13.4	44.0	0.108	12	0.79	0.99	12.9	sand
					Mean:	16.2	
					St. Dev.	6.9	

Case number:	47
Earthquake:	1978 Miyagiken-Oki
Magnitude:	6.5
Location:	Nakamura-4
References:	Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Iwasaki and Tokida (1984), Iwasaki (1986), Cetin (2000), Cetin
Nature of Failure:	Sand boils, cracking
GPS LAT	38.198586
GPS LONG	140.936386
Liq. layer consist of:	medium sand and sandy silt
Geological Unit:	river dyke
Site Response Anlaysis:	No
Comments:	Cetin (2000) "The site is located in the inside base towards the north end of an embankment along the left bank of the Natori River. Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. Only the Nakamura site liquefied during this earthquake. The subject zone is seismically very active and had been shaken in 1897 and 1936 by the earthquakes of Magnitudes 7.3 and 7.7. SPT values were taken after main earthquake (M=7.4). SPT energy was estimated as 60 % by Seed et al. (84)"
	Borehole data is obtained from Iwasaki (1986)
	PI is assigned as 0 as FC=5%
	Vs12m is updated based on Vs-SPTN correlations.
	Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

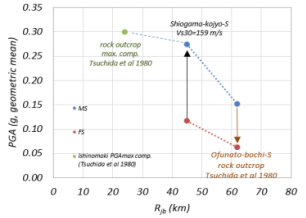
Shiogama-kojyo-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	103.1	62
FS	61.1		0.062		0.062	50	
Ishinomaki	293		0.299		0.299	80	24

Summary of Input Data

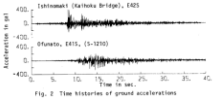
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	3.0 - 5.0		3.0 - 5.0	3.0 - 5.0
d_{crt} (m)	3.4	4.0	2.8	4.0	4.0
GWT (m)	0.61	0.5 ± 0.3	0.5	0.5 ± 0.1	0.5 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	63.4	65.4 ± 6.0	53.1	74.8 ± 6.5	74.8 ± 6.5
σ_v' (kPa)	36.5	31.0 ± 4.0	30.1	40.4 ± 3.5	40.4 ± 3.5
a_{max} (g)	0.12	0.120 ± 0.024	0.12	0.120 ± 0.036	0.120 ± 0.024
r_d	0.98	0.97 ± 0.058	0.97	0.98 ± 0.058	1.00 ± 0.058
CSR	0.135	0.160 ± 0.037	0.128	0.142 ± 0.044	0.144 ± 0.030
M_w	6.70	6.70	6.50	6.50	6.50
D_{50}	0.7	0.700 ± 0.150	-	0.700 ± 0.050	0.543 ± 0.178
% Fines	5	5.0 ± 1.0	5	5.0 ± 2.0	5.0 ± 8.6
% PI	-	-	-	-	0
N	5	5.6 ± 0.4	4.7	5.6 ± 0.4	5.6 ± 0.4
C_R	-	0.89	0.85	0.89	0.92
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.00	1.00	1.00	1.00	1.37
C_N	1.55	1.76	1.70	1.59	1.59
$(N_1)_{60}$	8	8.7 ± 0.7	6.9	7.9 ± 0.6	11.2 ± 0.7
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	213.4	-	213.4	248.4

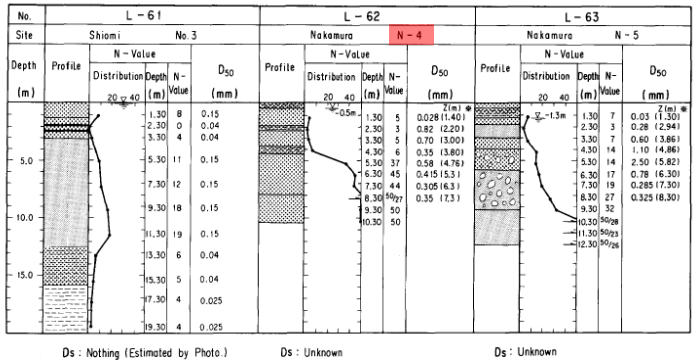
EVENT PARAMETERS

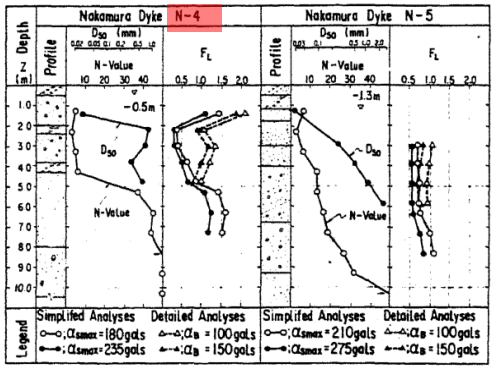
1978 Miyagiken-Oki	Seno et al (1980)	Foreshock parameters were assumed to be same with mainshock
Magnitude: 6.50	Length (km): 30	R_{rup} (km): -
Fault Type: thrust	Z_{tor} (km): 0	R_{jb} (km): 50-60 ± 30
Dip: 20	Width (km): 80	



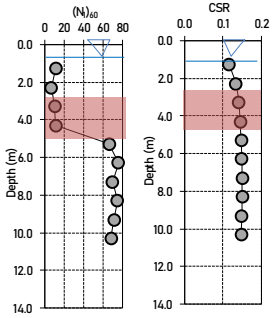
Mainshock record by Tsuchida et al (1980)







(B) N-4 and N-5
(at non-liquefied sites)



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		
1.3	4.3	0.116	5	2.00	0.86	11.8	medium sand	CN>2
2.3	7.5	0.133	3	2.00	0.89	7.3	sandy silt	CN>2
3.3	***10.8***	***0.141***	***5***	***1.73***	***0.91***	***10.7***	medium sand	
4.3	***14.1***	***0.145***	***6***	***1.53***	***0.93***	***11.7***	sandy silt	
5.3	17.4	0.147	37	1.39	0.94	66.3	medium sand	
6.3	20.7	0.149	45	1.29	0.95	75.4	medium sand	
7.3	24.0	0.149	44	1.20	0.96	69.4	medium sand	
8.3	27.2	0.149	50	1.13	0.97	74.8	medium sand	
9.3	30.5	0.149	50	1.07	0.97	71.3	medium sand	
10.3	33.8	0.148	50	1.02	0.98	68.2	medium sand	
					Mean:	11.2		
					St. Dev.	0.7		

Depth (m)	D50
1.4	0.028
2.2	0.820
3.0	***0.700***
3.8	***0.350***
4.8	***0.580***
5.30	0.415
6.30	0.305
7.30	0.350
Mean:	0.543
St. Dev.	0.178

Depth (m)		
0	*0.52*	sandy silt
0.52	*1.99*	medium sand
1.99	*2.39*	sandy silt
2.39	*3.82*	medium sand
3.82	*4.3*	sandy silt
4.3	*7.99*	medium sand
7.99	*10.47*	medium sand

Case number:	48
Earthquake:	1978 Miyagiken-Oki
Magnitude:	6.5
Location:	Nakamura-5
References:	Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface evidence of liquefaction
GPS LAT	38.198586
GPS LONG	140.936386
Liq. layer consist of:	coarse sand
Geological Unit:	river dyke
Site Response Anlaysis:	No
Comments:	Cetin (2000) "The site is located in the outside base at the north end of an embankment along the left bank of the Natori River. Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. Only the Nakamura site liquefied during this earthquake. The subject zone is seismically very active and had been shaken in 1897 and 1936 by the earthquakes of Magnitudes 7.3 and 7.7 SPT values were taken after main earthquake (M=7.4) SPT energy was estimated as 60 % by Seed et al. (84)"

Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.

PI is assigned as 0 as FC=4%

Vs12m is updated based on Vs-SPTN correlations.

Shiogama-kojyo-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	103.1	62
FS	61.1		0.062		0.062	50	
Ishinomaki	293		0.299		0.299	80	24

Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

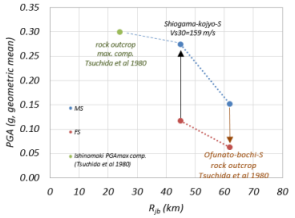
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	2.7 - 4.0		2.7 - 4.0	1.8 - 4.0
d_{crt} (m)	3.4	3.4	3.4	3.4	2.9
GWT (m)	1.22	1.3 ± 0.3	1.3	1.3 ± 0.1	1.3 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	63.4	53.7 ± 3.8	63.2	61.7 ± 4.1	52.8 ± 7.0
σ_v' (kPa)	42.2	33.3 ± 3.3	42.1	41.3 ± 2.3	37.0 ± 3.5
a_{max} (g)	0.12	0.120 ± 0.024	0.12	0.120 ± 0.036	0.120 ± 0.024
r_d	0.98	0.96 ± 0.050	0.96	0.97 ± 0.050	1.00 ± 0.044
CSR	0.115	0.120 ± 0.027	0.112	0.113 ± 0.035	0.111 ± 0.023
M_w	6.70	6.70	6.50	6.50	6.50
D_{50}	0.28	0.280 ± 0.030	-	0.280 ± 0.050	0.280 ± 0.050
% Fines	4	4.0 ± 1.0	4	4.0 ± 2.0	4.0 ± 8.6
% PI	-	-	-	-	0
N	7	7.1 ± 1.4	7	7.1 ± 1.5	5.0 ± 2.5
C_R	-	0.86	0.85	0.86	0.90
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.00	1.00	1.00	1.00	1.37
C_N	1.46	1.70	1.61	1.57	1.66
$(N_1)_{60}$	10	10.3 ± 2.0	9.6	9.6 ± 2.0	10.2 ± 5.1
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	189.0	-	189.0	256.0

EVENT PARAMETERS

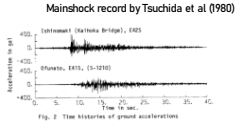
1978 Miyagiken-Oki
Magnitude: 6.50
Fault Type: thrust
Dip: 20

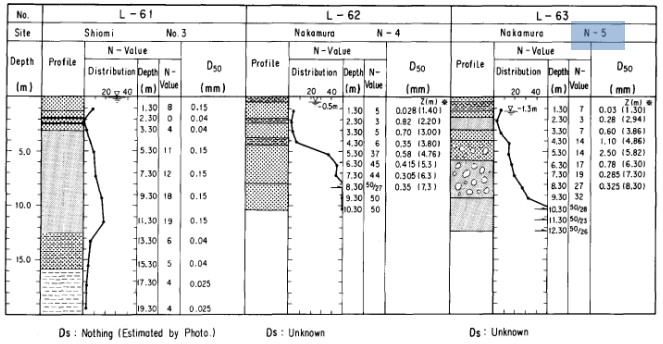
Seno et al (1980)
Length (km): 30
Z_{tor} (km): 0
Width (km): 80

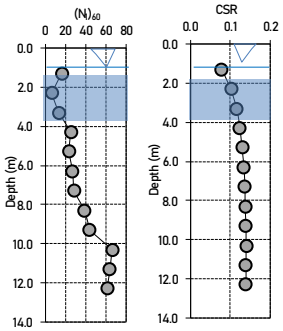
Foreshock parameters were assumed to be same with mainshock
R_{rup} (km): -
R_{jb} (km): 50-60 ± 30



Mainshock record by Tsuchida et al (1980)

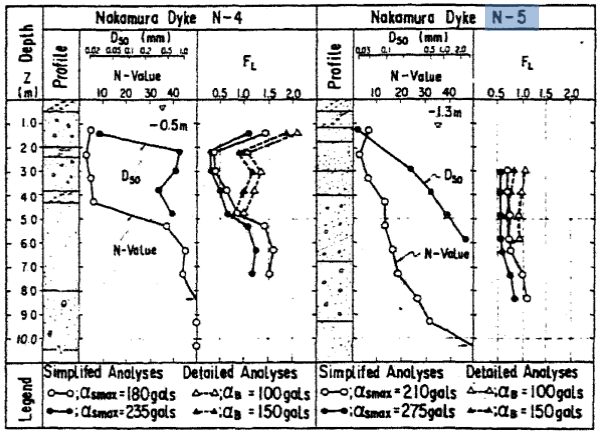






Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		
1.3	4.3	0.078	7	2.00	0.86	16.5	coarse sand	CN>2
2.3	***7.5***	***0.102***	***3***	***1.79***	***0.89***	***6.5***	***fine sand***	
3.3	***10.8***	***0.115***	***7***	***1.58***	***0.91***	***13.8***	***coarse sand***	
4.3	14.1	0.124	14	1.43	0.93	25.3	gravel and coarse sand	
5.3	17.4	0.129	14	1.31	0.94	23.7	gravel and coarse sand	
6.3	20.7	0.133	17	1.22	0.95	27.0	gravel and coarse sand	
7.3	24.0	0.136	19	1.15	0.96	28.7	sand with gravel	
8.3	27.2	0.138	27	1.09	0.97	38.8	sand with gravel	
9.3	30.5	0.139	32	1.03	0.97	44.0	fine sand	
10.3	33.8	0.139	50	0.99	0.98	66.1	fine sand	
11.3	37.1	0.139	50	0.95	0.98	63.6	fine sand	
12.3	40.4	0.138	50	0.91	0.99	61.4	fine sand	
					Mean:	10.2		
					St. Dev.	5.1		

Depth (m)	D50
1.3	0.030
2.9	***0.280***
3.9	***0.600***
4.9	1.100
5.8	2.500
6.3	0.780
7.3	0.285
8.3	0.325
Mean:	0.440
St. Dev.	0.226



(B) N-4 and N-5
(at non-liquefied sites)

Depth (m)		
0.0	0.5	silty sand
0.5	1.3	sandy silt
1.3	1.8	coarse sand
1.8	3.0	fine sand
3.0	4.0	coarse sand
4.0	6.8	gravel and coarse sand
6.8	9.3	sand with gravel
9.3	12.0	fine sand

Case number:	49
Earthquake:	1978 Miyagiken-Oki
Magnitude:	6.5
Location:	Oiiri 1
References:	Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), A.S. Cakmak (1986), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface evidence of liquefaction A.S. Cakmak (1986) "Soil Liquefaction Studies in Japan", Vol. 5 No.1 Jan 1986, Soil Dynamics & Earthquake Engineering.
GPS LAT	38.505719
GPS LONG	141.234144
Liq. layer consist of:	sand
Geological Unit:	river embankment
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. Only the Nakamura site liquefied during this earthquake. The subject zone is seismically very active and had been shaken in 1897 and 1936 by earthquakes of Magnitudes 7.3 and 7.7. Iwasaki et al (1978) paper did not mention Oiiri sites. However Cakmak et al. gave a representative depth vs. N profile for Oiiri 1. SPT values were taken after main earthquake (M=7.4). SPT energy is estimated as 60 % by Seed et al. (84)"

The borehole data is obtained from Iwasaki (1986). There are two borehole data available at the site.

Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.

PI is assigned as 0 as FC=5% by Seed et al (1985).

Vs12m is updated based on Vs-SPTN correlations.

Shiogama-kojyo-S	NS	EW	NS	EW	goe mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	goe mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	103.1	62
FS	61.1		0.062		0.062	50	
Ishinomaki	293		0.299		0.299	80	24

Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	4.3 - 7.6		4.3 - 7.6	5.8 - 6.8
d_{crt} (m)	6.4	5.9	6.4	5.9	6.3
GWT (m)	4.27	4.3 ± 0.6	4.3	4.3 ± 0.1	4.3 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 1.3	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 1.3	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	106.6	91.6 ± 10.9	106.3	105.6 ± 10.8	112.3 ± 3.9
σ_v' (kPa)	85.4	75.1 ± 8.5	85.2	89.1 ± 5.6	92.4 ± 2.8
a_{max} (g)	0.14	0.140 ± 0.024	0.14	0.140 ± 0.042	0.140 ± 0.028
r_d	0.95	0.73 ± 0.081	0.9	0.83 ± 0.081	0.86 ± 0.085
CSR	0.11	0.081 ± 0.018	0.102	0.090 ± 0.029	0.095 ± 0.021
M_w	6.70	6.70	6.50	6.50	6.50
D_{50}	0.34	0.340 ± 0.100	-	0.340 ± 0.050	0.340 ± 0.050
% Fines	5	5.0 ± 3.0	5	5.0 ± 2.0	5.0 ± 8.6
% PI	-	-	-	-	0
N	9	9.1 ± 1.7	9	9.2 ± 2.0	9.0 ± 1.5
C_R	-	0.95	0.95	0.95	0.95
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.00	1.00	1.00	1.00	1.37
C_N	1.05	1.13	1.10	1.07	1.05
$(N_1)_{60}$	9.5	9.8 ± 1.8	9.4	9.3 ± 2.0	12.3 ± 2.0
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	149.4	-	160.0	172.2

EVENT PARAMETERS

1978 Miyagiken-Oki — Seno et al (1980)

Magnitude: 6.50 — Length (km): 30

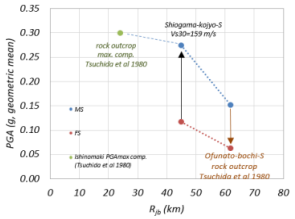
Fault Type: thrust — Z_{tor} (km): 0

Dip: 20 — Width (km): 80

Foreshock parameters were assumed to be same with mainshock

R_{rup} (km): -

R_{jb} (km): 30-35 ± 30



Mainshock record by Tsuchida et al (1980)

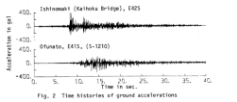
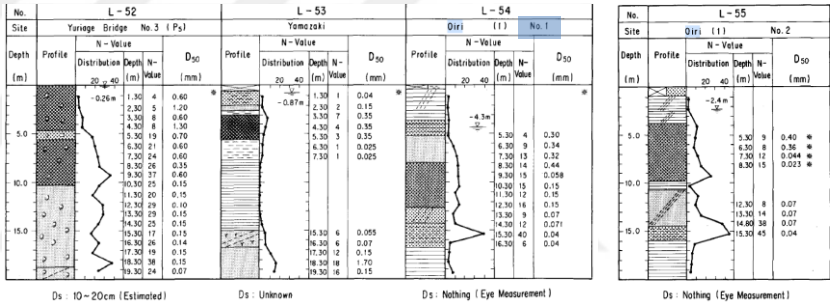
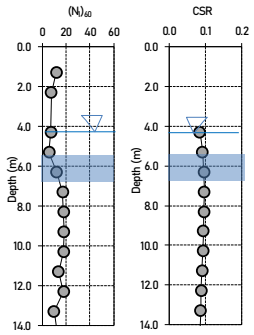


Fig. 2 Time histories of ground accelerations



Appendix 18



No:1		No:2	
Depth (m)	**N**	**Depth (m)**	**N**
1.3	5 clayey silt	1.3	2 silty clay
2.3	4 clayey silt	2.3	2 silty clay
4.3	5 sandy clay	4.3	11 coarse sand
5.3	4 sand	5.3	9 coarse sand
6.3	9 sand	6.3	8 coarse sand
7.3	13 sand	7.3	12 coarse sand
8.3	14 medium sa	8.3	15 coarse sand
9.3	15 medium sa	9.3	25 coarse sand
10.3	15 medium sa	10.3	3 clay
11.3	12 medium sa	11.3	12 silty sand
12.3	16 medium sa	12.3	8 silty sand
13.3	9 silty sand	13.3	14 silty sand
14.3	12 sandy silt	14.3	38 silty sand
15.3	40 sandy silt	15.3	45 sandy silt
16.3	6 sandy silt	16.3	9 clay
		17.3	6 clay
		18.3	5 clay
		19.3	4 clay

GWT (m)

4.3	No:1
2.4	No:2

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	D50	
1.3	4.3	NA	5	2.00	0.86	11.8		clayey silt
2.3	7.5	NA	4	1.60	0.89	7.8		clayey silt
4.3	14.1	0.085	5	1.17	0.93	7.4		sandy clay
5.3	17.4	0.091	4	1.10	0.94	5.7	0.30	sand transion zone. clayey? hence excluded.
6.3	***20.7***	***0.095***	***9***	***1.05***	***0.95***	***12.3***	***0.34***	***sand***
7.3	24.0	0.097	13	1.00	0.96	17.1	0.32	sand
8.3	27.2	0.096	14	0.96	0.97	17.8	0.44	medium sand
9.3	30.5	0.095	15	0.92	0.97	18.4	0.06	medium sand
10.3	33.8	0.093	15	0.89	0.98	17.8	0.15	medium sand
11.3	37.1	0.090	12	0.86	0.98	13.8	0.15	medium sand
12.3	40.4	0.088	16	0.83	0.99	17.9	0.15	medium sand
13.3	43.6	0.087	9	0.81	0.99	9.8	0.07	silty sand
14.3	46.9	0.085	12	0.78	0.99	12.8	0.07	sandy silt
15.3	50.2	0.085	40	0.76	0.99	41.5	0.04	sandy silt
16.3	53.5	0.084	6	0.74	0.99	6.1	0.04	sandy silt
					Mean:	12.3	0.34	
					St. Dev.	2.0	0.05	

Case number:	51
Earthquake:	1978 Miyagiken-Oki
Magnitude:	6.5
Location:	Yuriage Bridge 1
References:	Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface evidence of liquefaction
GPS LAT	38.182134
GPS LONG	140.946729
Liq. layer consist of:	fine sand with gravel
Geological Unit:	river deposit
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. Only the Nakamura site liquefied during this earthquake. The subject zone is seismically very active and had been shaken in 1897 and 1936 by the earthquakes of Magnitudes 7.3 and 7.7. SPT values were taken after main earthquake (M=7.4). SPT energy was estimated as 60 % by Seed et al. (1984)"
	The river bed was dry during the earthquake.
	The boiled sand was a poorly graded coarse sand.
	The ground around the piers settled and sand boils were observed.
	Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.

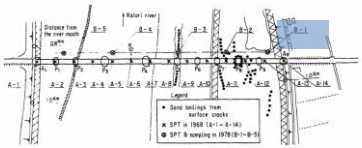


Fig. 10 Points of Sand Boils and Insitu Soil Tests at Yuriage Bridge

Shiogama-kojyo-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	103.1	62
FS	61.1		0.062	-	0.062	50	
Ishinomaki	293		0.299		0.299	80	24

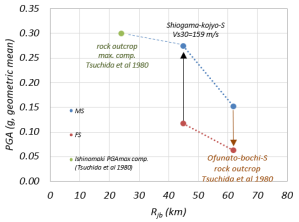
Gravel Content (%):	fine sand with gravel (content unkown)
CPT available:	**No**
Vs available:	**No**

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	3.0 - 4.0		3.0 - 4.0	2.8 - 4.8
d_{crt} (m)	4.3	3.5	4.3	3.5	3.8
GWT (m)	1.83	1.7 ± 0.3	1.8	1.7 ± 0.1	1.7 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	15.7 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.1 ± 0.5	20.6 ± 0.5
σ_v (kPa)	80.6	55.0 ± 3.2	80.2	59.2 ± 3.3	72.8 ± 7.0
σ_v' (kPa)	56.6	37.4 ± 3.2	56.1	41.6 ± 1.9	52.1 ± 3.9
a_{max} (g)	0.12	0.120 ± 0.024	0.12	0.120 ± 0.036	0.120 ± 0.024
r_d	0.97	0.94 ± 0.051	0.94	0.98 ± 0.051	0.99 ± 0.055
CSR	0.11	0.108 ± 0.024	0.105	0.109 ± 0.033	0.107 ± 0.023
M_w	6.70	6.70	6.50	6.50	6.50
D_{50}	0.4	0.400 ± 0.100	-	0.400 ± 0.050	0.280 ± 0.184
% Fines	10	5.0 ± 1.0	10	10.0 ± 2.0	10.0 ± 8.6
% PI	-	-	-	-	NAV
N	4	3.0 ± 1.3	4	3.0 ± 1.3	3.0 ± 1.3
C_R	-	0.87	0.95	0.87	0.92
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.00	1.00	1.00	1.00	1.37
C_N	1.27	1.60	1.41	1.56	1.40
$(N_1)_{60}$	5	4.1 ± 1.8	5.4	4.0 ± 1.8	5.2 ± 2.2
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	182.9	-	204.2	219.5

EVENT PARAMETERS

1978 Miyagiken-Oki	Seno et al (1980)	Foreshock parameters were assumed to be same with mainshock
Magnitude: 6.50	Length (km): 30	R_{rup} (km): -
Fault Type: thrust	Z_{tor} (km): 0	R_{jb} (km): 50-60 ± 30
Dip: 20	Width (km): 80	



Mainshock record by Tsuchida et al (1980)

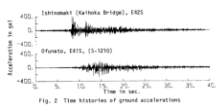


Fig. 2 Time histories of ground accelerations

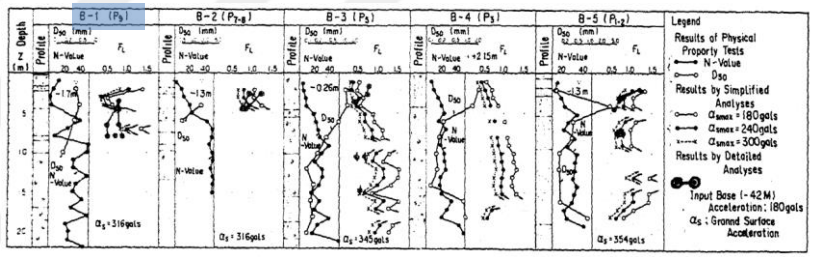
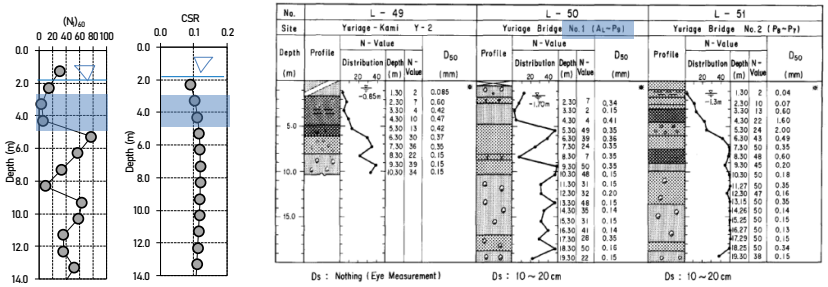


Fig. 11 F_L-values at Yuriage Bridge
(B-1, B-2, B-3; liquefied, B-4; liquefaction unconfirmed,
B-5; non-liquefied)



Appendix 17

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	D_{50}	
1.3	4.3	NA	13	2.00	0.86	30.7		fine sand with gravel close to surf.
2.3	7.5	0.090	7	1.68	0.89	14.3	0.340	fine sand with gravel fines transition
3.3	***10.8***	***0.103***	***2***	***1.47***	***0.91***	***3.7***	***0.150***	fine sand with gravel
4.3	***14.1***	***0.111***	***4***	***1.33***	***0.93***	***6.7***	***0.410***	fine sand with gravel
5.3	17.4	0.115	49	1.22	0.94	76.8	0.350	medium sand
6.3	20.7	0.118	39	1.13	0.95	57.5	0.360	medium sand
7.3	24.0	0.119	24	1.06	0.96	33.5	0.350	medium sand
8.3	27.2	0.120	7	1.00	0.97	9.3	0.350	medium sand with humus
9.3	30.5	0.119	50	0.95	0.97	63.5	0.350	medium sand
10.3	33.8	0.117	48	0.91	0.98	58.5	0.150	medium sand
11.3	37.1	0.115	31	0.87	0.98	36.4	0.150	fine sand with shell
12.3	40.4	0.112	32	0.84	0.99	36.2	0.200	fine sand with shell
13.3	43.6	0.109	48	0.81	0.99	52.5	0.150	fine sand with shell
14.3	46.9	0.106	35	0.78	0.99	37.1	0.140	fine sand with shell
15.3	50.2	0.104	31	0.76	0.99	31.9	0.150	fine sand with shell
16.3	53.5	0.102	41	0.74	0.99	41.0	0.140	fine sand with shell
17.3	56.8	0.100	28	0.72	0.99	27.3	0.350	medium sand with shell
18.3	60.0	0.099	50	0.70	1.00	47.5	0.160	medium sand with shell
19.3	63.3	0.098	22	0.68	1.00	20.4	0.150	fine sand with shell
					Mean:	5.2	0.280	
					St. Dev.	2.2	0.184	

Case number:	52
Earthquake:	1978 Miyagiken-Oki
Magnitude:	6.5
Location:	Yuriage Bridge 2
References:	Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Iwasaki (1986), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface evidence of liquefaction
GPS LAT:	38.182134
GPS LONG:	140.946729
Liq. layer consist of:	sand
Geological Unit:	river deposit
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. Only the Nakamura site liquefied during this earthquake. The subject zone is seismically very active and had been shaken in 1897 and 1936 by earthquakes of Magnitudes 7.3 and 7.7. Gravel percent exceeds 20 % by weight. (Seed et al, 84). SPT values were taken after main earthquake (M=7.4). SPT energy was estimated as 67 % by Seed et al. (84)"

Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax). Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.

The river bed was dry during the earthquake.

The boiled sand was a poorly graded coarse sand.

The ground around the piers settled and sand boils were observed.

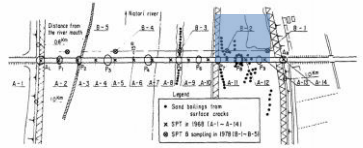


Fig. 10 Points of Sand Boils and Insitu Soil Tests at Yuriage Bridge

Shiogama-kojyo-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	103.1	62
FS	61.1		0.062		0.062	50	
Ishinomaki	293		0.299		0.299	80	24

Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	B	-	B	B
d_{crc} range (m)	-	1.8 - 3.0		1.8 - 3.0	1.8 - 3.8
d_{crc} (m)	3.4	2.4	2.5	2.4	2.8
GWT (m)	1.22	1.3 ± 0.3	1.2	1.3 ± 0.1	1.3 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	63.4	38.3 ± 3.6	46.1	42.9 ± 4.1	51.7 ± 6.9
σ_v' (kPa)	42.2	27.1 ± 3.1	34.1	31.7 ± 2.2	36.8 ± 3.7
a_{max} (g)	0.12	0.120 ± 0.024	0.12	0.120 ± 0.036	0.120 ± 0.024
r_d	0.98	0.98 ± 0.038	0.96	1.00 ± 0.038	1.00 ± 0.043
CSR	0.115	0.108 ± 0.025	0.112	0.105 ± 0.032	0.109 ± 0.023
M_w	6.70	6.70	6.50	6.50	6.50
D_{50}	1.6	1.600 ± 0.200	-	1.600 ± 0.050	0.335 ± 0.375
% Fines	7	7.0 ± 1.0	7	7.0 ± 2.0	7.0 ± 8.6
% PI	-	-	-	-	NAV
N	13	11.4 ± 1.6	10.1	11.4 ± 1.3	11.5 ± 1.1
C_R	-	0.82	0.85	0.82	0.90
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.12	1.12	1.12	1.12	1.37
C_N	1.46	1.88	1.68	1.79	1.66
$(N_1)_{60}$	21.5	19.7 ± 2.8	16.2	18.7 ± 2.2	23.5 ± 2.3
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	201.2	-	228.6	274.3

EVENT PARAMETERS

1978 Miyagiken-Oki — Seno et al (1980)

Magnitude: 6.50 — Length (km): 30

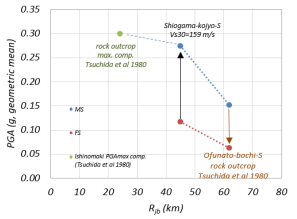
Fault Type: thrust — Z_{tor} (km): 0

Dip: 20 — Width (km): 80

Foreshock parameters were assumed to be same with mainshock

R_{rup} (km): -

R_{jb} (km): 50-60 ± 30



Mainshock record by Tsuchida et al (1980)

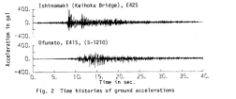


Fig. 2 Time histories of ground accelerations

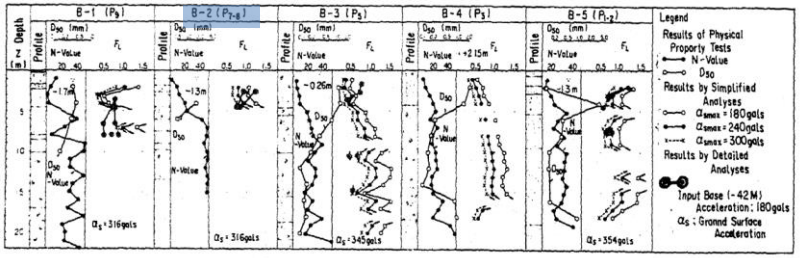
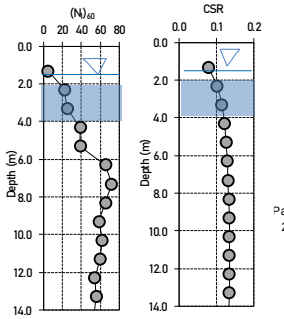
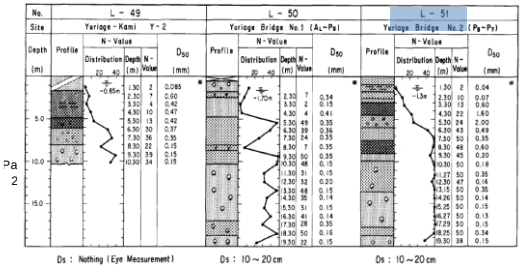


Fig. 11 FL-values at Yuriage Bridge
(B-1, B-2, B-3; liquefied, B-4; liquefaction unconfirmed,
B-5; non-liquefied)



References: Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Iwasaki (1986), Cetin (2000), Cetin et al (2004, 2018)



Appendix 17

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	D50	
1.3	4.3	0.078	2	2.00	0.86	4.7	0.040	sandy silt close to surf.
2.3	***7.5***	***0.102***	***10***	***1.80***	***0.89***	***21.9***	***0.070***	medium sand
3.3	***10.8***	***0.114***	***13***	***1.55***	***0.91***	***25.1***	***0.600***	coarse sand
4.3	14.1	0.121	22	1.39	0.93	38.6	1.600	coarse sand
5.3	17.4	0.126	24	1.26	0.94	39.0	2.000	medium sand with gravel
6.3	20.7	0.129	43	1.17	0.95	65.3	0.490	medium sand
7.3	24.0	0.131	50	1.09	0.96	71.6	0.350	medium sand
8.3	27.2	0.133	48	1.03	0.97	65.3	0.600	coarse sand
9.3	30.5	0.134	45	0.97	0.97	58.4	0.200	fine sand
10.3	33.8	0.134	50	0.93	0.98	62.1	0.180	medium sand with shell
11.3	37.1	0.135	50	0.89	0.98	59.7	0.350	medium sand with shell
12.3	40.4	0.134	47	0.85	0.99	54.1	0.160	medium sand with shell
13.3	43.6	0.134	50	0.82	0.99	55.6	0.350	medium sand with shell
14.3	46.9	0.133	50	0.79	0.99	53.8	0.140	fine sand with shell
15.3	50.2	0.132	50	0.77	0.99	52.2	0.150	fine sand with shell
16.3	53.5	0.131	50	0.75	0.99	50.7	0.130	fine sand with shell
17.3	56.8	0.129	50	0.72	0.99	49.3	0.150	fine sand with shell
18.3	60.0	0.128	50	0.71	1.00	48.0	0.340	medium sand
19.3	63.3	0.127	38	0.69	1.00	35.6	0.150	fine sand with gravel
					Mean:	23.5	0.335	
					St. Dev.	2.3	0.375	

Case number:	53
Earthquake:	1978 Miyagiken-Oki
Magnitude:	6.5
Location:	Yuriage Bridge 3
References:	Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Iwasaki (1986), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface evidence of liquefaction
GPS LAT	38.182134
GPS LONG	140.946729
Liq. layer consist of:	coarse sand with shell
Geological Unit:	river deposit
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. Only the Nakamura site liquefied during this earthquake. The subject zone is seismically very active and had been shaken in 1897 and 1936 by the earthquakes of Magnitudes 7.3 and 7.7 SPT values were taken after main earthquake (M=7.4) SPT energy was estimated as 60 % by Seed et al. (84)"
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.

The river bed was dry during the earthquake.
The boiled sand was a poorly graded coarse sand.
The ground around the piers settled and sand boils were observed.

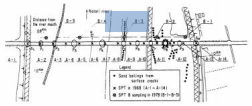


Fig. 10 Points of Sand Boils and Insitu Soil Tests at Yuriage Bridge

Shiogama-kojyo-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	103.1	62
FS	61.1		0.062		0.062	50	
Ishinomaki	293		0.299		0.299	80	24

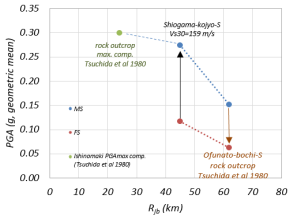
Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	B	-	B	B
d_{crc} range (m)	-	2.0 - 4.0		2.0 - 4.0	2.0 - 4.6
d_{crt} (m)	4.3	3.0	4.3	3.0	3.3
GWT (m)	0.30	0.3 ± 0.2	0.3	0.3 ± 0.1	0.3 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	80.6	49.2 ± 5.8	80.2	56.3 ± 6.4	62.0 ± 8.3
σ_v' (kPa)	41.8	22.3 ± 3.1	42.1	29.4 ± 3.4	32.1 ± 4.3
a_{max} (g)	0.12	0.120 ± 0.024	0.12	0.120 ± 0.036	0.120 ± 0.024
r_d	0.97	0.96 ± 0.045	0.94	0.98 ± 0.045	0.99 ± 0.049
CSR	0.145	0.166 ± 0.036	0.142	0.147 ± 0.045	0.150 ± 0.031
M_w	6.70	6.70	6.50	6.50	6.50
D_{50}	1.2	1.200 ± 0.200	-	1.200 ± 0.050	1.033 ± 0.379
% Fines	12	12.0 ± 2.0	12	12.0 ± 2.0	12.0 ± 8.6
% PI	-	-	-	-	NAV
N	8	7.1 ± 1.2	8	7.1 ± 1.0	6.9 ± 1.3
C_R	-	0.85	0.95	0.85	0.91
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.00	1.00	1.00	1.00	1.37
C_N	1.47	2.00	1.56	1.86	1.78
$(N_1)_{60}$	12	12.0 ± 2.1	11.8	11.2 ± 1.5	15.3 ± 2.8
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	189.0	-	201.2	231.6

EVENT PARAMETERS

1978 Miyagiken-Oki — Seno et al (1980)
Magnitude: 6.50 — Length (km): 30
Fault Type: thrust — Z_{tor} (km): 0
Dip: 20 — Width (km): 80

Foreshock parameters were assumed to be same with mainshock
R_{rup} (km): -
R_{jb} (km): 50-60 ± 30



Mainshock record by Tsuchida et al (1980)

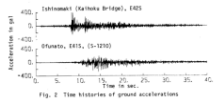


Fig. 2 Time histories of ground accelerations

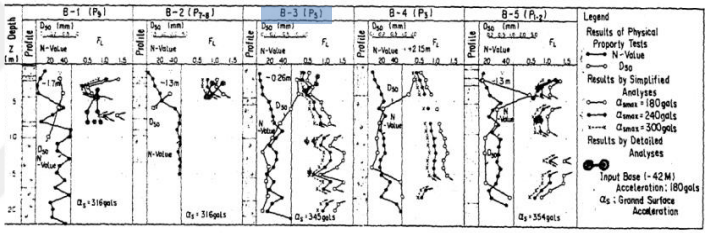
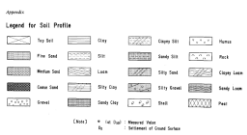
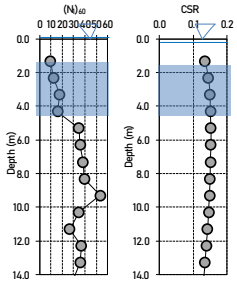
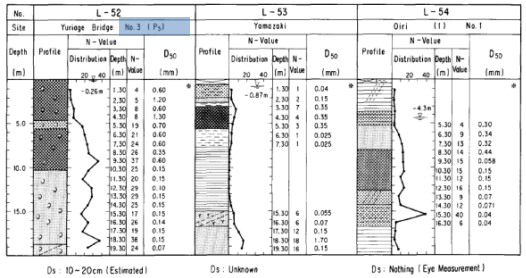


Fig. 11 F_L-values at Yuriage Bridge
(B-1, B-2, B-3; liquefied, B-4; liquefaction unconfirmed, B-5; non-liquefied)



References: Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Iwasaki (1986), Cetin (2000), Cetin et al (2004, 2





Appendix 18

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$			D50
1.3	4.3	0.135	4	2.00	0.86	9.4	coarse sand with shell	close to surf.	0.600
2.3	***7.5***	***0.145***	***5***	***2.00***	***0.89***	***12.2***	coarse sand with shell		***1.200***
3.3	***10.8***	***0.150***	***8***	***1.78***	***0.91***	***17.7***	coarse sand with shell		***0.600***
4.3	***14.1***	***0.152***	***8***	***1.57***	***0.93***	***15.9***	coarse sand with shell		***1.300***
5.3	17.4	0.152	19	1.42	0.94	34.7	medium sand with shell		0.700
6.3	20.7	0.152	21	1.31	0.95	35.7	coarse sand with shell		0.600
7.3	24.0	0.152	24	1.22	0.96	38.4	coarse sand with shell		0.600
8.3	27.2	0.150	26	1.15	0.97	39.4	coarse sand with shell		0.350
9.3	30.5	0.148	37	1.08	0.97	53.4	coarse sand with shell		0.600
10.3	33.8	0.146	25	1.03	0.98	34.5	fine sand with shell		0.150
11.3	37.1	0.143	20	0.99	0.98	26.5	fine sand with shell		0.150
12.3	40.4	0.139	29	0.95	0.99	36.9	fine sand with shell		0.100
13.3	43.6	0.136	29	0.91	0.99	35.6	fine sand with shell		0.150
14.3	46.9	0.132	25	0.88	0.99	29.7	fine sand with shell		0.150
15.3	50.2	0.129	17	0.85	0.99	19.6	fine sand with shell		0.150
16.3	53.5	0.126	26	0.82	0.99	29.1	fine sand with shell		0.140
17.3	56.8	0.123	19	0.80	0.99	20.6	fine sand with shell		0.150
18.3	60.0	0.121	38	0.78	1.00	40.2	fine sand with shell		0.150
19.3	63.3	0.119	24	0.76	1.00	24.8	silty fine sand with shell		0.070
				Mean:		15.3		**Mean:**	1.033
				St. Dev.		2.8		**St. Dev.**	0.379

Case number:	55
Earthquake:	1978 Miyagiken-Oki
Magnitude:	6.5
Location:	Yuriagekami-2
References:	Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Iwasaki (1986), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface evidence of liquefaction
GPS LAT	38.189551
GPS LONG	140.934866
Liq. layer consist of:	sand
Geological Unit:	river embankment
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. Only the Nakamura site liquefied during this earthquake. The subject zone is seismically very active and had been shaken in 1897 and 1936 by the earthquakes of Magnitudes 7.3 and 7.7. SPT values were taken after main earthquake (M=7.4). SPT energy was estimated as 60 % by Seed et al. (84)"
	The borehole data is redigitized from Iwasaki (1986)
	Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.
	PI is assigned as 0 as FC=0 by Prof. Seed.
	Vs12m is updated based on Vs - SPTN correlations.
Gravel Content (%):	NAV
CPT available:	**No**
Vs available:	**No**

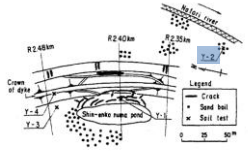


Fig. 7 Plan of Yuriage-kami Dyke and Points of Soil Tests

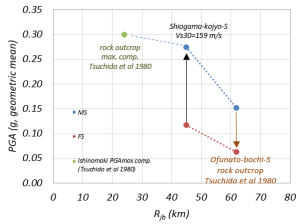
Shiogama-kojyo-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	103.1	62
FS	61.1		0.062		0.062	50	
Ishinomaki	293		0.299		0.299	80	24

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	2.0 - 5.5		2.0 - 5.5	2.0 - 5.5
d_{crt} (m)	4.3	3.8	4.3	3.8	3.8
GWT (m)	0.91	0.9 ± 0.3	0.9	0.9 ± 0.1	0.9 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	80.6	60.7 ± 9.8	80.2	68.2 ± 11.1	68.2 ± 11.1
σ_v' (kPa)	47.5	32.2 ± 5.0	47.1	39.7 ± 5.5	39.7 ± 5.5
a_{max} (g)	0.12	0.120 ± 0.024	0.12	0.120 ± 0.036	0.120 ± 0.024
r_d	0.97	0.95 ± 0.055	0.94	0.96 ± 0.055	0.99 ± 0.055
CSR	0.13	0.139 ± 0.032	0.125	0.129 ± 0.040	0.133 ± 0.028
M_w	6.70	6.70	6.50	6.50	6.50
D_{50}	0.4	0.400 ± 0.100	-	0.400 ± 0.050	0.478 ± 0.085
% Fines	0	0.0 ± 0.0	0	0.0 ± 2.0	0.0 ± 8.6
% PI	-	-	-	-	0
N	11	8.8 ± 3.4	11	8.8 ± 3.3	8.4 ± 3.1
C_R	-	0.88	0.95	0.88	0.92
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.00	1.00	1.00	1.00	1.37
C_N	1.38	1.73	1.45	1.60	1.60
$(N_1)_{60}$	15	13.3 ± 5.2	15.1	12.3 ± 4.7	16.8 ± 6.2
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	189.0	-	189.0	240.8

EVENT PARAMETERS

1978 Miyagiken-Oki	Seno et al (1980)	Foreshock parameters were assumed to be same with mainshock
Magnitude: 6.50	Length (km): 30	R_{rup} (km): -
Fault Type: thrust	Z_{tor} (km): 0	R_{jb} (km): 50-60 ± 30
Dip: 20	Width (km): 80	



Mainshock record by Tsuchida et al (1980)

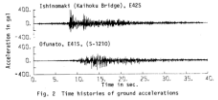
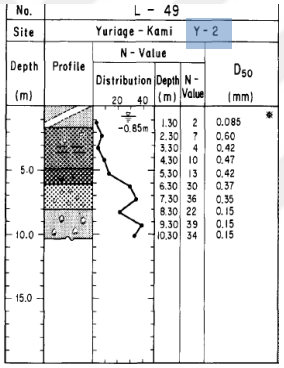


Fig. 2 Time histories of ground accelerations



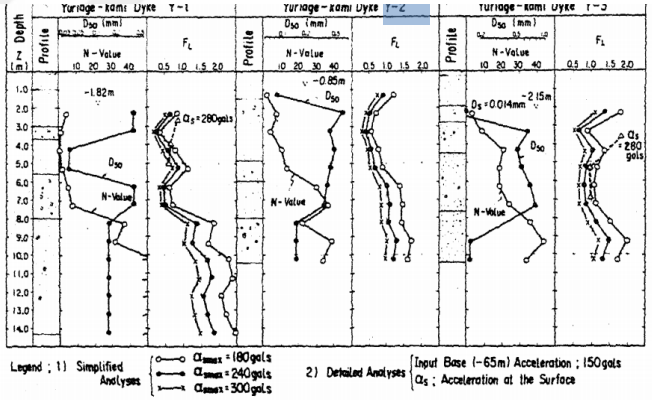
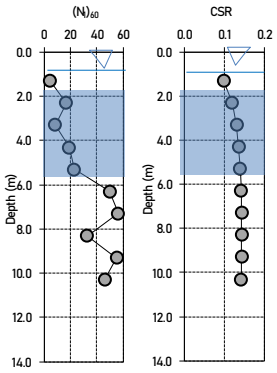


Fig. 9 F_L-values at Yuriage-kami Dyke
(Y-1, Y-2; liquefied, Y-3; non-liquefied)



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	D50 (mm)	
1.3	4.3	0.098	2	2.00	0.86	4.7	0.085	silty sand close to surf.
2.3	***7.5***	***0.120***	***7***	***1.96***	***0.89***	***16.6***	***0.600***	medium sand
3.3	***10.8***	***0.130***	***4***	***1.69***	***0.91***	***8.4***	***0.420***	medium sand
4.3	***14.1***	***0.136***	***10***	***1.51***	***0.93***	***19.1***	***0.470***	medium sand
5.3	***17.4***	***0.140***	***13***	***1.37***	***0.94***	***23.0***	***0.420***	coarse sand
6.3	20.7	0.142	30	1.27	0.95	49.6	0.370	medium sand with gravel
7.3	24.0	0.143	36	1.19	0.96	56.2	0.350	medium sand with gravel
8.3	27.2	0.144	22	1.12	0.97	32.6	0.150	fine sand with shell
9.3	30.5	0.143	39	1.06	0.97	55.1	0.150	fine sand with shell
10.3	33.8	0.142	34	1.01	0.98	46.0	0.150	fine sand with shell
					Mean:	16.8	0.478	
					St. Dev.	6.2	0.085	

Depth (m)		
0	1.7	silty sand
1.7	4.9	medium sand
4.9	6.1	coarse sand
6.1	8	medium sand with gravel
8	10.2	fine sand with shell

Case number:	424
Earthquake:	1978 Miyagiken-Oki
Magnitude:	6.5
Location:	Oiiri 2
References:	Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), A.S. Cakmak (1986), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface evidence of liquefaction — A.S. Cakmak (1986) "Soil Liquefaction Studies in Japan",
GPS LAT	38.505719 — coordinates are taken from NGL project, the exact location is unkown n. — Vol. 5 No.1 Jan 1986, Soil Dynamics & Earthquake Engineering.
GPS LONG	141.234144
Liq. layer consist of:	coarse sand
Geological Unit:	river embankment
Site Response Anlaysis:	No
Comments:	

The borehole data is obtained from Iwasaki (1986). There are two borehole data available at the site.

Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.

PI is assigned as 0 as FC=5% by Seed et al (1985).

Vs12m is updated based on Vs-SPTN correlations.

The borehole data for Oiri 2 is found and included. The site was not included in Idriss and Boulanger (2010) and Cetin et al. (2004, 2018)

Shiogama-kojyo-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	103.1	62
FS	61.1		0.062		0.062	50	
Ishinomaki	293		0.299		0.299	80	24

Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	-	-	-	No
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	3.8 - 6.8
d_{crt} (m)	6.4	-	-	-	5.3
GWT (m)	2.44	-	-	-	2.4 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	114.7	-	-	-	101.4 ± 10.5
σ_v' (kPa)	75.8	-	-	-	72.9 ± 5.7
a_{max} (g)	0.14	-	-	-	0.140 ± 0.028
r_d	0.95	-	-	-	0.93 ± 0.073
CSR	0.13	-	-	-	0.118 ± 0.026
M_w	6.70	-	-	-	6.50
D_{50}	0.36	-	-	-	0.340 ± 0.050
% Fines	4	-	-	-	4.0 ± 8.6
% PI	-	-	-	-	0
N	8	-	-	-	9.4 ± 2.1
C_R	-	-	-	-	0.94
C_s	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	1.11	-	-	-	1.18
$(N_1)_{60}$	9	-	-	-	14.3 ± 3.2
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	189.0

EVENT PARAMETERS

1978 Miyagiken-Oki — Seno et al (1980)

Magnitude: 6.50 — Length (km): 30

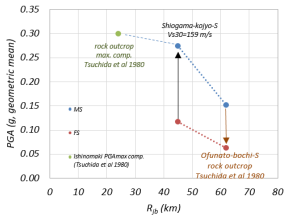
Fault Type: thrust — Z_{tor} (km): 0

Dip: 20 — Width (km): 80

Foreshock parameters were assumed to be same with mainshock

R_{rup} (km): -

R_{jb} (km): 30-35 ± 30



Mainshock record by Tsuchida et al (1980)

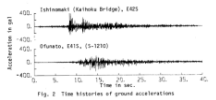
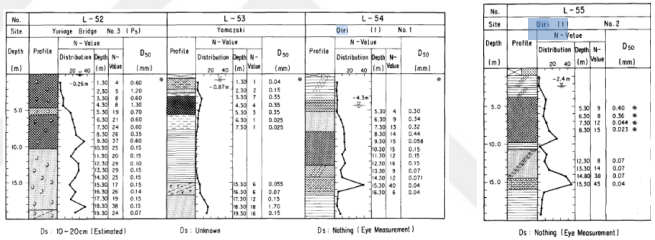


Fig. 2 Time histories of ground accelerations

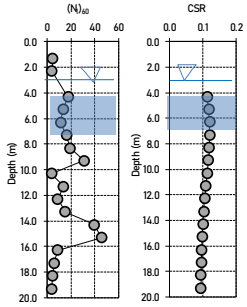
References: Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), A.S. Cakmak (1986), Cetin (2000), Cetin et al (2004, 2018)



Appendix 18

GWT (m)

4.3	No:1
2.4	No:2



No:1 Depth (m)	N		No:2 Depth (m)	N	
1.3	5	clayey silt	1.3	2	silty clay
2.3	4	clayey silt	2.3	2	silty clay
4.3	5	sandy clay	4.3	11	coarse sand
5.3	4	sand	5.3	9	coarse sand
6.3	9	sand	6.3	8	coarse sand
7.3	13	sand	7.3	12	coarse sand
8.3	14	medium sa	8.3	15	coarse sand
9.3	15	medium sa	9.3	25	coarse sand
10.3	15	medium sa	10.3	3	clay
11.3	12	medium sa	11.3	12	silty sand
12.3	16	medium sa	12.3	8	silty sand
13.3	9	silty sand	13.3	14	silty sand
14.3	12	sandy silt	14.3	38	silty sand
15.3	40	sandy silt	15.3	45	sandy silt
16.3	6	sandy silt	16.3	9	clay
			17.3	6	clay
			18.3	5	clay
			19.3	4	clay

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	D50	
1.3	4.3	NA	2	2.00	0.86	4.7		silty clay
2.3	7.5	NA	2	1.60	0.89	3.9		silty clay
4.3	***14.1***	***0.113***	***11***	***1.28***	***0.93***	***17.8***		coarse sand
5.3	***17.4***	***0.118***	***9***	***1.18***	***0.94***	***13.7***	***0.40***	coarse sand
6.3	***20.7***	***0.121***	***8***	***1.10***	***0.95***	***11.5***	***0.36***	*coarse sand*
7.3	24.0	0.121	12	1.04	0.96	16.3	0.04	coarse sand
8.3	27.2	0.119	15	0.98	0.97	19.5	0.02	coarse sand
9.3	30.5	0.117	25	0.94	0.97	31.1		coarse sand
10.3	33.8	0.113	3	0.89	0.98	3.6		clay
11.3	37.1	0.110	12	0.86	0.98	13.8		silty sand
12.3	40.4	0.106	8	0.83	0.99	8.9	0.07	silty sand
13.3	43.6	0.103	14	0.80	0.99	15.1	0.07	silty sand
14.3	46.9	0.100	38	0.77	0.99	39.8	0.07	silty sand
15.3	50.2	0.098	45	0.75	0.99	45.7	0.04	sandy silt
16.3	53.5	0.097	9	0.73	0.99	8.9		clay
17.3	56.8	0.096	6	0.71	0.99	5.8		clay
18.3	60.0	0.095	5	0.69	1.00	4.7		clay
19.3	63.3	0.094	4	0.67	1.00	3.7		clay
					Mean:	14.3	0.380	
					St. Dev.	3.2	0.028	

Late Prof Seed selected this layer. Dcrt=6.3 SPTN=8 D50=0.36

D50=0.04 sand? Silt? PI unkown

D50=0.02 sand? Silt? PI unkown

outlier

No information regarding PI of this layer. Prof. Seed might have information that we cannot acces hence his selection was kept.

Case number:	56
Earthquake:	1978 Miyagiken-Oki
Magnitude:	7.7 (Mw) USGS Centennial Earthquake Catalog
Location:	Nakajima-18
References:	Tsuchida et al (1979, 1980), Fear et al. (1995), Tohno et al (1981), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefied
GPS LAT	38.415014
GPS LONG	141.26592
Liq. layer consist of:	sand
Geological Unit:	Artificially filled sand next to ocean
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. Only the Nakamura site liquefied during this earthquake. The subject zone is seismically very active and had been shaken in 1897 and 1936 by earthquakes of Magnitudes 7.3 and 7.7. The original Tsuchida (1979) paper (in Japanese) could not be accessed. However the same author's paper of 1980 in English was used to obtain borelogs. Nakajima 18 site was identified as Site A by Tokimatsu (1983). SPT energy is estimated as 65 % by Seed et al. (1984)"

The original Tsuchida (1979) paper (in Japanese) is accessed. CB-15 seems to fit the data of Site A. The SPT values are redigitized. All the sites are artificially filled sand

Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.

PI is assigned as 0 since FC=3%.



Shiogama-kojyo-S	NS	EW	NS	EW	goe mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	goe mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	103.1	62
FS	61.1		0.062		0.062	50	
Ishinomaki	293		0.299		0.299	80	24

Gravel Content (%):	0.00
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	2.4 - 6.1		2.4 - 6.1	2.4 - 6.1
d_{crt} (m)	6.1	4.3	6.1	4.3	4.3
GWT (m)	2.44	2.4 ± 0.3	2.4	2.4 ± 0.1	2.4 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	18.1 ± 0.9	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	115.2	71.5 ± 11.3	115.3	78.2 ± 12.1	80.0 ± 12.7
σ_v' (kPa)	79.2	53.5 ± 6.0	79.2	60.3 ± 6.2	62.0 ± 6.8
a_{max} (g)	0.24	0.240 ± 0.048	0.24	0.240 ± 0.072	0.240 ± 0.048
r_d	0.96	0.92 ± 0.061	0.96	0.97 ± 0.061	0.97 ± 0.061
CSR	0.22	0.192 ± 0.043	0.217	0.197 ± 0.061	0.195 ± 0.042
M_w	7.40	7.40	7.70	7.70	7.70
D_{50}	0.35	0.350 ± 0.050	-	0.350 ± 0.050	0.350 ± 0.050
% Fines	3	3.0 ± 1.0	3	3.0 ± 2.0	3.0 ± 8.6
% PI	-	-	-	-	0
N	12	9.6 ± 4.0	12	9.6 ± 3.9	10.0 ± 4.3
C_R	-	0.90	0.95	0.90	0.93
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.09	1.09	1.09	1.09	1.37
C_N	1.09	1.34	1.13	1.30	1.28
$(N_1)_{60}$	14.5	12.6 ± 5.3	14.1	12.2 ± 5.0	16.2 ± 6.9
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	179.8	-	198.1	198.1

EVENT PARAMETERS

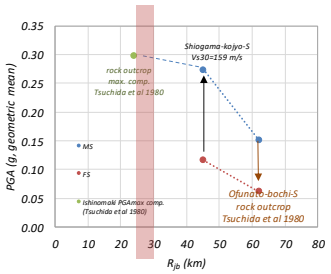
1978 Miyagiken-Oki

Magnitude: 7.70
Fault Type: thrust
Dip: 20

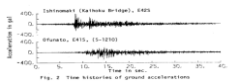
Seno et al (1980)

Length (km): 30
Z_{tor} (km): 0
Width (km): 80

Foreshock parameters were assumed to be same with mainshock
R_{rup} (km): -
R_{jb} (km): 25-30



Mainshock record by Tsuchida et al (1980)



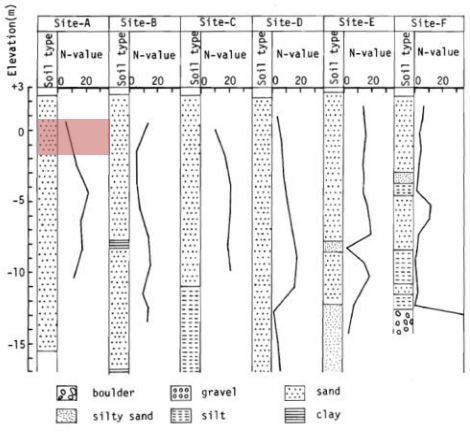
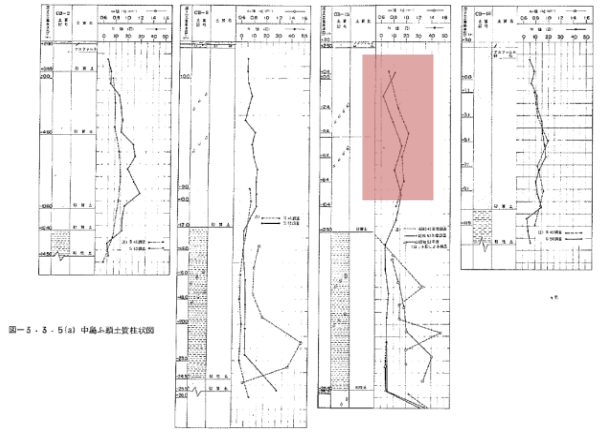


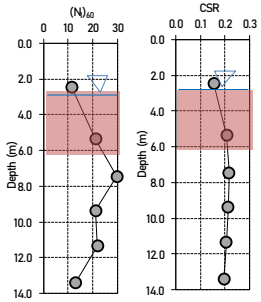
Fig. 3 Soil types and N-values of standard penetration test



図－5・8・5(a) 中島ふ頭土質柱状図

Pa

2116.22



References: Tsuchida et al (1979, 1980), Fear et al. (1995), Tohno et al (1981), Cetin (2000), Cetin et al (2004, 2018)

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
2.4	***8.0***	***0.154***	***6***	***1.55***	***0.89***	***11.3***	sand
5.4	***17.6***	***0.207***	***14***	***1.17***	***0.94***	***21.1***	sand
7.5	24.5	0.216	22	1.03	0.96	29.7	sand
9.4	30.7	0.213	17	0.93	0.97	21.1	sand
11.4	37.3	0.205	19	0.86	0.98	21.8	sand
13.4	44.0	0.196	12	0.79	0.99	12.9	sand
					Mean:	16.2	
					St. Dev.	6.9	

Case number:	57
Earthquake:	1978 Miyagiken-Oki
Magnitude:	7.7 (Mw) USGS Centennial Earthquake Catalog
Location:	Arahama
References:	Tohno and Yasuda (1981), Fear et al. (1995), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Sand volcanoes, houses tilted, ground settlement of ~20 cm. Uplifted buried sewage treatment tank.
GPS LAT	38.04258
GPS LONG	140.919003
Liq. layer consist of:	coarse sand with silt and gravel
Geological Unit:	Fill, Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Cetin (2000) "The site is located in Watari Town, district of Arahama. Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. The subject zone is seismically very active and had been shaken in 1897 and 1936 by earthquakes of Magnitudes 7.3 and 7.7. Arahama area is covered with very soft sandy deposits; about 9 m in thickness, N values generally less than 10. SPT values were taken before main earthquake (M=7.4) in 1974. SPT energy was estimated as 65 % by Seed et al. (84)"

The hatched zone is reclaimed land. Arahama sewage treatment tank remained intact due to its strong foundation. However the area has liquefied and surrounding ground settled about 20 cm. Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.

PI is assigned as 0 as FC=0.

V12m is updated based on Vs-SPTN correlations.

https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en



https://earthquake.usgs.gov/earthquakes/eventpage/usp0000v0f/executive

Shiogama-kojyo-S	NS	EW	NS	EW	goe mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	goe mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	103.1	62
FS	61.1		0.062		0.062	50	
Ishinomaki	293		0.299		0.299	80	24

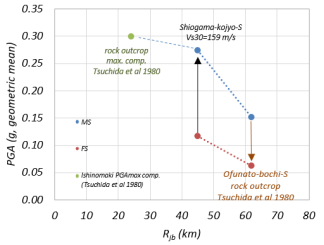
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crc} range (m)	-	2.0 - 8.0		2.0 - 8.0	2.0 - 8.6
d_{crt} (m)	6.4	5.0	6.4	5.0	5.3
GWT (m)	0.91	0.9 ± 0.3	0.9	0.9 ± 0.1	0.9 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	17.3 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	121.0	85.2 ± 17.5	121.3	93.0 ± 19.0	98.7 ± 20.9
σ_v' (kPa)	67.2	45.0 ± 8.3	67.2	52.9 ± 9.3	55.6 ± 10.2
a_{max} (g)	0.2	0.200 ± 0.040	0.2	0.200 ± 0.060	0.200 ± 0.040
r_d	0.95	0.91 ± 0.070	0.95	0.94 ± 0.070	0.98 ± 0.073
CSR	0.22	0.224 ± 0.051	0.223	0.216 ± 0.067	0.227 ± 0.049
M_w	7.40	7.40	7.70	7.70	7.70
D_{50}	0.6	0.450 ± 0.080	-	0.450 ± 0.050	0.450 ± 0.050
% Fines	0	0.0 ± 0.0	0	0.0 ± 2.0	0.0 ± 8.6
% PI	-	-	-	-	0
N	10	8.9 ± 2.5	10	8.9 ± 2.4	9.0 ± 2.2
C_R	-	0.92	0.95	0.92	0.94
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.09	1.09	1.09	1.09	1.37
C_N	1.18	1.46	1.23	1.39	1.35
$(N_1)_{60}$	13	13.1 ± 3.6	12.8	12.4 ± 3.3	15.6 ± 3.8
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	185.9	-	185.9	222.5

EVENT PARAMETERS

1978 Miyagiken-Oki	Seno et al (1980)	
Magnitude: 7.70	Length (km): 30	
Fault Type: thrust	Z_{tor} (km): 0	R_{rup} (km): -
Dip: 20	Width (km): 80	R_{jb} (km): 55-65



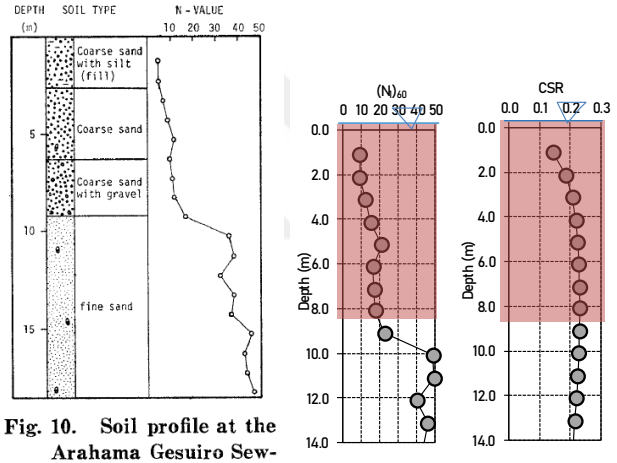


Fig. 10. Soil profile at the Arahama Gesuiro Sewage Plant (Site A-9). Data from Watari Town

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
1.1	3.6	0.143	4	2.00	0.86	9.4	coarse sand with silt (fill)
2.2	***7.1***	***0.188***	***4***	***1.93***	***0.89***	***9.4***	coarse sand with silt (fill)
3.2	***10.3***	***0.208***	***6***	***1.68***	***0.91***	***12.5***	coarse sand
4.1	***13.6***	***0.219***	***8***	***1.50***	***0.92***	***15.2***	coarse sand
5.2	***16.9***	***0.226***	***12***	***1.37***	***0.94***	***21.1***	coarse sand
6.1	***20.1***	***0.230***	***10***	***1.27***	***0.95***	***16.5***	coarse sand
7.1	***23.4***	***0.232***	***11***	***1.19***	***0.96***	***17.1***	coarse sand with gravel
8.1	***26.5***	***0.232***	***12***	***1.12***	***0.97***	***17.8***	coarse sand with gravel
9.1	29.8	0.231	16	1.06	0.97	22.6	coarse sand with gravel
10.1	33.1	0.228	36	1.01	0.98	48.7	fine sand
11.1	36.5	0.225	38	0.97	0.98	49.4	fine sand
12.1	39.8	0.221	32	0.93	0.99	40.1	fine sand
13.1	43.0	0.217	38	0.90	0.99	46.0	fine sand
14.1	46.4	0.212	37	0.87	0.99	43.3	fine sand
15.1	49.5	0.208	45	0.84	0.99	51.2	fine sand
16.1	52.9	0.205	42	0.81	0.99	46.3	fine sand
17.1	56.1	0.202	43	0.79	0.99	46.2	fine sand
18.1	59.3	0.200	47	0.77	1.00	49.2	fine sand
					Mean:	15.6	
					St. Dev.	3.8	

Case number:	58
Earthquake:	1978 Miyagiken-Oki
Magnitude:	7.7 (Mw) USGS Centennial Earthquake Catalog
Location:	Hiyori-18
References:	Tsuchida et al (1979, 1980), Fear et al. (1995), Tohno et al. (1981), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Not specifically given, but Seed et al (1984) defined the site as "liquefied."
GPS LAT	38.419355
GPS LONG	141.27366
Liq. layer consist of:	Sand
Geological Unit:	Artifically filled sand next to ocean
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. The subject zone is seismically very active and had been shaken in 1897 and 1936 by earthquakes of Magnitudes 7.3 and 7.7. The original Tsuchida (1979) paper (in Japanese) could not be accessed. However the same author's paper of 1980 in English was used to obtain borelogs. Hiyori-18 site was claimed by Tokimatsu (1993) to be by Site C. SPT energy was estimated as 65 % by Seed et al. (84)"

Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.

https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Shiogama-kojyo-S	NS	EW	NS	EW	goe mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	goe mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	103.1	62
FS	61.1		0.062		0.062	50	
Ishinomaki	293		0.299		0.299	80	24

Gravel Content (%):	0.00
CPT available:	No
Vs available:	No

Summary of Input Data

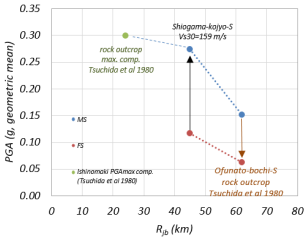
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	2.5 - 4.0		2.5 - 4.0	2.5 - 4.0
d_{crt} (m)	5.2	3.3	5.2	3.3	3.3
GWT (m)	2.44	2.4 ± 0.3	2.4	2.4 ± 0.1	2.4 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	17.3 ± 0.9	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	97.9	52.5 ± 4.7	98.2	57.6 ± 4.9	57.6 ± 4.9
σ_v' (kPa)	71.0	44.5 ± 3.6	71.2	49.6 ± 2.7	49.6 ± 2.7
a_{max} (g)	0.24	0.240 ± 0.048	0.24	0.240 ± 0.072	0.240 ± 0.048
r_d	0.96	0.97 ± 0.048	0.96	0.98 ± 0.048	0.98 ± 0.048
CSR	0.205	0.178 ± 0.039	0.207	0.177 ± 0.054	0.177 ± 0.037
M_w	1.00	7.40	7.70	7.70	7.70
D_{50}	0.15	0.150 ± 0.030	-	0.150 ± 0.050	0.150 ± 0.050
% Fines	20	20.0 ± 3.0	20	20.0 ± 2.0	20.0 ± 8.6
% PI	-	-	-	-	NAV
N	9	9.1 ± 2.0	9	9.1 ± 1.5	9.2 ± 1.1
C_R	-	0.86	0.95	0.86	0.91
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.09	1.09	1.09	1.09	1.37
C_N	1.15	1.47	1.19	1.43	1.43
$(N_1)_{60}$	11.5	12.5 ± 2.7	11.1	12.2 ± 2.0	16.3 ± 2.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	195.1	-	195.1	195.1

EVENT PARAMETERS

1978 Miyagiken-Oki
Magnitude: 7.70
Fault Type: thrust
Dip: 20

Seno et al (1980)
Length (km): 30
Z_{tor} (km): 0
Width (km): 80

Foreshock parameters were assumed to be same with mainshock
R_{rup} (km): -
R_{jb} (km): 22-30



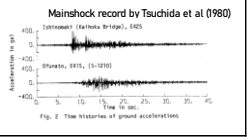


Fig. 2 Time histories of ground accelerations

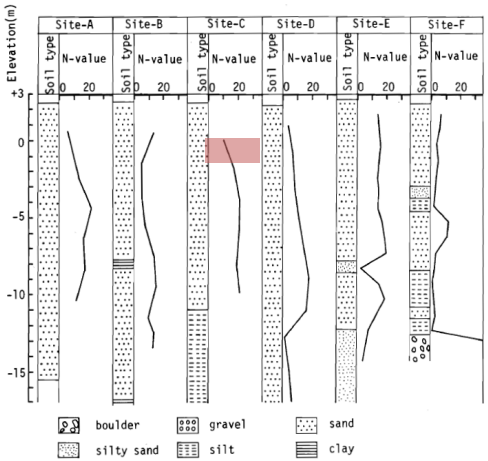
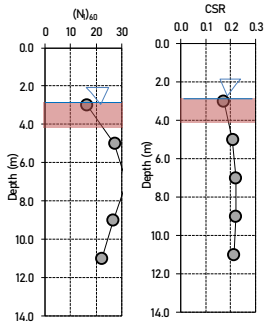


Fig. 3 Soil types and N-values of standard penetration test



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
3.0	***9.8***	***0.171***	***9.0***	***1.46***	***0.90***	***16.3***	sand
5.0	16.4	0.207	17.0	1.25	0.94	27.1	sand
7.0	23.0	0.220	22.0	1.10	0.96	31.8	sand
9.0	29.5	0.220	20.0	1.00	0.97	26.6	sand
11.0	36.1	0.214	18.0	0.92	0.98	22.2	sand
13.0	42.7	0.205	20.0	0.86	0.99	23.2	sand
					Mean:	16.3	
					St. Dev.	2.0	assigned

Case number:	61
Earthquake:	1978 Miyagiken-Oki
Magnitude:	7.7 (Mw) USGS Centennial Earthquake Catalog
Location:	Kitawabuchi 2
References:	Iwasaki et al. (1981), Fear et al. (1995), Tohno et al. (1981), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	sand boils fissures on the bank
GPS LAT	38.53346
GPS LONG	141.2157
Liq. layer consist of:	sand with gravel
Geological Unit:	old river bed
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Kitawabuchi 2 is located on the inside of the right bank of the Eai River. The ground generally consists of sand type soil, over interbedded clay and hard clay, overlying sand. 0-10 m consists of thin sand layers and sandy silt layers with shells where N<10; below 10 m is sand Iwasaki et al. (1981) predicted the liquefied layer at depth of 3-4 m. Tohno et al (1981) : Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. The subject zone is seismically very active and had been shaken in 1897 and 1936 by earthquakes of Magnitudes 7.3 and 7.7 liqeufaction occurred at the dike of Eai River; sand volcanoes were located on the old river bed near the right bank of the river and cracks were formed on the surface of the dike. The surface and the slope of the bank cracked at the site of the entrance to the old river bed; however the surface of the bed didn't subside The sand boil characteristics matched the characteristics of the sand layer at 3.5-5 m depth. SPT values were taken after main earthquake (M=7.4). SPT energy is estimated as 60 % by Seed et al. (1984)"
	Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.
	Vs12m is updated based on Vs-SPTN correlations.

Shiogama-kojyo-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	102.1	62
FS	61.1		0.062		0.062	50	
Ishinomaki	293		0.299		0.299	80	24

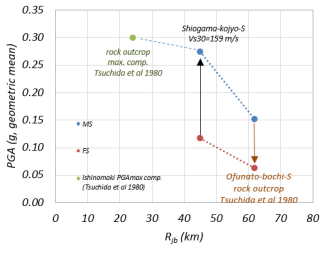
Gravel Content (%):	silty sand with gravel (content unknown)
CPT available:	No
Vs available:	No

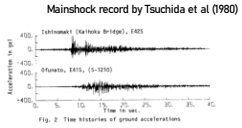
Summary of Input Data

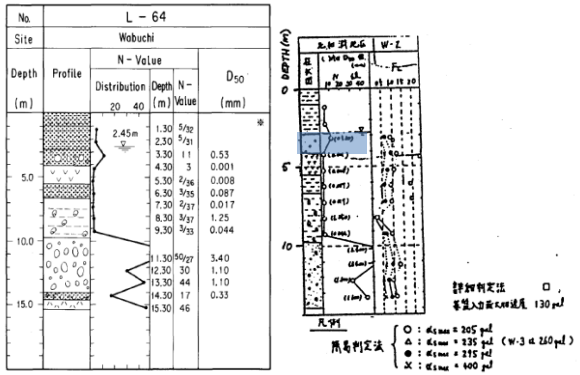
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	3.0 - 4.0		3.0 - 4.0	2.8 - 4.1
d_{crt} (m)	3.4	3.5	3.4	3.5	3.5
GWT (m)	3.0	3.0 ± 0.2	3.1	3.0 ± 0.1	2.5 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	15.7 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	17.3 ± 0.9	-	18.9 ± 0.5	20.6 ± 0.5
σ_v (kPa)	62.4	53.5 ± 3.5	62.2	56.7 ± 3.5	63.1 ± 4.7
σ_v' (kPa)	59.5	48.6 ± 2.6	59.1	51.8 ± 2.2	53.2 ± 2.7
a_{max} (g)	0.28	0.280 ± 0.056	0.28	0.280 ± 0.084	0.280 ± 0.056
r_d	0.98	0.85 ± 0.052	0.98	0.89 ± 0.052	0.98 ± 0.051
CSR	0.185	0.170 ± 0.036	0.187	0.177 ± 0.054	0.211 ± 0.044
M_w	7.40	7.40	7.70	7.70	7.70
D_{50}	0.53	0.530 ± 0.100	-	0.530 ± 0.050	0.530 ± 0.050
% Fines	5	5.0 ± 2.0	5	5.0 ± 2.0	5.0 ± 8.6
% PI	-	-	-	-	NAV
N	11	11.1 ± 2.4	11	11.1 ± 1.6	11.2 ± 1.2
C_R	-	0.87	0.85	0.87	0.91
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.00	1.00	1.00	1.00	1.37
C_N	1.24	1.41	1.32	1.40	1.38
$(N_1)_{60}$	13.5	13.5 ± 2.9	12.3	13.5 ± 2.0	19.3 ± 2.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	140.2	-	140.2	195.1

EVENT PARAMETERS

1978 Miyagiken-Oki	Seno et al (1980)	Foreshock parameters were assumed to be same with mainshock
Magnitude: 7.70	Length (km): 30	R_{rup} (km): -
Fault Type: thrust	Z_{tor} (km): 0	R_{jb} (km): 32-38
Dip: 20	Width (km): 80	

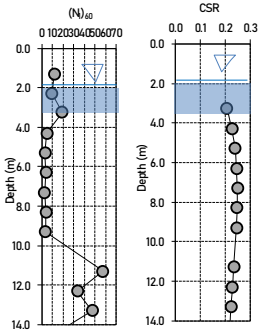






Ds : Nothing (Eye Measurement)

Appendix 22



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	D50	
1.3	4.3	NA	5.0	2.0	0.86	11.8		sandy silt
2.3	7.5	NA	5.0	1.6	0.89	9.7		sandy silt
3.3	***10.7***	***0.206***	***11.0***	***1.4***	***0.91***	***19.3***	***0.530***	*sand with gravel*
4.3	14.1	0.227	3.0	1.3	0.93	4.8	0.001	humus
5.3	17.4	0.239	2.0	1.2	0.94	3.0	0.008	humus
6.3	20.7	0.246	3.0	1.1	0.95	4.3	0.087	sandy silt
7.3	24.0	0.249	2.0	1.0	0.96	2.7	0.017	silt with shells
8.3	27.2	0.248	3.0	1.0	0.97	3.9	1.250	silt with shells
9.3	30.5	0.245	3.0	0.9	0.97	3.7	0.044	silt with shells
11.3	37.1	0.235	50.0	0.9	0.98	57.6	3.400	gravel
12.3	40.4	0.229	30.0	0.8	0.99	33.4	1.100	gravel
13.3	43.6	0.224	44.0	0.8	0.99	47.4	1.100	gravel
14.3	46.9	0.219	17.0	0.8	0.99	17.8	0.330	silty sand with gravel
15.3	50.2	0.216	46.0	0.7	0.99	46.7		Rock
					Mean:	19.3	0.530	
					St. Dev.	2.0	0.050	assigned

Case number:	62
Earthquake:	1978 Miyagiken-Oki
Magnitude:	7.7 (Mw) USGS Centennial Earthquake Catalog
Location:	Kitawabuchi-3
References:	Iwasaki et al. (1981), Fear et al. (1995), Tohno et al. (1981), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface evidence of liquefaction.
GPS LAT	38.53346
GPS LONG	141.2157
Liq. layer consist of:	sand
Geological Unit:	old river bed
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Kitawabuchi 3 is located on the inside of the right bank of the Eai River upstream from Kitawabuchi 2. The ground generally consists of sand type soil, over interbedded clay and Sand layer at depths of 3-10+ m. Tohno et al (1981) : Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. The subject zone is seismically very active and had been shaken in 1897 and 1936 by earthquakes of Magnitudes 7.3 and 7.7. Liqeufaction occurred at the dike of Esai River; sand volcanoes were located on the old river bed near the right bank of the river and cracks were formed on the surface of the dike. The surface and the slope of the bank cracked at the site of the entrance to the old river bed; however the surface of the bed didn't subside The sand boil characteristics matched the characteristics of the sand layer at 3.5-5 m depth. SPT values were taken after main earthquake (M=7.4) SPT energy is estimated as 73 % by Seed et al. (1984)"
	Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshock respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.
	PI is assigned as 0 as FC=0%.
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

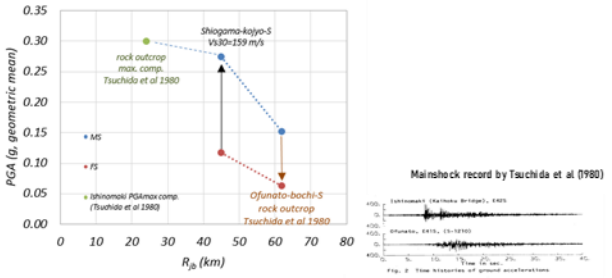
Shiogama-kojyo-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	137.8	161.2	0.140	0.164	0.152	103.1	62
FS	61.1		0.062		0.062	50	
Ishinomaki	293		0.299		0.299	80	24

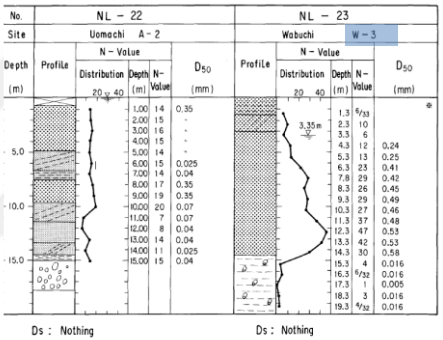
Summary of Input Data

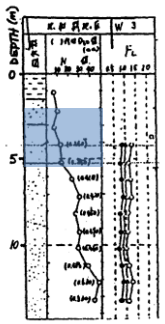
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	B	-	B	B
d_{critic} range (m)	-	3.0 - 5.5		3.0 - 5.5	3.9 - 5.8
d_{crt}(m)	6.1	4.3	4.8	4.3	4.9
GWT (m)	3.05	3.0 ± 0.9	3.1	3.0 ± 0.9	3.5 ± 0.9
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	17.3 ± 0.6	-	18.9 ± 0.5	20.6 ± 0.5
σ_v (kPa)	115.2	66.8 ± 7.7	90.2	76.0 ± 8.0	88.6 ± 7.4
σ_v' (kPa)	85.4	54.8 ± 7.8	73.2	63.9 ± 8.5	74.9 ± 7.1
a_{max} (g)	0.32	0.280 ± 0.056	0.28	0.280 ± 0.084	0.280 ± 0.056
r_d	0.96	0.96 ± 0.061	0.97	0.99 ± 0.061	0.99 ± 0.068
CSR	0.235	0.213 ± 0.057	0.216	0.214 ± 0.073	0.214 ± 0.052
M_w	7.40	7.40	7.70	7.70	7.70
D_{50}	0.41	0.410 ± 0.080	-	0.410 ± 0.050	0.410 ± 0.050
% Fines	0	0.0 ± 0.0	0	0.0 ± 2.0	0.0 ± 8.6
% PI	-	-	-	-	0
N	23	13.2 ± 5.1	13.2	13.2 ± 5.1	12.6 ± 0.2
C_R	-	0.90	0.95	0.90	0.93
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.21	1.21	1.21	1.21	1.37
C_N	1.05	1.32	1.16	1.26	1.16
$(N_1)_{60}$	29	18.9 ± 7.3	17.6	18.0 ± 6.9	18.7 ± 0.3
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	204.2	-	231.6	240.8

EVENT PARAMETERS

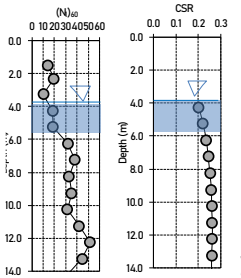
1978 Miyagiken-Oki	Seno et al (1980)	Foreshock parameters were assumed to be same with mainshock
Magnitude: 7.70	Length (km): 30	R_{rup} (km): -
Fault Type: thrust	Z_{tor} (km): 0	R_{jb} (km): 32-38
Dip: 20	Width (km): 80	







Appendix 30



References: Iwasaki et al. (1981), Fear et al. (1995), Tohno et al. (1981), Cetin (2000), Cetin et al (2004, 2018)

Water table info is not accurate.
GWT is now accurate from the borehole data by Iwasaki (1986)

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	D_{50}	
1.5	4.9	NA	6	1.98	0.87	14.1		sandy silt
2.3	7.5	NA	10	1.60	0.89	19.4		silty sand
3.3	10.7	NA	6	1.34	0.91	10.0		sand
4.3	***13.9***	***0.202***	***12***	***1.22***	***0.93***	***18.5***	***0.240***	sand
5.3	***17.2***	***0.221***	***13***	***1.13***	***0.94***	***18.9***	***0.250***	sand
6.3	20.5	0.234	23	1.06	0.95	31.8	0.410	sand
7.3	23.8	0.245	29	1.00	0.96	38.2	0.420	sand
8.3	27.1	0.252	26	0.95	0.97	32.8	0.450	sand
9.3	30.3	0.257	29	0.91	0.97	35.2	0.490	sand
10.3	33.6	0.260	27	0.87	0.98	31.5	0.460	sand
11.3	36.9	0.261	37	0.84	0.98	41.7	0.480	sand
12.3	40.2	0.261	47	0.81	0.99	51.3	0.530	sand
13.3	43.5	0.260	42	0.78	0.99	44.4	0.530	sand
14.3	46.8	0.258	30	0.76	0.99	30.8	0.580	sand
15.3	50.0	0.256	4	0.74	0.99	4.0	0.016	silt with shells
16.3	53.3	0.253	6	0.72	0.99	5.8	0.016	silt with shells
17.3	56.6	0.251	1	0.70	0.99	0.9	0.005	silt with shells
18.3	59.9	0.250	3	0.68	1.00	2.8	0.016	silt with shells
19.3	63.2	0.249	4	0.66	1.00	3.6	0.016	silt with shells
					Mean:	18.7	0.245	
					St. Dev.	0.3	0.007	

Case number:	64
Earthquake:	1978 Miyagiken-Oki
Magnitude:	7.7 (Mw) USGS Centennial Earthquake Catalog
Location:	Nakamura-1
References:	Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Iwasaki and Tokida (1984), Iwasaki (1986), Cetin (2000), Cetin et al (2004, 2018), NGL Project
Nature of Failure:	No surface evidence of liquefaction.
GPS LAT	38.198586
GPS LONG	140.936386
Liq. layer consist of:	sand and sandy silt
Geological Unit:	river dyke
Site Response Anlaysis:	No
Comments:	Cetin (2000) "The site is located in the inside base towards the north end of an embankment along the left bank of the Natori River. Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. The subject zone is seismically very active and had been shaken in 1897 and 1936 by earthquakes of Magnitudes 7.3 and 7.7. PGA is estimated as 0.18 g in Iwasaki (1978). Based on the results of cyclic triaxial test, the FS against liquefaction is calculated as less than 1 in the sand layer between the depths of 2-7 m. From Tohno et al. (1981) The river embankment was partially collapsed and cracked in both sides at Nakamura located ~3 km upstream from the mouth of Natori River. Sand boils were also observed after the February, 1978 (M=6.4) earthquake. The textural parameters of the liquefied soil revealed that the possibly liquefied layer is sandy deposits at 1.4-3 m. SPT values were taken after main earthquake (M=7.4). SPT energy is estimated as 67 % by Seed et al. (84)"
	Located in the inside base, towards the south end, of an embankment along the left bank of the Natori River. Merged information from Appendix 26 of Iwasaki (1986) and from Fig. 8(a) in Iwasaki and Tokida (1980).
	Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.
	Iwasaki and Tokida 1980 figure caption noted this site as liquefied however Iwasaki (1986), Seed et al (1985), Cetin et al (2004, 2018), Idriss and Boulanger (2010) noted the site as not liquefied hence the site is taken as no. PI is assigned as 0 as FC=4% by Seed et al (1985) and Cetin et al (2004, 2018)
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Shiogama-kojyo-S	NS	EW	NS	EW	goe mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	goe mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	103.1	62
FS	61.1		0.062		0.062	50	
Ishinomaki	293		0.299		0.299	80	24

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	2.0 - 4.0		2.0 - 4.0	2.0 - 4.0
d_{crt} (m)	3.4	3.0	3.4	3.0	3.0
GWT (m)	0.91	0.9 ± 0.3	0.9	0.9 ± 0.1	0.9 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	17.3 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	63.4	49.8 ± 6.0	63.2	56.9 ± 6.7	58.9 ± 7.0
σ_v' (kPa)	39.4	29.2 ± 3.7	39.1	36.3 ± 3.5	38.3 ± 3.8
a_{max} (g)	0.32	0.320 ± 0.064	0.32	0.320 ± 0.096	0.320 ± 0.064
r_d	0.98	0.98 ± 0.045	0.98	0.99 ± 0.045	0.99 ± 0.045
CSR	0.33	0.347 ± 0.079	0.329	0.324 ± 0.099	0.318 ± 0.066
M_w	7.40	7.40	7.70	7.70	7.70
D_{50}	0.28	0.280 ± 0.040	-	0.280 ± 0.050	0.280 ± 0.050
% Fines	4	4.0 ± 1.0	4	4.0 ± 2.0	4.0 ± 8.6
% PI	-	-	-	-	0
N	19	15.7 ± 4.2	19	15.8 ± 4.0	14.9 ± 3.8
C_R	-	0.85	0.85	0.85	0.90
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.12	1.12	1.12	1.12	1.37
C_N	1.49	1.81	1.45	1.67	1.63
$(N_1)_{60}$	31.5	26.8 ± 7.2	26.2	24.9 ± 6.4	29.9 ± 7.6
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	207.3	-	219.5	219.5

EVENT PARAMETERS

1978 Miyagiken-Oki	Seno et al (1980)	Foreshock parameters were assumed to be same with mainshock
Magnitude: 7.70	Length (km): 30	R_{rup} (km): -
Fault Type: thrust	Z_{tor} (km): 0	R_{jb} (km): 50-60
Dip: 20	Width (km): 80	

Mainshock record by Tsuchida et al (1980)

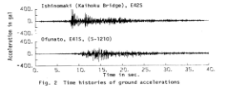
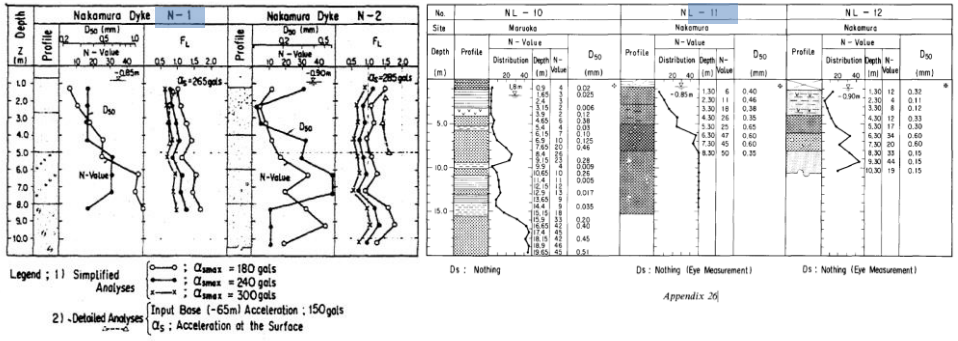
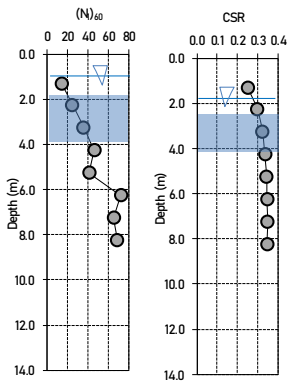


Fig. 2 Time histories of ground accelerations



(A) N-1 and N-2
(at liquefied sites)



References:
Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Iwasaki and Tokida (1984), Iwasaki (1986), Cetin (2000)

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N_1)_{60}$	D_{50}		
1.3	4.3	0.248	6	2.00	0.86	14.2	0.400	medium sand	CN>2
2.3	***7.4***	***0.298***	***11***	***1.83***	***0.89***	***24.5***	***0.460***	medium sand	
3.3	***10.7***	***0.322***	***18***	***1.57***	***0.91***	***35.2***	***0.380***	sandy silt	
4.3	13.9	0.335	26	1.40	0.93	46.1	0.350	sandy silt	
5.3	17.2	0.343	25	1.27	0.94	40.9	0.650	coarse sand with gravel	
6.3	20.5	0.346	47	1.18	0.95	71.9	0.600	coarse sand with gravel	
7.3	23.8	0.347	45	1.10	0.96	64.9	0.600	coarse sand with gravel	
8.3	27.1	0.345	50	1.03	0.97	68.4	0.350	medium sand with gravel	
					Mean:	29.9	0.420		
					St. Dev.	7.6	0.057		

Case number:	65
Earthquake:	1978 Miyagiken-Oki
Magnitude:	7.7 (Mw) USGS Centennial Earthquake Catalog
Location:	Nakamura-4
References:	Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Iwasaki and Tokida (1984), Iwasaki (1986), Cetin (2000), Cetin
Nature of Failure:	Sand boils, cracking.
GPS LAT	38.198586
GPS LONG	140.936386
Liq. layer consist of:	medium sand and sandy silt
Geological Unit:	river dyke
Site Response Anlaysis:	No
Comments:	Cetin (2000) "The site is located in the inside base towards the north end of an embankment along the left bank of Natori River Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. The subject zone is seismically very active and had been shaken in 1897 and 1936 by earthquakes of Magnitudes 7.3 and 7.7 PGA is estimated as 0.18 g in the paper. Based on the results of cyclic triaxial test, the FS against liquefaction is calculated as less than 1 in the sand layer between the depths of 2-7 m. From Tohno et al. (1981) The river embankment was partially collapsed and cracked in both sides at Nakamura located ~3 km upstream from the mouth of Natori River. Sand boils were also observed after the February, 1978 (M=6.4) earthquake. The textural parameters of the liquefied soil revealed that the possibly liquefied layer is sandy deposits at 1.4-3 m. SPT values were taken after main earthquake (M=7.4) SPT energy was estimated as 60 % by Seed et al. (1984)"
	Borehole data is obtained from Iwasaki (1986)
	PI is assigned as 0 as FC=5%
	Vs12m is updated based on Vs-SPTN correlations.
	Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Shiogama-kojyo-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	103.1	62
FS	61.1		0.062		0.062	50	
Ishinomaki	293		0.299		0.299	80	24

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	3.0 - 5.0		3.0 - 5.0	3.0 - 5.0
d_{crt} (m)	3.4	4.0	2.8	4.0	4.0
GWT (m)	0.61	0.5 ± 0.3	0.5	0.5 ± 0.1	0.5 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	63.4	65.4 ± 6.0	53.1	74.8 ± 6.5	74.8 ± 6.5
σ_v' (kPa)	36.5	31.0 ± 4.0	30.1	40.4 ± 3.5	40.4 ± 3.5
a_{max} (g)	0.32	0.320 ± 0.064	0.32	0.320 ± 0.096	0.320 ± 0.064
r_d	0.98	0.97 ± 0.058	0.99	0.98 ± 0.058	1.00 ± 0.058
CSR	0.355	0.426 ± 0.098	0.346	0.379 ± 0.116	0.383 ± 0.081
M_w	7.40	7.40	7.70	7.70	7.70
D_{50}	0.7	0.700 ± 0.150	-	0.700 ± 0.050	0.543 ± 0.178
% Fines	5	5.0 ± 1.0	5	5.0 ± 2.0	5.0 ± 8.6
% PI	-	-	-	-	0
N	5	5.6 ± 0.4	4.7	5.6 ± 0.4	5.6 ± 0.4
C_R	-	0.89	0.85	0.89	0.92
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.00	1.00	1.00	1.00	1.37
C_N	1.55	1.76	1.70	1.59	1.59
$(N_1)_{60}$	8	8.7 ± 0.7	6.9	7.9 ± 0.6	11.2 ± 0.7
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	213.4	-	213.4	248.4

EVENT PARAMETERS

1978 Miyagiken-Oki

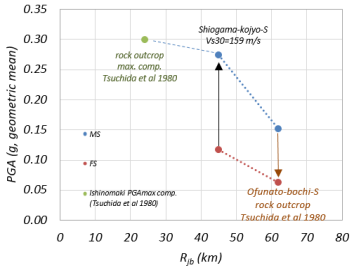
Magnitude: 7.70
Fault Type: thrust
Dip: 20

Seno et al (1980)

Length (km): 30
Z_{tor} (km): 0
Width (km): 80

Foreshock parameters were assumed to be same with mainshock

R_{rup} (km): -
R_{jb} (km): 50-60



Mainshock record by Tsuchida et al (1980)

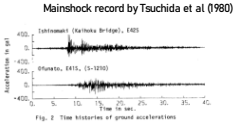
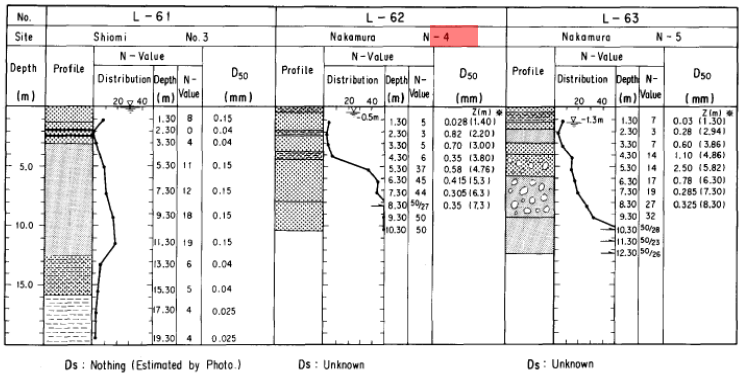
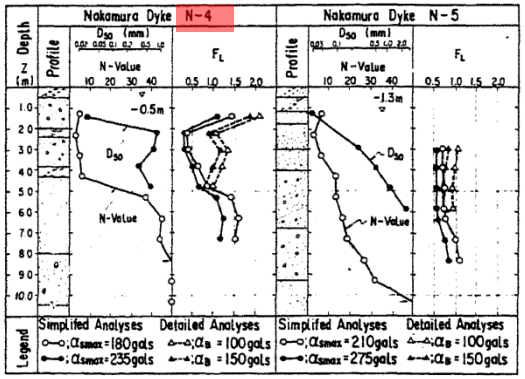
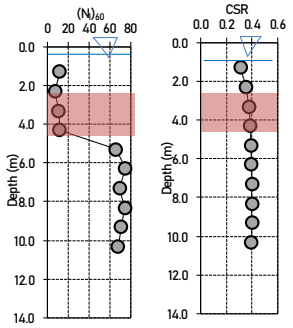


Fig. 2 Time histories of ground accelerations







(B) N-4 and N-5 (at non-liquefied sites)

Borehole data is obtained from Iwasaki (1986)

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		
1.3	4.3	0.310	5	2.00	0.86	11.8	medium sand	CN>2
2.3	7.5	0.355	3	2.00	0.89	7.3	sandy silt	CN>2
3.3	*10.8*	*0.375*	*5*	*1.73*	*0.91*	*10.7*	medium sand	
4.3	*14.1*	*0.386*	*6*	*1.53*	*0.93*	*11.7*	sandy silt	
5.3	17.4	0.393	37	1.39	0.94	66.3	medium sand	
6.3	20.7	0.397	45	1.29	0.95	75.4	medium sand	
7.3	24.0	0.399	44	1.20	0.96	69.4	medium sand	
8.3	27.2	0.400	50	1.13	0.97	74.8	medium sand	
9.3	30.5	0.399	50	1.07	0.97	71.3	medium sand	
10.3	33.8	0.397	50	1.02	0.98	68.2	medium sand	
					Mean:	11.2		
					St. Dev.	0.7		

Depth (m)	D50
1.4	0.028
2.2	0.820
3.0	*0.700*
3.8	*0.350*
4.8	*0.580*
5.30	0.415
6.30	0.305
7.30	0.350
Mean:	0.543
St. Dev.	0.178

Depth (m)		
0	*0.52*	sandy silt
0.52	*1.99*	medium sand
1.99	*2.39*	sandy silt
2.39	*3.82*	medium sand
3.82	*4.3*	sandy silt
4.3	*7.99*	medium sand
7.99	*10.47*	medium sand

Case number:	66
Earthquake:	1978 Miyagiken-Oki
Magnitude:	7.7 (Mw) USGS Centennial Earthquake Catalog
Location:	Nakamura-5
References:	Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Sand boils
GPS LAT	38.1986
GPS LONG	140.9364
Liq. layer consist of:	coarse sand
Geological Unit:	river dyke
Site Response Anlaysis:	No
Comments:	Cetin (2000) "The site is located in the outside base at the north end of an embankment along the left bank of the Natori River. PGA is estimated as 0.18 g in the paper. Based on the results of cyclic triaxial test, the FS against liquefaction is calculated as less than 1 in the sand layer between the depths of 2-7 m. From Tohno et al. (1981): The river embankment was partially collapsed and cracked in both sides at Nakamura located ~3 km upstream from the mouth of Natori River. Sand boils were also observed after the February, 1978 (M=6.4) earthquake. The textural parameters of the liquefied soil revealed that the possibly liquefied layer is sandy deposits at 1.4-3 m. SPT values were taken after main earthquake (M=7.4) SPT energy was estimated as 60 % by Seed et al. (1984)"

Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.

PI is assigned as 0 as FC=4%

Vs12m is updated based on Vs-SPTN correlations.

Shiogama-kojyo-S	NS	EW	NS	EW	goe mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	goe mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	103.1	62
FS	61.1		0.062		0.062	50	
Ishinomaki	293		0.299		0.299	80	24

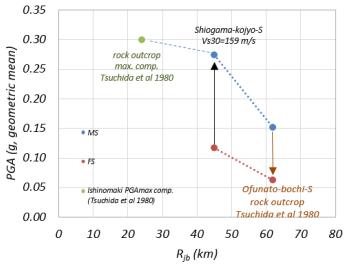
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

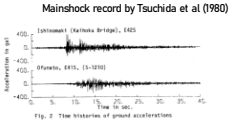
Summary of Input Data

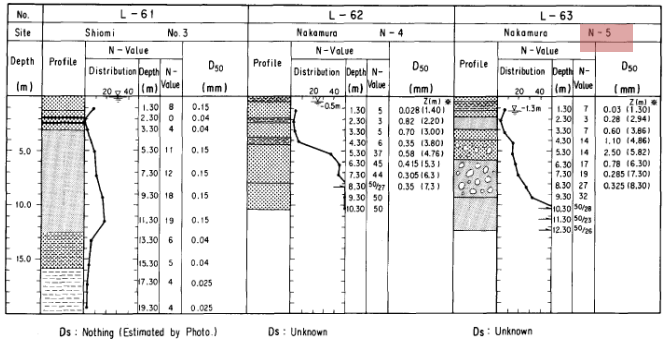
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	2.7 - 4.0		2.7 - 4.0	1.8 - 4.0
d_{crt} (m)	3.4	3.4	3.4	3.4	2.9
GWT (m)	1.22	1.3 ± 0.3	1.3	1.3 ± 0.1	1.3 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	63.4	53.7 ± 3.8	63.2	61.7 ± 4.1	52.8 ± 7.0
σ_v' (kPa)	42.2	33.3 ± 3.3	42.1	41.3 ± 2.3	37.0 ± 3.5
a_{max} (g)	0.32	0.320 ± 0.064	0.32	0.320 ± 0.096	0.320 ± 0.064
r_d	0.98	0.96 ± 0.050	0.306	0.97 ± 0.050	1.00 ± 0.044
CSR	0.305	0.320 ± 0.072	0.306	0.302 ± 0.092	0.296 ± 0.062
M_w	7.40	7.40	7.70	7.70	7.70
D_{50}	0.28	0.280 ± 0.030	-	0.280 ± 0.050	0.280 ± 0.050
% Fines	4	7.0 ± 2.0	4	4.0 ± 2.0	4.0 ± 8.6
% PI	-	-	-	-	0
N	7	7.1 ± 1.4	7	7.1 ± 1.5	5.0 ± 2.5
C_R	-	0.86	0.85	0.86	0.90
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.00	1.00	1.00	1.00	1.37
C_N	1.46	1.70	1.61	1.57	1.66
$(N_1)_{60}$	10	10.3 ± 2.0	9.6	9.6 ± 2.0	10.2 ± 5.1
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	189.0	-	189.0	256.0

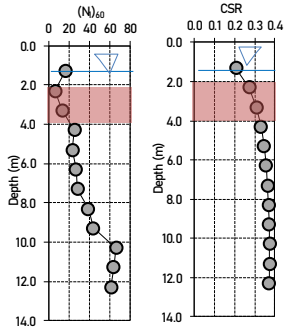
EVENT PARAMETERS

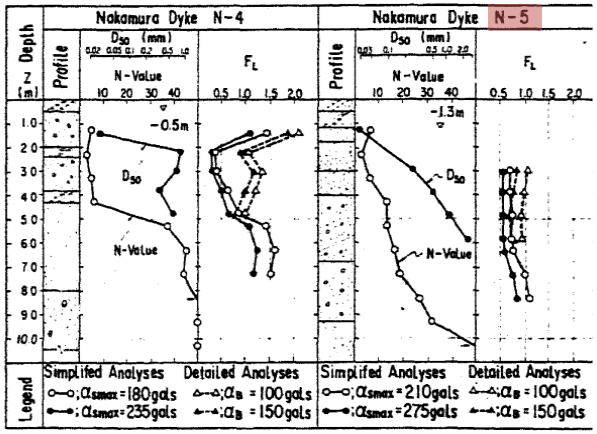
1978 Miyagiken-Oki	Seno et al (1980)	Foreshock parameters were assumed to be same with mainshock
Magnitude: 7.70	Length (km): 30	R_{rup} (km): -
Fault Type: thrust	Z_{tor} (km): 0	R_{jb} (km): 50-60
Dip: 20	Width (km): 80	











(B) N-4 and N-5
(at non-liquefied sites)

References: Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Cetin (2000), Cetin et al (2004, 2018)

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		
1.3	4.3	0.208	7	2.00	0.86	16.5	coarse sand	CN>2
2.3	***7.5***	***0.272***	***3***	***1.79***	***0.89***	***6.5***	***fine sand***	
3.3	***10.8***	***0.308***	***7***	***1.58***	***0.91***	***13.8***	***coarse sand***	
4.3	14.1	0.330	14	1.43	0.93	25.3	gravel and coarse sand	
5.3	17.4	0.345	14	1.31	0.94	23.7	gravel and coarse sand	
6.3	20.7	0.356	17	1.22	0.95	27.0	gravel and coarse sand	
7.3	24.0	0.363	19	1.15	0.96	28.7	sand with gravel	
8.3	27.2	0.369	27	1.09	0.97	38.8	sand with gravel	
9.3	30.5	0.372	32	1.03	0.97	44.0	fine sand	
10.3	33.8	0.374	50	0.99	0.98	66.1	fine sand	
11.3	37.1	0.374	50	0.95	0.98	63.6	fine sand	
12.3	40.4	0.373	50	0.91	0.99	61.4	fine sand	
					Mean:	10.2		
					St. Dev.	5.1		

Depth (m)	D50
1.3	0.030
2.9	***0.280***
3.9	***0.600***
4.9	1.100
5.8	2.500
6.3	0.780
7.3	0.285
8.3	0.325
Mean:	0.440
St. Dev.	0.226

Case number:	67
Earthquake:	1978 Miyagiken-Oki
Magnitude:	7.7 (Mw) USGS Centennial Earthquake Catalog
Location:	Oiiri 1
References:	Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), A.S. Cakmak (1986), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Iwasaki et al. (1978) No mention of Oiiri-1? Not given but according to Seed et al (1984) "liquefied."
GPS LAT	38.505719
GPS LONG	141.234144
Liq. layer consist of:	sand
Geological Unit:	river embankment
Site Response Anlaysis:	No
Comments:	Cetin (2000) "A.S. Cakmak (1986) "Soil Liquefaction Studies in Japan", Vol. 5 No.1 Jan 1986, Soil Dynamics & Earthquake Engineering. The subject zone is seismically very active and had been shaken in 1897 and 1936 by earthquakes of Magnitudes 7.3 and 7.7. Iwasaki et al (1978) paper did not mention Oiiri sites. However, Cakmak et al. gave a representative depth vs. N profile for Oiiri 1. Tohno et al (1981) : Liquefaction was observed at the dike of Old Kitakami River. Sand volcanoes were found on both sides of the base of the dike and in the vicinity of it. The boil material has the same characteristics of samd layer at depth of 4.5-7 m. SPT values were taken after main earthquake (M=7.4). SPT energy is estimated as 60 % by Seed et al. (84)"

Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.

PI is assigned as 0 as FC=5% by Seed et al (1985).

Vs12m is updated based on Vs-SPTN correlations.

Shiogama-kojyo-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	103.1	62
FS	61.1		0.062		0.062	50	
Ishinomaki	293		0.299		0.299	80	24

Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	4.3 - 7.6		4.3 - 7.6	5.8 - 6.8
d_{crt} (m)	6.4	5.9	6.4	5.9	6.3
GWT (m)	4.27	4.3 ± 0.6	4.3	4.3 ± 0.1	4.3 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 1.3	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 1.3	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	106.6	91.6 ± 10.9	106.3	105.6 ± 10.8	112.3 ± 3.9
σ_v' (kPa)	85.4	75.1 ± 8.5	85.2	89.1 ± 5.6	92.4 ± 2.8
a_{max} (g)	0.24	0.240 ± 0.048	0.24	0.240 ± 0.072	0.240 ± 0.048
r_d	0.95	0.74 ± 0.081	0.95	0.85 ± 0.081	0.88 ± 0.085
CSR	0.185	0.141 ± 0.035	0.185	0.157 ± 0.050	0.166 ± 0.037
M_w	7.40	7.40	7.70	7.70	7.70
D_{50}	0.34	0.340 ± 0.100	-	0.340 ± 0.050	0.340 ± 0.050
% Fines	5	5.0 ± 3.0	5	5.0 ± 2.0	5.0 ± 8.6
% PI	-	-	-	-	0
N	9	9.1 ± 2.1	9	9.2 ± 2.0	9.0 ± 1.5
C_R	-	0.95	0.95	0.95	0.95
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.00	1.00	1.00	1.00	1.37
C_N	1.05	1.13	1.10	1.07	1.05
$(N_1)_{60}$	9.5	9.8 ± 2.2	9.4	9.3 ± 2.0	12.3 ± 2.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	149.4	-	160.0	172.2

EVENT PARAMETERS

1978 Miyagiken-Oki

Magnitude: 7.70

Fault Type: thrust

Dip: 20

Seno et al (1980)

Length (km): 30

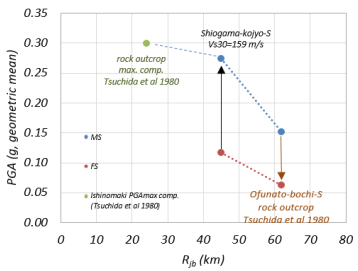
Z_{tor} (km): 0

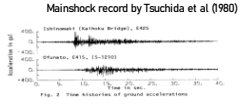
Width (km): 80

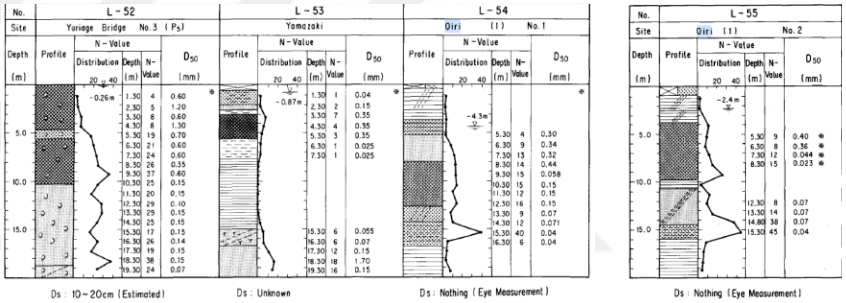
Foreshock parameters were assumed to be same with mainshock

R_{rup} (km): -

R_{jb} (km): 30-35

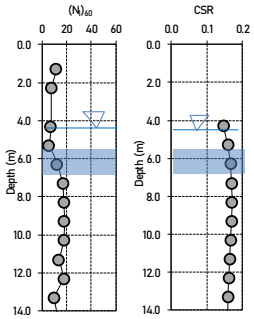






Appendix 18

References: Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), A.S. Cakmak (1986), Cetin (2000), Cetin et al (2004, 2018)



No:1		No:2	
Depth (m)	**N**	**Depth (m)**	**N**
1.3	5 clayey silt	1.3	2 silty clay
2.3	4 clayey silt	2.3	2 silty clay
4.3	5 sandy clay	4.3	11 coarse sand
5.3	4 sand	5.3	9 coarse sand
6.3	9 sand	6.3	8 coarse sand
7.3	13 sand	7.3	12 coarse sand
8.3	14 medium sa	8.3	15 coarse sand
9.3	15 medium sa	9.3	25 coarse sand
10.3	15 medium sa	10.3	3 clay
11.3	12 medium sa	11.3	12 silty sand
12.3	16 medium sa	12.3	8 silty sand
13.3	9 silty sand	13.3	14 silty sand
14.3	12 sandy silt	14.3	38 silty sand
15.3	40 sandy silt	15.3	45 sandy silt
16.3	6 sandy silt	16.3	9 clay
		17.3	6 clay
		18.3	5 clay
GWT (m)		19.3	4 clay
4.3	No:1		
2.4	No:2		

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	D50	
1.3	4.3	NA	5	2.00	0.86	11.8		clayey silt
2.3	7.5	NA	4	1.60	0.89	7.8		clayey silt
4.3	14.1	0.146	5	1.17	0.93	7.4		sandy clay
5.3	17.4	0.159	4	1.10	0.94	5.7	0.30	sand transion zone. clayey? hence excluded.
6.3	***20.7***	***0.166***	***9***	***1.05***	***0.95***	***12.3***	***0.34***	***sand***
7.3	24.0	0.170	13	1.00	0.96	17.1	0.32	sand
8.3	27.2	0.171	14	0.96	0.97	17.8	0.44	medium sand
9.3	30.5	0.169	15	0.92	0.97	18.4	0.06	medium sand
10.3	33.8	0.167	15	0.89	0.98	17.8	0.15	medium sand
11.3	37.1	0.164	12	0.86	0.98	13.8	0.15	medium sand
12.3	40.4	0.162	16	0.83	0.99	17.9	0.15	medium sand
13.3	43.6	0.160	9	0.81	0.99	9.8	0.07	silty sand
14.3	46.9	0.159	12	0.78	0.99	12.8	0.07	sandy silt
15.3	50.2	0.158	40	0.76	0.99	41.5	0.04	sandy silt
16.3	53.5	0.157	6	0.74	0.99	6.1	0.04	sandy silt
					Mean:	12.3	0.34	
					St. Dev.	2.0	0.05	

Case number:	69
Earthquake:	1978 Miyagiken-Oki
Magnitude:	7.7 (Mw) USGS Centennial Earthquake Catalog
Location:	Yuriage Bridge 1
References:	Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Sand boils out of surface cracks, Damage to Yuriagegami Bridge, cracked piers, etc.
GPS LAT	38.182134
GPS LONG	140.946729
Liq. layer consist of:	fine sand with gravel
Geological Unit:	river deposit
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Yuriage Br. 1 is located near pier 9 of the Yuriagegami Bridge, which crosses Natori River. Pier 9 is the closest to the right bank of the river. PGA estimations of 0.24 and 0.3 g were used by Iwasaki et al (1978). Based on cyclic triaxial test results, the sand layer at depth range of 2-6 m is predicted to be liquefied. Tohno et al. (1981): Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. The subject zone is seismically very active and had been shaken in 1897 and 1936 by earthquakes of Magnitudes 7.3 and 7.7. The dry river bed was cracked parallel to the river near Yuriage-Ohashi Bridge, and liquefied sands seeped out from the cracks. Some cracks were found near the piers of the Yuriage-Ohashi Birdge and the ground around the piers settled. The boiled soil was a poorly graded coarse sand. Iwasaki and Tokida (1980) identified the liquefied layer as at depths of 2-5 m.

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	3.0 - 4.0		3.0 - 4.0	2.8 - 4.8
d_{crt} (m)	4.3	3.5	4.3	3.5	3.8
GWT (m)	1.83	1.7 ± 0.3	1.8	1.7 ± 0.1	1.7 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	15.7 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.1 ± 0.5	20.6 ± 0.5
σ_v (kPa)	80.6	55.0 ± 3.2	80.2	59.2 ± 3.3	72.8 ± 7.0
σ_v' (kPa)	56.6	37.4 ± 3.2	56.1	41.6 ± 1.9	52.1 ± 3.9
a_{max} (g)	0.24	0.240 ± 0.048	0.24	0.240 ± 0.072	0.240 ± 0.048
r_d	0.97	0.95 ± 0.051	0.97	0.97 ± 0.051	0.98 ± 0.055
CSR	0.215	0.217 ± 0.048	0.216	0.216 ± 0.066	0.213 ± 0.045
M_w	7.40	7.40	7.70	7.70	7.70
D_{50}	0.4	0.400 ± 0.100	-	0.400 ± 0.050	0.280 ± 0.184
% Fines	10	5.0 ± 1.0	10	10.0 ± 2.0	10.0 ± 8.6
% PI	-	-	-	-	NAV
N	4	3.0 ± 1.3	4	3.0 ± 1.3	3.0 ± 1.3
C_R	-	0.87	0.95	0.87	0.92
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.00	1.00	1.00	1.00	1.37
C_N	1.27	1.60	1.41	1.56	1.40
$(N_1)_{60}$	5	4.1 ± 1.8	5.4	4.0 ± 1.7	5.2 ± 2.2
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	182.9	-	204.2	219.5

EVENT PARAMETERS

1978 Miyagiken-Oki	Seno et al (1980)	Foreshock parameters were assumed to be same with mainshock
Magnitude: 7.70	Length (km): 30	R_{rup} (km): -
Fault Type: thrust	Z_{tor} (km): 0	R_{jb} (km): 50-60
Dip: 20	Width (km): 80	

Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.

Shiogama-kojyo-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	103.1	62
FS	61.5		0.062		0.062	90	
Ishinomaki	293		0.299		0.299	80	24

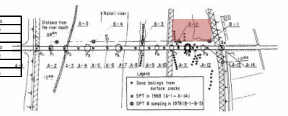
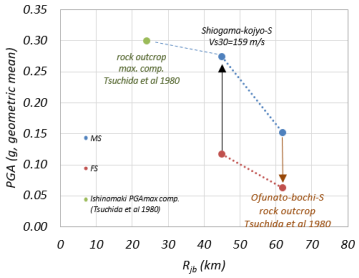


Fig. 10 Points of Sand Boils and Insitu Soil Tests at Yuriage Bridge



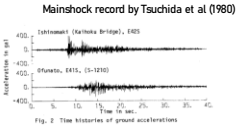


Fig. 2 Time histories of ground accelerations

Gravel Content (%):	fine sand with gravel (content unkown)
CPT available:	No
Vs available:	No

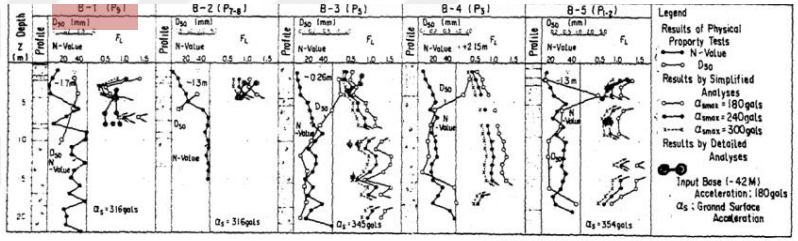
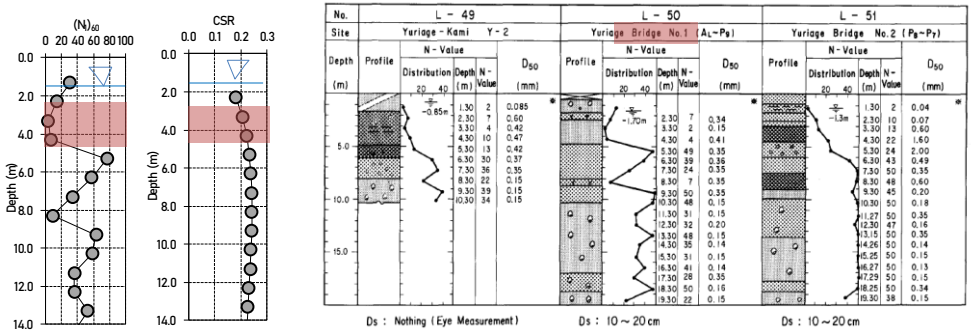


Fig. 11 F_L-values at Yuriage Bridge
(B-1, B-2, B-3; liquefied, B-4; liquefaction unconfirmed, B-5; non-liquefied)

References: Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Cetin (2000), Cetin et al (2004, 2018)



Appendix 17

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	D_{50}	
1.3	4.3	NA	13	2.00	0.86	30.7		fine sand with gravel close to surf.
2.3	7.5	0.181	7	1.68	0.89	14.3	0.340	fine sand with gravel fines transition
3.3	***10.8***	***0.207***	***2***	***1.47***	***0.91***	***3.7***	***0.150***	fine sand with gravel
4.3	***14.1***	***0.222***	***4***	***1.33***	***0.93***	***6.7***	***0.410***	fine sand with gravel
5.3	17.4	0.232	49	1.22	0.94	76.8	0.350	medium sand
6.3	20.7	0.238	39	1.13	0.95	57.5	0.360	medium sand
7.3	24.0	0.241	24	1.06	0.96	33.5	0.350	medium sand
8.3	27.2	0.242	7	1.00	0.97	9.3	0.350	medium sand with humus
9.3	30.5	0.241	50	0.95	0.97	63.5	0.350	medium sand
10.3	33.8	0.239	48	0.91	0.98	58.5	0.150	medium sand
11.3	37.1	0.235	31	0.87	0.98	36.4	0.150	fine sand with shell
12.3	40.4	0.231	32	0.84	0.99	36.2	0.200	fine sand with shell
13.3	43.6	0.227	48	0.81	0.99	52.5	0.150	fine sand with shell
14.3	46.9	0.222	35	0.78	0.99	37.1	0.140	fine sand with shell
15.3	50.2	0.218	31	0.76	0.99	31.9	0.150	fine sand with shell
16.3	53.5	0.215	41	0.74	0.99	41.0	0.140	fine sand with shell
17.3	56.8	0.212	28	0.72	0.99	27.3	0.350	medium sand with shell
18.3	60.0	0.210	50	0.70	1.00	47.5	0.160	medium sand with shell
19.3	63.3	0.209	22	0.68	1.00	20.4	0.150	fine sand with shell
					Mean:	5.2	0.280	
					St. Dev.	2.2	0.184	

Case number:	70
Earthquake:	1978 Miyagiken-Oki
Magnitude:	7.7 (Mw) USGS Centennial Earthquake Catalog
Location:	Yuriage Bridge 2
References:	Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Iwasaki (1986), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Sand boils out of surface cracks, Damage to Yuriagegami Bridge, cracked piers, etc.
GPS LAT	38.1821
GPS LONG	140.9467
Liq. layer consist of:	sand
Geological Unit:	river deposit
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Yuriage Br. 2 is located near pier 7 of the Yuriagegami Bridge, which crosses Natori River. Pier 7 is towards the right bank of the river. PGA estimations of 0.24 and 0.3 g were used by Iwasaki et al (1978). Based on cyclic triaxial test results, the sand layer at depth range of 2-5 m is predicted to be liquefied. Tohno et al. (1981): Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. The subject zone is seismically very active and had been shaken in 1897 and 1936 by earthquakes of Magnitudes 7.3 and 7.7 The dry river bed was cracked parallel to the river near Yuriage-Ohashi Bridge, and liquefied sands seeped out from the cracks. Some cracks were found near the piers of the Yuriage-Ohashi Birdge and the ground around the piers settled. The boiled soil was a poorly graded coarse sand. Iwasaki and Tokida (1980). identified the liquefied layer as at depths of 2-5 m. Gravel percent exceeds 20 % by weight. (Seed et al, 1984). SPT values were taken after main earthquake (M=7.4). SPT energy was estimated as 67 % by Seed et al. (1984)"

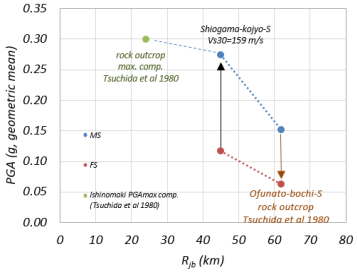
Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	1.8 - 3.0		1.8 - 3.0	1.8 - 3.8
d_{crt} (m)	3.4	2.4	2.5	2.4	2.8
GWT (m)	1.22	1.3 ± 0.3	1.2	1.3 ± 0.1	1.3 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	63.4	38.3 ± 3.6	46.1	42.9 ± 4.1	51.7 ± 6.9
σ_v' (kPa)	42.2	27.1 ± 3.1	34.1	31.7 ± 2.2	36.8 ± 3.7
a_{max} (g)	0.24	0.240 ± 0.048	0.24	0.240 ± 0.072	0.240 ± 0.048
r_d	0.98	0.98 ± 0.038	0.99	1.00 ± 0.038	1.00 ± 0.043
CSR	0.23	0.216 ± 0.050	0.212	0.210 ± 0.064	0.219 ± 0.046
M_w	7.40	7.40	7.70	7.70	7.70
D_{50}	1.6	1.600 ± 0.200	-	1.600 ± 0.050	0.335 ± 0.375
% Fines	7	7.0 ± 1.0	7	7.0 ± 2.0	7.0 ± 8.6
% PI	-	-	-	-	NAV
N	13	11.4 ± 1.6	10.1	11.4 ± 1.3	11.5 ± 1.1
C_R	-	0.82	0.85	0.82	0.90
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.12	1.12	1.12	1.12	1.37
C_N	1.46	1.88	1.68	1.79	1.66
$(N_1)_{60}$	21.5	19.7 ± 2.8	16.2	18.7 ± 2.2	23.5 ± 2.3
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	201.2	-	228.6	274.3

EVENT PARAMETERS

1978 Miyagiken-Oki	Seno et al (1980)	Foreshock parameters were assumed to be same with mainshock
Magnitude: 7.70	Length (km): 30	R_{rup} (km): -
Fault Type: thrust	Z_{tor} (km): 0	R_{jb} (km): 50-60
Dip: 20	Width (km): 80	

Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.



The river bed was dry during the earthquake.

The boiled sand was a poorly graded coarse sand.

The ground around the piers settled and sand boils were observed.

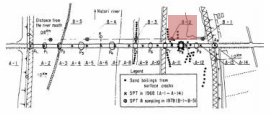


Fig. 10 Points of Sand Boils and Insitu Soil Tests at Yuriage Bridge

Mainshock record by Tsuchida et al (1980)

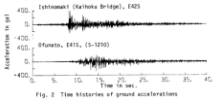


Fig. 2 Time histories of ground accelerations

Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

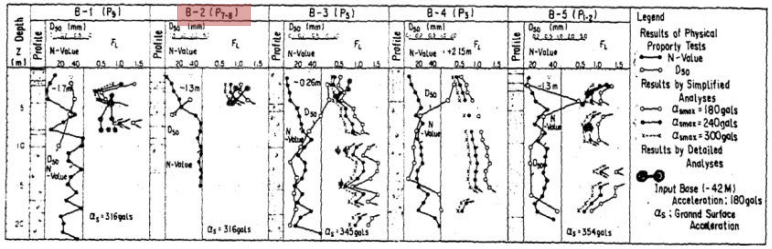
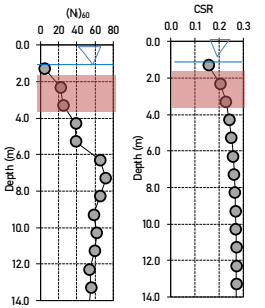
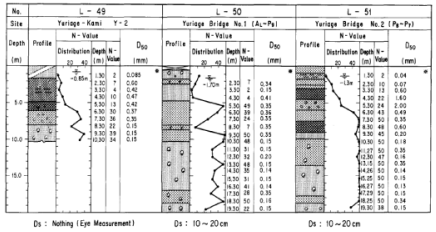


Fig. 11 F_L-values at Yuriage Bridge
(B-1, B-2, B-3; liquefied, B-4; liquefaction unconfirmed,
B-5; non-liquefied)



References: Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Iwasaki (1986), Cetin (2000), Cetin et al (2004, 2018)



Appendix 17

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	D50	
1.3	4.3	0.156	2	2.00	0.86	4.7	0.040	sandy silt close to surf.
2.3	***7.5***	***0.205***	***10***	***1.80***	***0.89***	***21.9***	***0.070***	medium sand
3.3	***10.8***	***0.229***	***13***	***1.55***	***0.91***	***25.1***	***0.600***	coarse sand
4.3	14.1	0.243	22	1.39	0.93	38.6	1.600	coarse sand
5.3	17.4	0.252	24	1.26	0.94	39.0	2.000	medium sand with gravel
6.3	20.7	0.258	43	1.17	0.95	65.3	0.490	medium sand
7.3	24.0	0.263	50	1.09	0.96	71.6	0.350	medium sand
8.3	27.2	0.266	48	1.03	0.97	65.3	0.600	coarse sand
9.3	30.5	0.269	45	0.97	0.97	58.4	0.200	fine sand
10.3	33.8	0.270	50	0.93	0.98	62.1	0.180	medium sand with shell
11.3	37.1	0.271	50	0.89	0.98	59.7	0.350	medium sand with shell
12.3	40.4	0.272	47	0.85	0.99	54.1	0.160	medium sand with shell
13.3	43.6	0.272	50	0.82	0.99	55.6	0.350	medium sand with shell
14.3	46.9	0.271	50	0.79	0.99	53.8	0.140	fine sand with shell
15.3	50.2	0.270	50	0.77	0.99	52.2	0.150	fine sand with shell
16.3	53.5	0.269	50	0.75	0.99	50.7	0.130	fine sand with shell
17.3	56.8	0.267	50	0.72	0.99	49.3	0.150	fine sand with shell
18.3	60.0	0.266	50	0.71	1.00	48.0	0.340	medium sand
19.3	63.3	0.264	38	0.69	1.00	35.6	0.150	fine sand with gravel
					Mean:	23.5	0.335	
					St. Dev.	2.3	0.375	

Case number:	71
Earthquake:	1978 Miyagiken-Oki
Magnitude:	7.7 (Mw) USGS Centennial Earthquake Catalog
Location:	Yuriage Bridge 3
References:	Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Iwasaki (1986), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Sand boils out of surface cracks, Damage to Yuriagegami Bridge, cracked piers, etc.
GPS LAT	38.182134
GPS LONG	140.946729
Liq. layer consist of:	coarse sand with shell
Geological Unit:	river deposit
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Yuriage Br. 3 is located near pier 5 of the Yuriagegami Bridge, which crosses Natori River. Pier 5 is towards the center of the river. PGA estimations of 0.24 and 0.3 g were used by Iwasaki et al (1978). Based on cyclic triaxial test results, the sand layer at depth range of 1-2 m is predicted to be liquefied. Tohno et al. (1981): Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. The subject zone is seismically very active and had been shaken in 1897 and 1936 by earthquakes of Magnitudes 7.3 and 7.7. The dry river bed was cracked parallel to the river near Yuriage-Ohashi Bridge, and liquefied sands seeped out from the cracks. Some cracks were found near the piers of the Yuriage-Ohashi Birdge and the ground around the piers settled. The boiled soil was a poorly graded coarse sand. Iwasaki and Tokida (1980) identified the liquefied layer as at depths of 2-5 m. SPT values were taken after main earthquake (M=7.4) SPT energy was estimated as 60 % by Seed et al. (1984)"

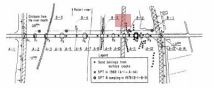


Fig. 10 Points of Sand Boils and Insitu Soil Tests at Yuriage Bridge

Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.

Shiogama-kojyo-S	NS	EW	NS	EW	geo.mean	Epicentral distance	Rjb
MS	264.9	277.6	0.270	0.278	0.274	99.9	45
FS	108	129.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	geo.mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	103.1	62
FS	61.1		0.062		0.062	93	
Ishinomaki	293		0.299		0.299	80	24

The river bed was dry during the earthquake.

The boiled sand was a poorly graded coarse sand.

The ground around the piers settled and sand boils were observed.

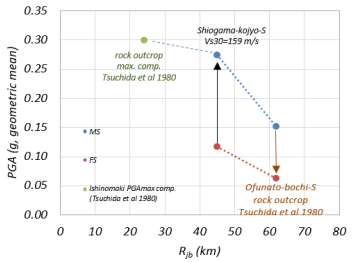
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

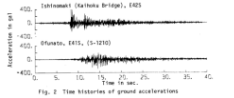
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	2.0 - 4.0		2.0 - 4.0	2.0 - 4.6
d_{crt} (m)	4.3	3.0	4.3	3.0	3.3
GWT (m)	0.30	0.3 ± 0.2	0.3	0.3 ± 0.1	0.3 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	80.6	49.2 ± 5.8	80.2	56.3 ± 6.4	62.0 ± 8.3
σ_v' (kPa)	41.8	22.3 ± 3.1	42.1	29.4 ± 3.4	32.1 ± 4.3
a_{max} (g)	0.24	0.240 ± 0.048	0.24	0.240 ± 0.072	0.240 ± 0.048
r_d	0.97	0.96 ± 0.045	0.97	0.99 ± 0.045	0.99 ± 0.049
CSR	0.29	0.332 ± 0.073	0.293	0.295 ± 0.090	0.300 ± 0.063
M_w	7.40	7.40	7.70	7.70	7.70
D_{50}	1.2	1.200 ± 0.200	-	1.200 ± 0.050	1.033 ± 0.379
% Fines	12	12.0 ± 2.0	12	12.0 ± 2.0	12.0 ± 8.6
% PI	-	-	-	-	NAV
N	8	7.1 ± 1.2	8	7.1 ± 1.0	6.9 ± 1.3
C_R	-	0.85	0.95	0.85	0.91
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.00	1.00	1.00	1.00	1.37
C_N	1.47	2.00	1.56	1.86	1.78
$(N_1)_{60}$	12	12.0 ± 2.1	11.8	11.2 ± 1.5	15.3 ± 2.8
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	189.0	-	201.2	231.6

EVENT PARAMETERS

1978 Miyagiken-Oki	Seno et al (1980)	Foreshock parameters were assumed to be same with mainshock
Magnitude: 7.70	Length (km): 30	R_{rup} (km): -
Fault Type: thrust	Z_{tor} (km): 0	R_{jb} (km): 50-60
Dip: 20	Width (km): 80	



Mainshock record by Tsuchida et al (1980)



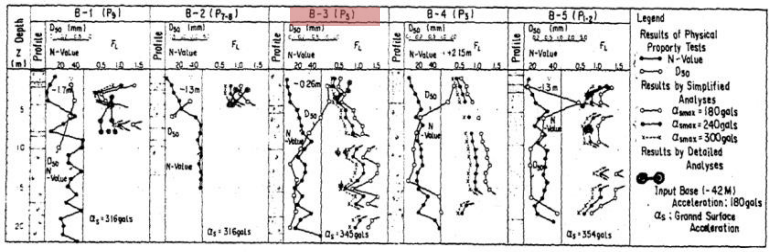
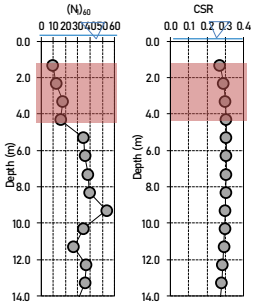
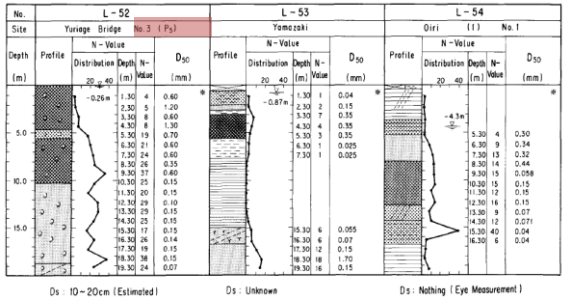


Fig. 11 F_L-values at Yuriage Bridge
(B-1, B-2, B-3; liquefied, B-4; liquefaction unconfirmed,
B-5; non-liquefied)





Appendix 18

References: Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Iwasaki (1986), Cetin (2000), Cetin et al (2004, 2018)

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$			D50
1.3	4.3	0.270	4	2.00	0.86	9.4	coarse sand with shell	close to surf.	0.600
2.3	***7.5***	***0.291***	***5***	***2.00***	***0.89***	***12.2***	coarse sand with shell		***1.200***
3.3	***10.8***	***0.300***	***8***	***1.78***	***0.91***	***17.7***	coarse sand with shell		***0.600***
4.3	***14.1***	***0.304***	***8***	***1.57***	***0.93***	***15.9***	coarse sand with shell		***1.300***
5.3	17.4	0.306	19	1.42	0.94	34.7	medium sand with shell		0.700
6.3	20.7	0.306	21	1.31	0.95	35.7	coarse sand with shell		0.600
7.3	24.0	0.305	24	1.22	0.96	38.4	coarse sand with shell		0.600
8.3	27.2	0.303	26	1.15	0.97	39.4	coarse sand with shell		0.350
9.3	30.5	0.300	37	1.08	0.97	53.4	coarse sand with shell		0.600
10.3	33.8	0.296	25	1.03	0.98	34.5	fine sand with shell		0.150
11.3	37.1	0.291	20	0.99	0.98	26.5	fine sand with shell		0.150
12.3	40.4	0.286	29	0.95	0.99	36.9	fine sand with shell		0.100
13.3	43.6	0.280	29	0.91	0.99	35.6	fine sand with shell		0.150
14.3	46.9	0.274	25	0.88	0.99	29.7	fine sand with shell		0.150
15.3	50.2	0.268	17	0.85	0.99	19.6	fine sand with shell		0.150
16.3	53.5	0.264	26	0.82	0.99	29.1	fine sand with shell		0.140
17.3	56.8	0.260	19	0.80	0.99	20.6	fine sand with shell		0.150
18.3	60.0	0.256	38	0.78	1.00	40.2	fine sand with shell		0.150
19.3	63.3	0.254	24	0.76	1.00	24.8	silty fine sand with shell		0.070
				Mean:		15.3		**Mean:**	1.033
				St. Dev.		2.8		**St. Dev.**	0.379

Case number:	72
Earthquake:	1978 Miyagiken-Oki
Magnitude:	7.7 (Mw) USGS Centennial Earthquake Catalog
Location:	Yuriage Bridge 5
References:	Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Iwasaki (1986), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface evidence of liquefaction.
GPS LAT	38.182134
GPS LONG	140.946729
Liq. layer consist of:	fine sand with gravel
Geological Unit:	river deposit
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Yuriage Br. 5 is located near pier 1 of the Yuriagegami Bridge, which crosses the Natori River. Pier 5 is the closest pier to the left bank of the river. PGA estimations of 0.24 and 0.3 g were used by Iwasaki et al (1978). Based on cyclic triaxial test results, the sand layer at depth range of 3-9 m is predicted to be liquefied. However no surface evindence of liquefaction exists. Tohno et al. (1981): Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. The subject zone is seismically very active and had been shaken in 1897 and 1936 by earthquakes of Magnitudes 7.3 and 7.7 The dry river bed was cracked parallel to the river near Yuriage-Ohashi Bridge, and liquefied sands seeped out from the cracks. Some cracks were found near the piers of the Yuriage-Ohashi Birdge and the ground around the piers settled. The boiled soil was a poorly graded coarse sand. Iwasaki and Tokida (1980) identified the potentially liquefiable layer at depths of 2-5 m. SPT values were taken after main earthquake (M=7.4) SPT energy is estimated as 67 % by Seed et al. (1984)"

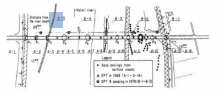


Fig. 10 Points of Sand Boils and Insitu Soil Tests at Yuriage Bridge

Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.

The river bed was dry during the earthquake.

The ground around the piers settled and sand boils were observed.

FC was given as 17% at 7.3 m depth by Prof. Seed. Same FC is used as the layer is same (fine sand layer).

Critical layer is updated.

Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

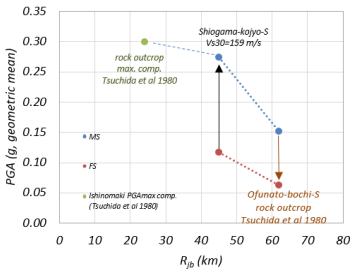
Shiogama-kojyo-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	103.1	62
FS	61.1		0.062		0.062	50	
Ishinomaki	293		0.299		0.299	80	24

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	6.0 - 9.0		6.0 - 9.0	3.0 - 8.0
d_{crt} (m)	7.3	7.5	7.3	7.5	5.5
GWT (m)	1.22	1.3 ± 0.3	1.2	1.3 ± 0.2	1.3 ± 0.2
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	18.1 ± 0.9	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	138.2	131.7 ± 10.9	138.3	146.6 ± 10.3	111.2 ± 17.3
σ_v' (kPa)	78.2	70.8 ± 7.5	78.2	85.7 ± 5.9	69.9 ± 9.3
a_{max} (g)	0.24	0.240 ± 0.048	0.24	0.240 ± 0.072	0.240 ± 0.048
r_d	0.94	0.86 ± 0.099	0.94	0.98 ± 0.099	0.99 ± 0.076
CSR	0.26	0.251 ± 0.059	0.26	0.261 ± 0.083	0.246 ± 0.053
M_w	7.40	7.40	7.70	7.70	7.70
D_{50}	0.35	0.350 ± 0.080	-	0.350 ± 0.050	0.5-5 ± 0.050
% Fines	17	17.0 ± 3.0	17	17.0 ± 2.0	17.0 ± 8.6
% PI	-	-	-	-	NAV
N	17	20.5 ± 6.7	17	20.5 ± 6.7	17.7 ± 2.3
C_R	-	0.99	0.95	0.99	0.94
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.12	1.12	1.12	1.12	1.37
C_N	1.10	1.16	1.11	1.09	1.21
$(N_1)_{60}$	21	26.3 ± 8.6	20.1	24.6 ± 8.0	27.4 ± 3.6
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	201.2	-	237.7	243.8

EVENT PARAMETERS

1978 Miyagiken-Oki	Seno et al (1980)	Foreshock parameters were assumed to be same with mainshock
Magnitude: 7.70	Length (km): 30	R_{rup} (km): -
Fault Type: thrust	Z_{tor} (km): 0	R_{jb} (km): 50-60
Dip: 20	Width (km): 80	



Mainshock record by Tsuchida et al (1980)

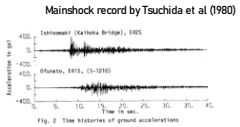


Fig. 2 Time histories of ground accelerations

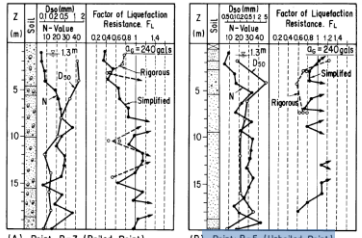


Fig. 10. Boring logs, SPT N-values, and F_L-values (liquefaction resistance factor) at two points, Yuriage Bridge

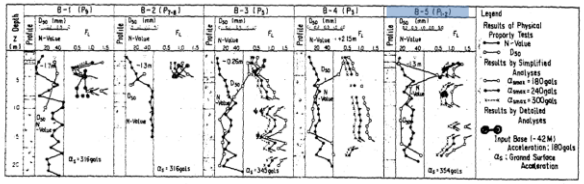
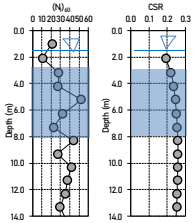
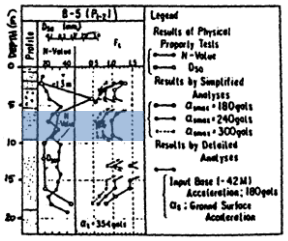


Fig. 11 F_L-values at Yuriage Bridge
(B-1, B-2, B-3; liquefied, B-4; liquefaction unconfirmed, B-5; non-liquefied)

References: Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Iwasaki (1986), Cetin (2000), Cetin et al (2004, 2018)





Depth (m)	Depth (ft)	CSR	N	C_N	C_E	$(N1)_{60}$		
1.0	3.3	NA	9.0	2.00	0.86	21.0	silty sand	
2.1	6.9	0.193	5.0	1.75	0.88	10.6	fine sand	silt? or silty?
3.2	*10.5*	*0.220*	*15.0*	*1.50*	*0.91*	*27.9*	*fine sand with gravel*	
4.2	*13.8*	*0.234*	*16.0*	*1.35*	*0.93*	*27.3*	*fine sand with gravel*	
5.2	17.1	0.244	33.0	1.23	0.94	52.3	fine sand with gravel	gravel??
6.3	*20.7*	*0.251*	*22.0*	*1.14*	*0.95*	*32.5*	*fine sand*	
7.3	*24.0*	*0.255*	*16.0*	*1.07*	*0.96*	*22.4*	*fine sand*	
8.3	27.2	0.257	33.0	1.01	0.97	44.0	fine sand	gravel??
9.3	*30.5*	*0.258*	*21.0*	*0.99*	*0.97*	*29.7*	*fine sand*	
10.3	33.8	0.258	34.0	0.91	0.98	41.5	fine sand	
11.3	37.1	0.257	32.0	0.88	0.98	37.6	fine sand	
12.3	40.4	0.254	31.0	0.84	0.99	35.2	fine sand	
13.3	43.6	0.252	27.0	0.81	0.99	29.6	fine sand	
14.3	46.9	0.248	34.0	0.78	0.99	36.1	fine sand	
15.3	50.2	0.245	30.0	0.76	0.99	30.9	fine sand	
16.3	53.5	0.242	25.0	0.74	0.99	25.1	fine sand	
17.3	56.8	0.239	14.0	0.72	0.99	13.7	fine sand	
18.3	60.0	0.237	20.0	0.70	1.00	19.0	fine sand	
19.3	63.3	0.235	41.0	0.68	1.00	38.0	fine sand	
20.0	65.6	0.234	17.0	0.67	1.00	15.5	fine sand	
					Mean:	27.4		
					St. Dev.	3.6		

Case number:	74
Earthquake:	1978 Miyagiken-Oki
Magnitude:	7.7 (Mw) USGS Centennial Earthquake Catalog
Location:	Yuriagekami-2
References:	Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Iwasaki (1986), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Sand boils.
GPS LAT	38.189551
GPS LONG	140.934866
Liq. layer consist of:	sand
Geological Unit:	river embankment
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Yuriagekami-2 is located by the edge of the Natori river, on the right bank of the river. PGA is estimated as 0.18 g by Iwasaki et al (1978). Based on cyclic triaxial test results, the liquefied layer is peridicted to be the sand layer at depth of 1-6 m. Tohno et al. (1981): Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. The subject zone is seismically very active and had been shaken in 1897 and 1936 by earthquakes of Magnitudes 7.3 and 7.7. The river embankment was partially collapsed and cracked on both sides at Yuriagekami. Cracks were observed both on and at the base of the dike. Also sand volcanoes were found along the dike. SPT values were taken after main earthquake (M=7.4). SPT energy was estimated as 60 % by Seed et al. (1984)"
	The borehole data is redigitized from Iwasaki (1986).
	Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.
	PI is assigned as 0 as FC=0 by Prof. Seed.
	Vs12m is updated based on Vs - SPTN correlations.
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

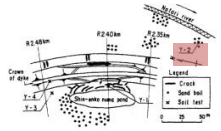


Fig. 7 Plan of Yuriage-kami Dyke and Points of Soil Tests

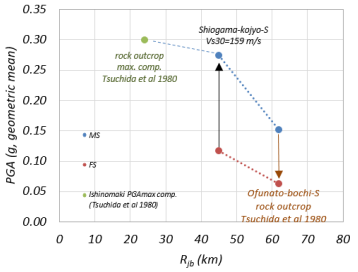
Shiogama-kojyo-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	103.1	62
FS	61.1		0.062		0.062	50	
Ishinomaki	293		0.299		0.299	80	24

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	2.0 - 5.5		2.0 - 5.5	2.0 - 5.5
d_{GTL} (m)	4.3	3.8	4.3	3.8	3.8
GWT (m)	0.91	0.9 ± 0.3	0.9	0.9 ± 0.1	0.9 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	80.6	60.7 ± 9.8	80.2	68.2 ± 11.1	68.2 ± 11.1
σ_v' (kPa)	47.5	32.2 ± 5.0	47.1	39.7 ± 5.5	39.7 ± 5.5
a_{max} (g)	0.24	0.240 ± 0.048	0.24	0.240 ± 0.072	0.240 ± 0.048
r_d	0.97	0.95 ± 0.055	0.97	0.97 ± 0.055	1.00 ± 0.055
CSR	0.255	0.279 ± 0.064	0.258	0.260 ± 0.080	0.267 ± 0.056
M_w	7.40	7.40	7.70	7.70	7.70
D_{50}	0.4	0.400 ± 0.100	-	0.400 ± 0.050	0.478 ± 0.085
% Fines	0	0.0 ± 0.0	0	0.0 ± 2.0	0.0 ± 8.6
% PI	-	-	-	-	0.0
N	11	8.8 ± 3.4	11	8.8 ± 3.3	8.4 ± 3.1
C_R	-	0.88	0.95	0.88	0.92
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.00	1.00	1.00	1.00	1.37
C_N	1.38	1.73	1.45	1.60	1.60
$(N_1)_{60}$	15	13.3 ± 5.2	15.1	12.3 ± 4.7	16.8 ± 6.2
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	189.0	-	189.0	240.8

EVENT PARAMETERS

1978 Miyagiken-Oki	Seno et al (1980)	Foreshock parameters were assumed to be same with mainshock
Magnitude: 7.70	Length (km): 30	R_{rup} (km): -
Fault Type: thrust	Z_{tor} (km): 0	R_{jb} (km): 50-60
Dip: 20	Width (km): 80	



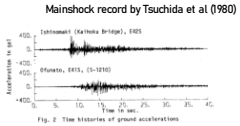
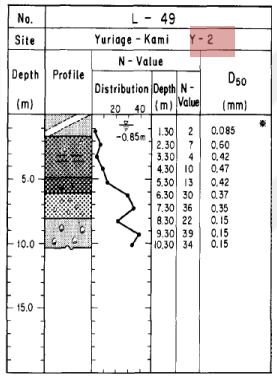
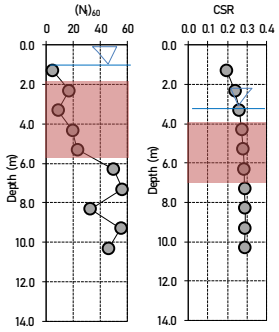


Fig. 2 Time histories of ground accelerations



Ds : Nothing (Eye Measurement)



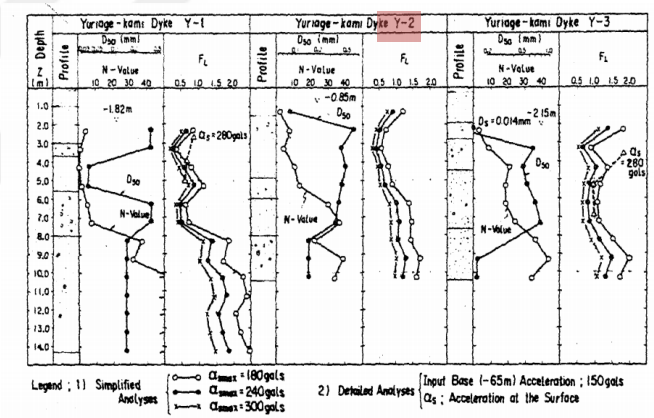


Fig. 9 F_L-values at Yuriage-kami Dyke
(Y-1, Y-2; liquefied, Y-3; non-liquefied)

References: Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Iwasaki (1986), Cetin (2000), Cetin et al (2004, 2018)

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	D50 (mm)	
1.3	4.3	0.195	2	2.00	0.86	4.7	0.085	silty sand close to surf.
2.3	***7.5***	***0.239***	***7***	***1.96***	***0.89***	***16.6***	***0.600***	medium sand
3.3	***10.8***	***0.260***	***4***	***1.69***	***0.91***	***8.4***	***0.420***	medium sand
4.3	***14.1***	***0.273***	***10***	***1.51***	***0.93***	***19.1***	***0.470***	medium sand
5.3	***17.4***	***0.280***	***13***	***1.37***	***0.94***	***23.0***	***0.420***	coarse sand
6.3	20.7	0.285	30	1.27	0.95	49.6	0.370	medium sand with gravel
7.3	24.0	0.288	36	1.19	0.96	56.2	0.350	medium sand with gravel
8.3	27.2	0.289	22	1.12	0.97	32.6	0.150	fine sand with shell
9.3	30.5	0.289	39	1.06	0.97	55.1	0.150	fine sand with shell
10.3	33.8	0.288	34	1.01	0.98	46.0	0.150	fine sand with shell
					Mean:	16.8	0.478	
					St. Dev.	6.2	0.085	

Case number:	75
Earthquake:	1978 Miyagiken-Oki
Magnitude:	7.7 (Mw) USGS Centennial Earthquake Catalog
Location:	Yuriagekami-3
References:	Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Iwasaki (1986), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface evidence of liquefaction.
GPS LAT	38.189959
GPS LONG	140.934281
Liq. layer consist of:	sand with gravel
Geological Unit:	river embankment
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Yuriagekami-3 is located at the base of the dike on the right bank of the Natori River, not far from the Shin-enko numa pond. PGA is estimated as 0.18 g by Iwasaki et al (1978). Tohno et al. (1981): Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. The subject zone is seismically very active and had been shaken in 1897 and 1936 by earthquakes of Magnitudes 7.3 and 7.7 The river embankment was partially collapsed and cracked on both sides at Yuriagekami. Cracks were observed both on and at the base of the dike. Also sand volcanoes were found along the dike. SPT values were taken after main earthquake (M=7.4). SPT energy was estimated as 67 % by Seed et al. (1984)"
	Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.
	PI is assigned as 0 as FC=0% given by Prof. Seed.
	Borehole data is obtained from Iwasaki (1986)
	Critical layer is slightly updated as the borehole is redigitized.
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

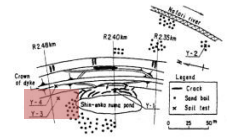


Fig. 7 Plan of Yuriage-kami Dyke and Points of Soil Tests

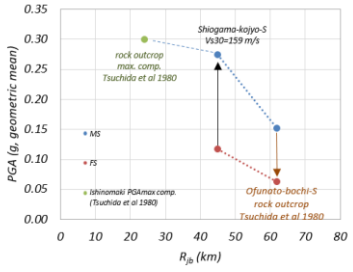
Shiogama-kojyo-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	geo mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	103.1	62
FS	61.1		0.062		0.062	50	
Ishinomaki	293		0.299		0.299	80	24

Summary of Input Data

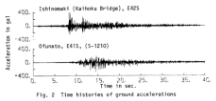
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	4.5 - 7.5		4.5 - 7.5	3.8 - 7.9
d_{crt} (m)	5.5	6.0	5.5	6.0	5.9
GWT (m)	2.13	2.2 ± 0.3	2.1	2.2 ± 0.1	2.2 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	18.1 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	103.7	101.9 ± 9.5	103.3	113.0 ± 10.1	113.6 ± 14.2
σ_v' (kPa)	70.6	64.1 ± 5.4	70.2	75.2 ± 5.4	77.2 ± 7.7
a_{max} (g)	0.24	0.240 ± 0.048	0.24	0.240 ± 0.072	0.240 ± 0.048
r_d	0.96	0.91 ± 0.082	0.96	0.97 ± 0.082	0.99 ± 0.080
CSR	0.22	0.227 ± 0.051	0.22	0.227 ± 0.071	0.227 ± 0.050
M_w	7.40	7.40	7.70	7.70	7.70
D_{50}	0.6	0.600 ± 0.015	-	0.600 ± 0.050	0.638 ± 0.138
% Fines	0	0.0 ± 0.0	0	0.0 ± 2.0	0.0 ± 8.6
% PI	-	-	-	-	0
N	20	21.0 ± 1.9	20	21.1 ± 1.9	20.7 ± 2.0
C_R	-	0.95	0.95	0.95	0.95
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.12	1.12	1.12	1.12	1.37
C_N	1.15	1.22	1.16	1.16	1.15
$(N_1)_{60}$	26	27.3 ± 2.5	24.6	26.0 ± 2.3	30.7 ± 3.0
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	201.2	-	216.4	243.8

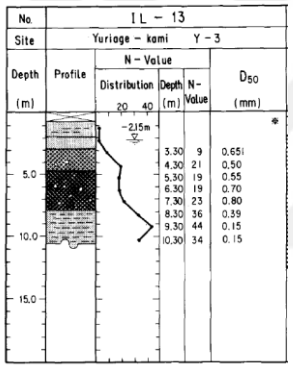
EVENT PARAMETERS

1978 Miyagiken-Oki	Seno et al (1980)	Foreshock parameters were assumed to be same with mainshock
Magnitude: 7.70	Length (km): 30	R_{rup} (km): -
Fault Type: thrust	Z_{tor} (km): 0	R_{jb} (km): 50-60
Dip: 20	Width (km): 80	



Mainshock record by Tsuchida et al (1980)





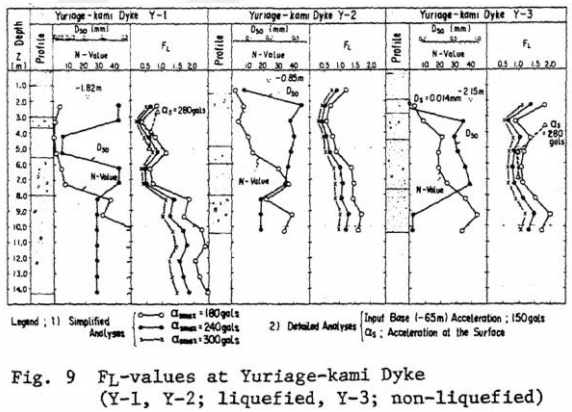
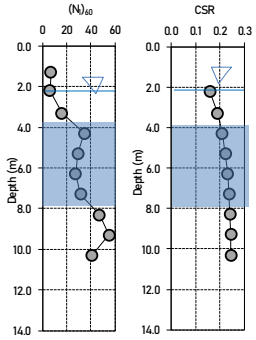


Fig. 9 F_L-values at Yuriage-kami Dyke
(Y-1, Y-2; liquefied, Y-3; non-liquefied)



References:
Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), Iwasaki (1986), Cetin (2000), Cetin et al (2004, 2018)

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	D50 (mm)	
1.3	4.3	NA	3	2.00	0.86	7.1		sandy silt
2.2	7.2	0.158	3	1.64	0.89	6.0		fine sand
3.3	10.8	0.191	9	1.43	0.91	16.0	0.651	medium sand with gravel
4.3	***14.1***	***0.209***	***21***	***1.30***	***0.93***	***34.5***	***0.500***	medium sand with gravel
5.3	***17.4***	***0.222***	***19***	***1.19***	***0.94***	***29.2***	***0.550***	coarse sand with gravel
6.3	***20.7***	***0.231***	***19***	***1.11***	***0.95***	***27.5***	***0.700***	coarse sand with gravel
7.3	***24.0***	***0.237***	***23***	***1.05***	***0.96***	***31.6***	***0.800***	coarse sand with gravel
8.3	27.2	0.241	36	0.99	0.97	47.1	0.390	sandy silt
9.3	30.5	0.244	44	0.94	0.97	55.2	0.150	sandy silt
10.3	33.8	0.245	34	0.90	0.98	41.0	0.150	sandy silt
					Mean:	30.7	0.638	
					St. Dev.	3.0	0.138	

excluded do not represent the sand layer, this is a transion zone SPT N value

Case number:	425
Earthquake:	1978 Miyagiken-Oki
Magnitude:	7.7
Location:	Oiiri 2
References:	Iwasaki et al. (1978), Fear et al. (1995), Tohno et al. (1981), A.S. Cakmak (1986), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	sand boils — A.S. Cakmak (1986) "Soil Liquefaction Studies in Japan", Vol. 5 No.1 , Soil Dynamics & Earthquake Engineering.
GPS LAT	38.505719 — coordinates are taken from NGL project, the exact location is unkown n.
GPS LONG	141.234144
Liq. layer consist of:	coarse sand
Geological Unit:	river embankment
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Prior to the main shock of M=7.4, an earthquake of magnitude 6.7 occurred. Only the Nakamura site liquefied during this earthquake. The subject zone is seismically very active and had been shaken in 1897 and 1936 by earthquakes of Magnitudes 7.3 and 7.7. Iwasaki et al (1978) paper did not mention Oiiri sites. However Cakmak et al. gave a representative depth vs. N profile for Oiiri 1. SPT values were taken after main earthquake (M=7.4). SPT energy is estimated as 60 % by Seed et al. (1984)"
	The borehole data is obtained from Iwasaki (1986). There are two borehole data available at the site.
	Shiogama-kojyo-S SMS has a Rjb distance of 45 km. The acceleration recording was available at PARI. The Mw=6.5 event produced a PGA of 0.106 g and 0.129 g, geometric mean of which is 0.117 g. The Mw=7.7 event produced 0.270 g and 0.278 g, geometric mean of which is 0.274 g at the SMS site. Vs30m is estimated by assuming the Vs values extend up to 30 m for the SMS. Vs30m is estimated as 159 m/s at the SMS which is similar to the site. Another digital recording obtained from PARI is Ofunato SMS. Vs values were not documented. PGA values recorded as 0.140 g and 0.164 g for the mainshock, geometric mean of which is 0.152 g. The PGA is recorded as 0.062 g for the foreshock. Rjb is estimated about 62 km for the station. Note that Tsuchida et al 1980 presents a-t record from Ishinomaki as 293 gals (PGAmax), Rjb is estimated as 24 km. Offunato and Ishinomaki SMS are located on rock outcrop (Tsuchida et al (1980)). A local model is developed and it was concluded that Prof. Seed PGA selection are reasonable values for the foreshock and mainshcok respectively. The borehole data is redigitized and the soil classification was noted next to each SPT.
	PI is assigned as 0 as FC=5% by Seed et al (1985).
	Vs12m is updated based on Vs-SPTN correlations.
	The borehole data for Oiri 2 is found and included. The site was not included in Idriss and Boulanger (2010) and Cetin et al. (2004)
	Outside dike: Sand volcanoes were observed on both sides of the base of the dike and in the adjacent field (Tohno and Yasuda 1981). Inside dike: The "textural parameters" of ejected sands "are similar to that of the insitu sandy deposits at 4.5 m to 7.0 m in depth" (Tohno and Yasuda 1981).
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Shiogama-kojyo-S	NS	EW	NS	EW	goe mean	Epicentral distance	Rjb
MS	264.9	272.8	0.270	0.278	0.274	99.9	45
FS	104	126.4	0.106	0.129	0.117	111.5	
Ofunato-bochi-S	NS	EW	NS	EW	goe mean	Epicentral distance	Rjb
MS	137.6	161.2	0.140	0.164	0.152	103.1	62
FS	61.1		0.062		0.062	50	
Ishinomaki	293		0.299		0.299	80	24

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	3.8 - 6.8
d_{crt} (m)	6.4	-	-	-	5.3
GWT (m)	2.44	-	-	-	2.4 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	114.7	-	-	-	101.4 ± 10.5
σ_v' (kPa)	75.8	-	-	-	72.9 ± 5.7
a_{max} (g)	0.24	-	-	-	0.240 ± 0.048
r_d	0.95	-	-	-	0.94 ± 0.073
CSR	0.225	-	-	-	0.205 ± 0.044
M_w	7.70	-	-	-	7.70
D_{50}	0.36	-	-	-	0.340 ± 0.050
% Fines	4	-	-	-	4.0 ± 8.6
% PI	-	-	-	-	0
N	8	-	-	-	9.4 ± 2.1
C_R	-	-	-	-	0.94
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	1.11	-	-	-	1.18
$(N_1)_{60}$	9	-	-	-	14.3 ± 3.2
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	189.0

EVENT PARAMETERS

1978 Miyagiken-Oki — Seno et al (1980)

Magnitude: 7.70 — Length (km): 30

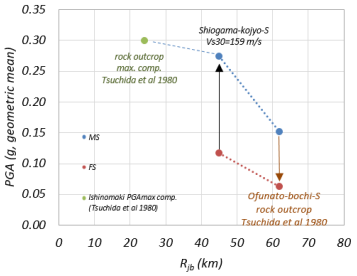
Fault Type: thrust — Z_{tor} (km): 0

Dip: 20 — Width (km): 80

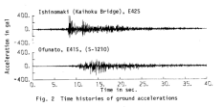
Foreshock parameters were assumed to be same with mainshock

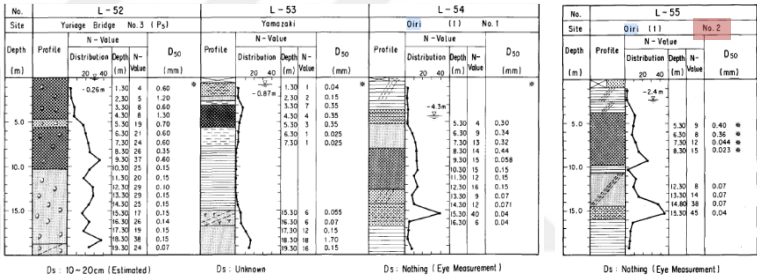
R_{rup} (km): -

R_{jb} (km): 30-35

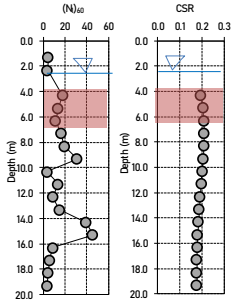


Mainshock record by Tsuchida et al (1980)





Appendix 18



No:1

Depth (m)	N		
1.3	5	clayey silt	
2.3	4	clayey silt	
4.3	5	sandy clay	
5.3	4	sand	
6.3	9	sand	
7.3	13	sand	
8.3	14	ıedium san	
9.3	15	ıedium san	
10.3	15	ıedium san	
11.3	12	ıedium san	
12.3	16	ıedium san	
13.3	9	silty sand	
14.3	12	sandy silt	
15.3	40	sandy silt	
16.3	6	sandy silt	

No:2

Depth (m)	N	
1.3	2	silty clay
2.3	2	silty clay
4.3	11	coarse sand
5.3	9	coarse sand
6.3	8	coarse sand
7.3	12	coarse sand
8.3	15	coarse sand
9.3	25	coarse sand
10.3	3	clay
11.3	12	silty sand
12.3	8	silty sand
13.3	14	silty sand
14.3	38	silty sand
15.3	45	sandy silt
16.3	9	clay
17.3	6	clay
18.3	5	clay
19.3	4	clay

GWT (m)

4.3	No:1
2.4	No:2

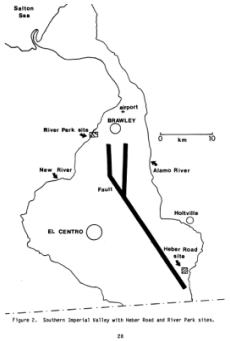
Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	D50	
1.3	4.3	NA	2	2.00	0.86	4.7		silty clay
2.3	7.5	NA	2	1.60	0.89	3.9		silty clay
4.3	***14.1***	***0.195***	***11***	***1.28***	***0.93***	***17.8***		coarse sand
5.3	***17.4***	***0.205***	***9***	***1.18***	***0.94***	***13.7***	***0.40***	coarse sand
6.3	***20.7***	***0.209***	***8***	***1.10***	***0.95***	***11.5***	***0.36***	*coarse sand*
7.3	24.0	0.211	12	1.04	0.96	16.3	0.04	coarse sand
8.3	27.2	0.209	15	0.98	0.97	19.5	0.02	coarse sand
9.3	30.5	0.206	25	0.94	0.97	31.1		coarse sand
10.3	33.8	0.202	3	0.89	0.98	3.6		clay
11.3	37.1	0.197	12	0.86	0.98	13.8		silty sand
12.3	40.4	0.192	8	0.83	0.99	8.9	0.07	silty sand
13.3	43.6	0.187	14	0.80	0.99	15.1	0.07	silty sand
14.3	46.9	0.184	38	0.77	0.99	39.8	0.07	silty sand
15.3	50.2	0.181	45	0.75	0.99	45.7	0.04	sandy silt
16.3	53.5	0.179	9	0.73	0.99	8.9		clay
17.3	56.8	0.178	6	0.71	0.99	5.8		clay
18.3	60.0	0.177	5	0.69	1.00	4.7		clay
19.3	63.3	0.176	4	0.67	1.00	3.7		clay
					Mean:	14.3	0.380	
					St. Dev.	3.2	0.028	

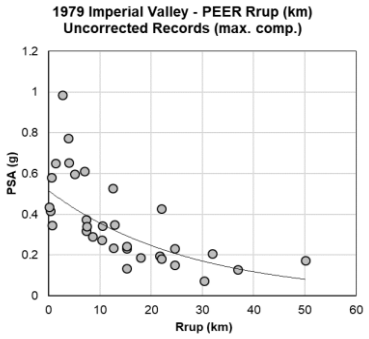
Late Prof Seed selected this layer. Dcrt=6.3 SPTN=8 D50=0.36

D50=0.04 sand? Silt? PI unkown
D50=0.02 sand? Silt? PI unkown
outlier

No information regarding PI of this layer. Prof. Seed might have information that we cannot acces hence his selection was kept.

Case number:	76
Earthquake:	1979 Imperial Valley
Magnitude:	6.53 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Heber Road A1
References:	Bennett et al. (1981), Youd and Bennett (1983), Andrus and Stokoe (1997), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface manifestation of liquefaction
GPS LAT	32.73049583
GPS LONG	-115.3858486
Liq. layer consist of:	Sand (SP)
Geological Unit:	Relict Holocene channel, Quaternary alluvium and marine deposits--Pleistocene to Holocene
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "The Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much as 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The principal rivers are the Alamo and New Rivers along which many sand boils were developed on fluvial deposits. Heber Road site is ~1.6 km to the fault rupture plane. AGR and BCR are two stations that are located ~ 7 kms southeast of Heber Road site. The peak acceleration recorded at station AGR at an epicentral distance of 1.8 km is 0.35 and 0.23 g. The station is underlain by deep alluvium and the motion is free field. At Bonds Corner, 5.2 km southern terminus of the fault rupture and 6 km form the southeast of the Heber Road site, PGA was recorded as 0.76 and 0.58 g. Seed et al (1984) used a PGA value of 0.78 g. It is believed that directivity effects play a major role in the intensity of shaking. Higher intensity shakings (0.83 g) were recorded at the northern section of the fault. Based on the recorded motion and earthquake specific PGA contour maps, PGA was estimated as in the range of 0.4-0.7 g. Site response analyses based PGA estimation was in the range of ~ 0.45 to 0.50 ASTM D1586-67 procedures were followed for SPT tests. 10" outside diameter hollow-stem auger was used with Safe-T- Driver and safety hammer for the drillings in 1979 and 1981. Donut Hammer with rope cathead was used for the drillings in in 1982. Energy ratios are adopted as 68 and 66 % for safety and donut hammers respectively." SMS data is downloaded from COSMOS, a local PGA model is contstructed and the PGA selection seems correct. The fault parameters are obtained from Arculeta (1984). The fault surface rupture is obtained from Bennett et al (1984) Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes



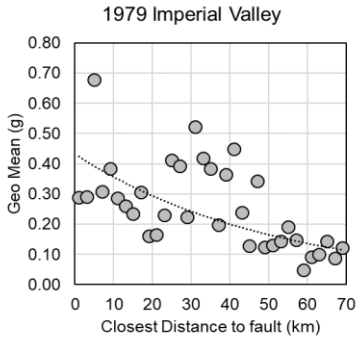


Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	B	-	A	A
d_{crtc} range (m)	-	1.8 - 5.0		1.8 - 5.0	1.8 - 5.0
d_{crt} (m)	3.7	3.4	2.9	3.4	3.4
GWT (m)	1.83	1.8 ± 0.9	1.8	1.8 ± 0.1	1.8 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	19.6 ± 0.6	-	19.6 ± 0.5	19.6 ± 0.5
σ_v (kPa)	67.7	59.8 ± 11.2	53.1	59.8 ± 10.6	59.8 ± 10.6
σ_v' (kPa)	49.7	44.1 ± 7.7	42.1	44.1 ± 5.4	44.1 ± 5.4
a_{max} (g)	0.78	0.470 ± 0.050	0.78	0.470 ± 0.071	0.470 ± 0.071
r_d	0.97	0.82 ± 0.010	0.97	0.82 ± 0.010	0.82 ± 0.025
CSR	0.67	0.325 ± 0.074	0.62	0.340 ± 0.055	0.340 ± 0.056
M_w	6.60	6.50	6.53	6.53	6.53
D_{50}	0.112	0.112 ± 0.010	-	0.111 ± 0.007	0.111 ± 0.007
% Fines	25	25.0 ± 4.0	12	13.0 ± 3.9	13.0 ± 3.9
% PI	-	-	-	-	NAV
N	28	32.9 ± 2.6	30.4	32.9 ± 2.6	33.6 ± 2.1
C_R	-	0.82	0.85	0.82	0.89
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	0.00	1.13	1.13	1.13	1.13
C_N	1.35	1.48	1.30	1.52	1.52
$(N_1)_{60}$	39.5	45.2 ± 3.6	37.8	46.5 ± 3.7	51.6 ± 3.2
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

EVENT PARAMETERS

1979 Imperial Valley	Archuleta (1984)	
Magnitude: 6.53	Length (km): 35	
Fault Type: primarly right l	Z_{tor} (km): 0	R_{rup} (km): 2.5
Dip: 80 NE	Width (km): 13	R_{jb} (km): 2.5





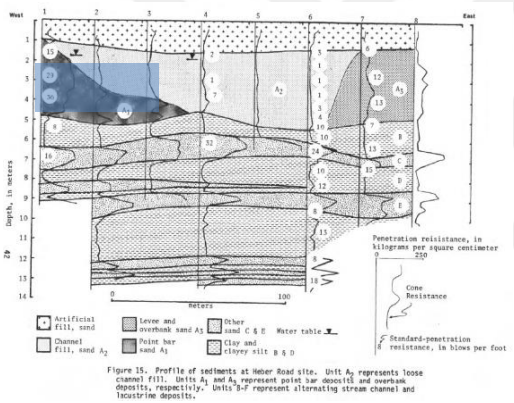
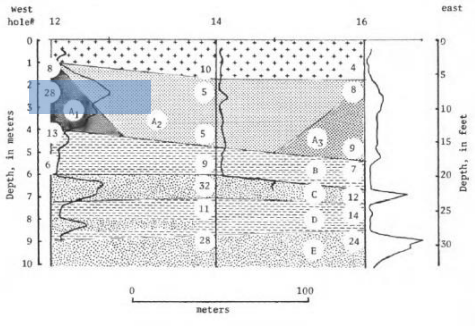
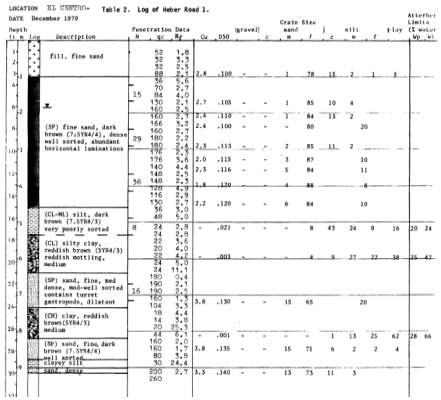


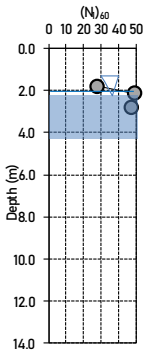
Figure 15. Profile of sediments at Heber Road site. Unit A_2 represents loose channel fill. Units A_1 and A_3 represent point bar deposits and overbank deposits, respectily. Units B-F represent alternating stream channel and lacustrine deposits.

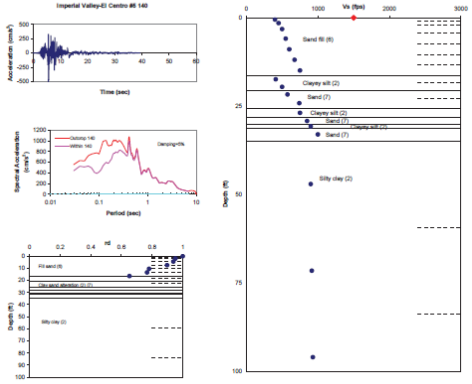


Cetin (2000)



Heber Road A1 – Imperial Valley (1979)

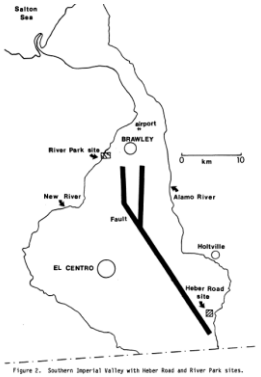


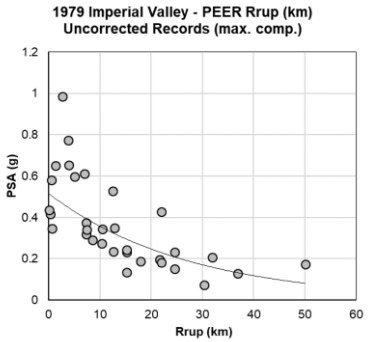


	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
BH-1	1.8	5.9		15	1.89	0.85	27.4	
BH-12	***2.1***	***7.0***		***28***	***1.80***	***0.86***	***49.1***	SP
BH-1 Donut	***2.5***	***8.0***		***32***	***1.71***	***0.87***	***54.0***	SP
BH-1 Donut	***2.8***	***9.2***		***29***	***1.63***	***0.88***	***47.2***	SP
BH-1	***3.4***	***11.0***		***35***	***1.53***	***0.89***	***54.0***	SP
BH-1	***3.8***	***12.5***		***36***	***1.45***	***0.90***	***53.5***	SP
						Mean:	51.6	
						St. Dev.	3.2	

	D_{50} (mm)	FC %	silt	clay	
	0.105	14	14	0	
	0.11	15	15	0	
	0.1	20	20	0	
	0.113	13	13	0	
	0.115	10	10	0	
	0.116	11	11	0	
	0.12	8	8	0	
Mean:	0.111	13.0	13.0	0.0	
St. Dev.	0.007	3.9	3.9	2.3	assigned

Case number:	77
Earthquake:	1979 Imperial Valley
Magnitude:	6.53 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Heber Road A2
References:	Youd and Bennett (1983), "Liquefaction sites, Imperial Valley, CA", Benett et. al. (1979), Cetin (2000), Cetin (2004, 2018)
Nature of Failure:	Liquefaction-induced lateral spreading shifted the road as much as 7 ft.
GPS LAT	32.73049583 southward toward a 6.6 ft deep depression. Ground cracks and scaprs formed.
GPS LONG	-115.3858486 Sand boils erupted at several placed along the spread.
Liq. layer consist of:	Silty Sand (SM)
Geological Unit:	Relict Holocene channel
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "The Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much as 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The principal rivers are the Alamo and New Rivers along which many sand boils were developed on fluvial deposits. Heber Road site is ~1.6 km to the fault rupture plane. AGR and BCR are two stations that are located ~ 7 kms southeast of Heber Road site. The peak acceleration recorded at station AGR at an epicentral distance of 1.8 km is 0.35 and 0.23 g. The station is underlain by deep alluvium and the motion is free field. At Bonds Corner, 5.2 km southern terminus of the fault rupture and 6 km form the southeast of the Heber Road site, PGA was recorded as 0.76 and 0.58 g. Seed et al (1984) used a PGA value of 0.78 g. It is believed that directivity effects play a major role in the intensity of shaking. Higher intensity shakings (0.83 g) were recorded at the northern section of the fault. Based on the recorded motion and earthquake specific PGA contour maps, PGA was estimated as in the range of 0.4-0.7 g. Site response analyses based PGA estimation was in the range of ~ 0.45 to 0.50 ASTM D1586-67 procedures were followed for SPT tests. 10" outside diameter hollow-stem auger was used with Safe-T- Driver and safety hammer for the drillings in 1979 and 1981. Donut Hammer with rope cathead was used for the drillings in in 1982. Energy ratios are adopted as 68 and 66 % for safety and donut hammers respectively."
	SMS data is downloaded from COSMOS, a local PGA model is contstructed and the PGA selection seems correct.
	The fault parameters are obtained from Arculeta (1984). The fault surface rupture is obtained from Bennett et al (1984)
	Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).





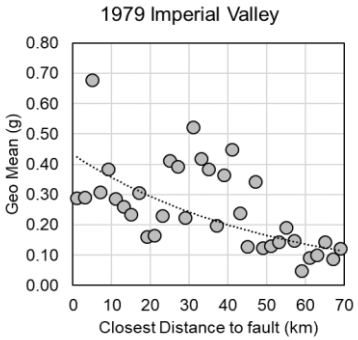
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

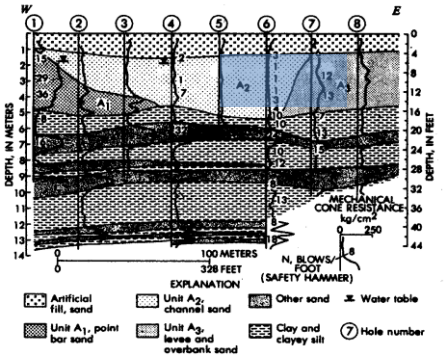
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	A	A
d_{crtc} range (m)	-	1.8 - 4.6		1.8 - 4.6	1.8 - 4.6
d_{crt} (m)	3.7	3.2	3.7	3.2	3.2
GWT (m)	1.83	1.8 ± 0.9	1.8	1.8 ± 0.1	1.8 ± 0.1
γ_{moist} (kN/m^3)	-	14.1 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
σ_v (kPa)	67.7	46.8 ± 7.1	68.2	52.9 ± 8.0	52.9 ± 8.0
σ_v' (kPa)	49.7	32.8 ± 8.7	50.1	39.0 ± 3.7	39.0 ± 3.7
a_{max} (g)	0.78	0.470 ± 0.050	0.78	0.470 ± 0.071	0.470 ± 0.071
r_d	0.97	0.78 ± 0.020	0.96	0.78 ± 0.020	0.78 ± 0.024
CSR	0.67	0.352 ± 0.101	0.661	0.324 ± 0.054	0.324 ± 0.054
M_w	6.60	6.50	6.53	6.53	6.53
D_{50}	0.119	0.110 ± 0.010	-	0.116 ± 0.013	0.116 ± 0.013
% Fines	29	29.0 ± 4.5	18	20.9 ± 5.0	20.9 ± 5.0
% PI	-	-	-	-	NAV
N	1	2.7 ± 1.7	2	2.4 ± 1.5	2.4 ± 1.4
C_R	-	0.74	0.85	0.81	0.89
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	0.00	1.13	1.13	1.13	1.13
C_N	1.35	1.71	1.51	1.61	1.61
$(N_1)_{60}$	1.5	3.8 ± 2.4	2.9	3.5 ± 2.2	3.8 ± 2.3
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

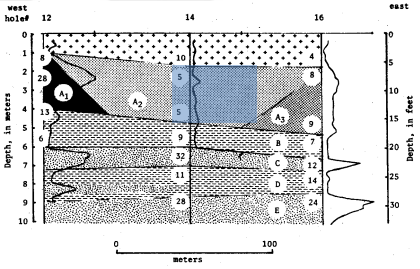
EVENT PARAMETERS

1979 Imperial Valley	Archuleta (1984)	
Magnitude: 6.53	Length (km): 35	
Fault Type: primarily right l	Z_{tor} (km): 0	R_{rup} (km): 2.5
Dip: 80 NE	Width (km): 13	R_{jb} (km): 2.5

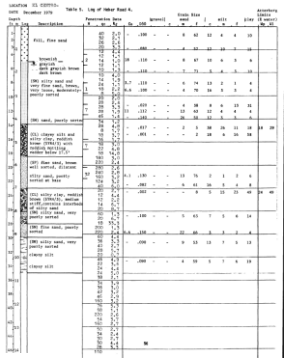


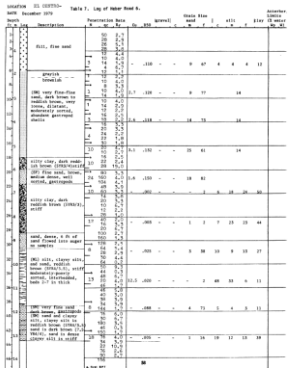




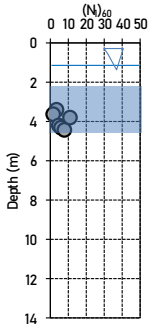


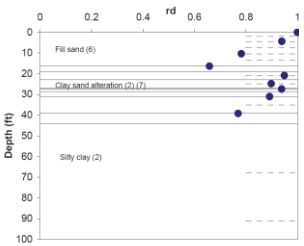
Cetin (2000)

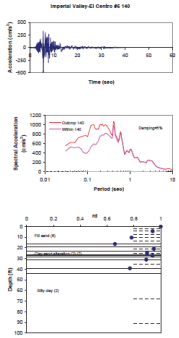


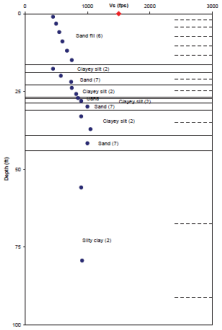


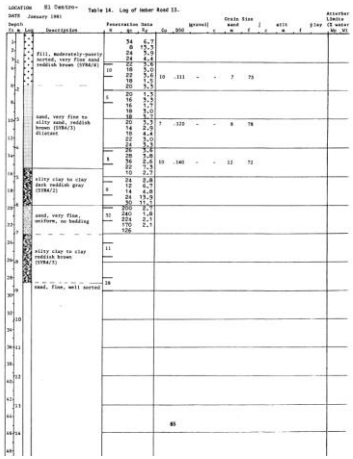
Heber Road A2 – Imperial Valley (1979)











	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
BH-6	1.2	3.9		3	2.00	0.83	5.7	fill, fine sand
BH-6	***2***	***6.6***		***1***	***1.84***	***0.86***	***1.8***	SM
BH-14	2.3	7.5		5	1.78	0.87	8.7	very fine sand to silty sand
BH-6	***2.8***	***9.2***		***1***	***1.68***	***0.88***	***1.7***	SM
BH-4	***3***	***9.8***		***1***	***1.65***	***0.88***	***1.7***	SM
BH-5 Donut	***3.4***	***11.2***		***2***	***1.59***	***0.89***	***3.2***	***BH-5 Donut***
BH-6	***3.6***	***11.8***		***1***	***1.56***	***0.90***	***1.6***	SM
BH-4	3.8	12.5		7	1.53	0.90	11.0	SM
BH-6	***4.2***	***13.8***		***3***	***1.48***	***0.91***	***4.6***	SM
BH-5 Donut	***4.3***	***14.1***		***4***	***1.47***	***0.91***	***6.1***	***BH-5 Donut***
BH-14	***4.4***	***14.4***		***5***	***1.46***	***0.91***	***7.5***	very fine sand to silty sand
BH-6	***4.7***	***15.4***		***4***	***1.42***	***0.92***	***5.9***	SM
						Mean:	3.8	
						St. Dev.	2.3	

	D_{50} (mm)	FC %	sand	silt	clay	
	0.11	***20***	***80***	***16***	***4***	***Log 4***
	0.1	***26***	***74***	***22***	***4***	***Log 4***
	0.02	58	42	27	31	Log 4
	0.112	***24***	***76***	***20***	***4***	***Log 4***
	0.14	***24***	***76***	***18***	***6***	***Log 4***
	0.11	***24***	***76***	***12***	***12***	***Log 6***
	0.12	***14***	***86***	***14***	***0***	***Log 6***
	0.118	***14***	***87***	***14***	***0***	***Log 6***
Mean:	0.116	20.9	79.3	16.6	4.3	
St. Dev.	0.013	5.0	5.3	3.6	4.1	

Case number:	78
Earthquake:	Imperial Valley
Magnitude:	6.53 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Heber Road A3
References:	Youd and Bennett (1983), "Liquefaction sites, Imperial Valley, CA", Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface manifestation of liquefaction
GPS LAT	32.73049583
GPS LONG	-115.3858486
Liq. layer consist of:	silt sand
Geological Unit:	Relict Holocene channel
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "The Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much as 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The principal rivers are the Alamo and New Rivers along which many sand boils were developed on fluvial deposits. Heber Road site is ~1.6 km to the fault rupture plane. AGR and BCR are two stations that are located ~ 7 kms southeast of Heber Road site. The peak acceleration recorded at station AGR at an epicentral distance of 1.8 km is 0.35 and 0.23 g. The station is underlain by deep alluvium and the motion is free field. At Bonds Corner, 5.2 km southern terminus of the fault rupture and 6 km form the southeast of the Heber Road site, PGA was recorded as 0.76 and 0.58 g. Seed et al (1984) used a PGA value of 0.78 g. It is believed that directivity effects play a major role in the intensity of shaking. Higher intensity shakings (0.83 g) were recorded at the northern section of the fault. Based on the recorded motion and earthquake specific PGA contour maps, PGA was estimated as in the range of 0.4-0.7 g. Site response analyses based PGA estimation was in the range of ~ 0.45 to 0.50 ASTM D1586-67 procedures were followed for SPT tests. 10" outside diameter hollow-stem auger was used with Safe-T- Driver and safety hammer for the drillings in 1979 and 1981. Donut Hammer with rope cathead was used for the drillings in in 1982. Energy ratios are adopted as 68 and 66 % for safety and donut hammers respectively." SMS data is downloaded from COSMOS, a locally calibrated ground motion model is contstructed and the PGA selection seems correct. The fault parameters are obtained from Arculeta (1984). The fault surface rupture is obtained from Bennett et al (1984) Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes

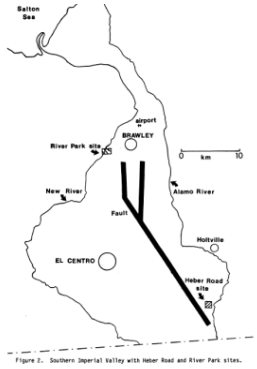
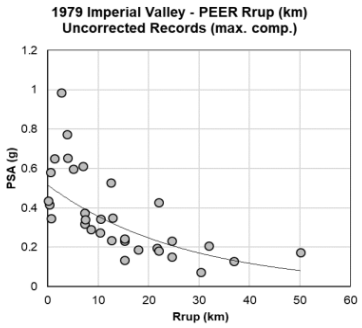


Figure 2. Southern Imperial Valley with Heber Road and River Park sites.

28



Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	B	-	A	A
d_{crtc} range (m)	-	1.8 - 4.9		1.8 - 4.9	1.8 - 4.9
d_{crt} (m)	4.3	3.4	4.0	3.4	3.4
GWT (m)	1.83	1.8 ± 0.9	1.8	1.8 ± 0.1	1.8 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	79.7	52.6 ± 8.8	79.2	57.6 ± 9.8	57.6 ± 9.8
σ_v' (kPa)	55.7	37.3 ± 8.4	56.1	42.4 ± 4.9	42.4 ± 4.9
a_{max} (g)	0.78	0.470 ± 0.050	0.78	0.470 ± 0.071	0.470 ± 0.071
r_d	0.96	0.75 ± 0.025	0.95	0.75 ± 0.025	0.75 ± 0.025
CSR	0.695	0.330 ± 0.085	0.69	0.311 ± 0.052	0.311 ± 0.052
M_w	6.60	6.50	6.53	6.53	6.53
D_{50}	0.094	0.100 ± 0.010	-	0.094 ± 0.004	0.094 ± 0.004
% Fines	37	37.0 ± 5.0	25	25.3 ± 5.2	25.3 ± 5.2
% PI	-	-	-	-	NAV
N	13	13.1 ± 4.1	13	13.0 ± 4.2	12.9 ± 4.0
C_R	-	0.82	0.85	0.82	0.89
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	0.00	1.13	1.13	1.13	1.13
C_N	1.28	1.60	1.29	1.55	1.55
$(N_1)_{60}$	17.5	19.5 ± 6.1	16.2	18.6 ± 6.0	20.2 ± 6.3
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

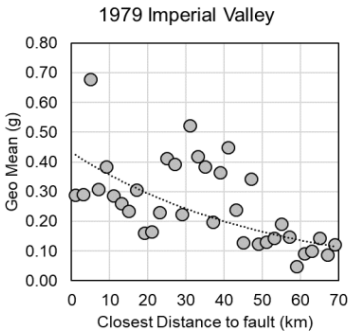
EVENT PARAMETERS

Imperial Valley — Archuleta (1984)

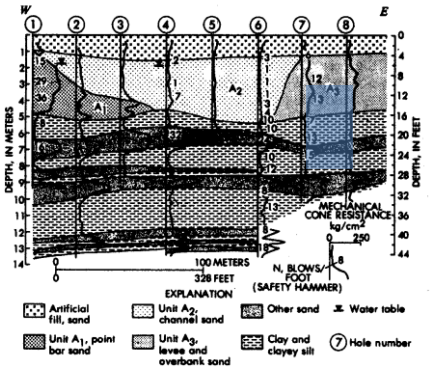
Magnitude: 6.53 — Length (km): 35

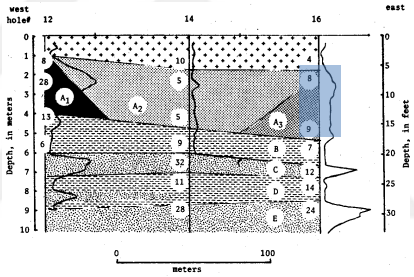
Fault Type: primarily right l — Z_{tor} (km): 0 — R_{rup} (km): 2.5

Dip: 80 NE — Width (km): 13 — R_{jb} (km): 2.5

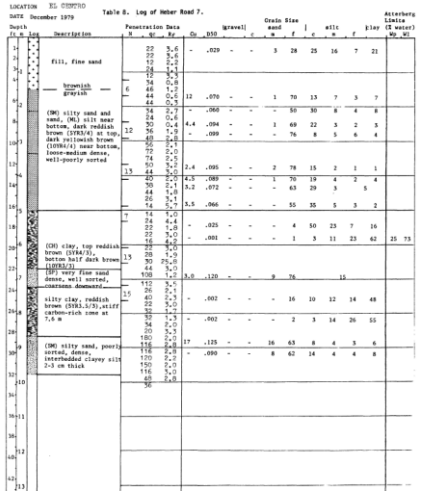




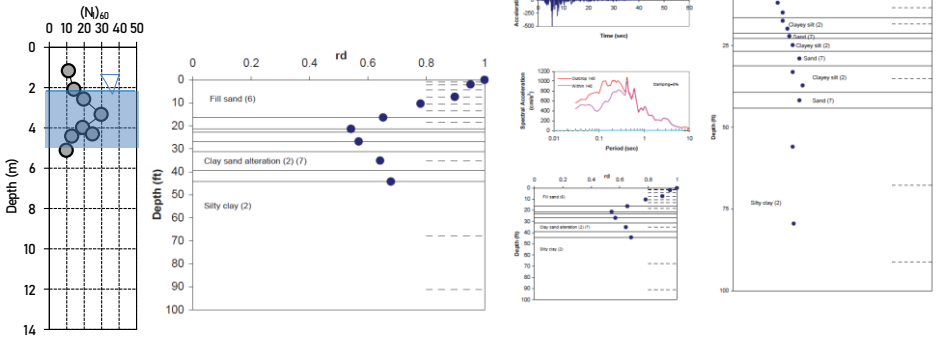


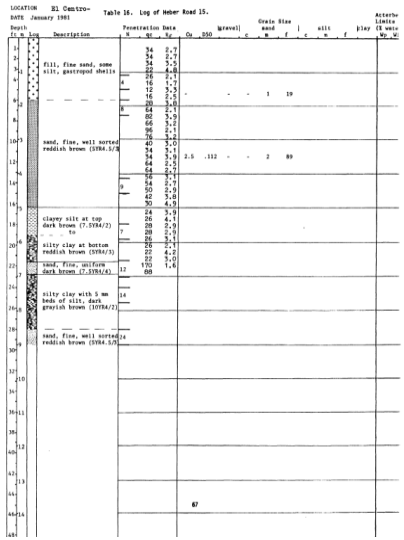


Cetin (2000)



Heber Road A3 – Imperial Valley (1979)





	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
BH-7	1.2	3.9		6	2.00	0.83	11.3	silty sand
BH-16	*2.1*	*6.9*		*8*	*1.81*	*0.86*	*14.1*	***sand***
BH-7	*2.6*	*8.5*		*12*	*1.69*	*0.87*	*20.1*	silty sand
BH-8	*3.35*	*11.0*		*19*	*1.55*	*0.89*	*29.8*	***BH-8***
BH-7	*4*	*13.1*		*13*	*1.45*	*0.91*	*19.4*	silty sand
BH-8	*4.3*	*14.1*		*17*	*1.41*	*0.91*	*24.8*	***BH-8***
BH-16	*4.4*	*14.4*		*9*	*1.40*	*0.91*	*13.0*	***sand***
BH-7	5.1	16.7		7	1.32	0.93	9.7	CH
						Mean:	20.2	
						St. Dev.	6.3	

	D_{50} (mm)	FC %	sand	silt	clay
	0.070	30	71	23	7
	0.060	50	50	42	8
	0.094	*30*	*70*	*27*	*3*
	0.099	*23*	*76*	*19*	*4*
	0.095	*19*	*80*	*18*	*1*
	0.089	*29*	*71*	*25*	*4*
	0.072	37	63	32	5
Mean:	0.094	25.3	74.3	22.3	3.0
St. Dev.	0.004	5.2	4.6	4.4	1.4

Case number:	79
Earthquake:	1979 Imperial Valley Earthquake
Magnitude:	6.53 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Kornbloom B
References:	Bennett et al. (1984) and Fear et al. (1995), James Gerard Bierschwale. (1984), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface evidence of liquefaction Youd, T.L., Wieczorek G. F., (1984), "Liquefaction during the 1981 and
GPS LAT	33.1146681 Previous Earthquakes Near Westmorland, CA" Open File Rep. 84-680
GPS LONG	-115.645238 No surface evidence of liquefaction
Liq. layer consist of:	silty sand
Geological Unit:	Holocene sediment is as thick as 330 ft.
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "The Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much ad 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The principal rivers are the Alamo and New Rivers along which many sand boils were developed on fluvial deposits. A: silty clay, stiff-lacustrine and/or flood plain deposit, B: silty and sandy silt-fluvial and perhaps fluvial deltaic deposition, C: silty clay to clay, stiff-lacustrine and/or flood plain deposit, D: interbedded silt and sand-loose to medium dense E: Uniform sand with some silt-medium dense to dense, F: interbedded silt and sand - loose to medium dense. D-F :fluvial and perhaps fluvial-deltaic deposition PGA was recorded at the ground level of a two-story building as 0.13 g (CAL) which is ~23 km from the north terminus of the fault and ~16 km north of the north terminus of the fault, PGA is recorded as 0.11 g.(Westmorland). The site is 25 km north of the north terminus of the fault and ~9 km from the Westmorland seismographic station. PGA was estimated as 0.12 g by Andrus and Stoke (NCEER, 97). Due to rapid dissipation of wave energy beyond the north terminus of the fault, PGA may be lower than what is recorded at Westmorland. Based on earthquake specific attenuation relationship, PGA was estimated as 0.06-0.1 g. A value of 0.13 is adopted for the study based on site response analysis results. Energy ratio ~68 %"
	SMS data is downloaded from COSMOS, a local PGA model is contstructed and the PGA selection seems correct.
	The fault parameters are obtained from Arculeta (1984). The fault surface rupture is obtained from Bennett et al (1984)
	Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Do not exist in this EQ	No	No	No	No
Data Class		A	-	A	A
d_{crtc} range (m)		2.6 - 5.2		2.7 - 5.3	2.7 - 5.3
d_{crt} (m)	4.3	3.9	4.3	4.0	4.0
GWT (m)	2.74	2.7 ± 0.3	2.7	2.7 ± 0.1	2.7 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	77.5	59.9 ± 7.4	77.2	67.7 ± 8.3	67.7 ± 8.3
σ_v' (kPa)	62.6	48.7 ± 4.3	62.2	55.0 ± 4.2	55.0 ± 4.2
a_{max} (g)		0.130 ± 0.010	0.13	0.130 ± 0.020	0.130 ± 0.020
r_d	0.97	0.83 ± 0.030	0.95	0.83 ± 0.030	0.83 ± 0.029
CSR		0.090 ± 0.010	0.099	0.086 ± 0.014	0.086 ± 0.014
M_w		6.50	6.53	6.53	6.53
D_{50}	0.045	0.045 ± 0.020	-	0.045 ± 0.008	0.045 ± 0.008
% Fines	92	92.0 ± 10.0	92	83.0 ± 9.6	83.0 ± 9.6
% PI	-	-	-	-	NAV
N	5	5.4 ± 2.6	5	5.4 ± 3.1	5.5 ± 3.1
C_R	-	0.85	0.85	0.85	0.91
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E		1.13	1.13	1.13	1.13
C_N	1.22	1.40	1.29	1.36	1.36
$(N_1)_{60}$	6.5	7.2 ± 3.5	6.2	7.1 ± 4.1	7.7 ± 4.3
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

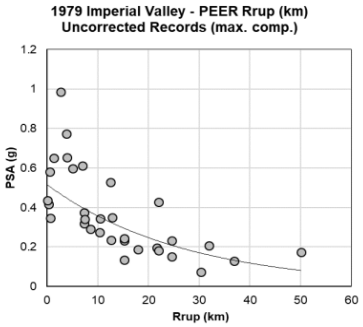
EVENT PARAMETERS

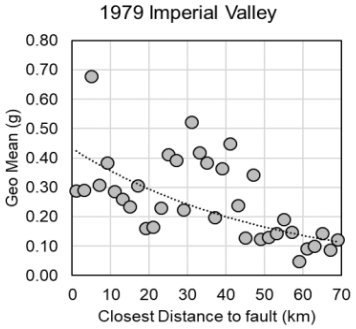
1979 Imperial Valley Earthquake Archuleta (1984)

Magnitude: 6.53 Length (km): 35

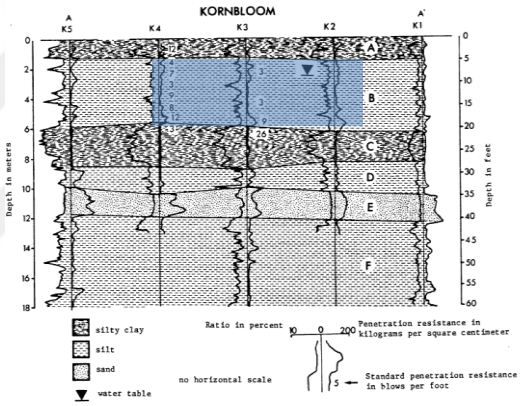
Fault Type: primarly right l Z_{tor} (km): 0 R_{rup} (km): 21.5

Dip: 80 NE Width (km): 13 R_{jb} (km): 21.5

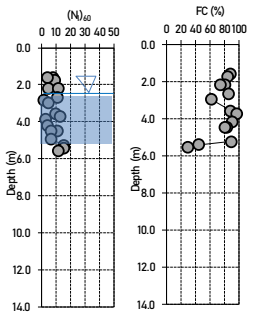


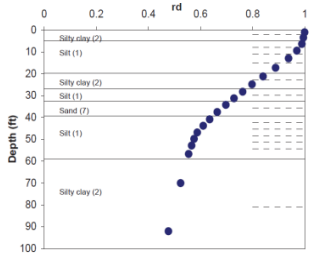


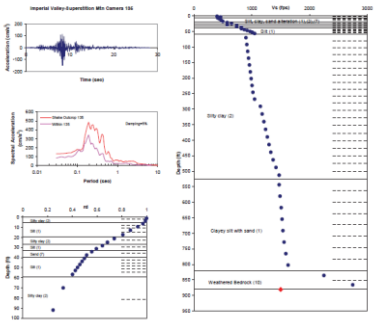




Cetin (2000)





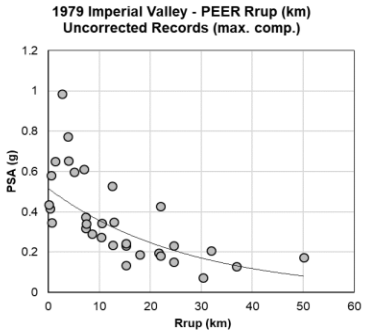


Kornbloom – Imperial Valley (1979)

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
K-4	1.60	5.25		4	2.00	0.85	7.7
K-4 b	1.75	5.75		5	1.92	0.85	9.3
SK4-5	***1.60***	***5.25***		***2***	***2.00***	***0.85***	***3.8***
K-3	***2.21***	***7.25***		***3***	***1.71***	***0.86***	***5.0***
K-4	***2.21***	***7.25***		***7***	***1.71***	***0.86***	***11.7***
K-4 b	***2.67***	***8.75***		***7***	***1.56***	***0.88***	***10.8***
SK4-5	***2.82***	***9.25***		***1***	***1.52***	***0.88***	***1.5***
K-4	***2.97***	***9.75***		***3***	***1.50***	***0.88***	***4.5***
K-4 b	***3.58***	***11.75***		***7***	***1.41***	***0.90***	***10.1***
K-4	***3.73***	***12.25***		***9***	***1.40***	***0.90***	***12.8***
SK4-5	***3.89***	***12.75***		***2***	***1.38***	***0.90***	***2.8***
K-3	***4.19***	***13.75***		***3***	***1.34***	***0.91***	***4.2***
K-4	***4.50***	***14.75***		***8***	***1.31***	***0.92***	***10.9***
K-4 b	***4.50***	***14.75***		***5***	***1.31***	***0.92***	***6.8***
SK4-5	***4.95***	***16.25***		***5***	***1.27***	***0.92***	***6.6***
K-4	***5.26***	***17.25***		***12***	***1.24***	***0.93***	***15.7***
K-4 b	5.41	17.75		12	1.23	0.93	15.5
K-3	5.56	18.25		9	1.22	0.93	11.6
						Mean:	7.7
						St. Dev.	4.3

	FC	sand	silt	clay	D50	WN	WL	PI	LI
clayey silt (CL)	88.0	12.0	65.0	23.0	0.019	26.0	29.0	11.0	0.7
sandy silt (ML)	84.0	16.0	74.0	10.0	0.038				
silt and silty clay		-	-	-	-				
sandy silt (ML)	***80.0***	***21.0***	***73.0***	***7.0***	***0.044***				
sandy silt (ML)	***74.0***	***26.0***	***68.0***	***6.0***	***0.052***				
silt (ML)	***86.0***	***14.0***	***83.0***	***3.0***	***0.049***				
sand to silty sand		-	-	-	-				
sandy silt	***62.0***	***38.0***	***53.0***	***9.0***	***0.056***	***28.0***			
silt (ML)	***88.0***	***12.0***	***79.0***	***9.0***	***0.042***				
silt (ML)	***96.0***	***4.0***	***83.0***	***13.0***	***0.028***	***30.0***			
sand to silty sand		-	-	-	-				
silt (ML)	***91.0***	***9.0***	***79.0***	***12.0***	***0.039***				
sandy silt (ML)	***83.0***	***17.0***	***74.0***	***9.0***	***0.047***	***29.0***			
sandy silt (ML)	***81.0***	***19.0***	***71.0***	***10.0***	***0.042***				
sand to silty sand		-	-	-	-				
silt (ML)	***89.0***	***11.0***	***83.0***	***6.0***	***0.048***				
silty sand (SM)	44.0	56.0	40.0	4.0	0.700				
silty sand (SM)	30.0	70.0	29.0	1.0	0.082				
	83.0	17.1	74.6	8.4	0.045				
	9.6	9.7	9.3	3.0	0.008				

Case number:	80
Earthquake:	1979 Imperial Valley
Magnitude:	6.53 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	McKim Ranch A
References:	Bennett et al. (1984) and Fear et al. (1995), James Gerard Bierschwale. (1984), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Fissures developed and as many as one
GPS LAT	32.868815 hundred sand boils erupted at this location. The sand boils occurred between
GPS LONG	-115.45636 two continuous fissures, some 10-15 m apart, that parallel each other in an
Liq. layer consist of:	silty sand (SM) arcuate north-to-south zone approximately 1.8 km long.
Geological Unit:	Holocene sediment is as thick as 330 ft
Site Response Anlaysis:	No
Comments:	Cetin (2000) "The Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much ad 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The principal rivers are the Alamo and New Rivers along which many sand boils were developed on fluvial deposits. Located between the Alamo River and the Redwood Canal. A: very fine sand (fining upwards)-loose sand that filled the relic channel. B: stiff silty clay McKim Ranch Site is 6 km from the northern terminus of the fault rupture. The earthquake specific PGA contour maps indicate a PGA level of 0.5-0.8g. 2-3 km away from site, at the seismagraphic station EO4 located on deep alluvium (>300m), PGA was recorded as 0.49g. Energy ratio ~68 %" SMS data is downloaded from COSMOS, a local PGA model is contstructed and the PGA selection seems correct. The fault parameters are obtained from Arculeta (1984). The fault surface rupture is obtained from Bennett et al (1984)
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes



Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	A	-	B	B
d_{crtc} range (m)	-	1.5 - 4.0		1.5 - 4.0	1.5 - 4.0
d_{cr1} (m)	2.1	2.7	2.1	2.7	2.7
GWT (m)	1.52	1.5 ± 0.3	1.5	1.5 ± 0.1	1.5 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	15.7 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	38.4	42.0 ± 6.5	38.1	49.4 ± 7.7	49.4 ± 7.7
σ_v' (kPa)	32.4	30.0 ± 3.9	32.1	37.5 ± 3.9	37.5 ± 3.9
a_{max} (g)	0.51	0.510 ± 0.050	0.51	0.510 ± 0.153	0.510 ± 0.153
r_d	0.99	0.95 ± 0.042	0.98	0.94 ± 0.042	0.94 ± 0.042
CSR	0.39	0.442 ± 0.072	0.385	0.411 ± 0.127	0.411 ± 0.127
M_w	6.60	6.40	6.53	6.53	6.53
D_{50}	0.105	0.105 ± 0.003	-	0.106 ± 0.005	0.106 ± 0.005
% Fines	31	31.0 ± 3.0	31	19.8 ± 3.5	19.8 ± 3.5
% PI	-	-	-	-	NAV
N	3	5.3 ± 2.6	3	5.4 ± 2.6	5.4 ± 2.6
C_R	-	0.79	0.80	0.79	0.88
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.05	1.13	1.13	1.13	1.13
C_N	1.62	1.79	1.70	1.65	1.65
$(N_1)_{60}$	4	8.5 ± 4.2	4.6	7.9 ± 3.8	8.8 ± 4.2
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	0.0	-	160.0	Not Listed

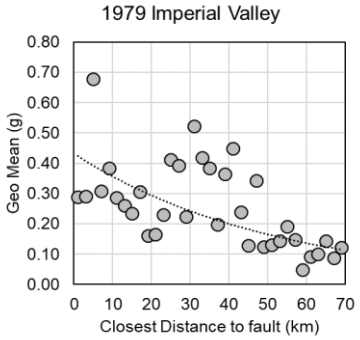
EVENT PARAMETERS

1979 Imperial Valley — Archuleta (1984)

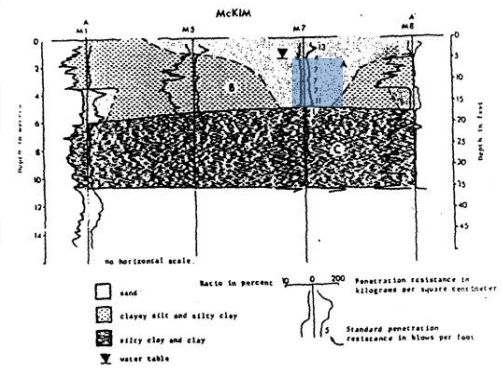
Magnitude: 6.53 — Length (km): 35

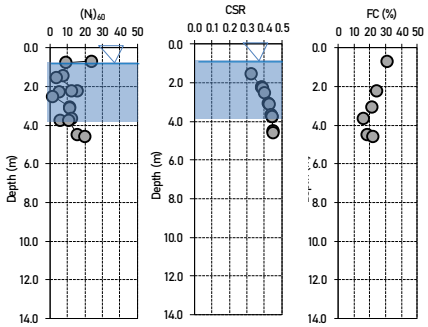
Fault Type: primarly right l — Z_{tor} (km): 0 — R_{rup} (km): 2.9

Dip: 80 NE — Width (km): 13 — R_{jb} (km): 2.9









	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
M-7	0.69	2.3	NA	13	2.00	0.81	24.0	silty sand (SM)
SM-7	0.76	2.5	NA	5	2.00	0.82	9.3	sand to silty sand
M-7	***1.45***	***4.8***	***NA***	***4***	***2.00***	***0.84***	***7.6***	
SM-7	***1.52***	***5.0***	***0.322***	***2***	***1.96***	***0.84***	***3.8***	sand
M-2	***2.21***	***7.3***	***0.382***	***9***	***1.76***	***0.86***	***15.6***	sand
M-7	***2.21***	***7.3***	***0.382***	***7***	***1.76***	***0.86***	***12.1***	sand (SM)
SM-7	***2.29***	***7.5***	***0.387***	***3***	***1.75***	***0.87***	***5.1***	sand
M-3	***2.51***	***8.3***	***0.400***	***1***	***1.69***	***0.87***	***1.7***	sand
SM-7	***3.05***	***10.0***	***0.423***	***7***	***1.59***	***0.89***	***11.2***	sand
M-7	***3.09***	***10.2***	***0.425***	***7***	***1.58***	***0.89***	***11.1***	sand (SM)
SM-7	***3.66***	***12.0***	***0.440***	***8***	***1.49***	***0.90***	***12.2***	sand
M-3	***3.73***	***12.3***	***0.441***	***4***	***1.48***	***0.90***	***6.0***	silty sand
M-7	***3.73***	***12.3***	***0.441***	***7***	***1.48***	***0.90***	***10.6***	sand (SM)
M-7	4.50	14.8	0.450	11	1.38	0.92	15.7	sand (SM)
SM-7	4.57	15.0	0.450	14	1.37	0.92	19.9	sand
						Mean:	8.8	
						St. Dev.	4.2	

Depth (ft)	FC	sand	silt	clay	D_{50}	
2.3	31.0	69.0	18.0	13.0	0.1	M-7
2.5		-	-	-	-	SM-7
4.8		***-***	***-***	***-***	***-***	***M-7***
5.0		***-***	***-***	***-***	***-***	***SM-7***
7.3		***-***	***-***	***-***	***-***	***M-2***
7.3	***24.0***	***76.0***	***14.0***	***10.0***	***0.1***	***M-7***
7.5		***-***	***-***	***-***	***-***	***SM-7***
8.3		***-***	***-***	***-***	***-***	***M-3***
9.4	***21.0***	***79.0***	***11.0***	***10.0***	***0.1***	***M-7***
10.0		***-***	***-***	***-***	***-***	***SM-7***
10.2	***16.0***	***84.0***	***9.0***	***7.0***	***0.1***	***M-7***
12.0		***-***	***-***	***-***	***-***	***SM-7***
12.3		***-***	***-***	***-***	***-***	***M-3***
12.3	***18.0***	***82.0***	***11.0***	***7.0***	***0.1***	***M-7***
14.8	22.0	78.0	15.0	7.0	0.1	M-7
15.0		-	-	-	-	SM-7
	19.8	80.3	11.3	8.5	0.106	
	3.5	3.5	2.1	1.7	0.005	

Case number:	81
Earthquake:	1979 Imperial Valley
Magnitude:	6.53 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Radio Tower B1
References:	James Gerard Bierschwale. (1984), Bennett et al. (1984) and Fear et al. (1995), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefied during both the 1979 and 1981 earthquakes. Several sandboils
GPS LAT	33.010639 expelled considerable volumes of water and sand and created a new pond
GPS LONG:	-115.521375 near the radio tower at the site. Small fissures devepoed around the pond
Liq. layer consist of:	sandy silt and sand (SM-ML) and larger fissures developed at the margin of the river flood plane locally in the
Geological Unit:	Holocene sediment is as thick as 3 adjacent bluffs.
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "The Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much ad 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The principal rivers are the Alamo and New Rivers along which many sand boils were developed on fluvial deposits. A: very poorly sorted, soft brown clay and silt-flood plain deposit, B: brown, loose to med.dense silt to fine sand- sediment at base is well sorted, very fine sand fining upwards to poorly sorted silt-channel deposit, C: very stiff brown clayey silt to clay-lacustrine, D: med dense sand, Radio Tower Site is 12 km from the northern terminus of the fault rupture. 0.22g and 0.16 of PGA was recorded at BRA recording site which is 9-10 km from the northern terminus of the fault rupture. Based on the earthquake specific PGA contours, the estimated PGA at the River site is ~0.2 g. However, site response analyses results suggested a slightly lower value: 0.18 g Energy ratio ~68 %"
	SMS data is downloaded from COSMOS, a local PGA model is contstructed and the PGA selection seems correct.
	The fault parameters are obtained from Arculeta (1984). The fault surface rupture is obtained from Bennett et al (1984)
	Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	Yes	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	3.0 - 5.5		3.0 - 5.5	3.0 - 5.5
d_{crt} (m)	3.4	4.3	3.4	4.3	4.3
GWT (m)	2.13	2.0 ± 0.3	2.1	2.0 ± 0.1	2.0 ± 0.1
γ_{moist} (kN/m^3)	-	14.1 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	14.9 ± 0.6	-	18.1 ± 0.5	18.1 ± 0.5
σ_v (kPa)	61.0	62.0 ± 6.5	62.2	72.2 ± 7.7	72.2 ± 7.7
σ_v' (kPa)	49.0	39.9 ± 4.0	50.1	50.1 ± 3.8	50.1 ± 3.8
a_{max} (g)	0.2	0.180 ± 0.019	0.2	0.180 ± 0.027	0.180 ± 0.027
r_d	0.96	0.97 ± 0.030	0.96	0.97 ± 0.030	0.97 ± 0.030
CSR	0.16	0.162 ± 0.025	0.154	0.164 ± 0.026	0.164 ± 0.026
M_w	6.60	6.50	6.53	6.53	6.53
D_{50}	0.047	0.047 ± 0.015	-	0.074 ± 0.037	0.074 ± 0.037
% Fines	75	75.0 ± 10.0	64	43.5 ± 29.0	43.5 ± 29.0
% PI	-	-	-	-	NAV
N	2	4.5 ± 3.4	2	4.5 ± 3.4	4.5 ± 3.2
C_R	-	0.86	0.85	0.86	0.91
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	0.00	1.13	1.13	1.13	1.13
C_N	1.36	1.55	1.49	1.42	1.42
$(N_1)_{60}$	3	6.8 ± 5.2	2.9	6.2 ± 4.7	6.5 ± 4.7
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

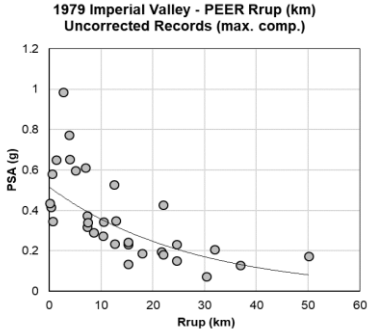
EVENT PARAMETERS

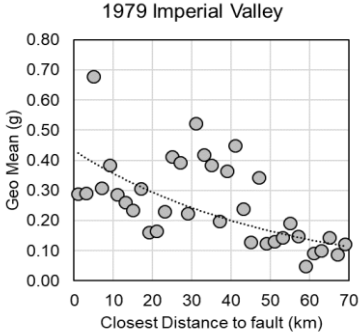
1979 Imperial Valley — Archuleta (1984)

Magnitude: 6.53 — Length (km): 35

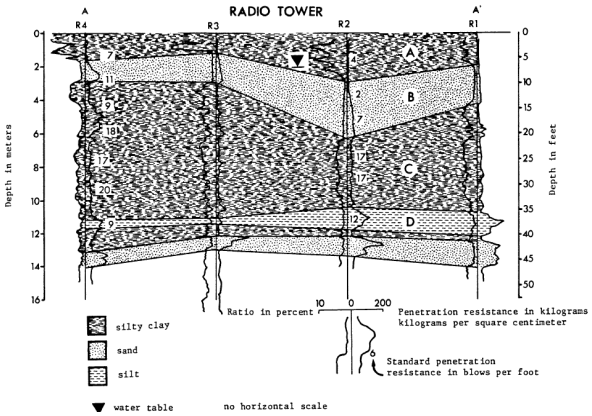
Fault Type: primarily right l — Z_{tor} (km): 0 — R_{rup} (km): 8.0

Dip: 80 NE — Width (km): 13 — R_{jb} (km): 8.0

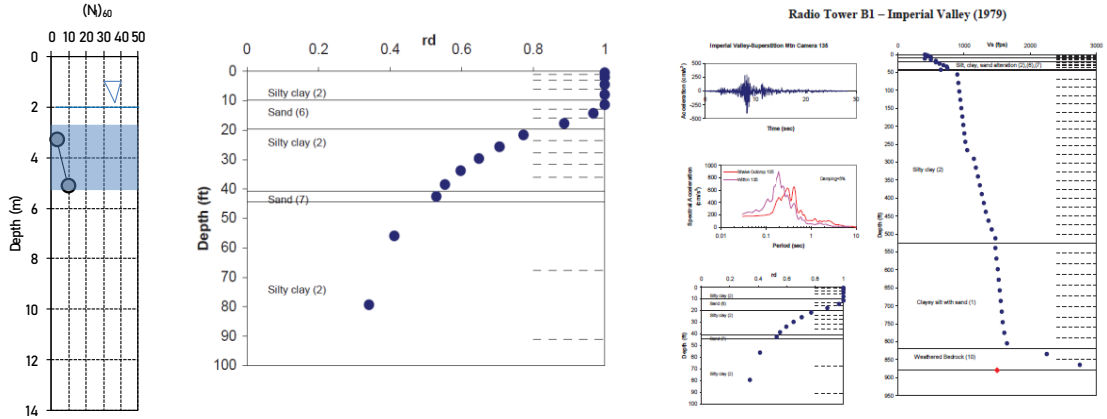








Cetin (2000)

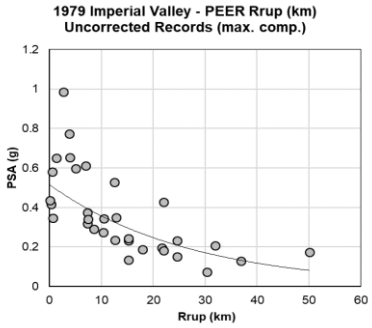


	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
R2	*3.3*	*10.8*		*2*	*1.55*	*0.89*	*3.1*
R2	*5.1*	*16.7*		*7*	*1.33*	*0.93*	*9.8*
						Mean:	6.5
						St. Dev.	4.7

sandy silt (ML)
sand (SM)

Depth (m)	FC	sand	silt	clay	D50
3.3	*64.0*	*36.0*	*59.0*	*5.0*	*0.047*
5.1	*23.0*	*77.0*	*22.0*	*1.0*	*0.100*
23.15	*18.0*	*82.0*	*13.0*	*5.0*	*0.125*
	43.5	56.5	40.5	3.0	0.074
	29.0	29.0	26.2	2.8	0.037

Case number:	82
Earthquake:	1979 Imperial Valley
Magnitude:	6.53 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Radio Tower B2
References:	Bierschwale (1984), Bennett et al. (1984) and Fear et al. (1995), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefied during both the 1979 and 1981 earthquakes. Several sandboils
GPS LAT	33.010639 expelled considerable volumes of water and sand and created a new pond
GPS LONG:	-115.521375 near the radio tower at the site. Small fissures developed around the pond
Liq. layer consist of:	sand (SM) and larger fissures developed at the margin of the river flood plane locally in the
Geological Unit:	Holocene sediment is as thick as 3 adjacent bluffs. This borelog is from the "nonliquefied" section
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "The Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much ad 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The principal rivers are the Alamo and New Rivers along which many sand boils were developed on fluvial deposits. A: very poorly sorted, soft brown clay and silt-flood plain deposit B: brown, loose to med.dense silt to fine sand- sediment at base is well sorted, very fine sand fining upwards to poorly sorted silt-channel deposit, C: very stiff brown clayey silt to clay-lacustrine, D: med dense sand. Radio Tower Site is 12 km from the northern terminus of the fault rupture. 0.22g and 0.16 of PGA was recorded at BRA recording site which is 9-10 km from the northern terminus of the fault rupture. Based on the earthquake specific PGA contours, the estimated PGA at the River site is ~0.2 g. However, site response analyses results suggested a slightly lower value: 0.18 g Energy ratio ~68 %" SMS data is downloaded from COSMOS, a local PGA model is contstructed and the PGA selection seems correct. The fault parameters are obtained from Arculeta (1984). The fault surface rupture is obtained from Bennett et al (1984) Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes



Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	2.0 - 3.0		2.0 - 3.0	2.0 - 3.0
d_{crt} (m)	2.3	2.5	2.3	2.5	2.5
GWT (m)	2.13	2.0 ± 0.3	2.1	2.0 ± 0.1	2.0 ± 0.1
γ_{moist} (kN/m^3)	-	14.1 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	14.9 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	39.8	35.8 ± 2.8	40.1	40.9 ± 3.2	40.9 ± 3.2
σ_v' (kPa)	38.4	30.9 ± 3.2	38.1	36.0 ± 1.9	36.0 ± 1.9
a_{max} (g)	0.2	0.160 ± 0.019	0.2	0.180 ± 0.027	0.180 ± 0.027
r_d	0.98	0.99 ± 0.020	0.98	0.99 ± 0.020	0.99 ± 0.019
CSR	0.13	0.120 ± 0.019	0.132	0.132 ± 0.021	0.132 ± 0.021
M_w	6.60	6.50	6.53	6.53	6.53
D_{50}	0.1	0.100 ± 0.020	-	0.100 ± 0.050	0.100 ± 0.050
% Fines	30	30.0 ± 5.0	30	18.0 ± 2.0	18.0 ± 8.6
% PI	-	-	-	-	NAV
N	11	11.0 ± 1.8	11	11.3 ± 1.4	11.4 ± 1.2
C_R	-	0.77	0.80	0.77	0.87
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	1.05	1.13	1.13	1.13	1.13
C_N	1.51	1.76	1.53	1.68	1.68
$(N_1)_{60}$	13	17.0 ± 2.8	15.2	16.6 ± 2.0	18.8 ± 2.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

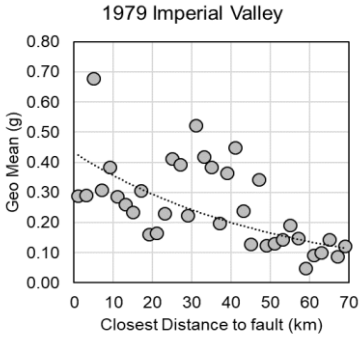
EVENT PARAMETERS

1979 Imperial Valley Archuleta (1984)

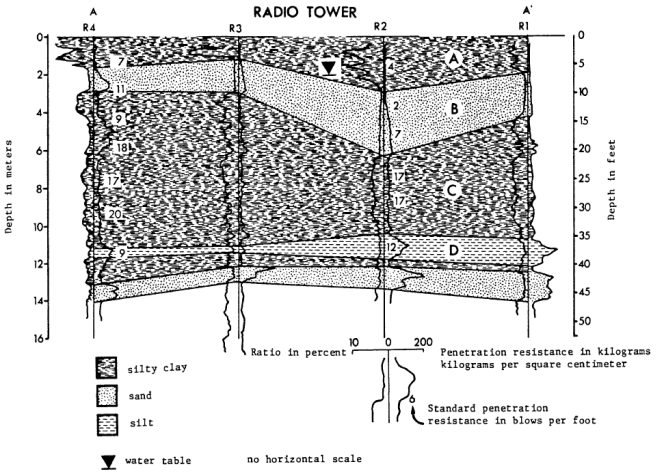
Magnitude: 6.53 Length (km): 35

Fault Type: primarily right l Z_{tor} (km): 0 R_{rup} (km): 8.0

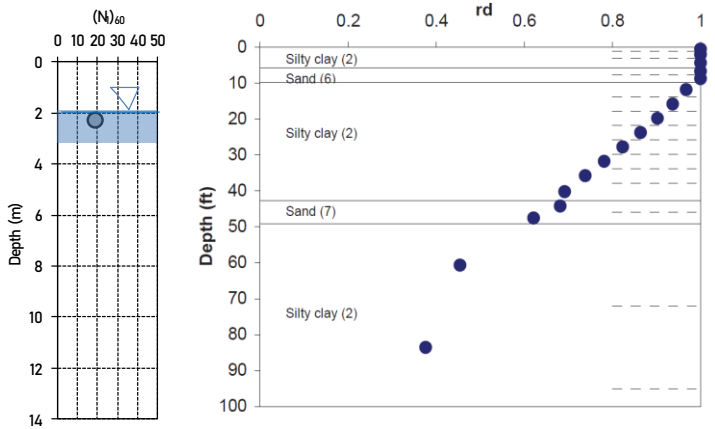
Dip: 80 NE Width (km): 13 R_{jb} (km): 8.0



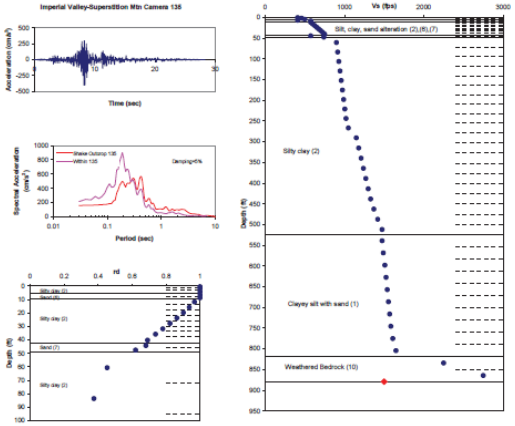




Cetin (2000)



Radio Tower B2 – Imperial Valley (1979)



	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		FC	silt	clay	D50
R4	*2.3*	*7.3*		*11*	*1.74*	*0.87*	*18.8*	sand (SM)	*18.0*	*17.0*	*1.0*	*0.1*
						Mean:	18.8		18.0	17.0	1.0	0.100
						St. Dev.	2.0	assigned	8.6	8.3	2.3	0.050

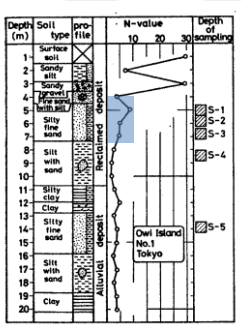
Case number:	84
Earthquake:	1980 Mid-Chiba
Magnitude:	6.1
Location:	Owi-1
References:	Ishihara et al (1979, 1980, 1981), Fear et al. (1995), Cetin (2000), Cetin (2004, 2018)
Nature of Failure:	No significant pore pressure generation
GPS LAT	35.583832
GPS LONG	139.765416
Liq. layer consist of:	Silty Fine Sand and Fine sand with silt
Geological Unit:	Reclaimed land
Site Response Anlaysis:	No
Comments:	Cetin (2000) "Owi Island No 1 is located on the west side of Tokyo Bay. The island was reclaimed from 1961 to 1969 with soils dredged fom the nearby seabed to open a navigation route.Soils with different grain sizes were transported in slurry through pipes and discharged in the area. When the soil surface reached the sea level, several kinds of waste soils were dumped on top of the dredged fill and alluvial deposits to 200-300'. In the vicinity of river the ground is relatively Two set of piezometers were embedded at two depths, I and II were installed 5m apart at depths of 6 and 13 m. III and IV were also embedded 5 m apart at depths 6 and 14 m parallel to, and 5 m from the first set. A seismograph was installed at the surface. A PGA of 45 gal due to a small magnitude EQ Mw ~4-5 has not triggered the pore pressure transducers. Piezometers I and II were destroyed during the earthquake. The epicenter was located 15 km southeast of the City of Chiba, and had a focal depth of ~20 km. The intensity of shaking sorrounding the Tokyo Bay was V (JMAS). PGA was recorded as 95 and 65 gal respectively in two normal directions. Pore pressure started to increase after the PGA exceeded 60 gal and excess pore pressure reached to the maximum values of 0.75 and 1.32 m at depths 6 and 14 m. 50 % of the excess pore pressure dissipated within 10 seconds. No excess pore pressure remained at depth 14 m (FC=27) after 2 hours. Seed et al estimated the CSR that will trigger the liquefaction based on laboratory test results on frozen samples. It is believed that he used number of cycles of 5-6 to represent a M=6.1 earthquake. CSR that will cause liquefaction in 5-6 cycles was predicted for depths 4.9 and 13.9 as 0.37 and 0.35 respectively based on lab data. The CSR estimated due to earthquake was estimated as 0.232 and 0.224. So he predicted that a PGA of 0.145g (~1.5x0.95) would cause liquefaction. CSR estimates were not multiplied by 0.65. SPT values were taken before the earthquake. SPT energy is estimated as 65 % by Seed et al. (84)"
	An earthquake with a magnitude of 6.1 shook the area of Tokyo Bay at 2: 54 a.m. On September 25, 1980.
	USGS catalog has one event M=6.0 in Tokyo area whose epicenter is a bit different than what Ishihara paper suggests.
	The date and time seems to be same hence the USGS focal mechanism parameters is used.
	https://earthquake.usgs.gov/earthquakes/eventpage/usp00019ym/executive
	Vs12m and Vs30 are calculated based on Vs data.
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	No	No	No	No	No
Data Class	-	A	-	A	A
$d_{crtc.}$ range (m)	-	4.0 - 7.0		4.0 - 7.0	3.6 - 7.2
d_{crt} (m)	6.1	5.5	6.1	5.5	5.4
GWT (m)	0.91	0.9 ± 0.3	0.9	1.0 ± 0.1	1.0 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.9	-	18.9 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.5	-	18.9 ± 0.5	20.6 ± 0.5
σ_v (kPa)	108.5	90.2 ± 8.6	108.3	103.9 ± 9.7	109.7 ± 12.6
σ_v' (kPa)	57.6	45.2 ± 4.9	57.1	59.7 ± 5.1	66.4 ± 6.9
a_{max} (g)	0.1	0.095 ± 0.001	0.095	0.079 ± 0.004	0.080 ± 0.004
r_d	0.96	0.75 ± 0.076	0.89	0.81 ± 0.076	0.92 ± 0.075
CSR	0.12	0.092 ± 0.011	0.104	0.072 ± 0.008	0.079 ± 0.008
M_w	1.26	6.10	6.00	6.10	6.10
D_{50}	0.18	0.180 ± 0.020	-	0.120 ± 0.026	0.120 ± 0.026
% Fines	13	13.0 ± 1.0	13	30.0 ± 16.5	41.3 ± 16.5
% PI	-	-	-	-	NAV
N	5	4.6 ± 0.4	5	5.8 ± 2.3	5.8 ± 2.3
C_R	-	0.86	0.95	0.94	0.94
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.15	1.15
C_E	1.09	1.09	1.09	1.09	1.37
C_N	1.26	1.46	1.36	1.30	1.24
$(N_1)_{60}$	7	6.3 ± 0.6	7.1	8.9 ± 3.5	10.5 ± 4.3
V_{s30m} (m/s)	-	-	-	-	193.6
V_{s12m} (m/s)	-	149.4	-	149.4	182.9

EVENT PARAMETERS

1980 Mid-Chiba	9/25/1980	
Magnitude: 6.10	epicenter 35.450°N 139.964°E	
Fault Type: reverse	Z_{tor} (km): NA	R_{rup} (km): NA
Dip: 36	Width (km): NA	R_{jb} (km): NA



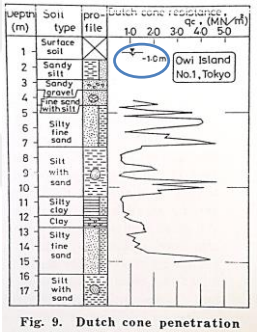
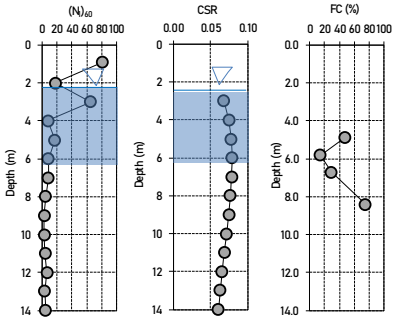


Fig. 9. Dutch cone penetration test results at the test site



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
0.9	3.0	NA	30	2.00	0.85	80.4	Surface Soil
2	6.6	0.068	7	1.85	0.88	18.0	Sandy Silt
3	9.8	0.075	29	1.58	0.90	65.3	Sandy Gravel
4	***13.1***	***0.078***	***4***	***1.41***	***0.92***	***8.2***	Fine sand with silt
5	***16.4***	***0.079***	***9***	***1.28***	***0.94***	***16.9***	Silty Fine Sand
6	***19.7***	***0.078***	***5***	***1.18***	***0.95***	***8.8***	Silty Fine Sand
7	***23.0***	***0.077***	***5***	***1.10***	***0.96***	***8.3***	Silty Fine Sand
8	26.2	0.075	3	1.04	0.97	4.7	Silt with Sand
9	29.5	0.072	2	0.98	0.97	3.0	Silt with Sand
10	32.8	0.069	2	0.94	0.98	2.9	Silt with Sand
11	36.1	0.066	3	0.89	0.98	4.1	Silty Clay
12	39.4	0.063	5	0.86	0.99	6.6	Clay
13	42.7	0.060	3	0.83	0.99	3.9	Silty Fine Sand
14	45.9	0.058	4	0.80	0.99	5.0	Silty Fine Sand
15	49.2	0.057	4	0.77	0.99	4.8	Silty Fine Sand
16.0	52.5	0.056	3	0.75	0.99	3.5	Silt with Sand
					Mean:	10.5	
					St. Dev.	4.3	

	d (m)	D_{10} (mm)	D_{50} (mm)	D_{60} (mm)	FC %
	4.9	-	***0.090***	***0.120***	***47.0***
	5.8	***0.045***	***0.140***	***0.160***	***14.0***
	6.7	***0.070***	***0.130***	***0.160***	***29.0***
	8.4	-	-	0.004	75.0
Mean:	5.8	0.058	0.120	0.111	41.3
St. Dev.	0.9	0.018	0.026	0.023	16.5

Case number:	86
Earthquake:	1981 WestMorland
Magnitude:	5.6 (M_L)
Location:	Kornbloom B
References:	Bennett et al. (1984) and Fear et al. (1995), Bierschwale. (1984), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	More than one hundred sand boils erupted at this site.
GPS LAT	33.1146681
GPS LONG	-115.645238
Liq. layer consist of:	silty sand
Geological Unit:	Natural deposit (Holocene sediment in the upper 330 ft, underlained by Quaternary alluvium and marine deposits)
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "Youd, T.L., Wieczorek G. F., (1984), "Liquefaction during the 1981 and Previous Earthquakes Near Westmorland, CA" Open File Rep. 84-680 More than one hundred sand boils erupted at this site. The boils are widely scattered but generally occurred in poorly defined bands. Some of the boils erupted along short ground fissures. The unique aspect of the Kombloom site is that the liquefied sediments were primarily silty material. …the extent of the liquefiable silt layer is from 5-22'. The Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much as 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The principal rivers are the Alamo and New Rivers along which many sand boils were developed on fluvial deposits. A: silty clay, stiff-lacustrine and/or flood plain deposit B: silty and sandy silt-fluvial and perhaps fluvial deltaic deposition C: silty clay to clay, stiff-lacustrine and/or flood plain deposit D: interbedded silt and sand-loose to medium dense E: Uniform sand with some silt-medium dense to dense F: interbedded silt and sand - loose to medium dense. D-F :fluvial and perhaps fluvial-deltaic deposition PGA was estimated based on earthquake specific attenuation relationship for alluvium sites as min. 0.24, mean 0.28 and max 0.46 g. at the site. Based on site specific response analyses, PGA was estimated as 0.19 g Energy ratio ~68 %"
	Sharp et al (1986) "no clear evidence of surface faulting has yet been found in the epicentral area."
	Rupture plane is obtained from aftershcok distribution.
	SMS data is downloaded from COSMOS, a local PGA model is contstructed and the PGA selection seems correct.
	The fault parameters are obtained from USGS, PEER, NGL.
	Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes



Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	A	-	A	A
d_{crtc} range (m)	-	2.6 - 5.2	-	2.7 - 5.3	2.7 - 5.3
d_{crt} (m)	-	3.9	4.3	4.0	4.0
GWT (m)	-	2.7 ± 0.3	2.7	2.7 ± 0.1	2.7 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-	59.9 ± 7.4	77.2	67.7 ± 8.3	67.7 ± 8.3
σ_v' (kPa)	-	48.7 ± 4.3	62.2	55.0 ± 4.2	55.0 ± 4.2
a_{max} (g)	-	0.190 ± 0.025	0.32	0.190 ± 0.029	0.190 ± 0.029
r_d	-	0.83 ± 0.012	0.93	0.90 ± 0.012	0.90 ± 0.029
CSR	-	0.140 ± 0.020	0.24	0.137 ± 0.022	0.137 ± 0.022
M_w	-	5.90	5.90	5.90	5.90
D_{50}	-	0.045 ± 0.020	-	0.045 ± 0.008	0.045 ± 0.008
% Fines	-	92.0 ± 10.0	92	83.0 ± 9.6	83.0 ± 9.6
% PI	-	-	-	-	NAV
N	-	5.4 ± 2.6	5	5.4 ± 3.1	5.5 ± 3.1
C_R	-	0.85	0.85	0.85	0.91
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.13	1.13	1.13	1.13
C_N	-	1.40	1.29	1.36	1.36
$(N_1)_{60}$	-	7.2 ± 3.5	6.2	7.1 ± 4.1	7.7 ± 4.3
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

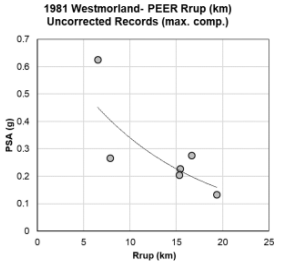
EVENT PARAMETERS

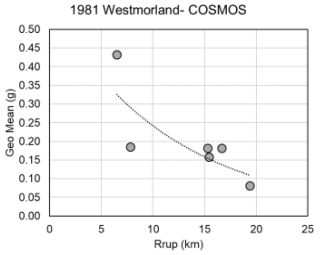
1981 WestMorland

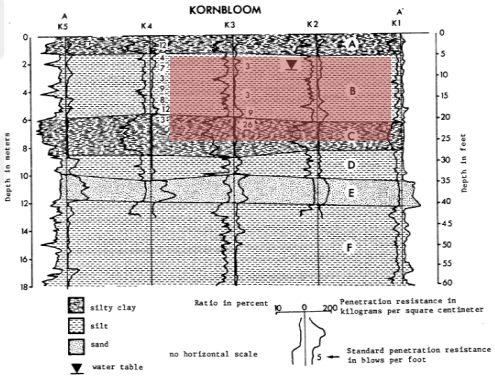
Magnitude: 5.90 Length (km): -

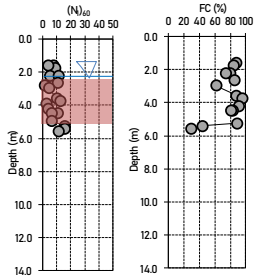
Fault Type: strike slip Z_{tor} (km): - R_{rup} (km): 2.4

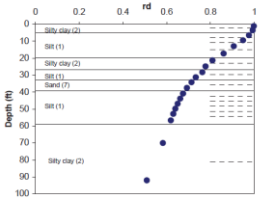
Dip: 90 Width (km): - R_{jb} (km): 2.4



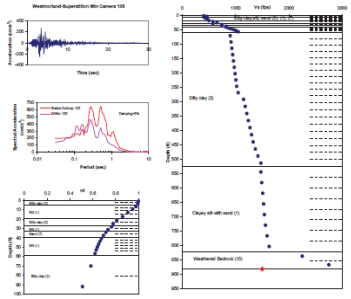








Cetin (2000)



	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
K-4	1.60	5.25		4	2.00	0.85	7.7
K-4 b	1.75	5.75		5	1.92	0.85	9.3
SK4-5	***1.60***	***5.25***		***2***	***2.00***	***0.85***	***3.8***
K-3	***2.21***	***7.25***		***3***	***1.71***	***0.86***	***5.0***
K-4	***2.21***	***7.25***		***7***	***1.71***	***0.86***	***11.7***
K-4 b	***2.67***	***8.75***		***7***	***1.56***	***0.88***	***10.8***
SK4-5	***2.82***	***9.25***		***1***	***1.52***	***0.88***	***1.5***
K-4	***2.97***	***9.75***		***3***	***1.50***	***0.88***	***4.5***
K-4 b	***3.58***	***11.75***		***7***	***1.41***	***0.90***	***10.1***
K-4	***3.73***	***12.25***		***9***	***1.40***	***0.90***	***12.8***
SK4-5	***3.89***	***12.75***		***2***	***1.38***	***0.90***	***2.8***
K-3	***4.19***	***13.75***		***3***	***1.34***	***0.91***	***4.2***
K-4	***4.50***	***14.75***		***8***	***1.31***	***0.92***	***10.9***
K-4 b	***4.50***	***14.75***		***5***	***1.31***	***0.92***	***6.8***
SK4-5	***4.95***	***16.25***		***5***	***1.27***	***0.92***	***6.6***
K-4	***5.26***	***17.25***		***12***	***1.24***	***0.93***	***15.7***
K-4 b	5.41	17.75		12	1.23	0.93	15.5
K-3	5.56	18.25		9	1.22	0.93	11.6
						Mean:	7.7
						St. Dev.	4.3

	FC	sand	silt	clay	D50	WN	WL	PI	LI
clayey silt (CL)	88.0	12.0	65.0	23.0	0.019	26.0	29.0	11.0	0.7
sandy silt (ML)	84.0	16.0	74.0	10.0	0.038				
silt and silty clay		-	-	-	-				
sandy silt (ML)	***80.0***	***21.0***	***73.0***	***7.0***	***0.044***				
sandy silt (ML)	***74.0***	***26.0***	***68.0***	***6.0***	***0.052***				
silt (ML)	***86.0***	***14.0***	***83.0***	***3.0***	***0.049***				
sand to silty sand		-	-	-	-				
sandy silt	***62.0***	***38.0***	***53.0***	***9.0***	***0.056***	***28.0***			
silt (ML)	***88.0***	***12.0***	***79.0***	***9.0***	***0.042***				
silt (ML)	***96.0***	***4.0***	***83.0***	***13.0***	***0.028***	***30.0***			
sand to silty sand		-	-	-	-				
silt (ML)	***91.0***	***9.0***	***79.0***	***12.0***	***0.039***				
sandy silt (ML)	***83.0***	***17.0***	***74.0***	***9.0***	***0.047***	***29.0***			
sandy silt (ML)	***81.0***	***19.0***	***71.0***	***10.0***	***0.042***				
sand to silty sand		-	-	-	-				
silt (ML)	***89.0***	***11.0***	***83.0***	***6.0***	***0.048***				
silty sand (SM)	44.0	56.0	40.0	4.0	0.700				
silty sand (SM)	30.0	70.0	29.0	1.0	0.082				
	83.0	17.1	74.6	8.4	0.045				
	9.6	9.7	9.3	3.0	0.008				

Case number:	87
Earthquake:	1981 Westmorland
Magnitude:	5.9 (USGS)
Location:	Radio Tower B1
References:	Bierschwale (1984), Bennett et al (1984), Fear et al. (1995), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefied during both the 1979 and 1981 earthquakes. Several sandboils
GPS LAT	33.010639 expelled considerable volumes of water and sand and created a new pond
GPS LONG:	-115.521375 near the radio tower at the site. Small fissures devepoed around the pond
Liq. layer consist of:	sandy silt and sand (SM-ML) and larger fissures developed at the margin of the river flood plane locally in the
Geological Unit:	Natural deposit (Holocene sediment in the upper 330 ft, underlained by adjacent bluffs.
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "The Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much as 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The principal rivers are the Alamo and New Rivers along which many sand boils were developed on fluvial deposits. A: very poorly sorted, soft brown clay and silt-flood plain deposit B: brown, loose to med.dense silt to fine sand- sediment at base is well sorted very fine sand fining upwards to poorly sorted silt-channel deposit C: very stiff brown clayey silt to clay-lacustrine D: med dense sand Radio Tower Site is 10 km from the epicenter of the earthquake. At Brawley seismographic station which is ~ 4 km from the River Park site and at an epicentral distance of 16 km, PGA was recorded as 0.17 and 0.15g (deep alluvium site). Based on earthquake specific attenuation relationships the mean and standard deviation of PGA were estimated as 0.18 ± 0.025. PGA was estimated as ~ 0.20 g by Seed et al (1984). Based on site response analyses results, PGA was estimated as 0.17 g. Energy ratio ~68 %" Sharp et al (1986) "no clear evidence of surface faulting has yet been found in the epicentral area." Rupture plane is obtained from aftershcok distribution. SMS data is downloaded from COSMOS, a local PGA model is contstructed and the PGA selection seems correct. The fault parameters are obtained from USGS, PEER, NGL. Radio Tower B1 and B2 showed different field performance after 1981 Westmorland Earthquake. The sites are 75 m away from each other. Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes



Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	3.0 - 5.5	-	3.0 - 5.5	3.0 - 5.5
d_{crt} (m)	-	4.3	3.4	4.3	4.3
GWT (m)	-	2.0 ± 0.3	2.1	2.0 ± 0.1	2.0 ± 0.1
γ_{moist} (kN/m^3)	-	14.1 ± 0.5	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	14.9 ± 0.6	-	18.1 ± 0.5	18.1 ± 0.5
σ_v (kPa)	-	62.0 ± 6.5	62.2	72.2 ± 7.7	72.2 ± 7.7
σ_v' (kPa)	-	39.9 ± 3.9	50.1	50.1 ± 3.8	50.1 ± 3.8
a_{max} (g)	-	0.170 ± 0.020	0.2	0.170 ± 0.026	0.170 ± 0.026
r_d	-	0.89 ± 0.012	0.95	0.89 ± 0.012	0.89 ± 0.030
CSR	-	0.140 ± 0.023	0.152	0.142 ± 0.022	0.142 ± 0.023
M_w	-	5.90	5.90	5.90	5.90
D_{50}	-	0.047 ± 0.015	-	0.074 ± 0.037	0.074 ± 0.037
% Fines	-	75.0 ± 10.0	64	43.5 ± 29.0	43.5 ± 29.0
% PI	-	-	-	-	NAV
N	-	4.8 ± 3.7	2	4.5 ± 3.4	4.5 ± 3.2
C_R	-	0.80	0.85	0.86	0.91
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.13	1.13	1.13	1.13
C_N	-	1.55	1.49	1.42	1.42
$(N_1)_{60}$	-	6.8 ± 5.2	2.9	6.2 ± 4.7	6.5 ± 4.7
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

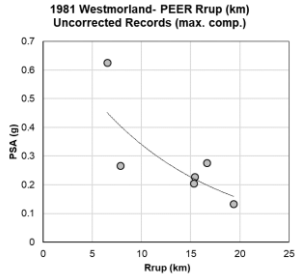
EVENT PARAMETERS

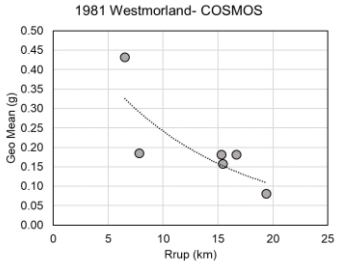
1981 Westmorland

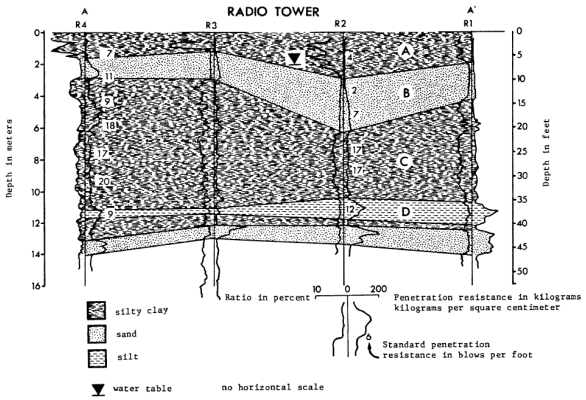
Magnitude: 5.90 Length (km): -

Fault Type: strike slip Z_{tor} (km): - R_{rup} (km): 13.7

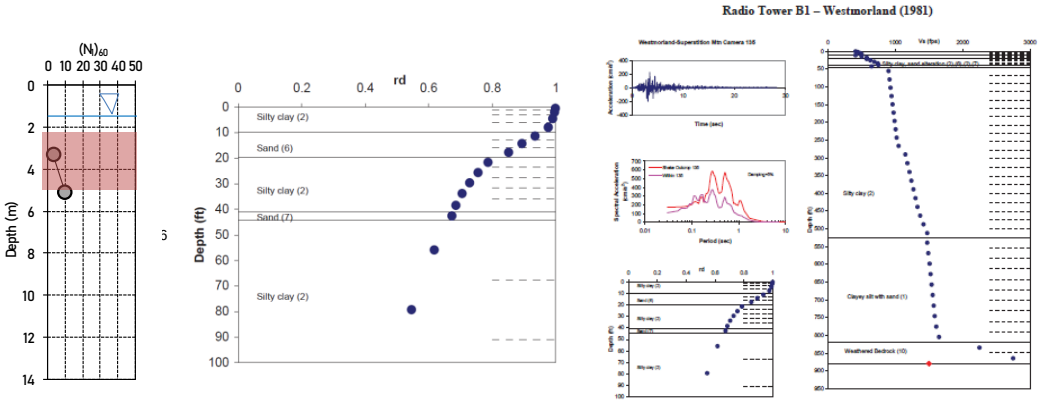
Dip: 90 Width (km): - R_{jb} (km): 13.7







Cetin (2000)



	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
R2	*3.3*	*10.8*		*2*	*1.55*	*0.89*	*3.1*
R2	*5.1*	*16.7*		*7*	*1.33*	*0.93*	*9.8*
						Mean:	6.5
						St. Dev.	4.7

	Depth (m)	FC	sand	silt	clay	D50
sandy silt (ML)	*3.3*	*64.0*	*36.0*	*59.0*	*5.0*	*0.047*
sand (SM)	*5.1*	*23.0*	*77.0*	*22.0*	*1.0*	*0.100*
	23.15	*18.0*	*82.0*	*13.0*	*5.0*	*0.125*
		43.5	56.5	40.5	3.0	0.074
		29.0	29.0	26.2	2.8	0.037

Case number:	88
Earthquake:	Westmorland
Magnitude:	5.6 (M_L)
Location:	Radio Tower B2
References:	Bierschwale (1984), Bennett et al (1984), Fear et al. (1995), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefied during both the 1979 and 1981 earthquakes. Several sandboils
GPS LAT	33.010639
GPS LONG	-115.521375
Liq. layer consist of:	sand (SM)
Geological Unit:	Natural deposit (Holocene sedimen
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "The Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much as 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The principal rivers are the Alamo and New Rivers along which many sand boils were developed on fluvial deposits. A: very poorly sorted, soft brown clay and silt-flood plain deposit B: brown, loose to med.dense silt to fine sand- sediment at base is well sorted very fine sand fining upwards to poorly sorted silt-channel deposit C: very stiff brown clayey silt to clay-lacustrine D: med dense sand Radio Tower Site is 10 km from the epicenter of the earthquake. At Brawley seismographic station which is ~ 4 km from the River Park site and at an epicentral distance of 16 km, PGA was recorded as 0.17 and 0.15g (deep alluvium site). Based on earthquake specific attenuation relationships the mean and standard deviation of PGA were estimated as 0.18 ± 0.025. PGA was estimated as ~ 0.20 g by Seed et al (1984). Based on site response analyses results, PGA was estimated as 0.17 g. Energy ratio ~68 %"
	Sharp et al (1986) "no clear evidence of surface faulting has yet been found in the epicentral area."
	Rupture plane is obtained from aftershcok distribution.
	SMS data is downloaded from COSMOS, a local PGA model is contstructed and the PGA selection seems correct.
	The fault parameters are obtained from USGS, PEER, NGL.
	Radio Tower B1 and B2 showed different field performance after 1981 Westmorland Earthquake. The sites are 75 m away from each other.
	Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).

expelled considerable volumes of water and sand and created a new pond near the radio tower at the site. Small fissures devepoed around the pond and larger fissures developed at the margin of the river flood plane locally in the adjacent bluffs. This borelog is from the "nonliquefied" section



Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?		No	No	No	No
Data Class		B	-	B	B
d_{crtc} range (m)		2.0 - 3.0		2.0 - 3.0	2.0 - 3.0
d_{crt} (m)		2.5	2.3	2.5	2.5
GWT (m)		2.0 ± 0.3	2.1	2.0 ± 0.1	2.0 ± 0.1
γ_{moist} (kN/m^3)		14.1 ± 0.5	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)		14.9 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)		35.8 ± 2.7	40.1	40.9 ± 3.2	40.8 ± 3.3
σ_v' (kPa)		30.9 ± 3.1	38.1	36.0 ± 1.9	36.0 ± 1.9
a_{max} (g)		0.160 ± 0.020	0.2	0.160 ± 0.024	0.160 ± 0.024
r_d		0.98 ± 0.010	0.97	0.98 ± 0.010	0.98 ± 0.019
CSR		0.115 ± 0.019	0.131	0.116 ± 0.018	0.116 ± 0.018
M_w		5.90	5.90	5.90	5.90
D_{50}		0.100 ± 0.020	-	0.100 ± 0.050	0.100 ± 0.050
% Fines		30.0 ± 5.0	30	18.0 ± 2.0	18.0 ± 8.6
% PI		-	-	-	NAV
N		11.0 ± 1.8	11	11.3 ± 1.4	11.3 ± 1.2
C_R		0.77	0.80	0.77	0.87
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.13	1.13	1.13	1.13
C_N		1.76	1.53	1.68	1.68
$(N_1)_{60}$		17.0 ± 2.8	15.2	16.6 ± 2.0	18.8 ± 2.0
V_{s30m} (m/s)		-	-	-	NAV
V_{s12m} (m/s)		160.0	-	160.0	NOT LISTED

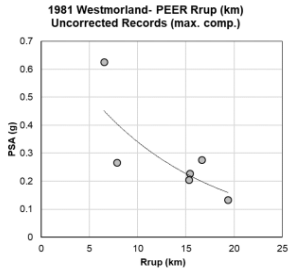
EVENT PARAMETERS

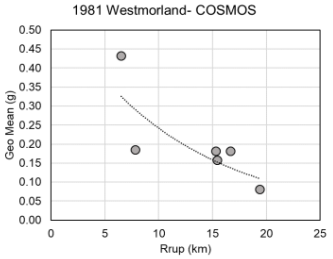
Westmorland

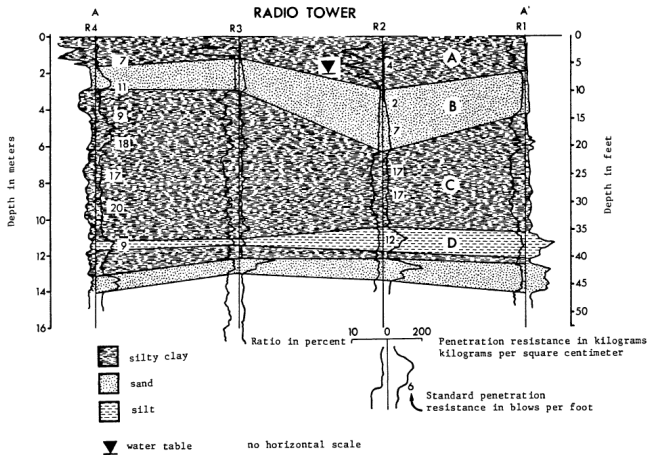
Magnitude: 5.90 Length (km): -

Fault Type: strike slip Z_{tor} (km): - R_{rup} (km): 13.7

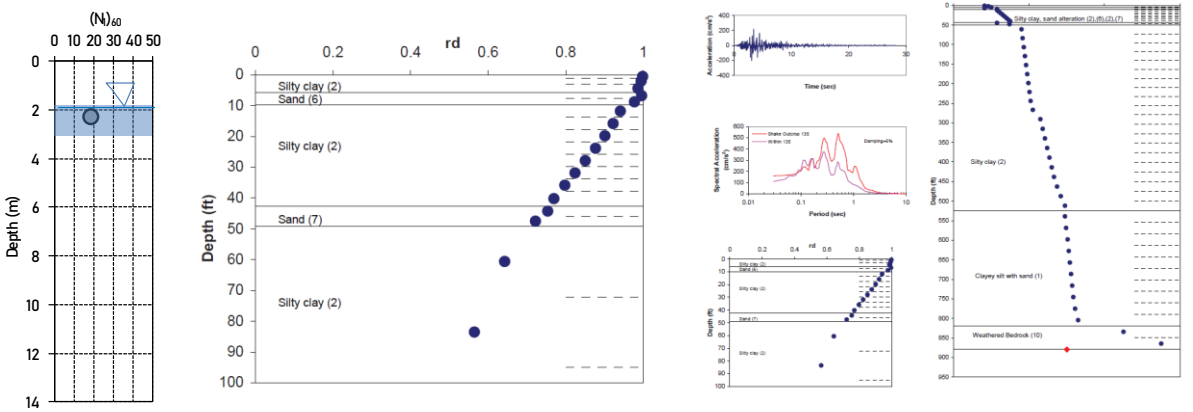
Dip: 90 Width (km): - R_{jb} (km): 13.7





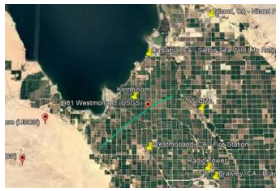


Cetin (2000)



	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		FC	silt	clay	D50
R4	*2.3*	*7.3*		*11*	*1.74*	*0.87*	*18.8*	sand (SM)	*18.0*	*17.0*	*1.0*	*0.1*
						Mean:	18.8		18.0	17.0	1.0	0.100
						St. Dev.	2.0	assigned	8.6	8.3	2.3	0.050

Case number:	90
Earthquake:	Westmorland
Magnitude:	5.6 (M_L)
Location:	River Park C
References:	Youd and Bennett (1983), Bennett et al (1981), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Hundreds of sand boils, a slump, and numerous small ground cracks. Water
GPS LAT	32.96954267 continued to seep from a few sand boils for two weeks.
GPS LONG	-115.5532487
Liq. layer consist of:	SP
Geological Unit:	Natural deposit (Holocene sediment in the upper 330 ft, underlained by Quaternary alluvium and marine deposits)
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "The Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much as 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The principal rivers are the Alamo and New Rivers along which many sand boils were developed on fluvial deposits. River Park Site is 14 km from the epicenter of the earthquake. At Brawley seismographic station which is ~ 4 km from the River Park site and at an epicentral distance of 16 km, PGA was recorded as 0.17 and 0.15g (deep alluvil site). PGA was estimated by Seed et al (1984) ~0.21 g. Based on site response analyses results, PGA was estimated as 0.17 g. ASTM D1586-67 procedures were followed for SPT tests. 10" outside diameter hollow-stem auger was used with Safe-T Driver and safety hammer. Energy ratio ~68 %. SPT blowcounts were taken in 1979 and 1981." Sharp et al (1986) "no clear evidence of surface faulting has yet been found in the epicentral area." Rupture plane is obtained from aftershcok distribution. SMS data is downloaded from COSMOS, a local PGA model is contstructed and the PGA selection seems correct. The fault parameters are obtained from USGS, PEER, NGL. Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes



Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?		No	No	No	No
Data Class		A	-	A	A
d_{crtc} range (m)		3.4 - 5.2		3.4 - 5.2	4.0 - 5.2
d_{crt} (m)		4.3	4.3	4.3	4.6
GWT (m)		0.3 ± 0.2	0.3	0.3 ± 0.1	0.3 ± 0.1
γ_{moist} (kN/m^3)		14.1 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)		17.3 ± 0.6	-	18.1 ± 0.5	18.1 ± 0.5
σ_v (kPa)		73.0 ± 5.9	83.2	76.6 ± 5.8	82.2 ± 4.2
σ_v' (kPa)		34.0 ± 3.5	45.1	37.6 ± 3.2	40.2 ± 2.7
a_{max} (g)		0.170 ± 0.020	0.21	0.170 ± 0.026	0.170 ± 0.026
r_d		0.97 ± 0.010	0.93	0.97 ± 0.010	0.97 ± 0.032
CSR		0.227 ± 0.030	0.237	0.218 ± 0.034	0.219 ± 0.035
M_w		5.90	5.90	5.90	5.90
D_{50}		0.150 ± 0.008	-	0.142 ± 0.020	0.142 ± 0.020
% Fines		18.0 ± 3.0	18	13.2 ± 4.4	13.2 ± 4.4
% PI		-	-	-	NAV
N		12.3 ± 4.7	11	12.4 ± 4.9	18.7 ± 4.1
C_R		0.86	0.85	0.86	0.87
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.13	1.13	1.13	1.13
C_N		1.68	1.44	1.64	1.59
$(N_1)_{60}$		20.2 ± 7.7	15.2	19.9 ± 7.8	29.5 ± 6.5
$V_{s,30m}$ (m/s)		-	-	-	NAV
V_{s12m} (m/s)		160.0	-	160.0	NOT LISTED

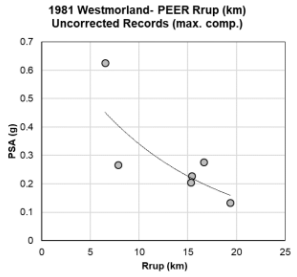
EVENT PARAMETERS

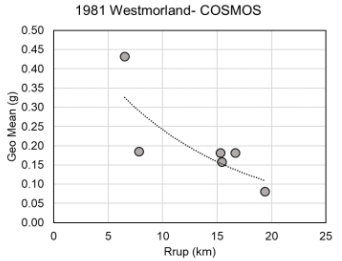
Westmorland

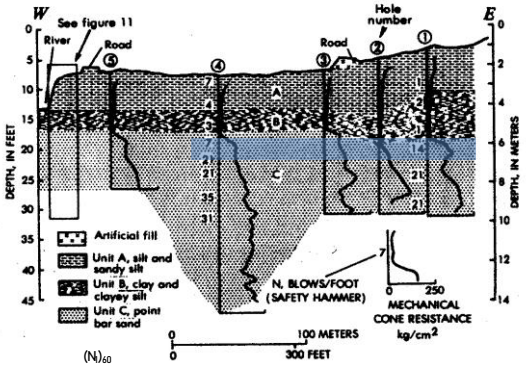
Magnitude: 5.90 Length (km): -

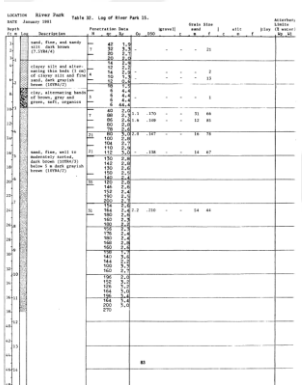
Fault Type: strike slip Z_{tor} (km): - R_{rup} (km): 15.5

Dip: 90 Width (km): - R_{jb} (km): 15.5









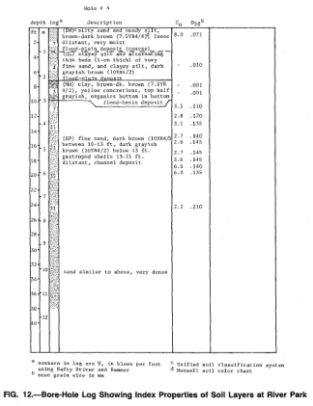
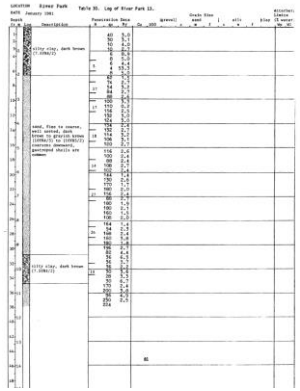
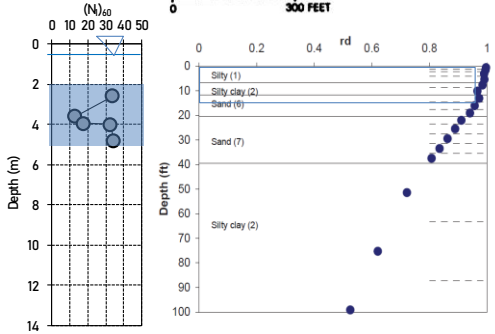


FIG. 12.—Bore-Hole Log Showing Index Properties of Soil Layers at River Park



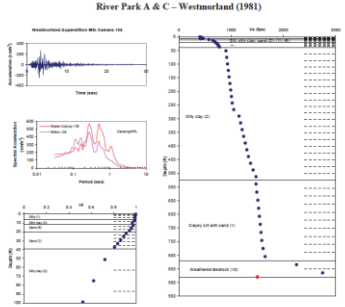
.22



	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
BH-13	2.6	8.5		17	2.00	0.87	33.7	sand CN=2
BH-4	3.6	11.8		7	1.78	0.90	12.7	***SP (probably MH transision hence excluded)***
BH-6	3.96	13.0		10	1.70	0.91	17.5	***SM-CL boundary hence excluded***
BH-4	***4***	***17.0***		***21***	***1.50***	***0.91***	***32.3***	SP
BH-4	***4.8***	***15.7***		***21***	***1.55***	***0.92***	***34.1***	SP
BH-1	***5.18***	***17.0***		***14***	***1.50***	***0.93***	***22.0***	SP
BH-1	6.5	21.3		21	1.35	0.94	30.2	SP
BH-1	7.5	24.6		21	1.26	0.95	28.5	SP
						Mean:	29.5	
						St. Dev.	6.5	

Cetin (2000)

Depth (m)	FC	sand	silt	clay	D50	
3.3	**12**	**88**	**9**	**3**	**0.110**	BH-4
3.5	**13**	**87**	**11**	**2**	**0.120**	BH-4
3.9	**11**	**88**	**9**	**2**	**0.135**	BH-4
4.4	**11**	**89**	**10**	**1**	**0.140**	BH-4
4.6	**10**	**90**	**9**	**1**	**0.145**	BH-4
5.1	**10**	**90**	**10**	**0**	**0.145**	BH-4
5.2	**9**	**91**	**9**	**0**	**0.180**	BH-1
5.2	**14**	**86**	**14**	**0**	**0.170**	BH-1
5.3	**13**	**87**	**10**	**3**	**0.145**	BH-4
5.7	**18**	**82**	**14**	**4**	**0.140**	BH-4
6.0	**24**	**76**	**20**	**4**	**0.135**	BH-4
6.4	7	93	7	0	0.115	BH-1
7.8	6	94	6	0	0.145	BH-1
Mean:	13.2	86.7	11.4	1.8	0.142	
St. Dev.	4.4	4.3	3.4	1.5	0.020	



Case number:	91
Earthquake:	1981 WestMorland
Magnitude:	5.6 (M_L)
Location:	Wildlife B
References:	Bennett et al. (1984) and Fear et al. (1995), Bierschwale. (1984), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Numerous sand boils, fissures, and slumped banks occurred along both
GPS LAT	33.0976 sides of a 3 km long stretch of Alamo River within the Wildlife Management
GPS LONG	-115.5306 Area. Sand boils and fissures extended as far as 100 m from the river.
Liq. layer consist of:	Silty Sand
Geological Unit:	Natural deposit (Holocene sediment in the upper 330 ft, underlained by Quaternary alluvium and marine deposits)
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "The Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much as 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The principal rivers are the Alamo and New Rivers along which many sand boils were developed on fluvial deposits. A: very loose and very soft interbedded micaceous sandy silt, silt and clayey silts (0-2.5 m) flood plain deposits B: very loose to loose moderately sorted sandy silt (2.5-6.8m); point bar deposits C: silty clay (medium to very stiff) and clayey silt (medium to stiff); lacustrine deposit. PGA was recorded at a one-story building underlain by deep alluvium as 0.21 g at epicentral distance of 9.2 km. There is no surface faulting. The site is located ~9.5 km from the epicenter. Also at WLF station PGA was recorded as 0.19 and 0.18 g. Based on site response analyses results, PGA was estimated as as 0.23 g. Energy ratio ~68 %."
	Sharp et al (1986) "no clear evidence of surface faulting has yet been found in the epicentral area."
	Rupture plane is obtained from aftershock distribution.
	The fault parameters are obtained from USGS, PEER, NGL.



Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	A	-	A	A
d_{crtc} range (m)	-	2.7 - 6.7	-	2.7 - 6.7	2.7 - 7.0
d_{crt} (m)	-	4.7	4.6	4.7	4.9
GWT (m)	-	0.9 ± 0.3	1.2	0.9 ± 0.1	1.2 ± 0.1
γ_{moist} (kN/m^3)	-	14.1 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	15.7 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-	73.0 ± 10.7	87.2	86.4 ± 12.6	87.9 ± 13.7
σ_v' (kPa)	-	35.5 ± 5.3	54.1	49.0 ± 6.3	52.0 ± 6.8
a_{max} (g)	-	0.230 ± 0.020	0.26	0.230 ± 0.012	0.230 ± 0.012
r_d	-	0.89 ± 0.013	0.92	0.89 ± 0.013	0.89 ± 0.034
CSR	-	0.240 ± 0.030	0.267	0.235 ± 0.014	0.225 ± 0.016
M_w	-	5.90	5.90	5.90	5.90
D_{50}	-	0.090 ± 0.005	-	0.109 ± 0.038	0.089 ± 0.012
% Fines	-	40.0 ± 3.0	30	26.2 ± 7.6	27.4 ± 9.0
% PI	-	-	-	-	0
N	-	7.8 ± 3.5	7.1	7.9 ± 3.5	8.0 ± 3.5
C_R	-	0.88	0.95	0.88	0.92
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.13	1.13	1.13	1.13
C_N	-	1.64	1.36	1.44	1.40
$(N_1)_{60}$	-	12.8 ± 5.7	10.3	11.3 ± 5.0	11.6 ± 5.1
V_{s30m} (m/s)	-	-	-	-	179.0
V_{s12m} (m/s)	-	160.0	-	160.0	131.0

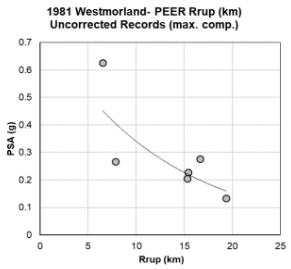
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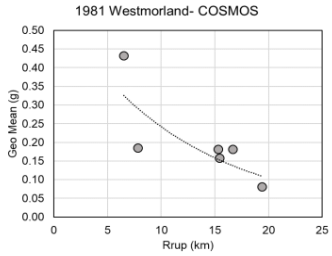
1981 WestMorland

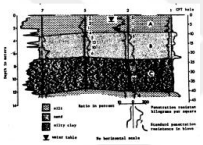
Magnitude: 5.90 Length (km): - R_{rup} (km): -

Fault Type: strike slip Z_{tor} (km): - R_{jb} (km): 5.1

Dip: 90 Width (km): -



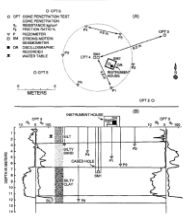


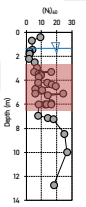


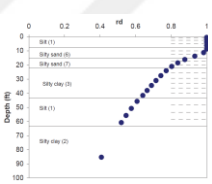


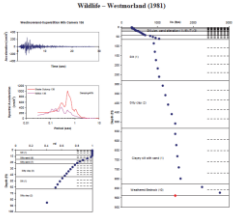


Cetin (2000)









Wildlife – Westmorland (1981)

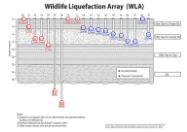
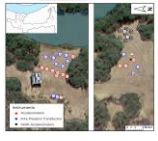


FIG. 2. Plan and Cross Section of Wildlife Site Showing Sediment Stratigraphy and Locations of Accelerometers and Piezometers (Bennett et al. 1984): (a) Plan View; and (b) Profile

Wildlife Liquefaction Array (WLA)





Case number:	92
Earthquake:	Westmorland
Magnitude:	5.6 (M_L), 5.9(Mw)
Location:	McKim Ranch A
References:	Bennett et al. (1984) and Fear et al. (1995), Bierschwale (1984), Andrus and Stokoe, (1997), Cetin (2000), Cetin et al (200-
Nature of Failure:	No surface evidence of liquefaction
GPS LAT	32.868815
GPS LONG	-115.45636
Liq. layer consist of:	silty sand (SM)
Geological Unit:	Natural deposit (Holocene sediment in the upper 330 ft, underlained by Quaternary alluvium and marine deposits)
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "The Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much as 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The principal rivers are the Alamo and New Rivers along which many sand boils were developed on fluvial deposits. Located between the Alamo River and the Redwood Canal. A: very fine sand (fining upwards)-loose sand that filled the relic channel. B: stiff silty clay Mc Kim Ranch is ~25 km from the epicenter of the earthquake. At SUP seismographic station which is ~ located at an epicentral distance of 24 km, PGA was recorded as 0.1 g (deep alluvial site). Based on earthquake specific attenuation relationship, the mean and standard deviation were estimated as 0.12 ± 0.06 g. PGA was estimated by Seed et al (1984) ~0.09 g. Energy ratio ~68 %" Sharp et al (1986) "no clear evidence of surface faulting has yet been found in the epicentral area." Rupture plane is obtained from aftershcok distribution. SMS data is downloaded from COSMOS, a local PGA model is contstructed and the PGA selection seems correct. The fault parameters are obtained from USGS, PEER, NGL. Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes



Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?		No	No	No	No
Data Class		B	-	A	A
d_{crtc} range (m)		1.5 - 4.0		1.5 - 4.0	1.5 - 4.0
d_{crt} (m)		2.7	2.1	2.7	2.7
GWT (m)		1.5 ± 0.3	1.5	1.5 ± 0.1	1.5 ± 0.1
γ_{moist} (kN/m^3)		14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)		15.7 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)		42.0 ± 6.5	38.1	49.4 ± 7.7	49.4 ± 7.7
σ_v' (kPa)		30.0 ± 3.9	32.1	37.5 ± 3.9	37.5 ± 3.9
a_{max} (g)		0.090 ± 0.023	0.09	0.090 ± 0.014	0.090 ± 0.014
r_d		0.93 ± 0.010	0.97	0.93 ± 0.010	0.93 ± 0.021
CSR		0.080 ± 0.022	0.068	0.072 ± 0.012	0.072 ± 0.012
M_w		5.90	5.90	5.90	5.90
D_{50}		0.105 ± 0.003	-	0.106 ± 0.005	0.106 ± 0.005
% Fines		31.0 ± 3.0	31	19.8 ± 3.5	19.8 ± 3.5
% PI		-	-	-	NAV
N		5.3 ± 2.6	3	5.4 ± 2.6	5.4 ± 2.6
C_R		0.79	0.80	0.79	0.88
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.13	1.13	1.13	1.13
C_N		1.79	1.70	1.65	1.65
$(N_1)_{60}$		8.5 ± 4.2	4.6	7.9 ± 3.8	8.8 ± 4.2
V_{s30m} (m/s)		-	-	-	NAV
V_{s12m} (m/s)		160.0	-	160.0	NOT LISTED

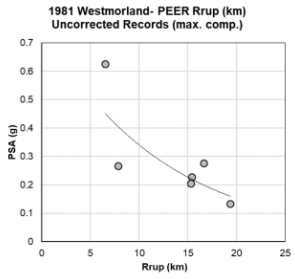
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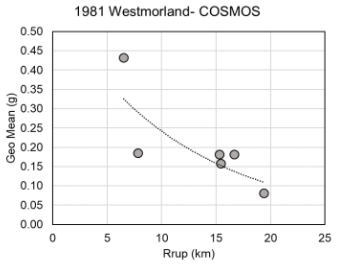
Westmorland

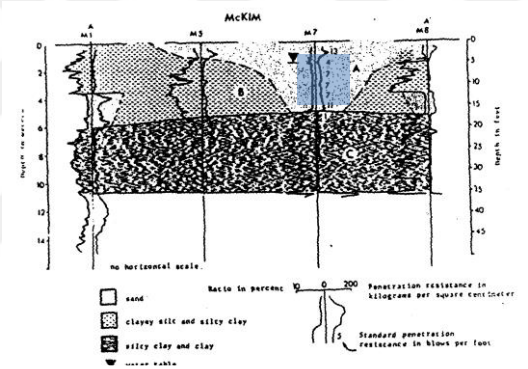
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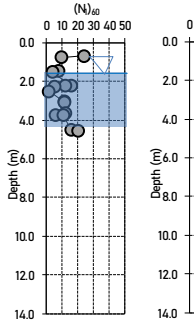
Fault Type: strike slip Z_{tor} (km): - R_{rup} (km): 21.7

Dip: 90 Width (km): - R_{jb} (km): 21.7

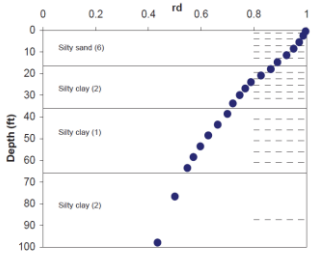




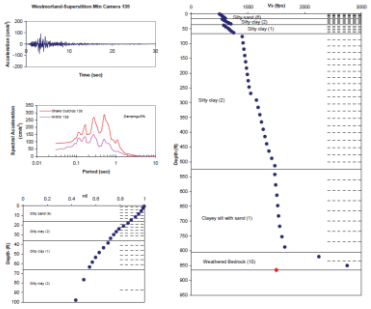




Cetin (2000)



McKim Ranch – Westmorland (1981)



	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
M-7	0.69	2.3		13	2.00	0.81	24.0	silty sand (SM)
SM-7	0.76	2.5		5	2.00	0.82	9.3	sand to silty sand
M-7	***1.45***	***4.8***		***4***	***2.00***	***0.84***	***7.6***	
SM-7	***1.52***	***5.0***		***2***	***1.96***	***0.84***	***3.8***	sand
M-2	***2.21***	***7.3***		***9***	***1.76***	***0.86***	***15.6***	sand
M-7	***2.21***	***7.3***		***7***	***1.76***	***0.86***	***12.1***	sand (SM)
SM-7	***2.29***	***7.5***		***3***	***1.75***	***0.87***	***5.1***	sand
M-3	***2.51***	***8.3***		***1***	***1.69***	***0.87***	***1.7***	sand
SM-7	***3.05***	***10.0***		***7***	***1.59***	***0.89***	***11.2***	sand
M-7	***3.09***	***10.2***		***7***	***1.58***	***0.89***	***11.1***	sand (SM)
SM-7	***3.66***	***12.0***		***8***	***1.49***	***0.90***	***12.2***	sand
M-3	***3.73***	***12.3***		***4***	***1.48***	***0.90***	***6.0***	silty sand
M-7	***3.73***	***12.3***		***7***	***1.48***	***0.90***	***10.6***	sand (SM)
M-7	4.50	14.8		11	1.38	0.92	15.7	sand (SM)
SM-7	4.57	15.0		14	1.37	0.92	19.9	sand
						Mean:	8.8	
						St. Dev.	4.2	

Depth (ft)	FC	sand	silt	clay	D50	
2.3	31.0	69.0	18.0	13.0	0.1	M-7
2.5		-	-	-	-	SM-7
4.8		***-***	***-***	***-***	***-***	***M-7***
5.0		***-***	***-***	***-***	***-***	***SM-7***
7.3		***-***	***-***	***-***	***-***	***M-2***
7.3	***24.0***	***76.0***	***14.0***	***10.0***	***0.1***	***M-7***
7.5		***-***	***-***	***-***	***-***	***SM-7***
8.3		***-***	***-***	***-***	***-***	***M-3***
9.4	***21.0***	***79.0***	***11.0***	***10.0***	***0.1***	***M-7***
10.0		***-***	***-***	***-***	***-***	***SM-7***
10.2	***16.0***	***84.0***	***9.0***	***7.0***	***0.1***	***M-7***
12.0		***-***	***-***	***-***	***-***	***SM-7***
12.3		***-***	***-***	***-***	***-***	***M-3***
12.3	***18.0***	***82.0***	***11.0***	***7.0***	***0.1***	***M-7***
14.8	22.0	78.0	15.0	7.0	0.1	M-7
15.0	-	-	-	-	-	SM-7
	19.8	80.3	11.3	8.5	0.106	
	3.5	3.5	2.1	1.7	0.005	

Case number:	93
Earthquake:	1983 Nihonkai-Chubu
Magnitude:	6.7 (Mw, USGS)
Location:	Aki City (Arayamotomachi)
References:	Yasuda and Tohno (1988)
Nature of Failure:	No Surface evidence of liquefaction
GPS LAT	39.68427
GPS LONG	140.08464
Liq. layer consist of:	fine sand
Geological Unit:	Late Pleistocene to Holocene sand dune deposits/Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Cetin (2000) "The Nihonkai-chubu Earthquake, with a magnitude of 7.7 occurred on May 26, 1983 in the northwest Japan and produced liquefaction sites in the coastal plain of Akita and Aomori Prefectures. About one month later, a magnitude 7.1 earthquake again hit the area and caused liquefaction at Aomori Prefecture but not at Akita. At Arayamotomachi Town in Akita City, liquefaction was caused along a narrow area by the main shock of Nihonkaichubu earthquake. The damage was concentrated in a small zone about 100 m in width and 500 m in length, in an area of land recently reclaimed over an old river by filling with sand from djacent sand dunes. At a point near the center of the liquefied area, a layer of very loose fine sand, with SPT N values of 0-6, forms a deposit extending from the ground surface to about 6 m in depth. The water table is very shallow, only 1 m in depth. The maximum surface acceleration was given as 0.2 and 0.15 g for the main and after shock respectively. The site has also liquefied during Niigata EQ. It is believed that a thin soil layer has liquefied during Niigata EQ. However, several meters of soil thickness is estimated to have been liquefied during Nihonkai-Chubu Earthquake."
	M=7.1 determined by the Japan Meteorological Agency. The Japan Meteorological Agency magnitude scale (Mj), are commonly used in routine processes. Hence Moment magnitude is updated as Mw=6.7 by USGS.
	SPT-N values are redigitized hence N1,60 is slighly updated.
	Vs12m is updated based on SPT-N - Vs correlations.
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	1.0 - 7.5	-	1.0 - 5.5	1.0 - 5.5
d_{crt} (m)	-	4.3	4.3	3.3	3.3
GWT (m)	-	1.0 ± 0.3	1	1.0 ± 0.1	1.0 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	15.7 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.1 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-	69.5 ± 18.0	69.2	56.5 ± 13.6	59.8 ± 14.2
σ_v' (kPa)	-	37.6 ± 8.1	37.1	34.4 ± 6.4	37.7 ± 6.9
a_{max} (g)	-	0.150 ± 0.030	0.15	0.150 ± 0.045	0.150 ± 0.045
r_d	-	0.84 ± 0.061	0.95	0.93 ± 0.048	0.98 ± 0.048
CSR	-	0.151 ± 0.036	0.172	0.150 ± 0.047	0.152 ± 0.047
M_w	-	7.10	6.80	7.10	6.70
D_{50}	-	0.150 ± 0.070	-	0.150 ± 0.050	0.150 ± 0.050
% Fines	-	15.0 ± 4.0	5	5.0 ± 2.0	5.0 ± 8.6
% PI	-	-	-	-	0
N	-	5.1 ± 2.8	2.6	4.4 ± 2.7	4.3 ± 1.9
C_R	-	0.90	0.95	0.86	0.91
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.60	1.70	1.72	1.64
$(N_1)_{60}$	-	8.9 ± 4.9	5.1	7.9 ± 4.8	8.8 ± 3.8
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	149.4	-	158.5	204.2

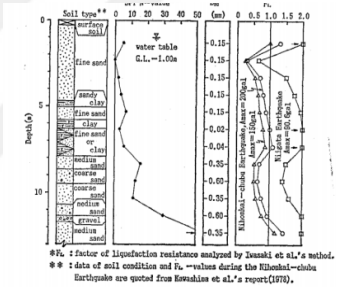
EVENT PARAMETERS

1983 Nihonkai-Chubu — Sato et al (1985)

Magnitude: 6.70 — Depth (Km): 14 (PARI9, 23.7 km (USGS)

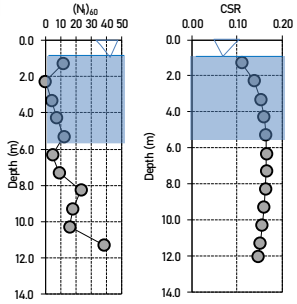
Fault Type: subduction zon — Z_{tor} (km): - — R_{rup} (km): -

Dip: 20 (eastward) — Width (km): 35 — R_{jb} (km): 94.0



*F_L : factor of liquefaction resistance analyzed by Iwasaki et al.'s method.
** : data of soil condition and F_L -values during the Niikawa-chuko Earthquake are quoted from Kawashima et al.'s report(1978).

Fig. 3. Soil profile and results of liquefaction analysis at Arayamotomachi in Akita



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	D50	
1.3	*4.2*	*0.110*	*5.0*	*2.00*	*0.86*	*11.8*	*0.15*	*fine sand*
2.3	7.4	0.138	0.0	1.88	0.89	0.0	0.15	fine sand
3.3	*10.8*	*0.152*	*2.0*	*1.63*	*0.91*	*4.1*	*0.15*	*fine sand*
4.3	*14.0*	*0.160*	*4.0*	*1.47*	*0.93*	*7.4*	*0.15*	*fine sand*
5.3	*17.4*	*0.164*	*7.0*	*1.34*	*0.94*	*12.1*	*0.15*	*fine sand*
6.3	20.7	0.165	3.0	1.25	0.95	4.9	0.02	clay seam
7.3	24.0	0.165	6.0	1.17	0.96	9.2	0.04	fine sand or clay
8.3	27.1	0.163	16.0	1.10	0.97	23.4	0.35	medium sand
9.3	30.4	0.160	13.0	1.05	0.97	18.1	0.60	coarse sand
10.3	33.7	0.155	12.0	1.00	0.98	16.1	0.35	coarse sand
11.3	37.0	0.151	30.0	0.96	0.98	38.6	0.60	medium sand
12.1	39.6	0.147	50.0	0.93	0.99	62.6	0.35	medium sand
					Mean:	8.8	0.150	
					St. Dev.	3.8	0.050	assigned

Case number:	96
Earthquake:	1983 Nihonkai-Chubu
Magnitude:	7.4 (Mw by USGS, NISEE)
Location:	Akita Station
References:	Iai et. al. (1989), KNET, Idriss and Boulanger (2010), Ilgac (2015), Cetin et al (2018)
Nature of Failure:	Liquefied and nonliquefied areas are defined by the boundary lines between artifically filled areas and the areas of
GPS LAT	39.74839 the Quaternary sediments which are shown in photos provided by Iai et. al. (1989)
GPS LONG	140.06673
Liq. layer consist of:	silty coarse sand with gravel
Geological Unit:	Quaternary sediments
Site Response Anlaysis:	No
Comments:	The site information is available in PARI (Akita-G) and also in Iai et al (1989). Tsuchida et. al (1985) shows the liquefied and non liquefied sites on Akita Port in Figure 8. The Akita Station is the strong ground motion station site. SMAC_B2 type accelerograph measured an acceleration value of 190 and 205 Gals in NS and EW directions. Geometric mean of 190 and 205 Gals is equal to 0.201 g. SPT procedures were not clearly documented. However, on page 66 in Iai et. al. (1989) for comparison with Seed et. al. 1985, an average Japanese SPT energy ratio of 73% was reported to be used. On the basis of this, with some uncertainty Iai et. al. N values may be adopted as N73 values. Note that Seed et. al. (1985) adopted an energy ratio of 73% for liquefied cases. The rationale behind this choice could be field data which is unknown to us or simply a conservative engineering judgement. Soil profile data is missing just N values and FC exist.From Technical Report of the Port and Horbour Research Institute Ministry of Transport, Japan No. 511 Marc. 1985 the borehole data could not be obtained. Site response by Iai et.al. exists however soil profile not known. There is an ambiguity if the site is free field or not in the vicinty of Akita Port Channel which is 10 m in depth. From Figure 8 the site is 75 m away from the channel. Note that the location of the site may not be correctly located in Figure 8 since the scale is very small and the coordinates of the borehole are not available. Additionally Quay walls are believed to be located 75 m away from site. Presence of Quay walls and due to proximity to the Akita Port Channel which 10 m free field stress boundary conditions may not be fulfilled. Hence cases within 20 m to the Quay walls and channel are eliminated. In Idriss and Boulanger (2010) Akita Station is divided into two case since there exist 2 borehole data. Note that for one borehole FC data is missing. In addition two boreholes at one site is against statistically independent assumption. Akita (1) and (2) are composed and represented as Akita Station by taking into account of two borehole data. NGL "SMAC-B2 type accelerograph, Strong-motion Observation Station in Akita Port (see location in Fig. 8 of Iai et al. 1989). The SMAC-B2 accelerograph installed there recorded the maximum accelerations of 190 and 205 Gals in N-S and E-W directions, respectively (Iai et al. 1989, Kurata et al. 1983). Original recordings were corrected to 219 Gal (N-S) and 235 Gal (E-W) by Kurata et al. (1983) to account for instrument limitations. Gals converted to units of g, acceleration of gravity." Akita station is a vertical array. Installation condition: Akita-G on ground G.L. 0m, Akita-GB in ground G.L. -13.3m. Digital reocrdings were available at the site. Both raw and corrected data are downloaded. Raw data suggest PGA of 0.194 g and 0.209 g and corrected data suggests 0.223 and 0.240 g by PARI. Sato et al (1985) "Strong motion stations used in the present study (squares) and the epicentral distribution of aftershocks during the period of May 26 to June 8, 1983 (KOSUGA et al., 1984). The solid star denotes the epicenter of the main shock and the open stars denote the epicenters of major aftershocks.
	Two aftershocks (M 6.0 and M 6.1) in the southern end occurred on June 9 and the largest aftershock (M 7.1) in the northern end occurred on June 21.
	M=7.7 determined by the Japan Meteorological Agency. The Japan Meteorological Agency magnitude scale (Mj), are commonly used in routine processes. Hence Moment magnitude is updated as Mw=7.4 by USGS.
	Vs12m is upated based on Vs-SPT correlations.
Gravel Content (%):	silty coarse sand with gravel (content unknown)
CPT available:	No
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	Akita 1 and 2 are seperate sites	No	No
Data Class	-	-		B	B
d_{crtc} range (m)	-	-		2.0 - 4.0	2.0 - 4.0
d_{crt} (m)	-	-		3.0	3.0
GWT (m)	-	-		1.8 ± 0.9	1.8 ± 0.9
γ_{moist} (kN/m^3)	-	-		18.9 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-		18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-	-		56.7 ± 6.4	56.7 ± 6.4
σ_v' (kPa)	-	-		44.4 ± 9.5	44.4 ± 9.5
a_{max} (g)	-	-		0.204 ± 0.010	0.201 ± 0.010
r_d	-	-		1.00 ± 0.045	0.99 ± 0.045
CSR	-	-		0.169 ± 0.037	0.166 ± 0.036
M_w	-	-		7.70	7.40
D_{50}	-	-		- ± -	NAV ± NAV
% Fines	-	-		2.7 ± 1.5	2.7 ± 1.5
% PI	-	-		-	NAV
N	-	-		10.3 ± 1.8	10.3 ± 1.8
C_R	-	-		0.85	0.85
C_S	-	-		1.00	1.00
C_B	-	-		1.00	1.00
C_E	-	-		1.22	1.22
C_N	-	-		1.51	1.51
$(N_1)_{60}$	-	-		16.0 ± 2.8	16.0 ± 2.8
V_{s30m} (m/s)	-	-		-	NAV
V_{s12m} (m/s)	-	-		266.7	216.1

EVENT PARAMETERS

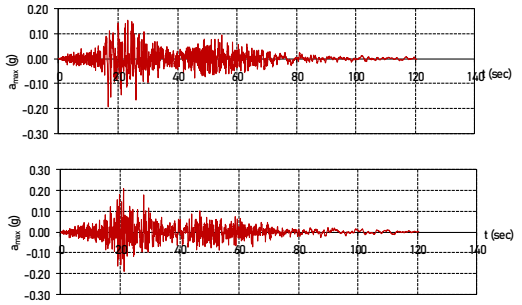
1983 Nihonkai-Chubu Sato et al (1985) USGS

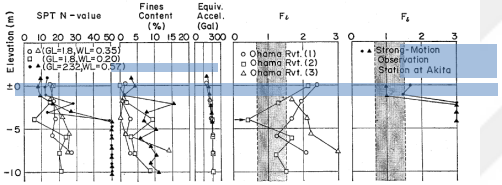
Magnitude: 7.40 Depth (Km): 14 (PARI), 23.7 km (USGS)

Fault Type: subduction zone Z_{tor} (km): - R_{rup} (km): -

Dip: 20 (eastward) Width (km): 35 R_{jb} (km): 90.0

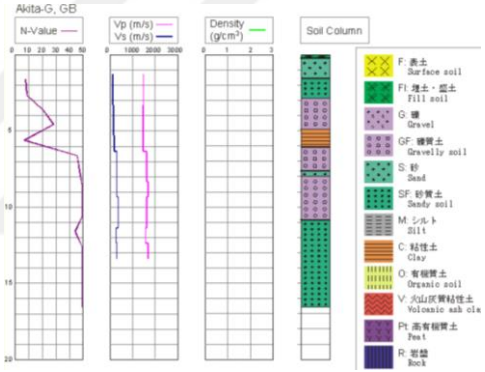
N_{H1}	18.3	Full Record https://www.eq.pari.go.jp/kyosin/en
N_{H2}	20.3	Thursday, May 26, 1983
N_{gm}	19.3	
PGA_{H1}	0.194	
PGA_{H2}	0.209	
PGA	0.201	
M_w	7.4	
$M_{w,cycle}$	7.1	
		Untill Liquefaction
$N_{H1,L}$	-	
$N_{H2,L}$	-	
$N_{gm,L}$	-	
PGA_{H1}	-	
PGA_{H2}	-	
PGA_L	-	
$M_{w,eq}$	-	
t_L	-	Epicentral distance (km) 108.5

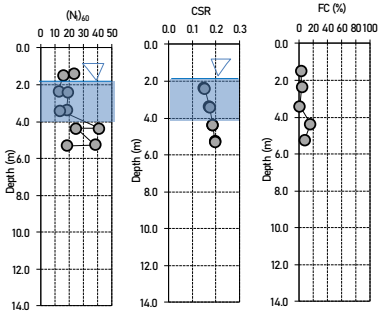




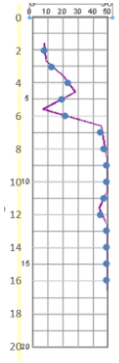
(e) Ohama No. 2 Former Revetment and the strong-motion observation station (Nonliquefied)

Fig. 9. Ground conditions and resulted liquefaction potentials at Akita Port during 1983 Nihonkai-Chubu Earthquake





PARI
https://www.pari.go.jp/en/



The data given in PARI does not match with the graphs of PARI and lai et al (1989). Hence the digitized values of lai et al (1989) is used since PARI only provides one borehole data.

Depth (m)	N	Vp	Vs	time (sec)
2	8	1500	150	0.013333
3	13	1500	150	0.006667
4	24	1470	170	0.005882
5	20	1460	160	0.00625
6	22	1460	200	0.005
7	46	1630	300	0.003333
8	48	1630	310	0.003226
9	50	1700	320	0.003125
10	50	1630	380	0.002632
11	48	1650	380	0.002632
12	46	1590	290	0.003448
13	50	1690	300	
14	50		$V_{s,12m}$ (m/s)	216.1075
15	50			
16	50			

Akita Station (1)

Depth (m)	N	
1.41	13	Akita Station (1)
2.43	12	Akita Station (1)
3.36	12	Akita Station (1)
4.37	28	Akita Station (1)
5.32	13	Akita Station (1)

Akita Station (2)

Depth (m)	N	
1.50	9	Akita Station (2)
2.35	8	Akita Station (2)
3.40	9	Akita Station (2)
4.37	17	Akita Station (2)
5.26	27	Akita Station (2)

Akita Station (1)

Depth (m)	N		FC
1.41	13	Akita Station (1)	-
1.50	9	Akita Station (2)	3.0
2.35	8	Akita Station (2)	4.0
2.43	12	Akita Station (1)	-
3.36	12	Akita Station (1)	-
3.40	9	Akita Station (2)	1.0
4.37	28	Akita Station (1)	-
4.37	17	Akita Station (2)	16.0
5.26	27	Akita Station (2)	8.0
5.32	13	Akita Station (1)	-

*This information is taken from NGL database

Depth (m)		
0	0.8	coarse sand with gravel
0.8	2.3	coarse sand
2.3	16.5	silty coarse sand with gravel
16.5	18	silty coarse sand with gravel
18	19.1	gravel

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
Akita Station (1)	1.4	4.6	NA	13	1.95	0.76	*23.5*	-	coarse sand
Akita Station (2)	***1.5***	***4.9***	***NA***	***9***	***1.89***	***0.77***	***15.9***	***3.0***	coarse sand
Akita Station (2)	***2.4***	***7.7***	***0.150***	***8***	***1.62***	***0.82***	***12.9***	***4.0***	silty coarse sand with gravel
Akita Station (1)	***2.4***	***8.0***	***0.152***	***12***	***1.61***	***0.82***	***19.3***	***-***	silty coarse sand with gravel
Akita Station (1)	***3.4***	***11.0***	***0.173***	***12***	***1.46***	***0.86***	***18.4***	***-***	silty coarse sand with gravel
Akita Station (2)	***3.4***	***11.2***	***0.173***	***9***	***1.45***	***0.86***	***13.8***	***1.0***	silty coarse sand with gravel
Akita Station (1)	4.4	14.3	0.187	28	1.34	0.90	*41.0*	-	silty coarse sand with gravel
Akita Station (2)	4.4	14.3	0.187	17	1.34	0.90	*24.9*	*16.0*	silty coarse sand with gravel
Akita Station (2)	5.3	17.3	0.196	27	1.25	0.93	*38.2*	*8.0*	silty coarse sand with gravel
Akita Station (1)	5.3	17.5	0.196	13	1.25	0.93	*18.3*	-	silty coarse sand with gravel
						Mean:	16.0	2.7	
						St. Dev.	2.8	1.5	

Case number:	98
Earthquake:	1983 Nihonkai-Chubu
Magnitude:	7.4 (Mw by USGS, NISEE)
Location:	Aki City (Arayamotomachi)
References:	Yasuda and Tohno (1988), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Sand boils, settled structures, sewage tanks floated.
GPS LAT	39.68427
GPS LONG	140.08464
Liq. layer consist of:	fine sand
Geological Unit:	Late Pleistocene to Holocene sand dune deposits/Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Cetin (2000) "The Nihonkai-chubu Earthquake, with a magnitude of 7.7 occurred on May 26, 1983 in the northwest Japan and produced liquefaction sites in the coastal plain of Akita and Aomori Prefectures. About one month later, a magnitude 7.1 earthquake again hit the area and caused liquefaction at Aomori Prefecture but not at Akita. At Arayamotomachi Town in Akita City, liquefaction was caused along a narrow area by the main shock of Nihonkaichubu earthquake. The damage was concentrated in a small zone about 100 m in width and 500 m in length, in an area of land recently reclaimed over an old river by filling with sand from djacent sand dunes. At a point near the center of the liquefied area, a layer of very loose fine sand, with SPT N values of 0-6, forms a deposit extending from the ground surface to about 6 m in depth. The water table is very shallow, only 1 m in depth. The maximum surface acceleration was given as 0.2 and 0.15 g for the main and after shock respectively. The site has also liquefied during Niigata EQ. It is believed that a thin soil layer has liquefied during Niigata EQ. However, several meters of soil thickness is estimated to have been liquefied during Nihonkai-Chubu Earthquake."
	M=7.7 determined by the Japan Meteorological Agency. The Japan Meteorological Agency magnitude scale (Mj), are commonly used in routine processes. Hence Moment magnitude is updated as Mw=7.4 by USGS.
	SPT-N values are redigitized hence N1,60 is slighly updated.
	Vs12m is updated based on SPT-N - Vs correlations.
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	1.0 - 7.5		1.0 - 5.5	1.0 - 5.5
d_{cr1} (m)	-	4.3	4.3	3.3	3.3
GWT (m)	-	1.0 ± 0.3	1	1.0 ± 0.1	1.0 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	15.7 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.1 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-	69.5 ± 18.0	69.2	56.5 ± 13.6	59.8 ± 14.2
σ_v' (kPa)	-	37.6 ± 8.1	37.1	34.4 ± 6.4	37.7 ± 6.9
a_{max} (g)	-	0.200 ± 0.040	0.2	0.200 ± 0.060	0.200 ± 0.060
r_d	-	0.85 ± 0.061	0.97	0.94 ± 0.048	0.98 ± 0.048
CSR	-	0.203 ± 0.048	0.234	0.200 ± 0.062	0.203 ± 0.063
M_w	-	7.70	7.70	7.70	7.40
D_{50}	-	0.150 ± 0.070	-	0.150 ± 0.050	0.150 ± 0.050
% Fines	-	15.0 ± 4.0	5	5.0 ± 2.0	5.0 ± 8.6
% PI	-	-	-	-	0
N	-	5.1 ± 2.8	2.6	4.4 ± 2.7	4.3 ± 1.9
C_R	-	0.90	0.95	0.86	0.91
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.60	1.70	1.72	1.64
$(N_1)_{60}$	-	8.9 ± 4.9	5.1	7.9 ± 4.8	8.8 ± 3.8
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	149.4	-	158.5	204.2

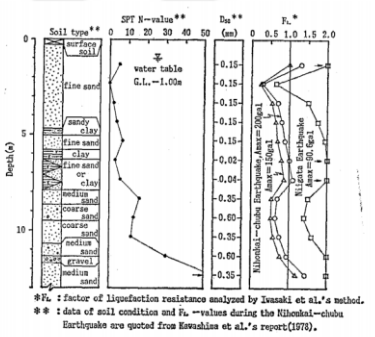
EVENT PARAMETERS

1983 Nihonkai-Chubu — Sato et al (1985)

Magnitude: 7.40 — Depth (Km): 14 (PARI9, 23.7 km (USGS)

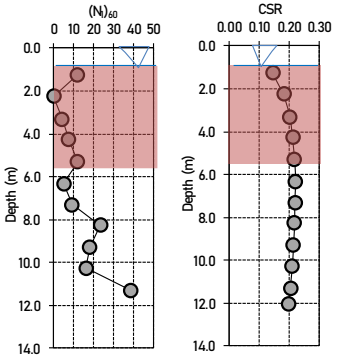
Fault Type: subduction zone — Z_{tor} (km): - — R_{rup} (km): -

Dip: 20 (eastward) — Width (km): 35 — R_{jb} (km): 94.0



*F_L : factor of liquefaction resistance analyzed by Iwasaki et al.'s method.
** : data of soil condition and F_L --values during the Nihonkai−chubu Earthquake are quoted from Kawashima et al.'s report(1978).

Fig. 3. Soil profile and results of liquefaction analysis at Arayamotomachi in Akita City



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	D50	
1.3	***4.2***	***0.147***	***5.0***	***2.00***	***0.86***	***11.8***	***0.15***	***fine sand***
2.3	7.4	0.184	0.0	1.88	0.89	0.0	0.15	fine sand outlier
3.3	***10.8***	***0.204***	***2.0***	***1.63***	***0.91***	***4.1***	***0.15***	***fine sand***
4.3	***14.0***	***0.214***	***4.0***	***1.47***	***0.93***	***7.4***	***0.15***	***fine sand***
5.3	***17.4***	***0.219***	***7.0***	***1.34***	***0.94***	***12.1***	***0.15***	***fine sand***
6.3	20.7	0.222	3.0	1.25	0.95	4.9	0.02	clay seam
7.3	24.0	0.221	6.0	1.17	0.96	9.2	0.04	fine sand or clay
8.3	27.1	0.219	16.0	1.10	0.97	23.4	0.35	medium sand
9.3	30.4	0.216	13.0	1.05	0.97	18.1	0.60	coarse sand
10.3	33.7	0.211	12.0	1.00	0.98	16.1	0.35	coarse sand
11.3	37.0	0.205	30.0	0.96	0.98	38.6	0.60	medium sand
12.1	39.6	0.201	50.0	0.93	0.99	62.6	0.35	medium sand
					Mean:	8.8	0.150	
					St. Dev.	3.8	0.050	assigned

Case number:	99
Earthquake:	1983 Nihonkai-Chubu
Magnitude:	7.4 (Mw by USGS, NISEE)
Location:	Gaiko
References:	Iai. et. al. (1989), Hamada and O'Rourke (1992), Ilgac (2015), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefied and nonliquefied areas are defined by the boundary lines between artifically filled
GPS LAT	39.764708 areas and the areas of the Quaternary sediments which are shown in photos provided by
GPS LONG	140.040157 Iai et. al. (1989)
Liq. layer consist of:	sand Lateral spreading, sand boils, ground fissures (Gaiko wharf, Hamada (1992)
Geological Unit:	Sand
Site Response Anlaysis:	No
Comments:	The Nihonkai-chubu Earthquake, with a magnitude of 7.7 occurred on May 26, 1983 in the northwest Japan and produced liquefaction sites in the coastal plain of Akita and Aomori Prefectures. About one month later, a magnitude 7.1 earthquake again hit the area. Akita Harbor suffered severe damage to its quay walls due to liquefaction. At Gaiko, which is an area newly reclaimed from the sea, liquefaction-induced ground displacements were observed. The quay wall, made of concrete caisson moved about 1.5 m and was tilted about 3 degrees. Tsuchida et. al (1985) shows the liquefied and non liquefied sites on Akita Port in Figure 8. Gaiko-1 and Gaiko-2 is located approximatly 2.76 km away from strong ground motion station in addition the two sites are very close to each other and soil profiles are very similar. In Cetin 2015 database these two sites are decided to be combained and represetnetd as Gaiko-1&2. SMAC_B2 type accelerograph measured an acceleration value of 190 and 205 Gals in NS and EW directions. "These two values are used for computing the rock outcrop motion. Then this rock outcrop motion is used as input for the earthquake response analysis at several sites." (Kurata et. al. 1983) In Figure 8 three digit numbers shows the maximum acceleration values obtained from ground response analysis. However this procedure is done for one component which is 215 Gals (EW) In order ro take into account multi-directional effects site response by Iai et.al. was scaled, maximum acceleration values of 215 and 205 Gals are obtained. Geometric mean of 215 and 204 Gals is equal to 0.214 g is assigned to site. SPT procedures were not clearly documented. However, on page 66 in Iai et. al. for comparison with Seed et. al. 1985, an average Japanese SPT energy ratio of 73% was reported to be used. On the basis of this, with some uncertainty Iai et. al. N values may be adopted as N73 values. Note that Seed et. al. (1985) adopted an energy ratio of 73% for liquefied cases. The rationale behind this choice could be field data which is unknown to us or simply a conservative engineering judgement. From Technical Report of the Port and Horbour Research Institute Ministry of Transport, Japan No. 511 Marc. 1985 the borehole data is obtained. Site response by Iai et.al. exists. There is an ambiguity if the site is free field or not in the vicinty of Akita Port Channel which is 10 m in depth. From Figure 8 the site is 37 m away from channel. Note that the location of the site may not be correctly located in Figure 8 since the scale is very small and the coordinates of the borehole are not available. Additionally Quay walls are believed to be located 37 m away from site. Presence of Quay walls and due to proximity to the Akita Port Channel which 10 m free field stress boundary conditions may not be fulfilled. Hence cases within 20 m to the Quay walls and channel are eliminated. Sato et al (1985) "Strong motion stations used in the present study (squares) and the epicentral distribution of aftershocks during the period of May 26 to June 8, 1983 (KOSUGA et al., 1984). The solid star denotes the epicenter of the main shock and the open stars denote the epicenters of major aftershocks. Two aftershocks (M 6.0 and M 6.1) in the southern end occurred on June 9 and the largest aftershock (M 7.1) in the northern end occurred on June 21. The fault of the main shock as estimated from the aftershock distribution is represented by a rectangle bent halfway along the fault length.". There was a typo in digitization of Gaiko 1 SPT depths. The data is redigitized. Previously Gaiko Wharf by Hamada and O'Rourke (1992) and Gaiko 1 and 2 by Iai et al (1989) were processed seperately. However it was understood that Iai's Gaiko 1 corresponds to Hamada's borehole 2 and similarly Iai's Gaiko 2 corresponds Hamada's borehole 1. Hence the sites are merged and Gaiko is processed as 1 case history. M=7.7 determined by the Japan Meteorological Agency. The Japan Meteorological Agency magnitude scale (Mj), are commonly used in routine processes. Hence Moment magnitude is updated as Mw=7.4 by USGS. Gaiko Wharf and Gaiko 1 and 2 were merged as the sites were same. Two borehole data measured in 1983 were used.
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Gaiko 1, Gaiko 2 and Gaiko Wharf B-2 are seperate sites	Gaiko 1, Gaiko 2 and Gaiko Wharf B-2 are seperate sites	Yes	Yes
Data Class	-			B	B
d_{crit} range (m)	-			3.0 - 18.0	1.5 - 15.0
d_{crt} (m)	-			10.5	8.2
GWT (m)	-			1.5 ± 0.1	1.5 ± 0.1
γ_{moist} (kN/m^3)	-			17.3 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-			18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-			196.1 ± 47.4	155.8 ± 42.7
σ_v' (kPa)	-			107.4 ± 23.1	89.4 ± 20.7
a_{max} (g)	-			0.214 ± 0.032	0.214 ± 0.032
r_d	-			0.62 ± 0.131	0.74 ± 0.107
CSR	-			0.158 ± 0.041	0.180 ± 0.038
M_w	-			7.70	7.40
D_{50}	-			- ± -	NAV ± NAV
% Fines	-			5.5 ± 6.9	4.6 ± 5.5
% PI	-			-	0
N	-			5.8 ± 1.8	6.1 ± 2.1
C_R	-			1.00	0.97
C_S	-			1.00	1.00
C_B	-			1.00	1.00
C_E	-			1.22	1.37
C_N	-			0.97	1.07
$(N_1)_{60}$	-			6.9 ± 2.1	8.6 ± 2.9
V_{s30m} (m/s)	-			-	NAV
V_{s12m} (m/s)	-			146.3	158.5

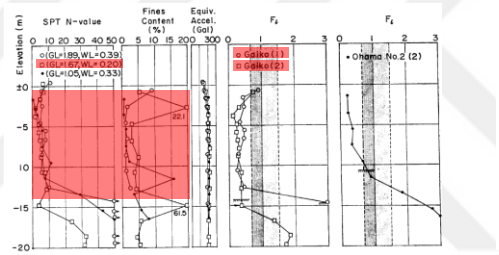
EVENT PARAMETERS

1983 Nihonkai-Chubu Sato et al (1985) USGS

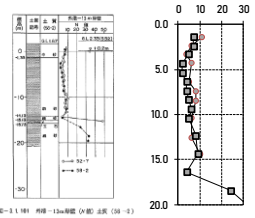
Magnitude: 7.40 Depth (Km): 14 (PARI9, 23.7 km (USGS)

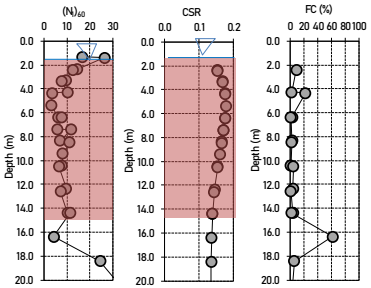
Fault Type: subduction zon Z_{tor} (km): - R_{rup} (km): -

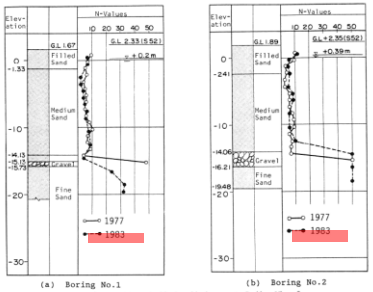
Dip: 20 (eastward) Width (km): 35 R_{jb} (km): 86.0



(a) Gaiko and Ohama No.2 (Liquefied)







(a) Boring No.1 (b) Boring No.2

Figure 41. Soil Conditions at Gaiko Wharf

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC		lai et al (1989) naming	
1.3	4.4	NA	7	2.00	0.87	*16.6*		Filled Sand	Gaiko-2	
1.4	4.6	NA	11	1.97	0.89	*26.3*		Filled Sand	Gaiko-1	
2.4	***7.8***	***0.165***	***7***	***1.68***	***0.89***	***14.3***		***Filled Sand***	***Gaiko-2***	
2.4	***7.8***	***0.166***	***6***	***1.67***	***0.91***	***12.5***	***9.0***	***Filled Sand***	***Gaiko-1***	
3.3	***10.7***	***0.181***	***5***	***1.52***	***0.91***	***9.4***		***Medium sand***	***Gaiko-2***	
3.4	***11.0***	***0.183***	***4***	***1.50***	***0.93***	***7.6***		***Filled Sand***		
4.3	***14.1***	***0.190***	***6***	***1.38***	***0.93***	***10.5***	***2.0***	***Filled Sand***	***Gaiko-1***	
4.3	***14.2***	***0.191***	***2***	***1.37***	***0.94***	***3.5***	***22.1***	***Medium sand***	***Gaiko-2***	
5.4	***17.6***	***0.193***	***2***	***1.27***	***0.95***	***3.3***		***Medium sand***	***Gaiko-2***	
6.4	***20.9***	***0.190***	***4***	***1.18***	***0.95***	***6.2***	***3.0***	***Medium sand***	***Gaiko-2***	
6.4	***21.0***	***0.190***	***5***	***1.18***	***0.96***	***7.8***	***1.0***	***Medium sand***	***Gaiko-1***	
7.4	***24.1***	***0.186***	***4***	***1.12***	***0.96***	***5.9***		***Medium sand***	***Gaiko-2***	
7.4	***24.2***	***0.185***	***8***	***1.12***	***0.97***	***11.8***		***Medium sand***	***Gaiko-1***	
8.3	***27.4***	***0.179***	***5***	***1.06***	***0.97***	***7.0***	***3.0***	***Medium sand***	***Gaiko-2***	
8.5	***27.9***	***0.178***	***8***	***1.05***	***0.97***	***11.2***	***2.0***	***Medium sand***	***Gaiko-1***	
9.4	***30.9***	***0.172***	***6***	***1.01***	***0.98***	***8.1***		***Medium sand***	***Gaiko-2***	
10.4	***34.1***	***0.166***	***6***	***0.97***	***0.98***	***7.8***	***1.0***	***Medium sand***	***Gaiko-1***	
10.5	***34.4***	***0.165***	***5***	***0.96***	***0.99***	***6.5***	***5.0***	***Medium sand***	***Gaiko-2***	
12.3	***40.4***	***0.156***	***8***	***0.90***	***0.99***	***9.7***	***4.0***	***Medium sand***	***Gaiko-2***	
12.6	***41.3***	***0.155***	***6***	***0.89***	***0.99***	***7.2***	***1.0***	***Medium sand***	***Gaiko-1***	
14.4	***47.2***	***0.150***	***9***	***0.84***	***0.99***	***10.2***	***4.0***	***Medium sand***	***Gaiko-2***	
14.4	***47.2***	***0.150***	***10***	***0.84***	***0.99***	***11.4***	***2.0***	***Medium sand***	***Gaiko-1***	
16.4	53.8	0.147	4	0.79	1.00	*4.3*	*61.5*	Medium sand	Gaiko-2	high FC, clayey?
18.4	60.5	0.145	24	0.75	1.00	*24.4*	*6.0*	Gravel	Gaiko-2	
20.3	66.5	0.145	33	0.72	1.00	*32.2*	*4.0*	Gravel	Gaiko-2	
21.3	70.0	0.145	32	0.70	0.82	*25.1*	*5.0*	Gravel	Gaiko-2	
					Mean:	**8.6**	**4.5**			
					St. Dev.	**2.9**	**5.7**			

lai et al. (1989) presents the measurement performed in 1983.

Depth (m)			
0	4.3	Filled Sand	Hamada
4.3	15.95	Medium sand	Boring
15.95	18.1	Gravel	No:2, lai
18.1	21.37	Fine Sand	Gaiko 1
0	3	Filled Sand	Hamada
3	16.8	Medium sand	Boring
16.8	17.4	Gravel	No:1, lai
17.4	33.71	Fine Sand	Gaiko 2

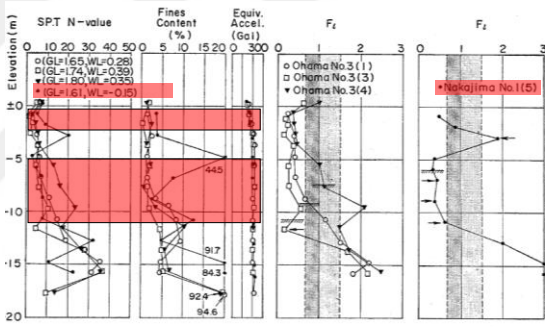
Case number:	102
Earthquake:	1983 Nihonkai-Chubu
Magnitude:	7.4 (Mw by USGS, NISEE)
Location:	Nakajima No. 1 (5)
References:	Iai et. al. (1989), Idriss and Boulanger (2010), Ilgac (2015), Cetin et al (2018)
Nature of Failure:	Liquefied and nonliquefied areas are defined by the boundary lines between artifically filled
GPS LAT	39.755653 areas and the areas of the Quaternary sediments which are shown in photos provided by Iai et. al. (1989)
GPS LONG	140.05786
Liq. layer consist of:	silt-sand-gravel
Geological Unit:	Artificial fill
Site Response Anlaysis:	No
Comments:	Tsuchida et. al (1985) shows the liquefied and non liquefied sites on Akita Port in Figure 8. Nakajima No. 1 (5) is 1.03 km away from strong ground motion station. SMAC_B2 type accelerograph measured an acceleration value of 190 and 205 Gals in NS and EW directions. "These two values are used for computing the rock outcrop motion. Then this rock outcrop motion is used as input for the earthquake response analysis at several sites." (Kurata et. al. 1983) In Figure 8 three digit numbers shows the maximum acceleration values obtained from ground response analysis. However this procedure is done for one component which is 209 Gals (EW) In order ro take into account multi-directional effects site response by Iai et.al. was scaled, maximum acceleration values of 209 and 199 Gals are obtained. Geometric mean of 209 and 199 Gals is equal to 0.208 g is assigned to site. SPT procedures were not clearly documented. However, on page 66 in Iai et. al. for comparison with Seed et. al. 1985, an average Japanese SPT energy ratio of 73% was reported to be used. On the basis of this, with some uncertainty Iai et. al. N values may be adopted as N73 values. Note that Seed et. al. (1985) adopted an energy ratio of 73% for liquefied cases. The rationale behind this choice could be field data which is unknown to us or simply a conservative engineering judgement. From Technical Report of the Port and Horbour Research Institute Ministry of Transport, Japan No. 511 Marc. 1985 the borehole data is obtained. Site response by Iai et.al. Exists. There is an ambiguity if the site is free field or not in the vicinty of Akita Port Channel which is 10 m in depth. From Figure 8 the site is 22 m away from channel. Note that the location of the site may not be correctly located in Figure 8 since the scale is very small and the coordinates of the borehole are not available. Additionally Quay walls are believed to be located 22 m away from site. Presence of Quay walls and due to proximity to the Akita Port Channel which 10 m free field stress boundary conditions may not be fulfilled. Hence cases within 20 m to the Quay walls and channel are eliminated. There exist two possibly liqueifed layer. Sato et al (1985) "Strong motion stations used in the present study (squares) and the epicentral distribution of aftershocks during the period of May 26 to June 8, 1983 (KOSUGA et al., 1984). The solid star denotes the epicenter of the main shock and the open stars denote the epicenters of major aftershocks. Two aftershocks (M 6.0 and M 6.1) in the southern end occurred on June 9 and the largest aftershock (M 7.1) in the northern end occurred on June 21. The fault of the main shock as estimated from the aftershock distribution is represented by a rectangle bent halfway along the fault length."
	M=7.7 determined by the Japan Meteorological Agency. The Japan Meteorological Agency magnitude scale (Mj), are commonly used in routine processes. Hence Moment magnitude is updated as Mw=7.4 by USGS.
	Vs12m is updated based on SPT-N - Vs correlations.
Gravel Content (%):	silt-sand-gravel (content unkown)
CPT available:	No
Vs available:	No

Summary of Input Data

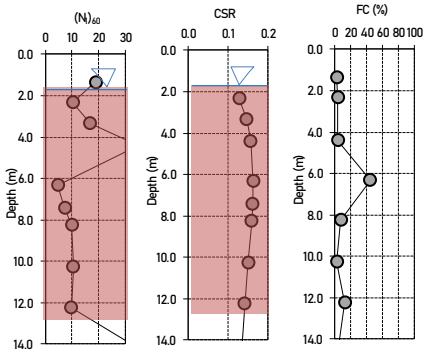
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	Yes	Yes	Yes
Data Class	-	-	-	B	A
d_{crtc} range (m)	-	-		2.0 - 13.0	2.0 - 13.0
d_{crt} (m)	-	-	6.5	7.5	7.5
GWT (m)	-	-	1.46	1.8 ± 0.1	1.8 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-	-	124.3	139.0 ± 34.8	139.0 ± 34.8
σ_v' (kPa)	-	-	74.2	82.6 ± 16.9	82.6 ± 16.9
a_{max} (g)	-	-	0.205	0.208 ± 0.031	0.208 ± 0.031
r_d	-	-	0.95	0.79 ± 0.099	0.85 ± 0.099
CSR	-	-	0.21	0.180 ± 0.036	0.193 ± 0.038
M_w	-	-	7.70	7.70	7.40
D_{50}	-	-	-	- ± -	NAV ± NAV
% Fines	-	-	8	14.6 ± 17.4	14.6 ± 17.4
% PI	-	-	-	-	NAV
N	-	-	7.3	6.5 ± 2.2	6.8 ± 2.5
C_R	-	-	0.95	0.99	0.96
C_S	-	-	1.00	1.00	1.00
C_B	-	-	1.00	1.00	1.00
C_E	-	-	1.22	1.22	1.37
C_N	-	-	1.18	1.11	1.11
$(N_1)_{60}$	-	-	9.9	8.7 ± 3.0	9.9 ± 3.7
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	160.0	176.8

EVENT PARAMETERS

1983 Nihonkai-Chubu	Sato et al (1985) USGS	
Magnitude: 7.40	Depth (Km): 14 (PARI9, 23.7 km (USGS)	
Fault Type: subduction zon	Z_{tor} (km): -	R_{rup} (km): -
Dip: 20 (eastward)	Width (km): 35	R_{jb} (km): 88.0



(b) Ohama No.3 and Nakajima No.1 (Liquefied)



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
1.3	4.4	NA	8.0	2.00	0.87	18.9	3.0	sand
2.3	***7.6***	***0.152***	***5.0***	***1.69***	***0.89***	***10.3***	***4.0***	***sand-gravel***
3.3	***11.0***	***0.175***	***9.0***	***1.51***	***0.91***	***16.9***	***-***	***sand-gravel***
4.4	14.4	0.187	20.0	1.37	0.93	34.7	4.0	sand-gravel anomallously high
6.3	***20.8***	***0.195***	***3.0***	***1.19***	***0.95***	***4.6***	***45.0***	***silt-sand***
7.4	***24.4***	***0.193***	***5.0***	***1.11***	***0.96***	***7.3***	***-***	***silt-sand***
8.2	***27.0***	***0.190***	***7.0***	***1.07***	***0.97***	***9.9***	***8.0***	***silt-sand***
10.3	***33.7***	***0.179***	***8.0***	***0.97***	***0.98***	***10.4***	***3.0***	***sand-gravel***
12.2	***40.2***	***0.169***	***8.0***	***0.90***	***0.99***	***9.7***	***13.0***	***sand***
14.3	47.0	0.161	32.0	0.84	0.99	36.3	5.0	sand
16.4	53.7	0.157	11.0	0.79	0.99	11.8	91.7	silt-sand
17.3	56.8	0.155	23.0	0.77	1.00	24.1	84.3	silt-sand
					Mean:	***9.9***	***14.6***	
					St. Dev.	***3.7***	***17.4***	

Case number:	103
Earthquake:	1983 Nihonkai-Chubu
Magnitude:	7.4 (Mw by USGS, NISEE)
Location:	Nakajima No. 2 (1)
References:	lai et. al. (1989), Idriss and Boulanger (2010), Ilgac (2015), Cetin et al (2018)
Nature of Failure:	Liquefied and nonliquefied areas are defined by the boundary lines between artifically filled
GPS LAT	39.756426 areas and the areas of the Quaternary sediments which are shown in photos provided by lai et. al. (1989)
GPS LONG	140.05719
Liq. layer consist of:	sand-gravel
Geological Unit:	Artificial Sand
Site Response Anlaysis:	No
Comments:	Tsuchida et. al (1985) shows the liquefied and non liquefied sites on Akita Port in Figure 8. Nakajima No. 2 (1) is 1.12 km away from strong ground motion station. SMAC_B2 type accelerograph measured an acceleration value of 190 and 205 Gals in NS and EW directions. "These two values are used for computing the rock outcrop motion. Then this rock outcrop motion is used as input for the earthquake response analysis at several sites." (Kurata et. Al. 1983) In Figure 8 three digit numbers shows the maximum acceleration values obtained from ground response analysis. However this procedure is done for one component which is 209 Gals (EW) In order ro take into account multi-directional effects site response by lai et.al. was scaled, maximum acceleration values of 209 and 199 Gals are obtained. Geometric mean of 209 and 199 Gals is equal to 0.208 g is assigned to site. SPT procedures were not clearly documented. However, on page 66 in lai et. al. for comparison with Seed et. al. 1985, an average Japanese SPT energy ratio of 73% was reported to be used. On the basis of this, with some uncertainty lai et. al. N values may be adopted as N73 values. Note that Seed et. al. (1985) adopted an energy ratio of 73% for liquefied cases. The rationale behind this choice could be field data which is unknown to us or simply a conservative engineering judgement. Site response by lai et.al. exists. From Technical Report of the Port and Horbour Research Institute Ministry of Transport, Japan No. 511 Marc. 1985 the borehole data is obtained. There is an ambiguity if the site is free field or not in the vicinty of Akita Port Channel which is 10 m in depth. From Figure 8 the site is 32 m away from channel. Note that the location of the site may not be correctly located in Figure 8 since the scale is very small and the coordinates of the borehole are not available. Additionally Quay walls are believed to be located 32 m away from site. Presence of Quay walls and due to proximity to the Akita Port Channel which 10 m free field stress boundary conditions may not be fulfilled. Hence cases within 20 m to the Quay walls and channel are eliminated. In lai et.al. first SPT-N value is missing hence It is taken from Technical Report of the Port and Horbour Research Institute Ministry of Transport. Sato et al (1985) "Strong motion stations used in the present study (squares) and the epicentral distribution of aftershocks during the period of May 26 to June 8, 1983 (KOSUGA et al., 1984). The solid star denotes the epicenter of the main shock and the open stars denote the epicenters of major aftershocks. Two aftershocks (M 6.0 and M 6.1) in the southern end occurred on June 9 and the largest aftershock (M 7.1) in the northern end occurred on June 21. The fault of the main shock as estimated from the aftershock distribution is represented by a rectangle bent halfway along the fault length."
	M=7.7 determined by the Japan Meteorological Agency. The Japan Meteorological Agency magnitude scale (Mj), are commonly used in routine processes. Hence Moment magnitude is updated as Mw=7.4 by USGS.
	Vs12m is upated based on Vs-SPT correlations.
Gravel Content (%):	sand gravel (content unkwon)
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	Yes	Yes	Yes
Data Class	-	-	-	A	A
d_{crtc} range (m)	-	-		2.0 - 9.0	2.0 - 9.0
d_{crt} (m)	-	-	7.1	5.5	5.5
GWT (m)	-	-	1.45	1.5 ± 0.1	1.5 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	18.9 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	-	136.3	107.1 ± 23.1	111.0 ± 24.2
σ_v' (kPa)	-	-	81.2	67.3 ± 11.7	71.2 ± 12.8
a_{max} (g)	-	-	0.205	0.207 ± 0.031	0.207 ± 0.031
r_d	-	-	0.94	0.90 ± 0.076	0.94 ± 0.076
CSR	-	-	0.213	0.193 ± 0.034	0.197 ± 0.035
M_w	-	-	7.70	7.70	7.40
D_{50}	-	-	-	- ± -	NAV
% Fines	-	-	3	2.0 ± 1.0	2.0 ± 1.0
% PI	-	-	-	-	0
N	-	-	10.4	4.7 ± 1.4	4.8 ± 1.1
C_R	-	-	0.95	0.94	0.94
C_S	-	-	1.00	1.00	1.00
C_B	-	-	1.00	1.00	1.00
C_E	-	-	1.22	1.22	1.37
C_N	-	-	1.12	1.23	1.19
$(N_1)_{60}$	-	-	13.5	6.6 ± 2.0	7.3 ± 1.7
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	172.2	189.0

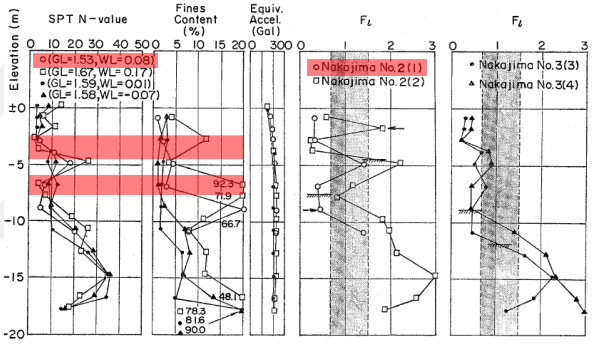
EVENT PARAMETERS

1983 Nihonkai-Chubu Sato et al (1985)

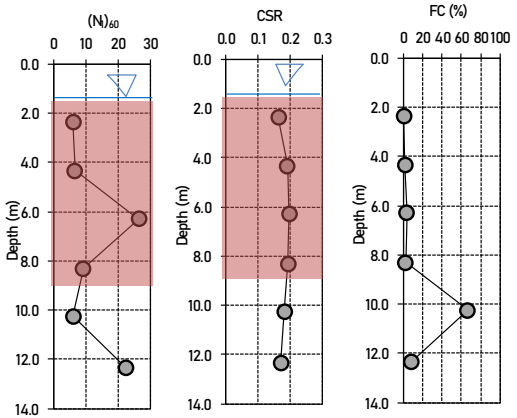
Magnitude: 7.40 Depth (Km): 14 (PARI9, 23.7 km (USGS)

Fault Type: subduction zon Z_{tor} (km): - R_{rup} (km): -

Dip: 20 (eastward) Width (km): 35 R_{jb} (km): 89.0



(c) Nakajima No. 2 and No. 3 (Liquefied)



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC		
2.4	***7.74***	***0.164***	***3***	***1.65***	***0.89***	***6.0***	***1.0***	***sand***	
4.3	***14.18***	***0.191***	***4***	***1.32***	***0.93***	***6.7***	***2.0***	***sand gravel***	
6.3	20.69	0.197	18	1.13	0.95	*26.4*	*4.0*	sand gravel	anamallously high
8.3	***27.30***	***0.193***	***7***	***1.00***	***0.97***	***9.3***	***3.0***	***sand gravel***	
10.3	33.64	0.183	5	0.91	0.98	*6.1*	*66.7*	silt sand	
12.4	40.53	0.171	20	0.84	0.99	*22.5*	*8.0*	sand	
					Mean:	7.3	2.0		
					St. Dev.	1.7	1.0		

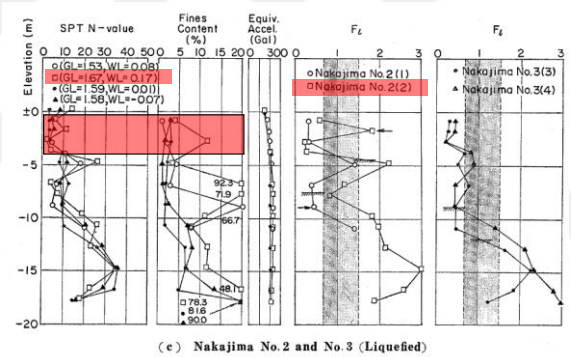
Case number:	104
Earthquake:	1983 Nihonkai-Chubu
Magnitude:	7.4 (Mw by USGS, NISEE)
Location:	Nakajima No. 2 (2)
References:	Iai et. al. (1989), KNET, Idriss and Boulanger (2010), Ilgac (2015), Cetin et al (2018)
Nature of Failure:	Liquefied and nonliquefied areas are defined by the boundary lines between artifically filled
GPS LAT	39.757497 areas and the areas of the Quaternary sediments which are shown in photos provided by Iai et. al. (1989)
GPS LONG	140.056283
Liq. layer consist of:	sand - gravel
Geological Unit:	Artificial fill
Site Response Anlaysis:	No
Comments:	Tsuchida et. al (1985) shows the liquefied and non liquefied sites on Akita Port in Figure 8. Nakajima No. 2 (2) is 1.24 km away from strong ground motion station. SMAC_B2 type accelerograph measured an acceleration value of 190 and 205 Gals in NS and EW directions. "These two values are used for computing the rock outcrop motion. Then this rock outcrop motion is used as input for the earthquake response analysis at several sites." (Kurata et. Al. 1983) In Figure 8 three digit numbers shows the maximum acceleration values obtained from ground response analysis. However this procedure is done for one component which is 204 Gals (EW) In order ro take into account multi-directional effects site response by Iai et.al. was scaled, maximum acceleration values of 204 and 194 Gals are obtained. Geometric mean of 204 and 194 Gals is equal to 0.203 g is assigned to site. SPT procedures were not clearly documented. However, on page 66 in Iai et. al. for comparison with Seed et. al. 1985, an average Japanese SPT energy ratio of 73% was reported to be used. On the basis of this, with some uncertainty Iai et. al. N values may be adopted as N73 values. Note that Seed et. al. (1985) adopted an energy ratio of 73% for liquefied cases. The rationale behind this choice could be field data which is unknown to us or simply From Technical Report of the Port and Horbour Research Institute Ministry of Transport, Japan No. 511 Marc. 1985 the borehole data is obtained. Site response by Iai et.al. exists. There is an ambiguity if the site is free field or not in the vicinty of Akita Port Channel which is 10 m in depth. From Figure 8 the site is 37 m away from channel. Note that the location of the site may not be correctly located in Figure 8 since the scale is very small and the coordinates of the borehole are not available. Additionally Quay walls are believed to be located 37 m away from site. Presence of Quay walls and due to proximity to the Akita Port Channel which 10 m free field stress boundary conditions may not be fulfilled. Hence cases within 20 m to the Quay walls and channel are eliminated. Sato et al (1985) "Strong motion stations used in the present study (squares) and the epicentral distribution of aftershocks during the period of May 26 to June 8, 1983 (KOSUGA et al., 1984). The solid star denotes the epicenter of the main shock and the open stars denote the epicenters of major aftershocks. Two aftershocks (M 6.0 and M 6.1) in the southern end occurred on June 9 and the largest aftershock (M 7.1) in the northern end occurred on June 21. The fault of the main shock as estimated from the aftershock distribution is represented by a rectangle bent halfway along the fault length." M=7.7 determined by the Japan Meteorological Agency. The Japan Meteorological Agency magnitude scale (Mj), are commonly used in routine processes. Hence Moment magnitude is updated as Mw=7.4 by USGS. Vs12m is updated based on SPT-N - Vs correlations.
Gravel Content (%):	sand gravel (content unkown)
CPT available:	No
Vs available:	No

Summary of Input Data

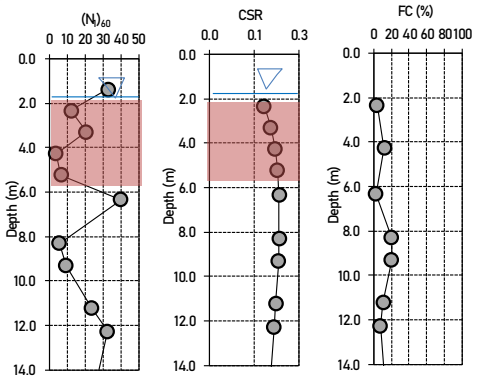
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	Yes	Yes	Yes
Data Class	-	-	-	A	A
d_{crtc} range (m)	-	-		2.0 - 5.7	2.0 - 5.7
d_{crt} (m)	-	-	3.8	3.9	3.9
GWT (m)	-	-	1.5	1.5 ± 0.1	1.5 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	18.9 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-	-	71.2	72.8 ± 11.7	72.8 ± 11.7
σ_v' (kPa)	-	-	48.1	49.7 ± 5.8	49.7 ± 5.8
a_{max} (g)	-	-	0.205	0.203 ± 0.030	0.203 ± 0.030
r_d	-	-	0.98	0.96 ± 0.056	0.98 ± 0.056
CSR	-	-	0.191	0.186 ± 0.031	0.189 ± 0.032
M_w	-	-	7.70	7.70	7.40
D_{50}	-	-	-	- ± -	- ± -
% Fines	-	-	7	8.0 ± 5.7	8.0 ± 5.7
% PI	-	-	-	-	0
N	-	-	6	5.9 ± 4.0	4.1 ± 2.5
C_R	-	-	0.85	0.88	0.92
C_S	-	-	1.00	1.00	1.00
C_B	-	-	1.00	1.00	1.00
C_E	-	-	1.22	1.22	1.37
C_N	-	-	1.50	1.43	1.43
$(N_1)_{60}$	-	-	9.3	9.0 ± 6.2	7.4 ± 4.5
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	182.9	201.2

EVENT PARAMETERS

1983 Nihonkai-Chubu	Sato et al (1985)	
Magnitude: 7.40	Depth (Km): 14 (PARI9, 23.7 km (USGS)	
Fault Type: subduction zon	Z_{tor} (km): -	R_{rup} (km): -
Dip: 20 (eastward)	Width (km): 35	R_{jb} (km): 89.0



(c) Nakajima No.2 and No.3 (Liquefied)



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC		
1.4	4.5	NA	14	1.98	0.87	*32.9*		sand gravel	
2.3	***7.7***	***0.161***	***6***	***1.68***	***0.89***	***12.3***	***4.0***	***sand gravel***	
3.3	***10.8***	***0.181***	***11***	***1.51***	***0.91***	***20.6***		***sand gravel***	***outlier***
4.3	***14.0***	***0.194***	***2***	***1.38***	***0.93***	***3.5***	***12.0***	***sand gravel***	
5.2	***17.2***	***0.202***	***4***	***1.28***	***0.94***	***6.6***		***sand***	
6.3	20.8	0.206	26	1.19	0.95	*40.1*	*3.0*	sand	***anamalously high***
8.3	27.3	0.207	4	1.06	0.97	5.6	20.0	silt	
9.3	30.6	0.204	7	1.01	0.97	9.4	20.0	silt sand	***the upper layer is more critic***
11.2	36.9	0.196	19	0.93	0.98	*23.8*	*11.0*	sand	
12.3	40.2	0.191	27	0.90	0.99	*32.7*	*8.0*	sand	
14.3	46.9	0.182	24	0.84	0.99	*27.3*	*12.0*	sand	
16.5	54.0	0.175	35	0.79	0.99	*37.4*	*12.0*	sand	
18.2	59.8	0.173	23	0.75	1.00	*23.5*	*20.0*	sand	
19.2	63.1	0.172	18	0.73	1.00	*18.0*		sand	
					Mean:	7.4	8.0		
					St. Dev.	4.5	5.7		

Case number:	105
Earthquake:	1983 Nihonkai-Chubu
Magnitude:	7.4 (Mw by USGS, NISEE)
Location:	Nakajima No. 3 (3)
References:	Iai et. al. (1989), KNET, Idriss and Boulanger (2010), Ilgac (2015), Cetin et al (2018)
Nature of Failure:	Liquefied and nonliquefied areas are defined by the boundary lines between artifically filled
GPS LAT	39.758092 areas and the areas of the Quaternary sediments which are shown in photos provided by Iai et. al. (1989)
GPS LONG	140.055848
Liq. layer consist of:	gravel - sand
Geological Unit:	artifical fill
Site Response Anlaysis:	No
Comments:	Tsuchida et. al (1985) shows the liquefied and non liquefied sites on Akita Port in Figure 8. Nakajima No. 3 (3) is 1.3 km away from strong ground motion station. SMAC_B2 type accelerograph measured an acceleration value of 190 and 205 Gals in NS and EW directions. "These two values are used for computing the rock outcrop motion. Then this rock outcrop motion is used as input for the earthquake response analysis at several sites." (Kurata et. Al. 1983) In Figure 8 three digit numbers shows the maximum acceleration values obtained from ground response analysis. However this procedure is done for one component which is 208 Gals (EW) In order ro take into account multi-directional effects site response by Iai et.al. was scaled, maximum acceleration values of 208 and 198 Gals are obtained. Geometric mean of 208 and 198 Gals is equal to 0.207 g is assigned to site. SPT procedures were not clearly documented. However, on page 66 in Iai et. al. for comparison with Seed et. al. 1985, an average Japanese SPT energy ratio of 73% was reported to be used. On the basis of this, with some uncertainty Iai et. al. N values may be adopted as N73 values. Note that Seed et. al. (1985) adopted an energy ratio of 73% for liquefied cases. The rationale behind this choice could be field data which is unknown to us or simply a conservative engineering judgement. From Technical Report of the Port and Horbour Research Institute Ministry of Transport, Japan No. 511 Marc. 1985 the borehole data is obtained. Site response by Iai et.al. exists. There is an ambiguity if the site is free field or not in the vicinty of Akita Port Channel which is 10 m in depth. From Figure 8 the site is 47 m away from channel. Note that the location of the site may not be correctly located in Figure 8 since the scale is very small and the coordinates of the borehole are not available. Additionally Quay walls are believed to be located 47 m away from site. Presence of Quay walls and due to proximity to the Akita Port Channel which 10 m free field stress boundary conditions may not be fulfilled. Hence cases within 20 m to the Quay walls and channel are eliminated. Sato et al (1985) "Strong motion stations used in the present study (squares) and the epicentral distribution of aftershocks during the period of May 26 to June 8, 1983 (KOSUGA et al., 1984). The solid star denotes the epicenter of the main shock and the open stars denote the epicenters of major aftershocks. Two aftershocks (M 6.0 and M 6.1) in the southern end occurred on June 9 and the largest aftershock (M 7.1) in the northern end occurred on June 21. The fault of the main shock as estimated from the aftershock distribution is represented by a rectangle bent halfway along the fault length."
	M=7.7 determined by the Japan Meteorological Agency. The Japan Meteorological Agency magnitude scale (Mj), are commonly used in routine processes. Hence Moment magnitude is updated as Mw=7.4 by USGS.
	Vs12m is updated based on SPT-N - Vs correlations.
Gravel Content (%):	gravel - sand (content unkown)
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	Yes	Yes	Yes
Data Class	-	-	-	A	A
d_{crit} range (m)	-	-		1.0 - 3.8	1.0 - 3.8
d_{crit} (m)	-	-	6.0	2.4	2.4
GWT (m)	-	-	1.58	1.6 ± 0.1	1.6 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	17.3 ± 0.5	17.3 ± 0.5
σ_v (kPa)	-	-	115.3	39.1 ± 8.1	39.1 ± 8.1
σ_v' (kPa)	-	-	71.2	31.0 ± 3.7	31.0 ± 3.7
a_{max} (g)	-	-	0.205	0.207 ± 0.031	0.207 ± 0.031
r_d	-	-	0.96	0.95 ± 0.037	0.97 ± 0.037
CSR	-	-	0.205	0.161 ± 0.030	0.164 ± 0.030
M_w	-	-	7.70	7.70	7.40
D_{50}	-	-	-	- ± -	NAV
% Fines	-	-	2	3.0 ± 2.0	3.0 ± 8.6
% PI	-	-	-	-	0
N	-	-	7.3	3.0 ± 0.1	3.0 ± 0.2
C_R	-	-	0.95	0.82	0.89
C_S	-	-	1.00	1.00	1.00
C_B	-	-	1.00	1.00	1.00
C_E	-	-	1.22	1.22	1.37
C_N	-	-	1.21	1.81	1.81
$(N_1)_{60}$	-	-	10.2	5.4 ± 0.2	6.6 ± 0.5
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	152.4	167.6

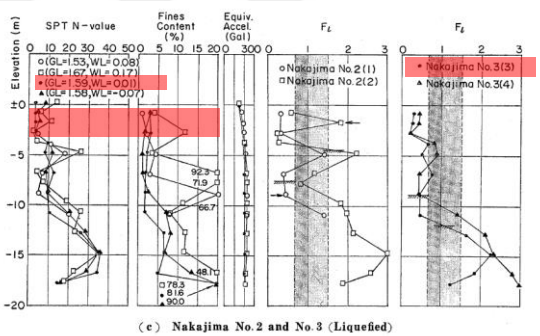
EVENT PARAMETERS

1983 Nihonkai-Chubu Sato et al (1985)

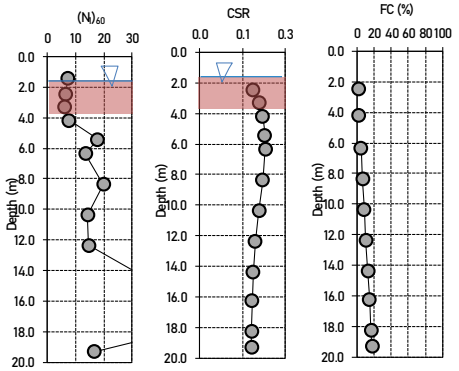
Magnitude: 7.40 Depth (Km): 14 (PARI9, 23.7 km (USGS)

Fault Type: subduction zone Z_{tor} (km): - R_{rup} (km): -

Dip: 20 (eastward) Width (km): 35 R_{jb} (km): 89.0



(c) Nakajima No.2 and No.3 (Liquefied)



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
1.4	***4.7***	***NA***	***3***	***2.00***	***0.87***	***7.1***		***gravel sand***
2.5	***8.1***	***0.166***	***3***	***1.80***	***0.89***	***6.6***	***3.0***	***gravel sand***
3.3	***10.9***	***0.185***	***3***	***1.64***	***0.91***	***6.1***		***gravel sand***
4.2	13.7	0.197	4	1.51	0.93	7.6	3.0	sand
5.4	17.8	0.204	10	1.37	0.94	17.7		sand
6.4	20.9	0.204	8	1.29	0.95	13.5	5.0	sand
8.4	27.5	0.197	13	1.16	0.97	19.9	7.0	sand
10.4	34.0	0.184	10	1.06	0.98	14.2	9.0	gravel sand
12.4	40.6	0.174	11	0.98	0.99	14.5	11.0	gravel sand
14.4	47.1	0.167	27	0.92	0.99	33.5	13.0	sand
16.3	53.4	0.163	36	0.87	0.99	42.4	15.0	sand
18.3	60.0	0.162	35	0.82	1.00	39.2	17.0	sand
19.3	63.4	0.162	15	0.80	1.00	16.4	18.0	sand
					Mean:	**6.6**	**3.0**	
					St. Dev.	**0.5**	**8.6**	assigned

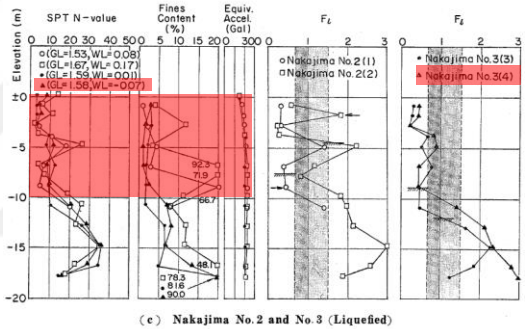
Case number:	106
Earthquake:	1983 Nihonkai-Chubu
Magnitude:	7.4 (Mw by USGS, NISEE)
Location:	Nakajima No. 3 (4)
References:	Iai et. al. (1989), KNET, Idriss and Boulanger (2010), Ilgac (2015), Cetin et al (2018)
Nature of Failure:	Liquefied and nonliquefied areas are defined by the boundary lines between artifically filled
GPS LAT	39.758806 areas and the areas of the Quaternary sediments which are shown in photos provided by Iai et. al. (1989)
GPS LONG	140.055179
Liq. layer consist of:	sand
Geological Unit:	artificial fill
Site Response Anlaysis:	No
Comments:	Tsuchida et. al (1985) shows the liquefied and non liquefied sites on Akita Port in Figure 8. Nakajima No. 3 (4) is 1.40 km awayfrom strong ground motion station. SMAC_B2 type accelerograph measured an acceleration value of 190 and 205 Gals in NS and EW directions. "These two values are used for computing the rock outcrop motion. Then this rock outcrop motion is used as input for the earthquake response analysis at several sites." (Kurata et. Al. 1983) In Figure 8 three digit numbers shows the maximum acceleration values obtained from ground response analysis. However this procedure is done for one component which is 203 Gals (EW) In order ro take into account multi-directional effects site response by Iai et.al. was scaled, maximum acceleration values of 203 and 193 Gals are obtained. Geometric mean of 203 and 193 Gals is equal to 0.202 g is assigned to site. SPT procedures were not clearly documented. However, on page 66 in Iai et. al. for comparison with Seed et. al. 1985, an average Japanese SPT energy ratio of 73% was reported to be used. On the basis of this, with some uncertainty Iai et. al. N values may be adopted as N73 values. Note that Seed et. al. (1985) adopted an energy ratio of 73% for liquefied cases. The rationale behind this choice could be field data which is unknown to us or simply a conservative engineering judgement. From Technical Report of the Port and Horbour Research Institute Ministry of Transport, Japan No. 511 Marc. 1985 the borehole data is obtained. Site response by Iai et.al. exists. There is an ambiguity if the site is free field or not in the vicinty of Akita Port Channel which is 10 m in depth. From Figure 8 the site is 38 m away from channel. Note that the location of the site may not be correctly located in Figure 8 since the scale is very small and the coordinates of the borehole are not available. Additionally Quay walls are believed to be located 38 m away from site. Presence of Quay walls and due to proximity to the Akita Port Channel which 10 m free field stress boundary conditions may not be fulfilled. Hence cases within 20 m to the Quay walls and channel are eliminated. Sato et al (1985) "Strong motion stations used in the present study (squares) and the epicentral distribution of aftershocks during the period of May 26 to June 8, 1983 (KOSUGA et al., 1984). The solid star denotes the epicenter of the main shock and the open stars denote the epicenters of major aftershocks. Two aftershocks (M 6.0 and M 6.1) in the southern end occurred on June 9 and the largest aftershock (M 7.1) in the northern end occurred on June 21. The fault of the main shock as estimated from the aftershock distribution is represented by a rectangle bent halfway along the fault length."
	M=7.7 determined by the Japan Meteorological Agency. The Japan Meteorological Agency magnitude scale (Mj), are commonly used in routine processes. Hence Moment magnitude is updated as Mw=7.4 by USGS.
	Vs12m is upated based on Vs-SPT correlations.
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

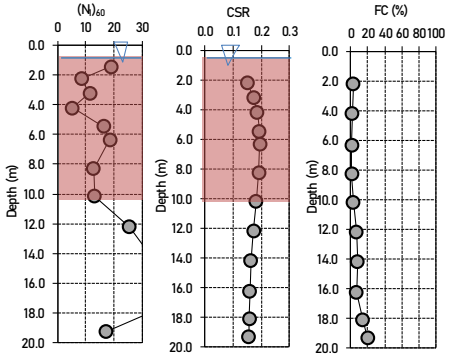
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	Yes	Yes	Yes
Data Class	-	-	-	A	A
d_{crtc} range (m)	-	-		1.8 - 11.2	1.8 - 11.2
d_{crt} (m)	-	-	5.7	6.5	6.5
GWT (m)	-	-	1.51	1.7 ± 0.1	1.7 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-	-	109.3	120.2 ± 29.7	120.2 ± 29.7
σ_v' (kPa)	-	-	68.2	72.6 ± 14.4	72.6 ± 14.4
a_{max} (g)	-	-	0.205	0.202 ± 0.030	0.202 ± 0.030
r_d	-	-	0.96	0.86 ± 0.087	0.90 ± 0.087
CSR	-	-	0.206	0.187 ± 0.035	0.195 ± 0.036
M_w	-	-	7.70	7.70	7.40
D_{50}	-	-	-	- ± -	NAV ± NAV
% Fines	-	-	2	2.0 ± 1.0	2.0 ± 1.0
% PI	-	-	-	-	0
N	-	-	8	7.8 ± 3.0	8.0 ± 2.9
C_R	-	-	0.95	0.96	0.95
C_S	-	-	1.00	1.00	1.00
C_B	-	-	1.00	1.00	1.00
C_E	-	-	1.22	1.22	1.37
C_N	-	-	1.24	1.18	1.18
$(N_1)_{60}$	-	-	11.5	10.8 ± 4.2	12.3 ± 4.5
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	167.6	182.9

EVENT PARAMETERS

1983 Nihonkai-Chubu	Sato et al (1985) USGS	
Magnitude: 7.40	Depth (Km): 14 (PARI9, 23.7 km (USGS)	
Fault Type: subduction zon	Z_{tor} (km): -	R_{rup} (km): -
Dip: 20 (eastward)	Width (km): 35	R_{jb} (km): 89.0



(c) Nakajima No. 2 and No. 3 (Liquefied)



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
1.4	4.7	NA	8	2.00	0.87	*19.0*		medium sand
2.2	***7.3***	***0.151***	***4***	***1.73***	***0.89***	***8.4***	***3.0***	***sand***
3.2	***10.5***	***0.173***	***6***	***1.54***	***0.91***	***11.5***		***sand***
4.2	***13.8***	***0.186***	***3***	***1.40***	***0.93***	***5.3***	***2.0***	***sand***
5.5	***17.9***	***0.194***	***10***	***1.27***	***0.94***	***16.3***		***sand***
6.4	***20.8***	***0.195***	***12***	***1.19***	***0.95***	***18.6***	***1.0***	***sand***
8.3	***27.2***	***0.191***	***9***	***1.07***	***0.97***	***12.7***	***1.0***	***sand***
10.2	***33.4***	***0.182***	***10***	***0.98***	***0.98***	***13.1***	***3.0***	***sand***
12.2	40.1	0.171	21	0.90	0.99	*25.6*	*7.0*	sand
14.2	46.5	0.164	29	0.85	0.99	*33.2*	*8.0*	sand
16.3	53.4	0.159	37	0.79	0.99	*39.9*	*7.0*	sand
18.1	59.4	0.156	30	0.76	1.00	*30.8*	*14.0*	sand
19.3	63.3	0.156	17	0.73	1.00	*17.0*	*20.0*	sand
					Mean:	12.3	2.0	
					St. Dev.	4.5	1.0	

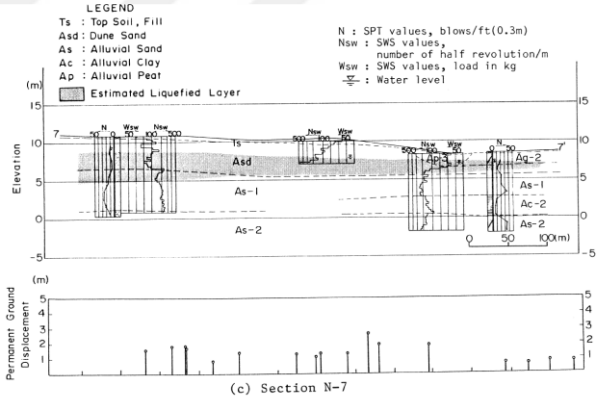
Case number:	107
Earthquake:	1983 Nihonkai-Chubu
Magnitude:	7.7 (M)
Location:	Noshiro N-7
References:	Hamada and O'Rourke (1992), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Lateral spreading
GPS LAT	40.20103
GPS LONG	140.02079
Liq. layer consist of:	alluvial and dune sand
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Cetin (2000) "The Nihonkai-chubu Earthquake, with a magnitude of 7.7 occurred on May 26, 1983 in the northwest Japan and produced liquefaction sites in the coastal plain of Akita and Aomori Prefectures. About one month later, a magnitude 7.1 earthquake again hit the area The site is gently sloped (1-3%). A particulary large displacement occurred on the slopes of Maeyama, a sand hill about 10 m higher than the surrounding area. On the northern slope of the hill, displacements began near the top and extended horizontally for more than 300 m in a northerly direction. The maximum surface acceleration at Akita City 115 km from the epicenter was 0.235 and 0.219 g. The PGA at the site, 100 km away from the epicenter was estimated as 0.25 g."
	Sato et al (1985) "Strong motion stations used in the present study (squares) and the epicentral distribution of aftershocks during the period of May 26 to June 8, 1983 (KOSUGA et al., 1984). The solid star denotes the epicenter of the main shock and the open stars denote the epicenters of major aftershocks. Two aftershocks (M 6.0 and M 6.1) in the southern end occurred on June 9 and the largest aftershock (M 7.1) in the northern end occurred on June 21. The fault of the main shock as estimated from the aftershock distribution is represented by a rectangle bent halfway along the fault length."
	M=7.7 determined by the Japan Meteorological Agency. The Japan Meteorological Agency magnitude scale (Mj), are commonly used in routine processes. Hence Moment magnitude is updated as Mw=7.4 by USGS.
	Vs12m is upated based on Vs-SPT correlations.
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	2.0 - 5.0	-	2.0 - 5.0	2.0 - 5.0
d_{crt} (m)	-	3.5	3.5	3.5	3.5
GWT (m)	-	1.8 ± 0.3	1.7	1.8 ± 0.1	1.8 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.9 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	55.1 ± 8.4	55.1	63.4 ± 9.5	66.4 ± 10.4
σ_v' (kPa)	-	37.9 ± 4.5	38.1	46.2 ± 4.7	49.2 ± 5.6
a_{max} (g)	-	0.250 ± 0.055	0.25	0.250 ± 0.075	0.250 ± 0.075
r_d	-	0.93 ± 0.052	0.98	0.95 ± 0.052	0.95 ± 0.052
CSR	-	0.219 ± 0.054	0.232	0.212 ± 0.066	0.208 ± 0.064
M_w	-	7.70	7.70	7.70	7.40
D_{50}	-	0.250 ± 0.020	-	0.250 ± 0.050	0.250 ± 0.050
% Fines	-	1.0 ± 1.0	1	1.0 ± 2.0	1.0 ± 8.6
% PI	-	-	-	-	0
N	-	9.8 ± 2.1	9.8	9.8 ± 2.1	9.9 ± 2.1
C_R	-	0.87	0.85	0.87	0.91
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.59	1.60	1.48	1.44
$(N_1)_{60}$	-	16.4 ± 3.6	16.2	15.3 ± 3.3	17.7 ± 3.8
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	170.7	-	170.7	170.7

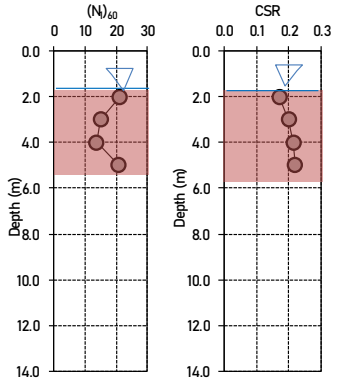
EVENT PARAMETERS

1983 Nihonkai-Chubu	Sato et al (1985) USGS	
Magnitude: 7.40	Depth (Km): 14 (PARI9, 23.7 km (USGS)	
Fault Type: subduction zon	Z_{tor} (km): -	R_{rup} (km): -
Dip: 20 (eastward)	Width (km): 35	R_{jb} (km): 66.0



(c) Section N-7

Figure 24. Soil Conditions and Estimated Liquefied Layer



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
2.0	*6.6*	*0.170*	*10.0*	*1.75*	*0.88*	*21.2*	Dune Sand
3.0	*9.8*	*0.200*	*8.0*	*1.52*	*0.90*	*15.1*	Dune Sand
4.0	*13.1*	*0.214*	*8.0*	*1.36*	*0.92*	*13.7*	Alluvial sand
5.0	*16.4*	*0.220*	*13.0*	*1.25*	*0.94*	*20.7*	Alluvial sand
					Mean:	17.7	
					St. Dev.	3.8	

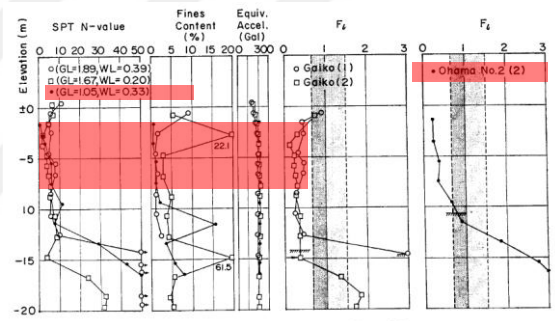
Case number:	108
Earthquake:	1983 Nihonkai-Chubu
Magnitude:	7.4 (Mw by USGS, NISEE)
Location:	Ohama No. 2 (2)
References:	Iai et. al. (1989), Idriss and Boulanger (2010), Ilgac (2015), Cetin et al (2018)
Nature of Failure:	Liquefied and nonliquefied areas are defined by the boundary lines between artifically filled
GPS LAT	39.768786 areas and the areas of the Quaternary sediments which are shown in photos provided by Iai et. al. (1989)
GPS LONG	140.048872
Liq. layer consist of:	sand
Geological Unit:	Artificial Sand
Site Response Anlaysis:	No
Comments:	Note that the location of the site may not be correctly located in Figure 8 Tsuchida et. al (1985) shows the liquefied and non liquefied sites on Akita Port in Figure 8. Ohama No. 2 (2) is 2.53 km away from strong ground motion station. SMAC_B2 type accelerograph measured an acceleration value of 190 and 205 Gals in NS and EW directions. "These two values are used for computing the rock outcrop motion. Then this rock outcrop motion is used as input for the earthquake response analysis at several sites." (Kurata et. Al. 1983) In Figure 8 three digit numbers shows the maximum acceleration values obtained from ground response analysis. However this procedure is done for one component which is 205 Gals (EW) In order ro take into account multi-directional effects site response by Iai et.al. was scaled, maximum acceleration values of 205 and 195 Gals are obtained. Geometric mean of 205 and 195 Gals is equal to 0.204 g is assigned to site. SPT procedures were not clearly documented. However, on page 66 in Iai et. al. for comparison with Seed et. al. 1985, an average Japanese SPT energy ratio of 73% was reported to be used. On the basis of this, with some uncertainty Iai et. al. N values may be adopted as N73 values. Note that Seed et. al. (1985) adopted an energy ratio of 73% for liquefied cases. The rationale behind this choice could be field data which is unknown to us or simply From Technical Report of the Port and Horbour Research Institute Ministry of Transport, Japan No. 511 Marc. 1985 the borehole data is obtained. Site response by Iai et.al. exists. There is an ambiguity if the site is free field or not in the vicinty of Akita Port Channel which is 10 m in depth. From Figure 8 the site is 38 m away from channel. Note that the location of the site may not be correctly located in Figure 8 since the scale is very small and the coordinates of the borehole are not available. Additionally Quay walls are believed to be located 38 m away from site. Presence of Quay walls and due to proximity to the Akita Port Channel which 10 m free field stress boundary conditions may not be fulfilled. Hence cases within 20 m to the Quay walls and channel are eliminated. Sato et al (1985) "Strong motion stations used in the present study (squares) and the epicentral distribution of aftershocks during the period of May 26 to June 8, 1983 (KOSUGA et al., 1984). The solid star denotes the epicenter of the main shock and the open stars denote the epicenters of major aftershocks. Two aftershocks (M 6.0 and M 6.1) in the southern end occurred on June 9 and the largest aftershock (M 7.1) in the northern end occurred on June 21. The fault of the main shock as estimated from the aftershock distribution is represented by a rectangle bent halfway along the fault length." M=7.7 determined by the Japan Meteorological Agency. The Japan Meteorological Agency magnitude scale (Mj), are commonly used in routine processes. Hence Moment magnitude is updated as Mw=7.4 by USGS. Vs12m is updated based on SPT-N - Vs correlations.
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

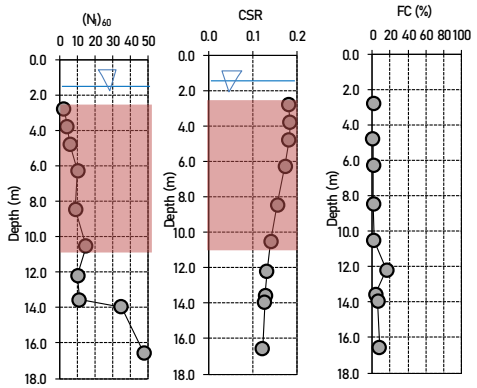
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	Yes	Yes	Yes
Data Class	-	-	-	A	A
d_{crtc} range (m)	-	-		2.2 - 11.3	2.2 - 11.3
d_{crt} (m)	-	-	5.2	6.8	6.8
GWT (m)	-	-	0.72	0.7 ± 0.1	0.7 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	17.3 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-	-	100.3	115.8 ± 26.4	125.3 ± 28.8
σ_v' (kPa)	-	-	56.1	56.5 ± 11.7	66.0 ± 14.1
a_{max} (g)	-	-	0.205	0.204 ± 0.031	0.204 ± 0.031
r_d	-	-	0.96	0.73 ± 0.090	0.77 ± 0.090
CSR	-	-	0.229	0.198 ± 0.039	0.194 ± 0.037
M_w	-	-	7.70	7.70	7.40
D_{50}	-	-	-	- ± -	NAV
% Fines	-	-	2	1.1 ± 0.5	1.1 ± 0.5
% PI	-	-	-	-	0
N	-	-	3.3	4.6 ± 2.9	4.7 ± 2.8
C_R	-	-	0.95	0.97	0.96
C_S	-	-	1.00	1.00	1.00
C_B	-	-	1.00	1.00	1.00
C_E	-	-	1.22	1.22	1.37
C_N	-	-	1.43	1.34	1.24
$(N_1)_{60}$	-	-	5.4	7.3 ± 4.6	7.6 ± 4.6
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	137.2	149.4

EVENT PARAMETERS

1983 Nihonkai-Chubu	Sato et al (1985)	
Magnitude: 7.40	Depth (Km): 14 (PARI, 23.7 km (USGS)	
Fault Type: subduction zon	Z_{tor} (km): -	R_{rup} (km): -
Dip: 20 (eastward)	Width (km): 35	R_{jb} (km): 86.0



(a) Gaiko and Ohama No.2 (Liquefied)



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
2.8	***9.09***	***0.207***	***1***	***1.84***	***0.90***	***2.3***	***1.0***	***sand***
3.8	***12.47***	***0.211***	***2***	***1.61***	***0.92***	***4.0***		***sand***
4.8	***15.58***	***0.208***	***3***	***1.46***	***0.93***	***5.6***	***0.5***	***sand***
6.3	***20.51***	***0.198***	***6***	***1.29***	***0.95***	***10.0***	***1.0***	***sand***
8.5	***27.72***	***0.178***	***6***	***1.12***	***0.97***	***8.9***	***1.0***	***sand***
10.5	***34.55***	***0.161***	***11***	***1.01***	***0.98***	***14.8***	***2.0***	***sand***
12.2	39.93	0.152	8	0.94	0.99	10.1	16.0	silt
13.6	44.46	0.147	9	0.89	0.99	10.9	4.0	sand
14.0	45.77	0.145	29	0.88	0.99	34.5	6.0	sand
16.6	54.30	0.141	43	0.81	0.99	47.3	8.0	sand
					Mean:	**7.6**	**1.1**	
					St. Dev.	**4.6**	**0.5**	

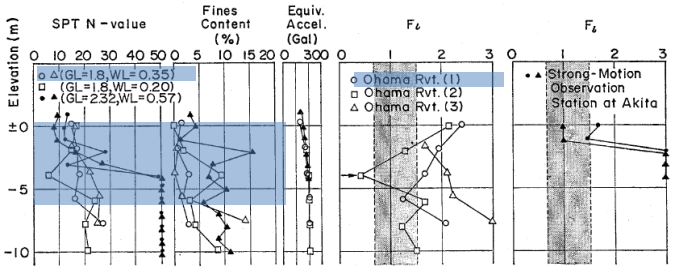
Case number:	109
Earthquake:	1983 Nihonkai-Chubu
Magnitude:	7.4 (Mw by USGS, NISEE)
Location:	Ohama No. Rvt. (1)
References:	Iai et. al. (1989), Idriss and Boulanger (2010), Ilgac (2015), Cetin et al (2018)
Nature of Failure:	Liquefied and nonliquefied areas are defined by the boundary lines between artifically filled
GPS LAT	39.767619 areas and the areas of the Quaternary sediments which are shown in photos provided by Iai et. al. (1989)
GPS LONG	140.049044
Liq. layer consist of:	NAV
Geological Unit:	Quaternary sediments
Site Response Anlaysis:	No
Comments:	Tsuchida et. al (1985) shows the liquefied and non liquefied sites on Akita Port in Figure 8. Ohama No. Rvt. (1) is 2.43 km away from strong ground motion station. SMAC_B2 type accelerograph measured an acceleration value of 190 and 205 Gals in NS and EW directions. "These two values are used for computing the rock outcrop motion. Then this rock outcrop motion is used as input for the earthquake response analysis at several sites." (Kurata et. Al. 1983) In Figure 8 three digit numbers shows the maximum acceleration values obtained from ground response analysis. However this procedure is done for one component which is 175 Gals (EW) In order ro take into account multi-directional effects site response by Iai et.al. was scaled, maximum acceleration values of 175 and 166 Gals are obtained. Geometric mean of 175 and 166 Gals is equal to 0.174 g is assigned to site. SPT procedures were not clearly documented. However, on page 66 in Iai et. al. for comparison with Seed et. al. 1985, an average Japanese SPT energy ratio of 73% was reported to be used. On the basis of this, with some uncertainty Iai et. al. N values may be adopted as N73 values. Note that Seed et. al. (1985) adopted an energy ratio of 73% for liquefied cases. The rationale behind this choice could be field data which is unknown to us or simply a conservative engineering judgement. Soil profile data is missing just N values and FC exist. From Technical Report of the Port and Horbour Research Institute Ministry of Transport, Japan No. 511 Marc. 1985 the borehole data could not be obtained. Site response by Iai et.al. exists however soil profile not known. There is an ambiguity if the site is free field or not in the vicinty of Akita Port Channel which is 10 m in depth. From Figure 8 the site is 76 m away from channel. Note that the location of the site may not be correctly located in Figure 8 since the scale is very small and the coordinates of the borehole are not available. Additionally Quay walls are believed to be located 76 m away from site. Presence of Quay walls and due to proximity to the Akita Port Channel which 10 m free field stress boundary conditions may not be fulfilled. Hence cases within 20 m to the Quay walls and channel are eliminated.
	Sato et al (1985) "Strong motion stations used in the present study (squares) and the epicentral distribution of aftershocks during the period of May 26 to June 8, 1983 (KOSUGA et al., 1984). The solid star denotes the epicenter of the main shock and the open stars denote the epicenters of major aftershocks. Two aftershocks (M 6.0 and M 6.1) in the southern end occurred on June 9 and the largest aftershock (M 7.1) in the northern end occurred on June 21. The fault of the main shock as estimated from the aftershock distribution is represented by a rectangle bent halfway along the fault length."
	M=7.7 determined by the Japan Meteorological Agency. The Japan Meteorological Agency magnitude scale (Mj), are commonly used in routine processes. Hence Moment magnitude is updated as Mw=7.4 by USGS.
Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	No	No	No
Data Class	-	-	-	B	B
$d_{crit.}$ range (m)	-	-		3.5 - 7.6	3.5 - 7.6
d_{cr1} (m)	-	-	4.5	5.5	5.6
GWT (m)	-	-	1.45	1.5 ± 0.9	1.5 ± 0.9
γ_{moist} (kN/m^3)	-	-	-	18.9 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	-	86.2	108.1 ± 13.4	112.0 ± 14.3
σ_v' (kPa)	-	-	55.1	67.8 ± 10.8	71.7 ± 10.7
a_{max} (g)	-	-	0.205	0.174 ± 0.026	0.174 ± 0.026
r_d	-	-	0.97	0.97 ± 0.076	0.97 ± 0.076
CSR	-	-	0.2	0.175 ± 0.038	0.172 ± 0.036
M_w	-	-	7.70	7.70	7.40
D_{50}	-	-	-	- ± -	NAV ± NAV
% Fines	-	-	2	3.0 ± 1.0	3.0 ± 1.0
% PI	-	-	-	-	0
N	-	-	15.8	17.2 ± 2.1	17.3 ± 2.8
C_R	-	-	0.95	0.94	0.94
C_S	-	-	1.00	1.00	1.00
C_B	-	-	1.00	1.00	1.00
C_E	-	-	1.22	1.22	1.37
C_N	-	-	1.28	1.22	1.19
$(N_1)_{60}$	-	-	23.5	24.0 ± 2.9	26.6 ± 4.3
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	213.4	213.4

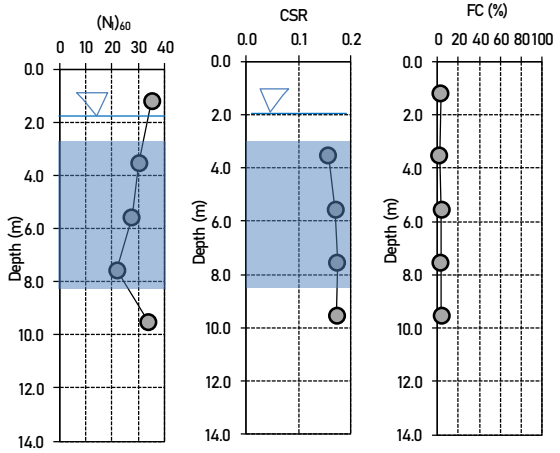
EVENT PARAMETERS

1983 Nihonkai-Chubu	Sato et al (1985)	
Magnitude: 7.40	Depth (Km): 14 (PAR19, 23.7 km (USGS)	
Fault Type: subduction zone	Z_{tor} (km): -	R_{rup} (km): -
Dip: 20 (eastward)	Width (km): 35	R_{jb} (km): 88.0



(e) **Ohama No. 2 Former Revetment and the strong-motion observation station (Nonliquefied)**

Fig. 9. Ground conditions and resulted liquefaction potentials at Akita Port during 1983 Nihonkai-Chubu Earthquake



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC
1.2	3.9	NA	15	2.00	0.86	35.3	3.0
3.5	***11.6***	***0.158***	***17***	***1.43***	***0.91***	***30.3***	***2.0***
5.6	***18.3***	***0.172***	***18***	***1.19***	***0.94***	***27.6***	***4.0***
7.6	***24.8***	***0.175***	***16***	***1.04***	***0.96***	***22.0***	***3.0***
9.5	31.3	0.173	27	0.94	0.98	33.9	4.0
					Mean:	**26.6**	**3.0**
					St. Dev.	**4.3**	**1.0**

Case number:	359 Cetin et al (2018) case number 97
Earthquake:	1983 Nihonkai-Chubu
Magnitude:	7.4 (Mw by USGS, NISEE)
Location:	AOM-RS (Aomori Railway Station) Dr. Mike Greenfield named is as AOM-Station.
References:	Yasuda and Tohno (1988), lai et al (1989), Greenfield (2017, 2018), PARI
Nature of Failure:	Observation at Aomori Railway Station during 1983 Nihonkai-Chubu earthquake: Yasuda and Tohno (1988)
GPS LAT	40.828947 Railway facility. Coordiates
GPS LONG	140.734833 approximate
Liq. layer consist of:	fine sand with medium sand, gravel
Geological Unit:	Af, reclaimed land composed of sand and gravel fill
Site Response Anlaysis:	No
Comments:	Greenfield (2017, 2018) summarizes the site as follows: "The Port and Rail Station are founded on reclaimed land that was constructed around 1945. Yasuda and Tohno (1988) describe an investigation at the Aomori Railway Station about 1 km away from Aomori-S.The Mw = 8.2 Tokachi-Oki earthquake occurred on May 16, 1968. The interface between Pacific Plate and the Okhotsk Plate ruptured and produced a powerful subduction-zone earthquake. The nearest distance to the fault rupture, Rrup, was about 140 km. The strong motion recorder Aomori-S recorded ground motions during the 1968 Tokachi-Oki earthquake, which PARI has cataloged in their online database. The Mw = 7.4 Nihnokai-Chubu earthquake occurred on May 26, 1983. A reverse fault in the back-arc region of the Sea of Japan ruptured, producing a devastating earthquake and tsunami. The rupture is classified as a subduction zone earthquake. The nearest distance to the fault rupture, Rrup, was about 120 km." Aomori railway station is located 1 km away from the strong ground motin station Aomori-S which recorded 1983 Nihonkai-Chubu. PARI provided NS and EW components of 97.9 gals (0.097 g) and 115.8 gals (0.118 g). Geometric mean of the two component is assigend as 0.107 g. Greenfield (2018) reported Peak ground acceleration as 0.133g.
	SPT profile is redigitized. Vs12m is updated based on Vs -SPT correlations.
	https://earthquake.usgs.gov/earthquakes/eventpage/usp0001vmy/executive
Gravel Content (%):	has gravel content (unkown)
CPT available:	No
Vs available:	No

indicate severe liquefaction occurred at Aomori Station. Surficial manifestation of liquefaction included many sand boils, rail and building settlement, and uplift of buried tanks.



Summary of Input Data

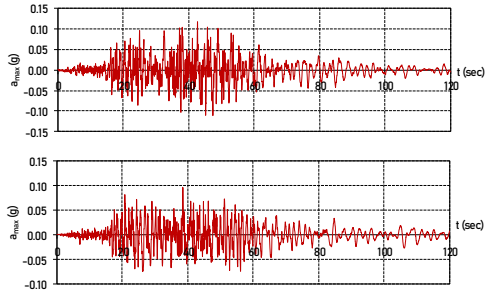
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	B	-	A	A
d_{crtc} range (m)	-	4.0 - 7.5	-	4.0 - 7.5	4.0 - 7.5
d_{crt} (m)	-	5.8	5.7	5.8	5.8
GWT (m)	-	0.0 ± 0.3	0	0.0 ± 0.1	0.0 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-	95.1 ± 10.3	95.0	108.7 ± 11.4	108.7 ± 11.4
σ_v' (kPa)	-	38.6 ± 5.9	38.0	52.2 ± 6.0	52.2 ± 6.0
a_{max} (g)	-	0.116 ± 0.018	0.116	0.116 ± 0.006	0.107 ± 0.005
r_d	-	0.80 ± 0.079	0.95	0.86 ± 0.079	0.85 ± 0.087
CSR	-	0.149 ± 0.030	0.178	0.135 ± 0.015	0.124 ± 0.015
M_w	-	7.70	7.70	7.70	7.40
D_{50}	-	0.250 ± 0.020	-	0.250 ± 0.050	0.250 ± 0.050
% Fines	-	3.0 ± 1.0	3	3.0 ± 2.0	5.0 ± 8.6
% PI	-	-	-	-	0
N	-	9.0 ± 0.9	9	9.0 ± 0.9	7.8 ± 1.4
C_R	-	0.94	0.95	0.94	0.95
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.58	1.58	1.40	1.40
$(N_1)_{60}$	-	16.3 ± 1.6	16.5	14.4 ± 1.4	14.0 ± 2.6
V_{s30m} (m/s)	-	-	-	-	NA
V_{s12m} (m/s)	-	158.5	-	158.5	161.3

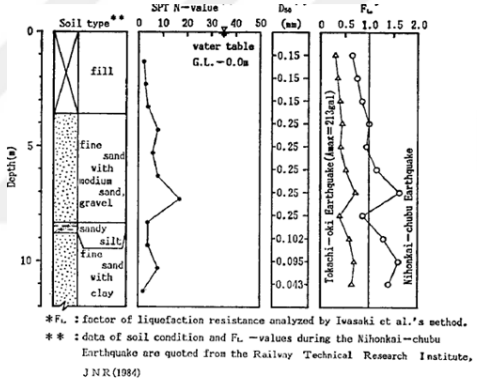
EVENT PARAMETERS

1983 Nihonkai-Chubu Sato et al (1985) USGS
Magnitude: 7.40 14 (PARI9, 23.7 km (USGS)
Fault Type: subduction zone Z_{tor} (km): - R_{rup} (km): 120.0
Dip: 20 (eastward) Width (km): 35 R_{jb} (km): 105.0

ACCELERATION TIME HISTORY

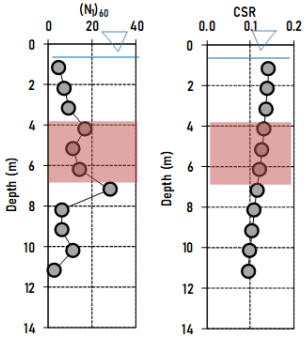
Aomori Strong Ground Motion Station Data





*F_L : factor of liquefaction resistance analyzed by Iwasaki et al.'s method.
** : data of soil condition and F_L -values during the Nihonkai-chubu Earthquake are quoted from the Railway Technical Research Institute, JNR(1984)

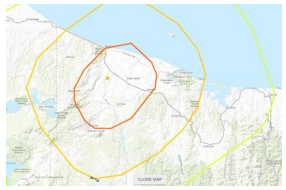
Fig. 12. Soil profile and results of liquefaction analysis at Aomori Station



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		D_{50}	
1.15	3.8	0.142	2	2.00	0.86	4.7	Fill	0.15	
2.15	7.1	0.140	3	2.00	0.89	7.3	Fill	0.15	
3.15	10.3	0.136	4	1.89	0.91	9.4	Fill	0.15	
4.15	***13.6***	***0.132***	***8***	***1.64***	***0.92***	***16.6***	***fine sand with medium sand, grav***	***0.25***	
5.15	***16.9***	***0.127***	***6***	***1.47***	***0.94***	***11.3***	***fine sand with medium sand, grav***	***0.25***	
6.15	***20.2***	***0.121***	***8***	***1.35***	***0.95***	***14.0***	***fine sand with medium sand, grav***	***0.25***	
7.15	23.5	0.116	17	1.25	0.96	27.9	fine sand with medium sand, gravel	0.25	
8.15	26.7	0.110	4	1.17	0.97	6.2	fine sand with medium sand, gravel	0.25	
9.15	30.0	0.104	4	1.11	0.97	5.9	fine sand with clay	0.10	
10.15	33.3	0.099	8	1.05	0.98	11.2	fine sand with clay	0.10	
11.15	36.6	0.095	2	1.00	0.98	2.7	fine sand with clay	0.04	
					Mean:	14.0	Mean:	0.250	
					St. Dev.	2.6	St. Dev.	0.050	assigned

BH data is from Yasuda and Tohno (1988)

Case number:	373
Earthquake:	1987 Edgecumbe Earthquake
Magnitude:	6.5 USGS (6.3 ML)
Location:	Brady Farm 1
References:	Christensen (1995), Zhao et al. (1997), NGL Project
Nature of Failure:	Localized Sand boils
GPS LAT	-37.918773 Coordinates are found by using Google Earth References: Christensen (1995), Zhao et al. (1997)
GPS LONG	176.843505
Liq. layer consist of:	Silty Sand
Geological Unit:	Alluvial Deposit
Site Response Anlaysis:	No
Comments:	PGA 0.4 ± 0.1 g estimated by Zhao et al. (1997)
	Site location and CPT sounding location are taken as the same
	Christensen 1995 "The site is level ground. A sample of the ejecta was colleceted after the Edgecumbe earthquake and analysis gave a D50 of 14 mm and FC of 3%. None of the material has this description but Bienvenue (8) stated that " several heaps of sands, crack with ejecta of sand on level ground... ....150 mm of fine sand with 2 layers of less than 2 mm pumice particles" Ejecta consisted of fine grey to clear brown sand with some white small pebbles." Christensen (1995) states that the ejecta has resulted from a combination of Soil layers with mean grain size between 0.04 mm to 0.1 mm.
	It was decided to include all the sand layer as potentially liquefiable.
	No information could be found regarding SPT energy. SPT in NZ area usually performed with automatic hammers hence 82% is adopted.
	PGA is taken as 0.37 g based on locally calibrated ground motion prediciton equations. This selection is consistent with Boulanger and Idriss (2014), Moss et al. (2006).
	https://earthquake.usgs.gov/earthquakes/eventpage/usp00032x6/map
	USGS *pga>0.5 g*
Gravel Content (%):	0
CPT available:	Yes
Vs available:	No



Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.5 - 7.0
d_{crt} (m)	-	-	-	-	4.8
GWT (m)	-	-	-	-	1.6 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	21.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	22.8 ± 0.5
σ_v (kPa)	-	-	-	-	106.3 ± 17.3
σ_v' (kPa)	-	-	-	-	75.5 ± 10.0
a_{max} (g)	-	-	-	-	0.370 ± 0.074
r_d	-	-	-	-	0.96 ± 0.067
CSR	-	-	-	-	0.325 ± 0.070
M_w	-	-	-	-	6.50
D_{50}	-	-	-	-	0.382 ± 0.337
% Fines	-	-	-	-	29.7 ± 16.9
% PI	-	-	-	-	NAV
N	-	-	-	-	8.8 ± 4.0
C_R	-	-	-	-	0.92
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.16
$(N_1)_{60}$	-	-	-	-	12.9 ± 5.9
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	201.2

EVENT PARAMETERS

1987 Edgecumbe Earthquake — cosmos strong ground motion database

Magnitude: 6.50 — footwall site

Fault Type: Normal Fault — Z_{tor} (km): 0 — R_{rup} (km): 6.5

Dip: 39 — Width (km): 3.5 — R_{jb} (km): 6.5

ACCELERATION TIME HISTORY



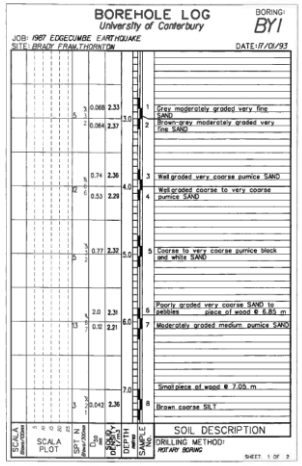


Figure C-16 Bore log BY1 from the Brady Farm site.

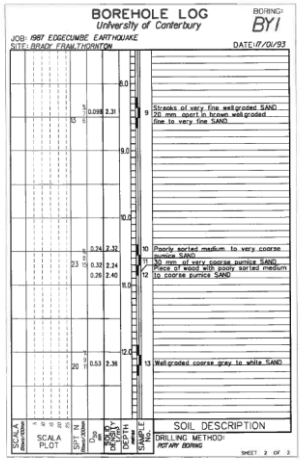
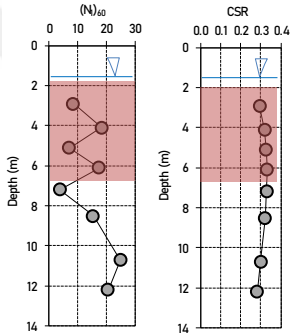


Figure C-17 Continuation of bore log BY1 from the Brady Farm site.

References: Christensen (1995), Zhao et al. (1997), NGL Project



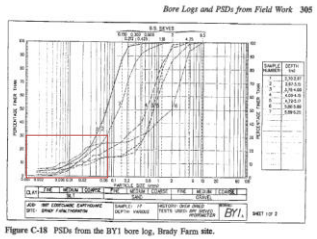


Figure C-18 PSDs from the BY1 bore log, Brady Farm site.

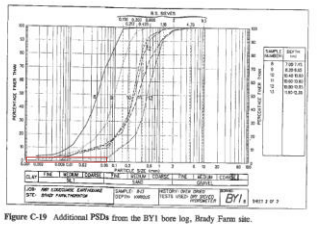


Figure C-19 Additional PSDs from the BY1 bore log, Brady Farm site.

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
Sand	*2.90*	*9.51*	*0.294*	*5*	*1.41*	*0.89*	*9*	
Sand	*4.10*	*13.45*	*0.318*	*12*	*1.23*	*0.91*	*18*	
Sand	*5.10*	*16.73*	*0.327*	*5*	*1.13*	*0.93*	*7*	plastic
Sand	*6.10*	*20.01*	*0.331*	*13*	*1.04*	*0.94*	*17*	
Silt	7.20	23.62	0.329	3	0.97	0.95	4	Thin layer/sand boils
Sand	8.50	27.89	0.322	13	0.90	0.97	15	
Sand	10.70	35.10	0.300	23	0.81	0.98	25	
Sand	12.20	40.03	0.283	20	0.77	0.98	21	
						Mean:	**12.9**	
						St. Dev.	**5.9**	

Depth (m)	D_{50}	ρ (t/m^3)	Depth (m)		FC
2.8	*0.068*	*2.33*	*2.7*	*2.97*	*50*
3.1	*0.064*	*2.37*	*2.97*	*3.15*	*50*
3.8	*0.740*	*2.36*	*3.75*	*4*	*14*
4.2	*0.530*	*2.29*	*4*	*4.15*	*19*
4.9	*0.770*	*2.32*	*4.72*	*5.17*	*14*
5.9	*2.000*	*2.31*	*5.8*	*5.89*	*23*
6.1	*0.120*	*2.21*	*5.89*	*6.25*	*31*
7.2	0.042	2.36	7	7.45	70
8.4	0.098	2.31	8.2	8.65	30
10.5	0.240	2.32	10.4	10.6	12
10.7	0.320	2.24	10.6	10.8	12
10.9	0.260	2.4	13.8	10.85	12
12.2	0.530	2.36	11.9	12.35	2
Mean:	**0.382**	**2.3**		**Mean:**	**29.7**
St. Dev.	**0.337**			**St. Dev.**	**16.9**

GWT (m)	
1.65	Water level is read from CPT sounding
1.68	
1.53	

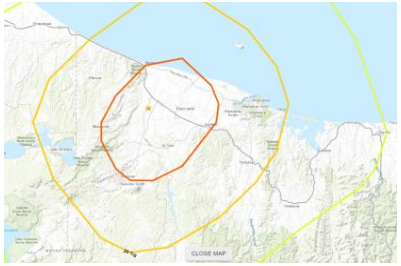
Case number:	375
Earthquake:	1987 Edgecumbe Earthquake
Magnitude:	6.5 USGS (6.3 ML)
Location:	Whakatane Pony Club
References:	Christensen (1995), Zhao et al. (1997), NZGD, NGL Project
Nature of Failure:	Lateral spreading, ground cracking, and sand boils
GPS LAT	-37.970416 Coordinates are found by using Google Earth References: Christensen (1995), Zhao et al. (1997)
GPS LONG	176.972787
Liq. layer consist of:	Sand
Geological Unit:	Alluvial Deposit
Site Response Anlaysis:	No
Comments:	Site location and CPT sounding location are taken as the same.
	No SPT data was available by Christensen 1995. The data is retrieved from NZGD.
	No information could be found regarding SPT energy. PGA 0.27 ± 0.1 g estimated by Zhao et al. (1997)
	No information regarding with FC
	Christensen (1995) "a match of ejecta D50 0.13 mm was made with a soil layer from a depth of 1.65 m."
	PC2 (Christensen 1995) is used. The other SPT (NZGD) is far away from the field observation.
	PGA is estimated as 0.29 g based on locally calibrated ground motion prediciton equations. IB 2014 estimated amax as 0.27 g, Moss et al 2006 as 0.27 g. No information could be found regarding SPT energy. SPT in NZ area usually performed with automatic hammers hence 82% is adopted.

NZGD



https://earthquake.usgs.gov/earthquakes/eventpage/usp00032x6/map

USGS 0.5>pga>0.2 g



Gravel Content (%):	0
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	4.0 - 6.9
d_{crt} (m)	-	-	-	-	5.5
GWT (m)	-	-	-	-	2.4 ± 0.9
γ_{moist} (kN/m^3)	-	-	-	-	20.5 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	22.1 ± 0.5
σ_v (kPa)	-	-	-	-	116.9 ± 11.0
σ_v' (kPa)	-	-	-	-	86.9 ± 9.9
a_{max} (g)	-	-	-	-	0.290 ± 0.058
r_d	-	-	-	-	0.91 ± 0.075
CSR	-	-	-	-	0.232 ± 0.056
M_w	-	-	-	-	6.50
D_{50}	-	-	-	-	0.186 ± 0.093
% Fines	-	-	-	-	28.3 ± 14.6
% PI	-	-	-	-	NAV
N	-	-	-	-	8.1 ± 3.7
C_R	-	-	-	-	0.93
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.08
$(N_1)_{60}$	-	-	-	-	11.1 ± 5.1
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	182.9

EVENT PARAMETERS

1987 Edgecumbe Earthquake		cosmos strong ground motin database	
Magnitude: 6.50		photos	footwall site
Fault Type: Normal Fault	Z_{tor} (km): 0		R_{rup} (km): 11.0
Dip: 39	Width (km): 3.5		R_{jb} (km): 11.0

ACCELERATION TIME HISTORY



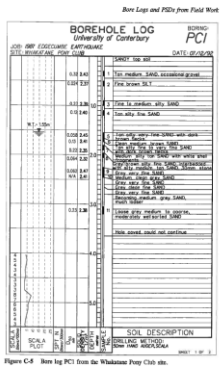


Figure C-5 Bore log PC1 from the Whakatane Pony Club site.

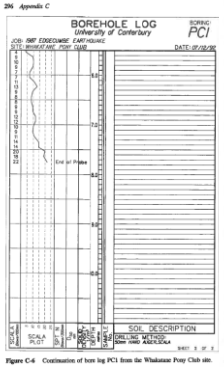


Figure C-6 Continuation of bore log PC1 from the Whakatane Pony Club site.

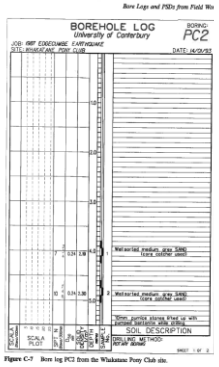


Figure C-7 Bore log PC2 from the Whakatane Pony Club site.

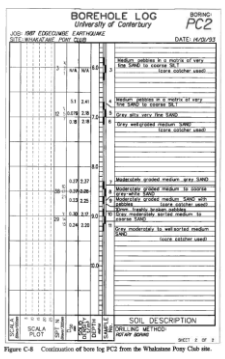
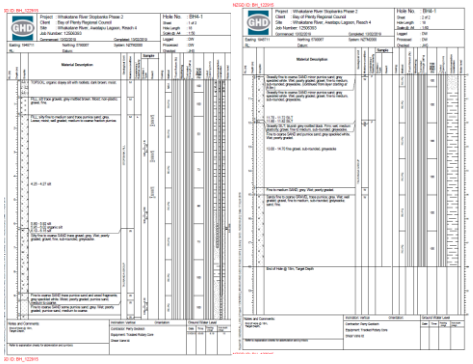
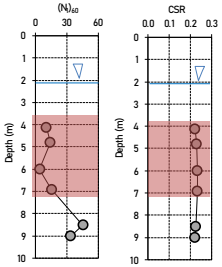


Figure C-8 Continuation of bore log PC2 from the Whakatane Pony Club site.





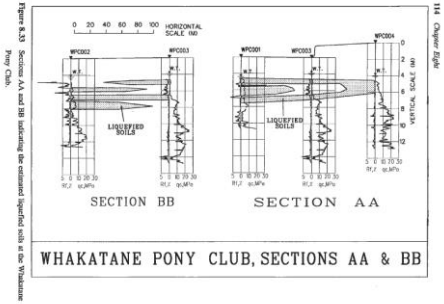


Figure 8.33 Sections AA and BB indicating the estimated liquefied soils at the Whakatane Pony Club.

WHAKATANE PONY CLUB, SECTIONS AA & BB

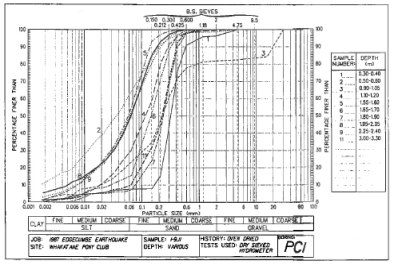


Figure C-9 PSDs from the PC1 bore log, Whakatane Pony Club site.

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	Borehole
Sand	*4.10*	*13.45*	*0.22*	*7*	*1.20*	*0.91*	*11*	PC2
Sand	*4.80*	*15.75*	*0.23*	*10*	*1.13*	*0.93*	*14*	PC2
Sand	*6.00*	*19.69*	*0.23*	*3*	*1.04*	*0.94*	*4*	PC2
Sand	*6.90*	*22.64*	*0.23*	*12*	*0.98*	*0.95*	*15*	PC2
Sand	8.50	27.89	0.22	38	0.90	0.97	45	PC2
Sand	9.00	29.53	0.22	29	0.88	0.97	34	PC2
						Mean:	**11.1**	
						St. Dev.	**5.1**	

above 4 m CPT indicates plastic material hence included

Depth (m)	D_{50}	ρ (t/m^3)
4.1	*0.24*	2.19
4.8	*0.24*	2.3
6.6	*5.1*	2.41
6.9	*0.079*	2.18
7.1	0.18	2.18
8.3	0.27	2.37
8.5	0.27	2.28
8.7	0.23	2.25
9.0	0.3	2.17
9.2	0.24	2.2
Mean:	**0.186**	**2.3**
St. Dev.	**0.093**	

Depth (m)		FC	FC
0.3	0.4		
0.5	0.5		
0.9	1		
1	1.2		
1.55	1.6		
1.65	1.7		7.0-70.0
1.8	1.9		
1.9	2		
2.25	2.4		
3	3.3		
3.5	4.2		
4.6	*5.05*	*18*	
6.7		*22*	
6.7	*7.05*	*45*	
7.1			10.0-50.0
8.30	8.35		
8.35	8.7		
8.7	8.75		
8.85	9.1		
9.1	9.3		
	Mean:	**28.3**	
	St. Dev.	**14.6**	

GWT (m)
1.55 SPT
2.35 CPT
2.2 CPT
1.9 CPT
3.97 CPT

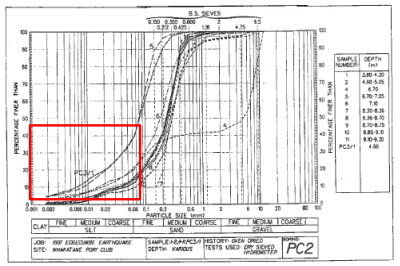


Figure C-10 PSDs from the PC2 bore log, Whakatane Pony Club site.

Case number:	376
Earthquake:	1987 Edgecumbe Earthquake
Magnitude:	6.5 USGS (6.3 ML)
Location:	Edgecumbe Substation
References:	Orense et al. (2020), NZGD
Nature of Failure:	liquefaction had been observed
GPS LAT	-37.986659
GPS LONG	176.830966
Liq. layer consist of:	Sand (SW)
Geological Unit:	river valley
Site Response Anlaysis:	No
Comments:	Orense et al. (2020) " ... While the power substation incurred damage to some of its transformers, only localised liquefaction was reported in the vicinity of Hydro Road (i.e. site #2) [1]. Thus, it can be surmised that the severity of liquefaction at both sites were minor to moderate....." Orense et al 2020. Pumice Sand. CPT exist. undisturbed soil samples were obtained at both sites to investigate the laboratory-derived cyclic resistance ratios. "On March 2 1987, at Olh 42m 34s UT an earthquake of magnitude (ML) 6.3 occurred near 37.91°S, 176.79°E close to the town of Edgecumbe in the North Island, New Zealand. The depth is provisionally estimated to be 12 ± 1 km. Seismic activity in the general area during the previous week culminated in a foreshock on March 2 of ML 5.2 at Olh 35m 37s. Four aftershocks with magnitudes in excess of 5.0 occurred on March 2 at Olh 51m 08s (ML 5.6), 02h 07m 23s (ML 5.1), 06h 56m 32s (ML 5.2) and 07h 55m 09s (ML 5.2). " Pender and Robertson (1987) ML=6.3 Orense et al 2020 Mw=6.5 (Mellsop et al 2017). Vs-12m (m/s) is calculated based on Vs measurements. PGA was suggested as 0.53 g by Orense et al. (2020). Based on the locally calibrated model conducted within the confines of this study amax is selected as 0.50 g. No information could be found regarding SPT energy. SPT in NZ area usually performed with automatic hammers hence 82% is adopted.
Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Attempt to locate the site on google earth. The coordinates were not presented by the authors so the given corrdinates are approximate.

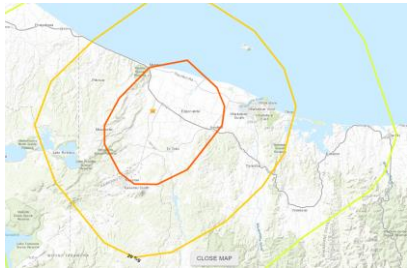


Orense et al. (2020)



https://earthquake.usgs.gov/earthquakes/eventpage/usp00032x6/map

USGS pga>0.5 g



Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{cr1c} range (m)	-	-	-	-	1.9 - 5.0
d_{cr1} (m)	-	-	-	-	3.5
GWT (m)	-	-	-	-	1.9 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	64.9 ± 10.7
σ_v' (kPa)	-	-	-	-	49.7 ± 5.7
a_{max} (g)	-	-	-	-	0.500 ± 0.100
r_d	-	-	-	-	0.85 ± 0.051
CSR	-	-	-	-	0.361 ± 0.078
M_w	-	-	-	-	6.50
D_{50}	-	-	-	-	-
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	9.9 ± 0.1
C_R	-	-	-	-	0.84
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.43
$(N_1)_{60}$	-	-	-	-	16.2 ± 0.2
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	135.0

EVENT PARAMETERS

1987 Edgecumbe Earthquake — cosmos strong ground motin database

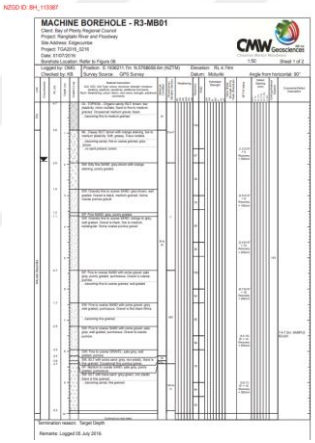
Magnitude: 6.50 — photos — footwall site

Fault Type: Normal Fault — Z_{tor} (km): 0 — R_{rup} (km): 0.8

Dip: 39 — Width (km): 3.5 — R_{jb} (km): 0.8

ACCELERATION TIME HISTORY





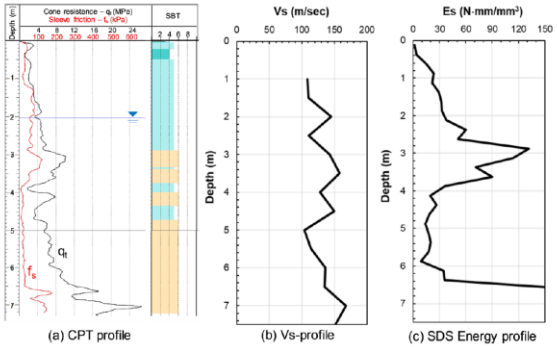
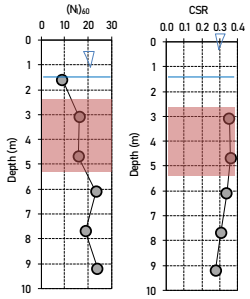


Figure 4: Results of field testing at Site #2.



	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
Silt	1.60	5.25	NA	4	1.91	0.86	9	above GWT
SW	***3.10***	***10.17***	***0.35***	***9***	***1.49***	***0.89***	***16***	
SW	***4.70***	***15.42***	***0.36***	***10***	***1.27***	***0.92***	***16***	
SP	6.10	20.01	0.34	16	1.14	0.94	23	
SW	7.70	25.26	0.31	14	1.03	0.96	19	
SM	9.20	30.18	0.28	19	0.95	0.97	24	
						Mean:	**16.2**	
						St. Dev.	**0.2**	

CN>2.0

Case number:	111
Earthquake:	1987 Elmore Ranch
Magnitude:	6.2 (Mw)
Location:	Radio Tower B1
References:	Bierschwale (1984), Bennett et al (1984), Fear et al. (1995), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface evidence of liquefaction
GPS LAT	33.010639
GPS LONG	-115.521375
Liq. layer consist of:	sandy silt and sand (SM-ML)
Geological Unit:	Holocene sediment is as thick as 330 ft
Site Response Anlaysis:	No
Comments:	Cetin (2000) "The Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much as 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The principal rivers are the Alamo and New Rivers along which many sand boils were developed on fluvial deposits. A: very poorly sorted, soft brown clay and silt-flood plain deposit B: brown, loose to med.dense silt to fine sand- sediment at base is well sorted very fine sand fining upwards to poorly sorted silt-channel deposit C: very stiff brown clayey silt to clay-lacustrine D: med dense sand PGA was recorded at the surface and at 6.7 m depth of Wildlife site as 0.126 and 0.077g respectively. The epicentral distance is ~25 km sligthly further than Wildlife site.The earthquake is very poorly monitored. Only one seismogram is available. Andrus and Stoke (NCEER, 97) predicted the PGA at the site as 0.11g. A PGA of 0.09 g was adopted for these studies. Energy ratio ~68 %" Surface rupture is obtained from Hudnutt et al (1989). Radio Tower B1 and B2 showed different field performance after 1981 Westmorland Earthquake. The sites are 75 m away from each other. Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes

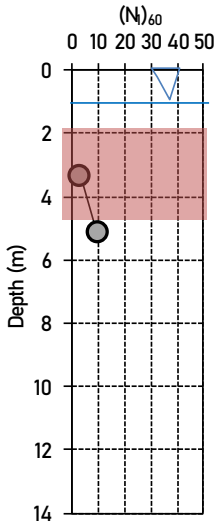
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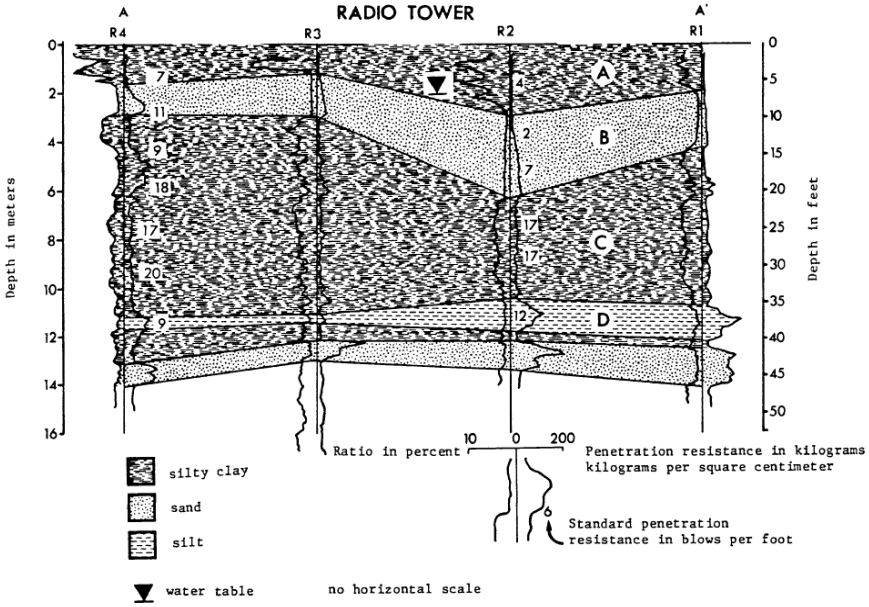
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	3.0 - 5.5	-	3.0 - 5.5	3.0 - 5.5
d_{crt} (m)	-	4.3	3.4	4.3	4.3
GWT (m)	-	2.0 ± 0.3	2.1	2.0 ± 0.1	2.0 ± 0.1
γ_{moist} (kN/m^3)	-	14.1 ± 0.5	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	14.9 ± 0.6	-	18.1 ± 0.5	18.1 ± 0.5
σ_v (kPa)	-	62.0 ± 6.5	62.2	72.2 ± 7.7	72.2 ± 7.7
σ_v' (kPa)	-	39.9 ± 3.9	50.1	50.1 ± 3.8	50.1 ± 3.8
a_{max} (g)	-	0.090 ± 0.025	0.09	0.090 ± 0.014	0.090 ± 0.014
r_d	-	0.97 ± 0.032	0.96	0.97 ± 0.032	0.97 ± 0.061
CSR	-	0.088 ± 0.026	0.069	0.082 ± 0.013	0.082 ± 0.014
M_w	-	6.20	6.22	6.20	6.22
D_{50}	-	0.047 ± 0.015	-	0.074 ± 0.037	0.074 ± 0.037
% Fines	-	75.0 ± 10.0	64	43.5 ± 29.0	43.5 ± 29.0
% PI	-	-	-	-	NAV
N	-	4.5 ± 3.4	2	4.5 ± 3.4	4.5 ± 3.2
C_R	-	0.86	0.85	0.86	0.91
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.13	1.13	1.13	1.13
C_N	-	1.55	1.49	1.42	1.42
$(N_1)_{60}$	-	6.8 ± 5.2	2.9	6.2 ± 4.7	6.5 ± 4.7
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

EVENT PARAMETERS

1987 Elmore Ranch

Magnitude: 6.22	Length (km): -	
Fault Type: strike slip	Z_{tor} (km): 0	R_{rup} (km): -
Dip: 90	Width (km): -	R_{jb} (km): 26.6





	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
R2	*3.3*	*10.8*		*2*	*1.55*	*0.89*	*3.1*	sandy silt (ML)
R2	*5.1*	*16.7*		*7*	*1.33*	*0.93*	*9.8*	sand (SM)
						Mean:	6.5	
						St. Dev.	4.7	

Depth (m)	FC	sand	silt	clay	D_{50}
3.3	*64.0*	*36.0*	*59.0*	*5.0*	*0.047*
5.1	*23.0*	*77.0*	*22.0*	*1.0*	*0.100*
23.15	*18.0*	*82.0*	*13.0*	*5.0*	*0.125*
	43.5	56.5	40.5	3.0	0.074
	29.0	29.0	26.2	2.8	0.037

Case number:	112
Earthquake:	1987 Elmore Ranch
Magnitude:	6.2 (Mw)
Location:	Wildlife B
References:	Bennett et al. (1984) and Fear et al. (1995), Bierschwale. (1984), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Site has not liquefied. Neither pore pressure ratios exceeding 1 nor surface evidence of liquefaction.
GPS LAT	33.0976
GPS LONG	-115.5306
Liq. layer consist of:	Silty Sand
Geological Unit:	Holocene floodplain
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "The Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much as 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The site is very closely monitored. Strong ground motion seismometers are available at the surface and at 6.7 m depth. Piezometers were installed almost at every meter depth along the potentially liquefiable layer of thickness 4 m. A: very loose and very soft interbedded micaceous sandy silt, silt and clayey silts (0-2.5 m) flood plain deposits B: very loose to loose moderately sorted sandy silt (2.5-6.8m); point bar deposits C: silty clay (medium to very stiff) and clayey silt (medium to stiff); lacustrine deposit. PGA was recorded at the surface and at 6.7 m depth as 0.126 and 0.077g respectively. The epicentral distance is 22.9 km. Energy ratio ~68 %"
	Rrup and Rjb is taken from PEER.
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes

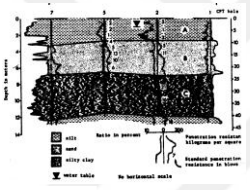
Summary of Input Data

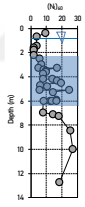
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	No	No	No	No
Data Class	-	A	-	A	A
d_{critc} range (m)	-	2.7 - 6.7	-	2.7 - 6.7	2.7 - 7.0
d_{cr1} (m)	-	4.7	4.6	4.7	4.9
GWT (m)	-	0.9 ± 0.3	1.2	0.9 ± 0.1	1.2 ± 0.1
γ_{moist} (kN/m^3)	-	14.1 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	15.7 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-	73.0 ± 10.7	87.2	86.4 ± 12.6	87.9 ± 13.7
σ_v' (kPa)	-	35.5 ± 5.3	54.1	49.0 ± 6.3	52.0 ± 6.8
a_{max} (g)	-	0.100 ± 0.005	0.133	0.130 ± 0.020	0.130 ± 0.007
r_d	-	0.75 ± 0.035	0.93	0.75 ± 0.035	0.75 ± 0.034
CSR	-	0.100 ± 0.011	0.138	0.112 ± 0.018	0.107 ± 0.008
M_w	-	6.20	6.22	6.20	6.22
D_{50}	-	0.090 ± 0.005	-	0.109 ± 0.038	0.089 ± 0.012
% Fines	-	40.0 ± 3.0	30	26.2 ± 7.6	27.4 ± 9.0
% PI	-	-	-	-	0
N	-	7.8 ± 3.5	7.1	7.9 ± 3.5	8.0 ± 3.5
C_R	-	0.88	0.95	0.88	0.92
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.13	1.13	1.13	1.13
C_N	-	1.64	1.36	1.44	1.40
$(N_1)_{60}$	-	12.8 ± 5.7	10.3	11.3 ± 5.0	11.6 ± 5.1
V_{s30m} (m/s)	-	-	-	-	179.0
V_{s12m} (m/s)	-	160.0	-	160.0	131.0

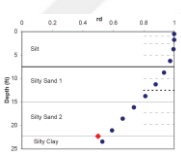
EVENT PARAMETERS

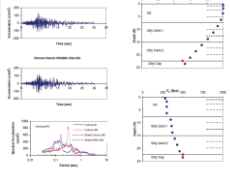
1987 Elmore Ranch

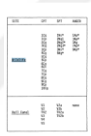
Magnitude: 6.22	Length (km): -		PEER
Fault Type: strike slip	Z_{tor} (km): 0		R_{rup} (km): 17.59
Dip: 90	Width (km): -		R_{jb} (km): 17.59





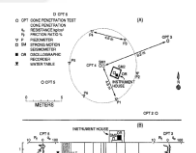


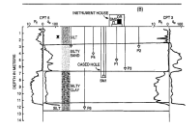


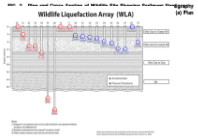




Cetin (2000)





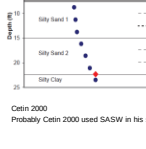


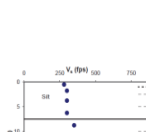






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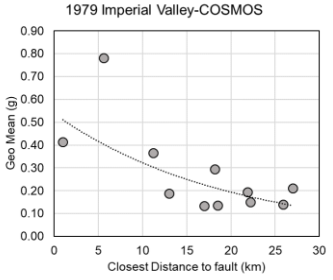
Case number:	113
Earthquake:	1987 Superstition Hills Earthquake
Magnitude:	6.54 (Mw)
Location:	Heber Road A1
References:	Bennett et al. (1981), Youd and Bennett (1983), Andrus and Stokoe (1997), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface manifestation of liquefaction
GPS LAT	32.73049583
GPS LONG	-115.3858486
Liq. layer consist of:	Sand (SP)
Geological Unit:	Relict Holocene channel
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "The Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much as 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The principal rivers are the Alamo and New Rivers along which many sand boils were developed on fluvial deposits. Heber Road site is ~60 km to the epicenter. Due to the lack of significant surface trace of the fault rupture, it is difficult to estimate the closest distance to the fault rupture. A soil PGA of 0.36g was recorded at El Centro array site # 5, which is ~15 km north of Heber Road site. Based on attenuation relationships, site response analyses and available recordings, a PGA in the range of 0.12-0.16 was estimated. Based on site response analyses results, a PGA value of 0.16 g was adopted. ASTM D1586-67 procedures were followed for SPT tests. 10" outside diameter hollow-stem auger was used with Safe-T- Driver and safety hammer for the drillings in 1979 and 1981. Donut Hammer with rope cathead was used for the drillings in in 1982. Energy ratios are adopted as 68 and 66 % for safety and donut hammers respectively."

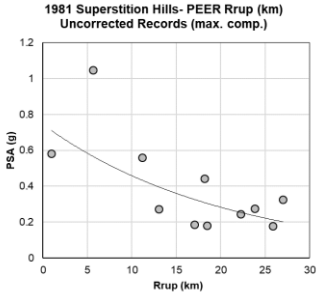
SMS rupture distances noted by COSMOS and PEER are slightly different than what is determined by this study.

SMS data is downloaded from COSMOS, a local PGA model is contstructed and the PGA selection seems correct.

The fault parameters and the fault surface rupture is obtained from Hudnutt et al (1989), USGS.

Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).





Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	No	No	No	No
Data Class	-	B	-	A	A
d_{crtc} range (m)	-	1.8 - 5.0	-	1.8 - 5.0	1.8 - 5.0
d_{cr1} (m)	-	3.4	3.4	3.4	3.4
GWT (m)	-	1.8 ± 0.9	2.1	1.8 ± 0.1	1.8 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	19.6 ± 0.6	-	19.6 ± 0.5	19.6 ± 0.5
σ_v (kPa)	-	59.8 ± 11.2	62.2	59.8 ± 10.6	59.8 ± 10.6
σ_v' (kPa)	-	44.1 ± 7.7	50.1	44.1 ± 5.4	44.1 ± 5.4
a_{max} (g)	-	0.156 ± 0.020	0.2	0.156 ± 0.023	0.156 ± 0.023
r_d	-	0.82 ± 0.022	0.96	0.96 ± 0.022	0.96 ± 0.025
CSR	-	0.123 ± 0.026	0.154	0.132 ± 0.022	0.132 ± 0.022
M_w	-	6.70	6.54	6.54	6.54
D_{50}	-	0.112 ± 0.010	-	0.111 ± 0.007	0.111 ± 0.007
% Fines	-	25.0 ± 4.0	12	13.0 ± 3.9	13.0 ± 3.9
% PI	-	-	-	-	NAV
N	-	32.0 ± 2.6	30.4	32.9 ± 2.6	33.6 ± 2.1
C_R	-	0.82	0.85	0.82	0.89
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.13	1.13	1.13	1.13
C_N	-	1.48	1.30	1.52	1.52
$(N_1)_{60}$	-	44.0 ± 3.6	37.8	46.5 ± 3.7	51.6 ± 3.2
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

EVENT PARAMETERS

1987 Superstition Hills Earthquake Hypocentral Depth (km): 9 Hudnutt et al (1989), USGS

Magnitude: 6.54 Length (km): 20

Fault Type: strike slip Z_{tor} (km): 0 R_{rup} (km): 31.0

Dip: 90 Width (km): - R_{jb} (km): 31.0

Nov 24, 1987, 1:16 PM

EQ Page Shake Map

https://earthquake https://earthquake.usgs.gov/earthquakes/eventpage/ci628016/map

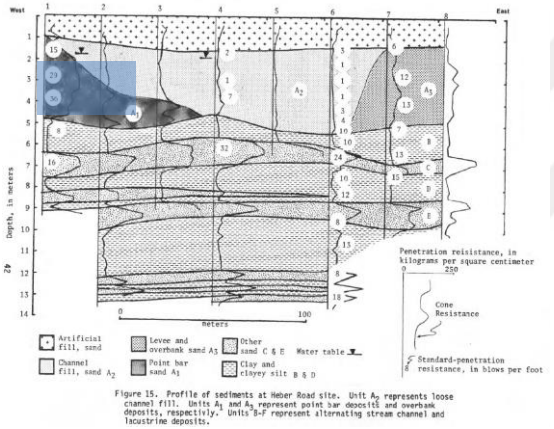
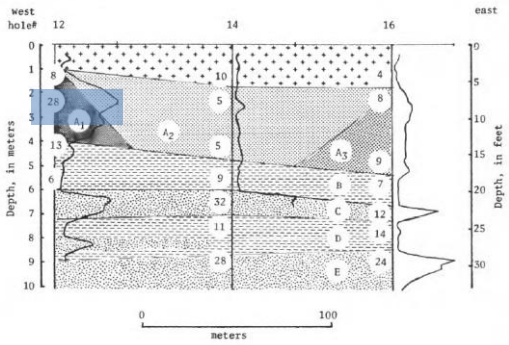
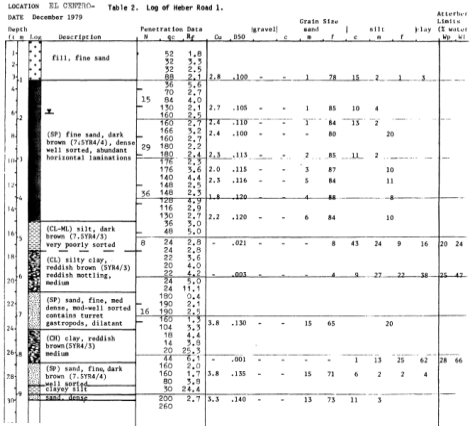
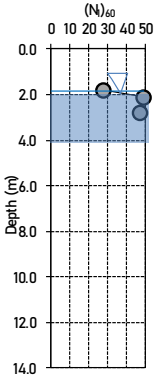


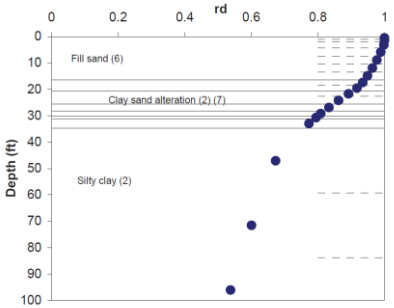
Figure 15. Profile of sediments at Heber Road site. Unit A_0 represents loose channel fill. Units A_1 and A_4 represent point bar deposits and overbank deposits, respectively. Units B-F represent alternating stream channel and lacustrine deposits.

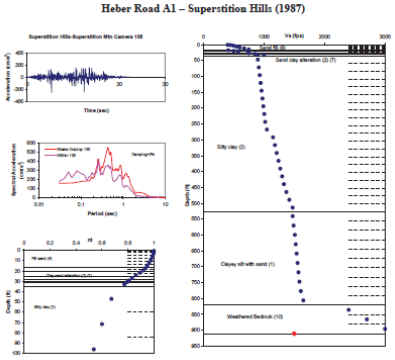


Cetin (2000)





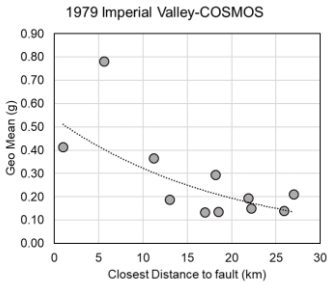


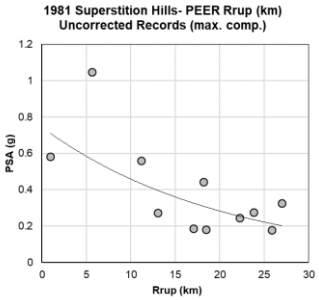


	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
BH-1	1.8	5.9		15	1.89	0.85	27.4	
BH-12	***2.1***	***7.0***		***28***	***1.80***	***0.86***	***49.1***	SP
BH-1 Donut	***2.5***	***8.0***		***32***	***1.71***	***0.87***	***54.0***	SP
BH-1 Donut	***2.8***	***9.2***		***29***	***1.63***	***0.88***	***47.2***	SP
BH-1	***3.4***	***11.0***		***35***	***1.53***	***0.89***	***54.0***	SP
BH-1	***3.8***	***12.5***		***36***	***1.45***	***0.90***	***53.5***	SP
						Mean:	51.6	
						St. Dev.	3.2	

	D_{50} (mm)	FC %	silt	clay
	0.105	14	14	0
	0.11	15	15	0
	0.1	20	20	0
	0.113	13	13	0
	0.115	10	10	0
	0.116	11	11	0
	0.12	8	8	0
Mean:	0.111	13.0	13.0	0.0
St. Dev.	0.007	3.9	3.9	0.0

Case number:	114
Earthquake:	Superstition Hills
Magnitude:	6.54 (Mw)
Location:	Heber Road A2
References:	Bennett et al. (1981), Youd and Bennett (1983), Andrus and Stokoe (1997), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface manifestation of liquefaction
GPS LAT	32.73049583
GPS LONG	-115.3858486
Liq. layer consist of:	Silty Sand (SM)
Geological Unit:	Relict Holocene channel
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "The Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much as 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The principal rivers are the Alamo and New Rivers along which many sand boils were developed on fluvial deposits. Heber Road site ~60 km to the epicenter. Due to the lack of significant surface trace of the fault rupture, it is difficult to estimate the closest distance to the fault rupture. A soil PGA of 0.36g was recorded at El Centro array site # 5, which is ~15 kms north of Heber Road site. Based on attenuation relationships, site response analyses and available recordings, a PGA in the range of 0.12-0.16 was estimated. Site response analysis results suggests a PGA value of 0.15 g. ASTM D1586-67 procedures were followed for SPT tests. 10" outside diameter hollow-stem auger was used with Safe-T- Driver and safety hammer for the drillings in 1979 and 1981. Donut Hammer with rope cathead was used for the drillings in in 1982. Energy ratios are adopted as 68 and 66 % for safety and donut hammers respectively." SMS rupture distances noted by COSMOS and PEER are slightly different than what is determined by this study. SMS data is downloaded from COSMOS, a local PGA model is contstructed and the PGA selection seems correct. The fault parameters and the fault surface rupture is obtained from Hudnutt et al (1989), USGS. Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes





Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?		No	No	No	No
Data Class		B	-	A	A
d_{crtc} range (m)		1.8 - 4.6		1.8 - 4.6	1.8 - 4.6
d_{crt} (m)		3.2	3.7	3.2	3.2
GWT (m)		1.8 ± 0.9	1.8	1.8 ± 0.1	1.8 ± 0.1
γ_{moist} (kN/m^3)		14.1 ± 1.3	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)		14.9 ± 1.3	-	17.3 ± 0.5	17.3 ± 0.5
σ_v (kPa)		46.8 ± 7.5	68.2	52.9 ± 8.0	52.9 ± 8.0
σ_v' (kPa)		32.8 ± 9.1	50.1	39.0 ± 3.7	39.0 ± 3.7
a_{max} (g)		0.150 ± 0.020	0.15	0.150 ± 0.023	0.150 ± 0.023
r_d		0.78 ± 0.024	0.96	0.95 ± 0.024	0.95 ± 0.024
CSR		0.120 ± 0.034	0.127	0.126 ± 0.021	0.126 ± 0.021
M_w		6.70	6.54	6.54	6.54
D_{50}		0.110 ± 0.010	-	0.116 ± 0.013	0.116 ± 0.013
% Fines		29.0 ± 4.5	18	20.9 ± 5.0	20.9 ± 5.0
% PI		-	-	-	NAV
N		2.4 ± 1.5	2	2.4 ± 1.5	2.4 ± 1.4
C_R		0.81	0.85	0.81	0.89
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.13	1.13	1.13	1.13
C_N		1.71	1.51	1.61	1.61
$(N_1)_{60}$		3.8 ± 2.4	2.9	3.5 ± 2.2	3.8 ± 2.3
$V_{s,30m}$ (m/s)		-	-	-	NAV
V_{s12m} (m/s)		160.0	-	160.0	NOT LISTED

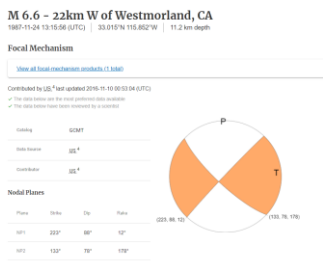
EVENT PARAMETERS

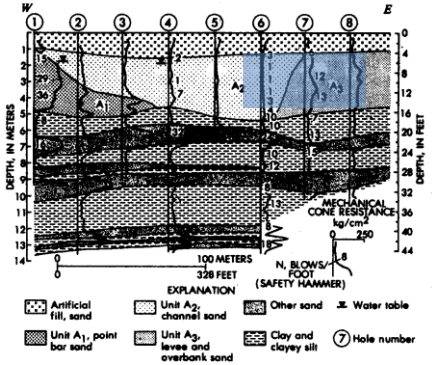
Superstition Hills	Hypocentral Depth (km): 9	Hudnutt et al (1989), USGS
Magnitude: 6.54	Length (km): 20	
Fault Type: strike slip	Z_{tor} (km): 0	R_{rup} (km): 31.0
Dip: 90	Width (km): -	R_{jb} (km): 31.0

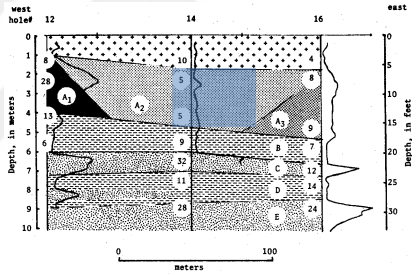
Nov 24, 1987, 1:16 PM

EQ Page Shake Map

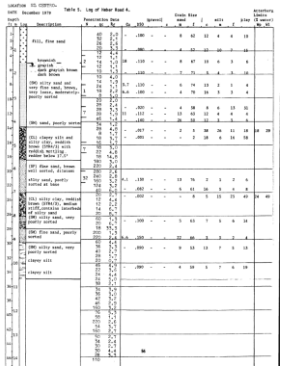
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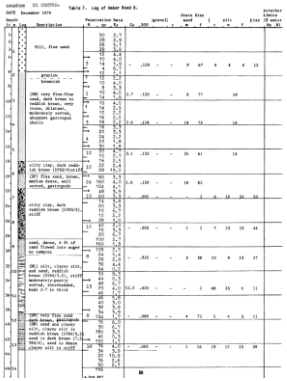


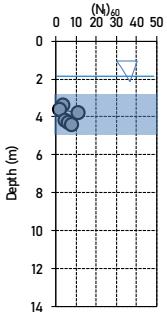


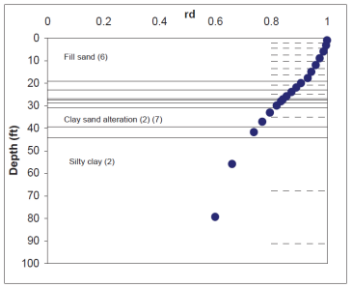


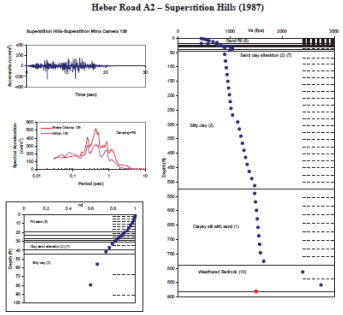
Cetin (2000)

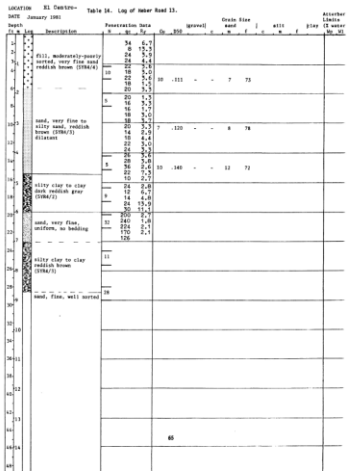












	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
BH-6	1.2	3.9		3	2.00	0.83	5.7	fill, fine sand
BH-6	***2***	***6.6***		***1***	***1.84***	***0.86***	***1.8***	SM
BH-14	2.3	7.5		5	1.78	0.87	8.7	very fine sand to silty sand
BH-6	***2.8***	***9.2***		***1***	***1.68***	***0.88***	***1.7***	SM
BH-4	***3***	***9.8***		***1***	***1.65***	***0.88***	***1.7***	SM
BH-5 Donut	***3.4***	***11.2***		***2***	***1.59***	***0.89***	***3.2***	***BH-5 Donut***
BH-6	***3.6***	***11.8***		***1***	***1.56***	***0.90***	***1.6***	SM
BH-4	3.8	12.5		7	1.53	0.90	11.0	SM
BH-6	***4.2***	***13.8***		***3***	***1.48***	***0.91***	***4.6***	SM
BH-5 Donut	***4.3***	***14.1***		***4***	***1.47***	***0.91***	***6.1***	***BH-5 Donut***
BH-14	***4.4***	***14.4***		***5***	***1.46***	***0.91***	***7.5***	very fine sand to silty sand
BH-6	***4.7***	***15.4***		***4***	***1.42***	***0.92***	***5.9***	SM
						Mean:	3.8	
						St. Dev.	2.3	

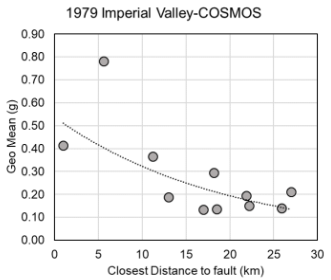
	D_{50} (mm)	FC %	sand	silt	clay	
	0.11	***20***	***80***	***16***	***4***	***Log 4***
	0.1	***26***	***74***	***22***	***4***	***Log 4***
	0.02	58	42	27	31	Log 4
	0.112	***24***	***76***	***20***	***4***	***Log 4***
	0.14	***24***	***76***	***18***	***6***	***Log 4***
	0.11	***24***	***76***	***12***	***12***	***Log 6***
	0.12	***14***	***86***	***14***	***0***	***Log 6***
	0.118	***14***	***87***	***14***	***0***	***Log 6***
Mean:	0.116	20.9	79.3	16.6	4.3	
St. Dev.	0.013	5.0	5.3	3.6	4.1	

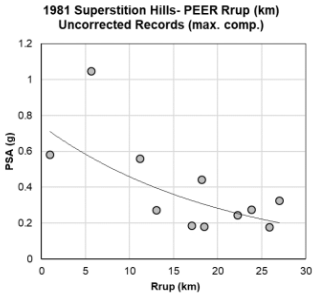
Earthquake:	Superstition Hills
Magnitude:	6.54 (Mw)
Location:	Heber Road A3
References:	Bennett et al. (1981), Youd and Bennett (1983), Andrus and Stokoe (1997), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface manifestation of liquefaction
GPS LAT	32.73049583
GPS LONG	-115.3858486
Liq. layer consist of:	silt sand
Geological Unit:	Relict Holocene channel
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "The Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much as 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The principal rivers are the Alamo and New Rivers along which many sand boils were developed on fluvial deposits. Heber Road site ~60 km to the epicenter. Due to the lack of significant surface trace of the fault rupture, it is difficult to estimate the closest distance to the fault rupture. A soil PGA of 0.36 g was recorded at El Centro array site # 5, which is ~15 kms north of Heber Road site. Based on attenuation relationships, site response analyses and available recordings, a PGA in the range of 0.12-0.16 g was estimated. Site response analysis results suggest a PGA value of 0.13 g. ASTM D1586-67 procedures were followed for SPT tests. 10" outside diameter hollow-stem auger was used with Safe-T- Driver and safety hammer for the drillings in 1979 and 1981. Donut Hammer with rope cathead was used for the drillings in in 1982. Energy ratios are adopted as 68 and 66 % for safety and donut hammers respectively." SMS rupture distances noted by COSMOS and PEER are slightly different than what is determined by this study. SMS data is downloaded from COSMOS, a local PGA model is contstructed and the PGA selection seems correct. The fault parameters and the fault surface rupture is obtained from Hudnutt et al (1989), USGS. Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	No	No	No	No
Data Class	-	B	-	A	A
d_{crc} range (m)	-	1.8 - 4.9	-	1.8 - 4.9	1.8 - 4.9
d_{crt} (m)	-	3.4	4.0	3.4	3.4
GWT (m)	-	1.8 ± 0.9	1.8	1.8 ± 0.1	1.8 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-	52.6 ± 8.8	79.2	57.6 ± 9.8	57.6 ± 9.8
σ_v' (kPa)	-	37.3 ± 8.4	56.1	42.4 ± 4.9	42.4 ± 4.9
a_{max} (g)	-	0.130 ± 0.020	0.13	0.130 ± 0.020	0.130 ± 0.020
r_d	-	0.75 ± 0.025	0.95	0.95 ± 0.025	0.95 ± 0.025
CSR	-	0.110 ± 0.026	0.115	0.109 ± 0.018	0.109 ± 0.018
M_w	-	6.70	6.54	6.54	6.54
D_{50}	-	0.100 ± 0.010	-	0.094 ± 0.004	0.094 ± 0.004
% Fines	-	37.0 ± 5.0	25	25.3 ± 5.2	25.3 ± 5.2
% PI	-	-	-	-	NAV
N	-	13.1 ± 4.1	13	13.0 ± 4.2	12.9 ± 4.0
C_R	-	0.82	0.85	0.82	0.89
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.13	1.13	1.13	1.13
C_N	-	1.60	1.29	1.55	1.55
$(N_1)_{60}$	-	19.5 ± 6.1	16.2	18.6 ± 6.0	20.2 ± 6.3
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

EVENT PARAMETERS

Superstition Hills	Hypocentral Depth (km): 9	Hudnutt et al (1989), USGS
Magnitude: 6.54	Length (km): 20	
Fault Type: strike slip	Z_{tor} (km): 0	R_{rup} (km): 31.0
Dip: 90	Width (km): -	R_{jb} (km): 31.0

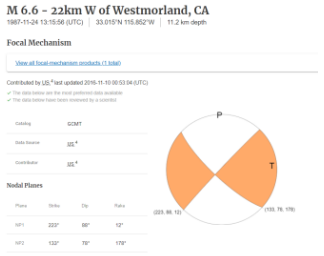


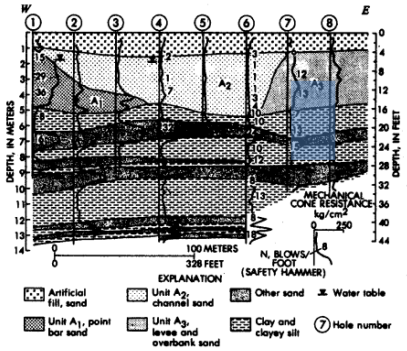


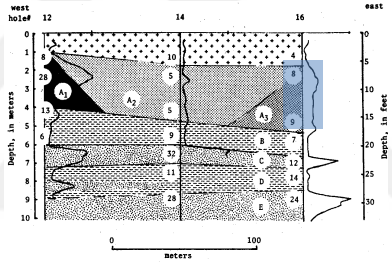
Nov 24, 1987, 1:16 PM

EQ Page Shake Map

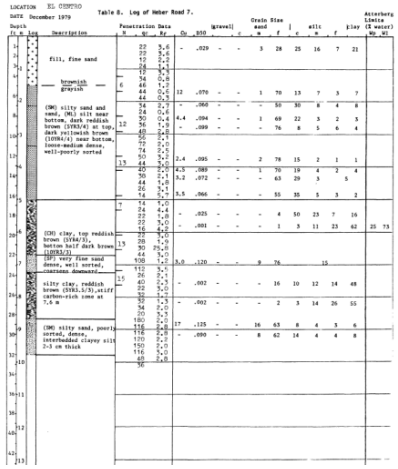
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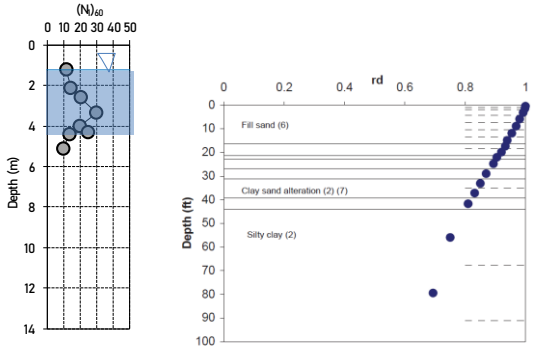




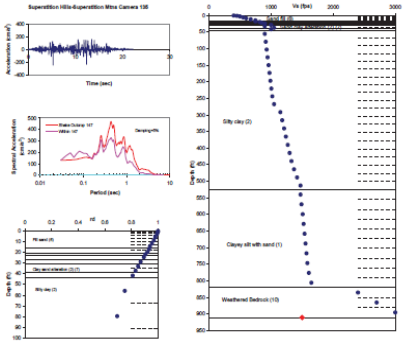


Cetin (2000)



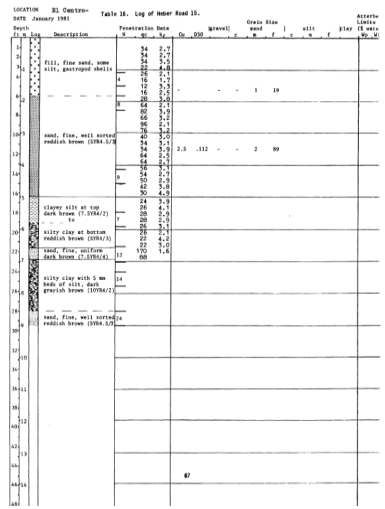


Heber Road A3 – Superstition Hills (1987)

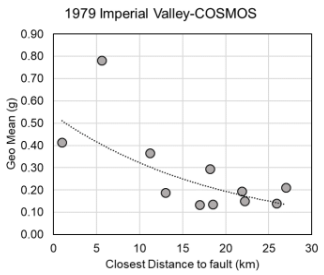


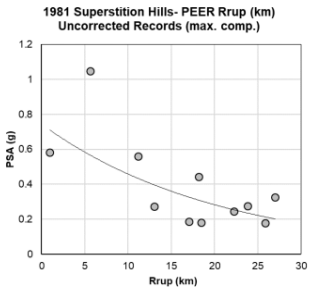
	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
BH-7	1.2	3.9		6	2.00	0.83	11.3	silty sand
BH-16	*2.1*	*6.9*		*8*	*1.81*	*0.86*	*14.1*	***sand***
BH-7	*2.6*	*8.5*		*12*	*1.69*	*0.87*	*20.1*	silty sand
BH-8	*3.35*	*11.0*		*19*	*1.55*	*0.89*	*29.8*	***BH-8***
BH-7	*4*	*13.1*		*13*	*1.45*	*0.91*	*19.4*	silty sand
BH-8	*4.3*	*14.1*		*17*	*1.41*	*0.91*	*24.8*	***BH-8***
BH-16	*4.4*	*14.4*		*9*	*1.40*	*0.91*	*13.0*	***sand***
BH-7	5.1	16.7		7	1.32	0.93	9.7	CH
						Mean:	20.2	
						St. Dev.	6.3	

	D_{50} (mm)	FC %	sand	silt	clay
	0.070	30	71	23	7
	0.060	50	50	42	8
	0.094	*30*	*70*	*27*	*3*
	0.099	*23*	*76*	*19*	*4*
	0.095	*19*	*80*	*18*	*1*
	0.089	*29*	*71*	*25*	*4*
	0.072	37	63	32	5
Mean:	0.094	25.3	74.3	22.3	3.0
St. Dev.	0.004	5.2	4.6	4.4	1.4



Case number:	116
Earthquake:	1987 Superstition Hills
Magnitude:	6.54 (Mw)
Location:	Kornbloom B
References:	Bennett et al. (1984) and Fear et al. (1995), Bierschwale. (1984), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface evidence of liquefaction
GPS LAT	33.1146681
GPS LONG	-115.645238
Liq. layer consist of:	silty sand
Geological Unit:	Holocene sediment is as thick as 330 ft.
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "Youd, T.L., Wieczorek G. F., (1984), "Liquefaction during the 1981 and Previous Earthquakes Near Westmorland, CA" Open File Rep. 84-680 Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much as 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The principal rivers are the Alamo and New Rivers along which many sand boils were developed on fluvial deposits. A: silty clay, stiff-lacustrine and/or flood plain deposit B: silty and sandy silt-fluvial and perhaps fluvial deltaic deposition C: silty clay to clay, stiff-lacustrine and/or flood plain deposit D: interbedded silt and sand-loose to medium dense E: Uniform sand with some silt-medium dense to dense F: interbedded silt and sand - loose to medium dense. D-F :fluvial and perhaps fluvial-deltaic deposition PGA was recorded at the Kornbloom road as 0.14 g (temp. seismograph) Site response analysis results suggest a slightly higher PGA of 0.17 g Energy ratio ~68 %."" SMS rupture distances noted by COSMOS and PEER are slightly different than what is determined by this study. SMS data is downloaded from COSMOS, a local PGA model is contstructed and the PGA selection seems correct. The fault parameters and the fault surface rupture is obtained from Hudnutt et al (1989), USGS. Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes





Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?		No	No	No	No
Data Class		A	-	A	A
d_{crtc} range (m)		2.6 - 5.2		2.7 - 5.3	2.7 - 5.3
d_{crt} (m)		3.9	4.3	4.0	4.0
GWT (m)		2.7 ± 0.3	2.7	2.7 ± 0.1	2.7 ± 0.1
γ_{moist} (kN/m^3)		14.9 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)		16.5 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)		59.9 ± 7.4	77.2	67.7 ± 8.3	67.7 ± 8.3
σ_v' (kPa)		48.7 ± 4.3	62.2	55.0 ± 4.2	55.0 ± 4.2
a_{max} (g)		0.174 ± 0.020	0.174	0.174 ± 0.026	0.174 ± 0.026
r_d		0.83 ± 0.030	0.95	0.94 ± 0.030	0.94 ± 0.029
CSR		0.130 ± 0.017	0.132	0.131 ± 0.021	0.131 ± 0.021
M_w		6.70	6.54	6.54	6.54
D_{50}		0.045 ± 0.020	-	0.045 ± 0.008	0.045 ± 0.008
% Fines		92.0 ± 10.0	92	83.0 ± 9.6	83.0 ± 9.6
% PI		-	-	-	NAV
N		5.4 ± 2.6	5	5.4 ± 3.1	5.5 ± 3.1
C_R		0.85	0.85	0.85	0.91
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.13	1.13	1.13	1.13
C_N		1.40	1.29	1.36	1.36
$(N_1)_{60}$		7.2 ± 3.5	6.2	7.1 ± 4.1	7.7 ± 4.3
$V_{s,30m}$ (m/s)		-	-	-	NAV
V_{s12m} (m/s)		160.0	-	160.0	NOT LISTED

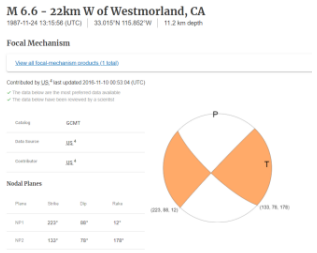
EVENT PARAMETERS

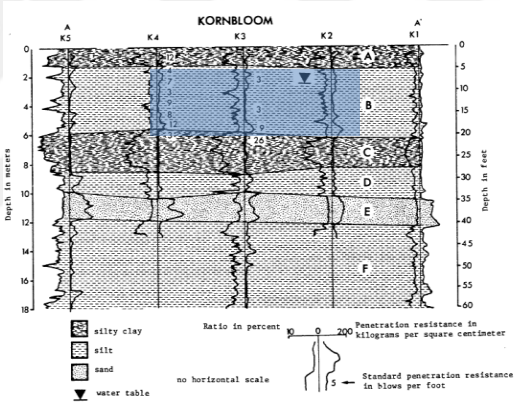
1987 Superstition Hills	Hypocentral Depth (km): 9	Hudnutt et al (1989), USGS
Magnitude: 6.54	Length (km): 20	
Fault Type: strike slip	Z_{tor} (km): 0	R_{rup} (km): 23.0
Dip: 90	Width (km): -	R_{jb} (km): 23.0

Nov 24, 1987, 1:16 PM

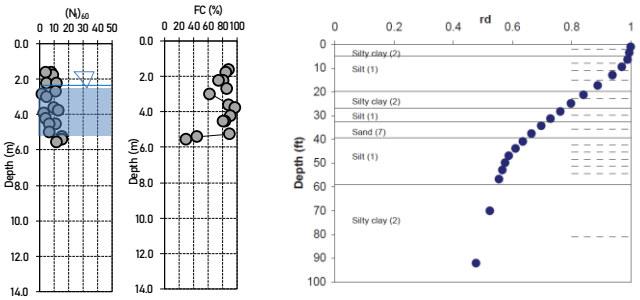
EQ Page Shake Map

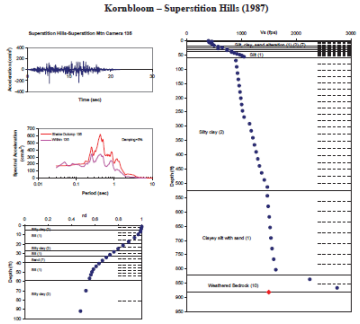
https://earthquake.usgs.gov/earthquakes/eventpage/ci628016/executive





Cetin (2000)

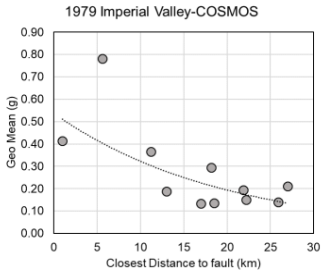


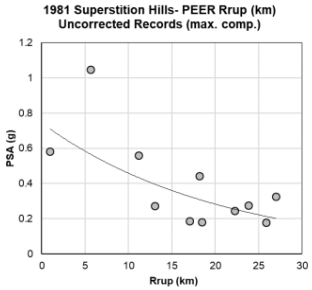


	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
K-4	1.60	5.25		4	2.00	0.85	7.7
K-4 b	1.75	5.75		5	1.92	0.85	9.3
SK4-5	***1.60***	***5.25***		***2***	***2.00***	***0.85***	***3.8***
K-3	***2.21***	***7.25***		***3***	***1.71***	***0.86***	***5.0***
K-4	***2.21***	***7.25***		***7***	***1.71***	***0.86***	***11.7***
K-4 b	***2.67***	***8.75***		***7***	***1.56***	***0.88***	***10.8***
SK4-5	***2.82***	***9.25***		***1***	***1.52***	***0.88***	***1.5***
K-4	***2.97***	***9.75***		***3***	***1.50***	***0.88***	***4.5***
K-4 b	***3.58***	***11.75***		***7***	***1.41***	***0.90***	***10.1***
K-4	***3.73***	***12.25***		***9***	***1.40***	***0.90***	***12.8***
SK4-5	***3.89***	***12.75***		***2***	***1.38***	***0.90***	***2.8***
K-3	***4.19***	***13.75***		***3***	***1.34***	***0.91***	***4.2***
K-4	***4.50***	***14.75***		***8***	***1.31***	***0.92***	***10.9***
K-4 b	***4.50***	***14.75***		***5***	***1.31***	***0.92***	***6.8***
SK4-5	***4.95***	***16.25***		***5***	***1.27***	***0.92***	***6.6***
K-4	***5.26***	***17.25***		***12***	***1.24***	***0.93***	***15.7***
K-4 b	5.41	17.75		12	1.23	0.93	15.5
K-3	5.56	18.25		9	1.22	0.93	11.6
						Mean:	7.7
						St. Dev.	4.3

	FC	sand	silt	clay	D50	WN	WL	PI	LI
clayey silt (CL)	88.0	12.0	65.0	23.0	0.019	26.0	29.0	11.0	0.7
sandy silt (ML)	84.0	16.0	74.0	10.0	0.038				
silt and silty clay									
sandy silt (ML)	***80.0***	***21.0***	***73.0***	***7.0***	***0.044***				
sandy silt (ML)	***74.0***	***26.0***	***68.0***	***6.0***	***0.052***				
silt (ML)	***86.0***	***14.0***	***83.0***	***3.0***	***0.049***				
sand to silty sand									
sandy silt	***62.0***	***38.0***	***53.0***	***9.0***	***0.056***	***28.0***			
silt (ML)	***88.0***	***12.0***	***79.0***	***9.0***	***0.042***				
silt (ML)	***96.0***	***4.0***	***83.0***	***13.0***	***0.028***	***30.0***			
sand to silty sand									
silt (ML)	***91.0***	***9.0***	***79.0***	***12.0***	***0.039***				
sandy silt (ML)	***83.0***	***17.0***	***74.0***	***9.0***	***0.047***	***29.0***			
sandy silt (ML)	***81.0***	***19.0***	***71.0***	***10.0***	***0.042***				
sand to silty sand									
silt (ML)	***89.0***	***11.0***	***83.0***	***6.0***	***0.048***				
silty sand (SM)	44.0	56.0	40.0	4.0	0.700				
silty sand (SM)	30.0	70.0	29.0	1.0	0.082				
	83.0	17.1	74.6	8.4	0.045				
	9.6	9.7	9.3	3.0	0.008				

Case number:	117
Earthquake:	Superstition Hills
Magnitude:	6.7 (Mw)
Location:	McKim Ranch A
References:	Bennett et al. (1984) and Fear et al. (1995), Bierschwale (1984), Andrus and Stokoe, (1997), Cetin (2000), Cetin et al (200-
Nature of Failure:	No surface manifestation of liquefaction
GPS LAT	32.868815
GPS LONG	-115.45636
Liq. layer consist of:	silty sand (SM)
Geological Unit:	Holocene sediment is as thick as 330 ft
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much as 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The principal rivers are the Alamo and New Rivers along which many sand boils were developed on fluvial deposits. Located between the Alamo River and the Redwood Canal. A: very fine sand (fining upwards)-loose sand that filled the relic channel. B: stiff silty clay Radio Tower Site is ~ 40 km away from the epicenter of the earthquake. The recorded PGA at the El Centro differential array site # 5 (0.36 g) suggest a high PGA. Contrary to this site response analyses results suggest a lower PGA (0.16 g) Energy ratio ~68 %." SMS rupture distances noted by COSMOS and PEER are slightly different than what is determined by this study. SMS data is downloaded from COSMOS, a local PGA model is contstructed and the PGA selection seems correct. The fault parameters and the fault surface rupture is obtained from Hudnutt et al (1989), USGS. Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes





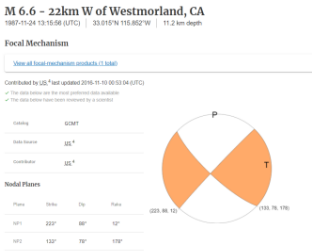
Summary of Input Data

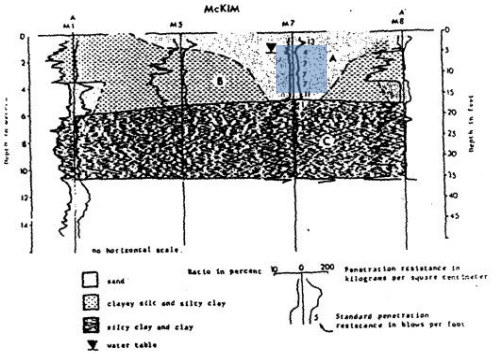
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?		No	No	No	No
Data Class		A	-	B	B
d_{crlc} range (m)		1.5 - 4.0		1.5 - 4.0	1.5 - 4.0
d_{cr1} (m)		2.7	2.1	2.7	2.7
GWT (m)		1.5 ± 0.3	1.5	1.5 ± 0.1	1.5 ± 0.1
γ_{moist} (kN/m^3)		14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)		15.7 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)		42.0 ± 6.5	38.1	49.4 ± 7.7	49.4 ± 7.7
σ_v' (kPa)		30.0 ± 3.9	32.1	37.5 ± 3.9	37.5 ± 3.9
a_{max} (g)		0.160 ± 0.020	0.16	0.160 ± 0.048	0.160 ± 0.048
r_d		0.95 ± 0.025	0.98	0.95 ± 0.025	0.95 ± 0.021
CSR		0.140 ± 0.024	0.121	0.130 ± 0.040	0.130 ± 0.040
M_w		6.70	6.54	6.54	6.54
D_{50}		0.105 ± 0.003	-	0.106 ± 0.005	0.106 ± 0.005
% Fines		31.0 ± 3.0	31	19.8 ± 3.5	19.8 ± 3.5
% PI		-	-	-	NAV
N		5.3 ± 2.6	3	5.4 ± 2.6	5.4 ± 2.6
C_R		0.79	0.80	0.79	0.88
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.13	1.13	1.13	1.13
C_N		1.79	1.70	1.65	1.65
$(N_1)_{60}$		8.5 ± 4.2	4.6	7.9 ± 3.8	8.8 ± 4.2
V_{s30m} (m/s)		-	-	-	NAV
V_{s12m} (m/s)		160.0	-	160.0	NOT LISTED

EVENT PARAMETERS

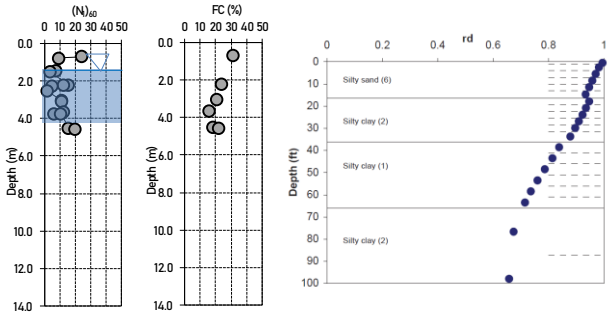
Superstition Hills	Hypocentral Depth (km): 9	Hudnutt et al (1989), USGS
Magnitude: 6.54	Length (km): 20	
Fault Type: strike slip	Z_{tor} (km): 0	R_{rup} (km): 19.0
Dip: 90	Width (km): -	R_{jb} (km): 19.0

Nov 24, 1987, 1:16 PM
EQ Page Shake Map
https://earthquake.usgs.gov/earthquakes/eventpage/ci628016/executive

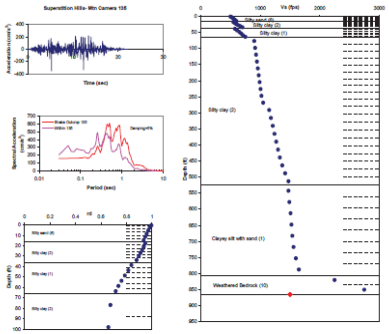




Cetin (2000)



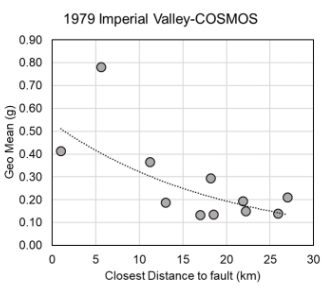
McKim Ranch A – Superstition Hills (1987)

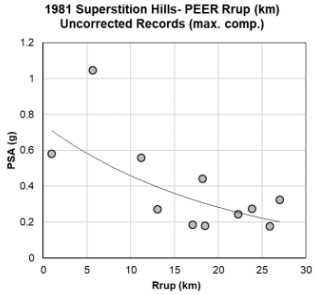


	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
M-7	0.69	2.3		13	2.00	0.81	24.0	silty sand (SM)
SM-7	0.76	2.5		5	2.00	0.82	9.3	sand to silty sand
M-7	***1.45***	***4.8***		***4***	***2.00***	***0.84***	***7.6***	
SM-7	***1.52***	***5.0***		***2***	***1.96***	***0.84***	***3.8***	sand
M-2	***2.21***	***7.3***		***9***	***1.76***	***0.86***	***15.6***	sand
M-7	***2.21***	***7.3***		***7***	***1.76***	***0.86***	***12.1***	sand (SM)
SM-7	***2.29***	***7.5***		***3***	***1.75***	***0.87***	***5.1***	sand
M-3	***2.51***	***8.3***		***1***	***1.69***	***0.87***	***1.7***	sand
SM-7	***3.05***	***10.0***		***7***	***1.59***	***0.89***	***11.2***	sand
M-7	***3.09***	***10.2***		***7***	***1.58***	***0.89***	***11.1***	sand (SM)
SM-7	***3.66***	***12.0***		***8***	***1.49***	***0.90***	***12.2***	sand
M-3	***3.73***	***12.3***		***4***	***1.48***	***0.90***	***6.0***	silty sand
M-7	***3.73***	***12.3***		***7***	***1.48***	***0.90***	***10.6***	sand (SM)
M-7	4.50	14.8		11	1.38	0.92	15.7	sand (SM)
SM-7	4.57	15.0		14	1.37	0.92	19.9	sand
						Mean:	8.8	
						St. Dev.	4.2	

Depth (ft)	FC	sand	silt	clay	D50	
2.3	31.0	69.0	18.0	13.0	0.1	M-7
2.5		-	-	-	-	SM-7
4.8		***-***	***-***	***-***	***-***	***M-7***
5.0		***-***	***-***	***-***	***-***	***SM-7***
7.3		***-***	***-***	***-***	***-***	***M-2***
7.3	***24.0***	***76.0***	***14.0***	***10.0***	***0.1***	***M-7***
7.5		***-***	***-***	***-***	***-***	***SM-7***
8.3		***-***	***-***	***-***	***-***	***M-3***
9.4	***21.0***	***79.0***	***11.0***	***10.0***	***0.1***	***M-7***
10.0		***-***	***-***	***-***	***-***	***SM-7***
10.2	***16.0***	***84.0***	***9.0***	***7.0***	***0.1***	***M-7***
12.0		***-***	***-***	***-***	***-***	***SM-7***
12.3		***-***	***-***	***-***	***-***	***M-3***
12.3	***18.0***	***82.0***	***11.0***	***7.0***	***0.1***	***M-7***
14.8	22.0	78.0	15.0	7.0	0.1	M-7
15.0	-	-	-	-	-	SM-7
	19.8	80.3	11.3	8.5	0.106	
	3.5	3.5	2.1	1.7	0.005	

Case number:	118
Earthquake:	1987 Superstition Hills
Magnitude:	6.54 (Mw)
Location:	Radio Tower B1
References:	Bierschwale (1984), Bennett et al (1984), Fear et al. (1995), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface evidence of liquefaction
GPS LAT	33.010639
GPS LONG	-115.521375
Liq. layer consist of:	sandy silt and sand (SM-ML)
Geological Unit:	Holocene sediment is as thick as 330 ft
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "The Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much ad 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The principal rivers are the Alamo and New Rivers along which many sand boils were developed on fluvial deposits. A: very poorly sorted, soft brown clay and silt-flood plain deposit B: brown, loose to med.dense silt to fine sand- sediment at base is well sorted very fine sand fining upwards to poorly sorted silt-channel deposit C: very stiff brown clayey silt to clay-lacustrine D: med dense sand PGA was recorded at the surface and at 6.7 m depth of Wildlife site as 0.18 and 0.17g respectively. The epicentral distance is ~30.2 km same as Wildlife site. Andrus and Stoke (NCEER, 97) predicted the PGA at the site as 0.2 g same as the PGA at Wildlife site. Site response analyses results also verify that Energy ratio ~68 %."
	Radio Tower B1 and B2 showed different field performance after 1981 Westmorland Earthquake. The sites are 75 m away from each other.
	SMS rupture distances noted by COSMOS and PEER are slightly different than what is determined by this study.
	SMS data is downloaded from COSMOS, a local PGA model is contstructed and the PGA selection seems correct.
	The fault parameters and the fault surface rupture is obtained from Hudnutt et al (1989), USGS.
	Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes





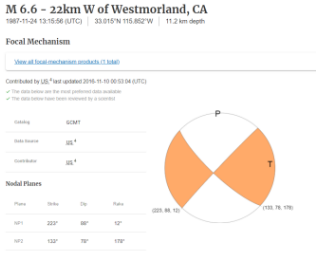
Summary of Input Data

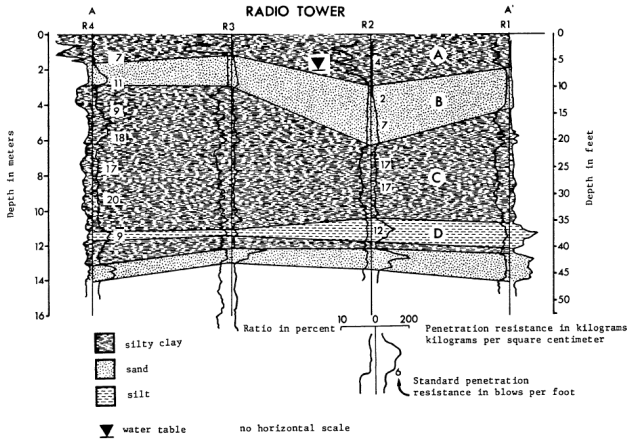
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?		No	No	No	No
Data Class		B	-	B	B
d_{cric} range (m)		3.0 - 5.5		3.0 - 5.5	3.0 - 5.5
d_{cri} (m)		4.3	3.4	4.3	4.3
GWT (m)		2.0 ± 0.3	2.1	2.0 ± 0.1	2.0 ± 0.1
γ_{moist} (kN/m^3)		14.1 ± 0.5	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)		14.9 ± 0.6	-	18.1 ± 0.5	18.1 ± 0.5
σ_v (kPa)		62.0 ± 6.5	62.2	72.2 ± 7.7	72.2 ± 7.7
σ_v' (kPa)		39.9 ± 3.9	50.1	50.1 ± 3.8	50.1 ± 3.8
a_{max} (g)		0.200 ± 0.040	0.2	0.200 ± 0.030	0.200 ± 0.030
r_d		0.94 ± 0.032	0.96	0.94 ± 0.032	0.94 ± 0.030
CSR		0.180 ± 0.042	0.154	0.176 ± 0.028	0.176 ± 0.028
M_w		6.60	6.54	6.54	6.54
D_{50}		0.047 ± 0.015	-	0.074 ± 0.037	0.074 ± 0.037
% Fines		75.0 ± 10.0	64	43.5 ± 29.0	43.5 ± 29.0
% PI		-	-	-	NAV
N		4.5 ± 3.4	2	4.5 ± 3.4	4.5 ± 3.2
C_R		0.86	0.85	0.86	0.91
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.13	1.13	1.13	1.13
C_N		1.55	1.49	1.42	1.42
$(N_1)_{60}$		6.8 ± 5.2	2.9	6.2 ± 4.7	6.5 ± 4.7
V_{s30m} (m/s)		-	-	-	NAV
V_{s12m} (m/s)		160.0	-	160.0	NOT LISTED

EVENT PARAMETERS

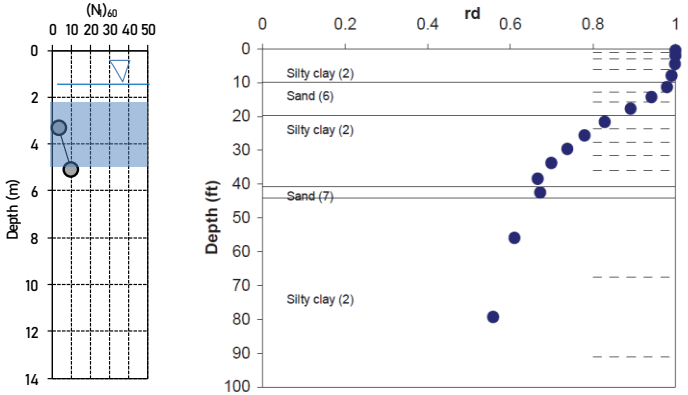
1987 Superstition Hills	Hypocentral Depth (km): 9	Hudnutt et al (1989), USGS
Magnitude: 6.54	Length (km): 20	
Fault Type: strike slip	Z_{tor} (km): 0	R_{rup} (km): 20.0
Dip: 90	Width (km): -	R_{jb} (km): 20.0

Nov 24, 1987, 1:16 PM
EQ Page Shake Map
https://earthquake.usgs.gov/earthquakes/eventpage/ci628016/executive

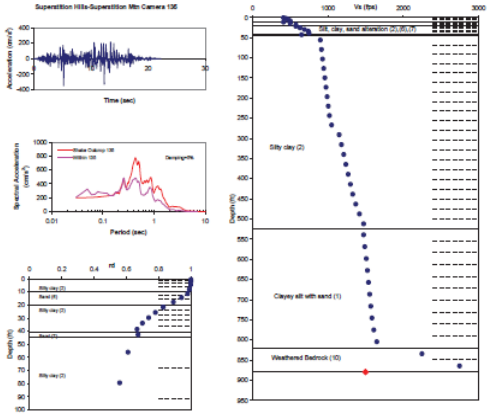




Cetin (2000)



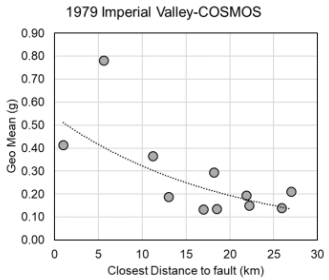
Radio Tower B1 – Superstition Hills (1987)

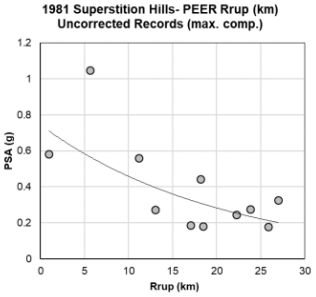


	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
R2	*3.3*	*10.8*		*2*	*1.55*	*0.89*	*3.1*	sandy silt (ML)
R2	*5.1*	*16.7*		*7*	*1.33*	*0.93*	*9.8*	sand (SM)
						Mean:	6.5	
						St. Dev.	4.7	

Depth (m)	FC	sand	silt	clay	D50
3.3	*64.0*	*36.0*	*59.0*	*5.0*	*0.047*
5.1	*23.0*	*77.0*	*22.0*	*1.0*	*0.100*
23.15	*18.0*	*82.0*	*13.0*	*5.0*	*0.125*
	43.5	56.5	40.5	3.0	0.074
	29.0	29.0	26.2	2.8	0.037

Case number:	119
Earthquake:	Superstition Hills
Magnitude:	6.54 (Mw)
Location:	Radio Tower B2
References:	Bierschwale (1984), Bennett et al (1984), Fear et al. (1995), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface manifastation of liquefaction
GPS LAT	33.010639
GPS LONG	-115.521375
Liq. layer consist of:	sand (SM)
Geological Unit:	Holocene sediment is as thick as 330 ft
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much as 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The principal rivers are the Alamo and New Rivers along which many sand boils were developed on fluvial deposits. A: very poorly sorted, soft brown clay and silt-flood plain deposit B: brown, loose to med.dense silt to fine sand- sediment at base is well sorted very fine sand fining upwards to poorly sorted silt-channel deposit C: very stiff brown clayey silt to clay-lacustrine D: med dense sand PGA was recorded at the surface and at 6.7 m depth of Wildlife site as 0.18 and 0.17g respectively. The epicentral distance is ~30.2 km same as Wildlife site. Andrus and Stoke (NCEER, 97) predicted the PGA at the site as 0.2 g same as the PGA at Wildlife site. Site response results suggest a PGA of 0.18g Energy ratio ~68 %."
	SMS rupture distances noted by COSMOS and PEER are slightly different than what is determined by this study.
	SMS data is downloaded from COSMOS, a local PGA model is contstructed and the PGA selection seems correct.
	The fault parameters and the fault surface rupture is obtained from Hudnutt et al (1989), USGS.
	Radio Tower B1 and B2 showed different field performance after 1981 Westmorland Earthquake. The sites are 75 m away from each other.
	Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes





Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?		No	No	No	No
Data Class		B	-	B	B
d_{crtc} range (m)		2.0 - 3.0		2.0 - 3.0	2.0 - 3.0
d_{crt} (m)		2.5	2.3	2.5	2.5
GWT (m)		2.0 ± 0.3	2.1	2.0 ± 0.1	2.0 ± 0.1
γ_{moist} (kN/m^3)		14.1 ± 0.9	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)		14.9 ± 1.3	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)		35.8 ± 3.2	40.1	40.9 ± 3.2	40.8 ± 3.3
σ_v' (kPa)		30.9 ± 3.5	38.1	36.0 ± 1.9	36.0 ± 1.9
a_{max} (g)		0.180 ± 0.020	0.18	0.180 ± 0.027	0.180 ± 0.027
r_d		0.99 ± 0.020	0.98	0.99 ± 0.020	0.99 ± 0.019
CSR		0.125 ± 0.021	0.119	0.132 ± 0.021	0.131 ± 0.021
M_w		6.70	6.54	6.54	6.54
D_{50}		0.100 ± 0.020	-	0.100 ± 0.050	0.100 ± 0.050
% Fines		30.0 ± 5.0	30	18.0 ± 2.0	18.0 ± 8.6
% PI		-	-	-	NAV
N		11.0 ± 1.8	11	11.3 ± 1.4	11.3 ± 1.2
C_R		0.77	0.80	0.77	0.87
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.13	1.13	1.13	1.13
C_N		1.76	1.53	1.68	1.68
$(N_1)_{60}$		17.0 ± 2.8	15.2	16.6 ± 2.0	18.8 ± 2.0
V_{s30m} (m/s)		-	-	-	NAV
V_{s12m} (m/s)		160.0	-	160.0	NOT LISTED

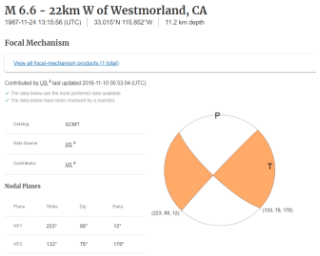
EVENT PARAMETERS

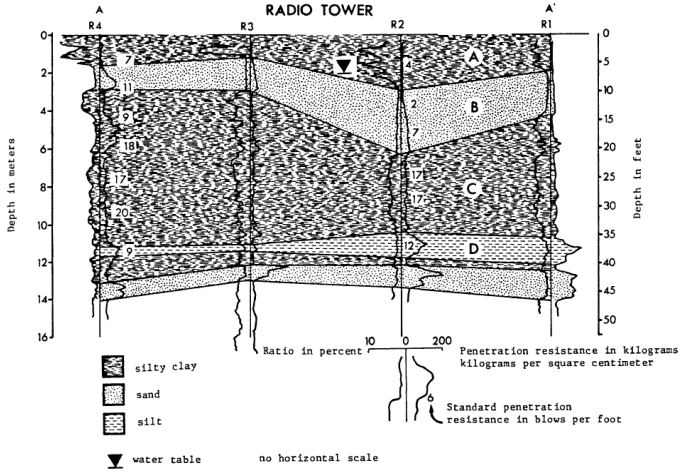
Superstition Hills	Hypocentral Depth (km): 9	Hudnutt et al (1989), USGS	
Magnitude: 6.54	Length (km): 20		
Fault Type: strike slip	Z_{tor} (km): 0	R_{rup} (km): 20.0	
Dip: 90	Width (km): -	R_{jb} (km): 20.0	

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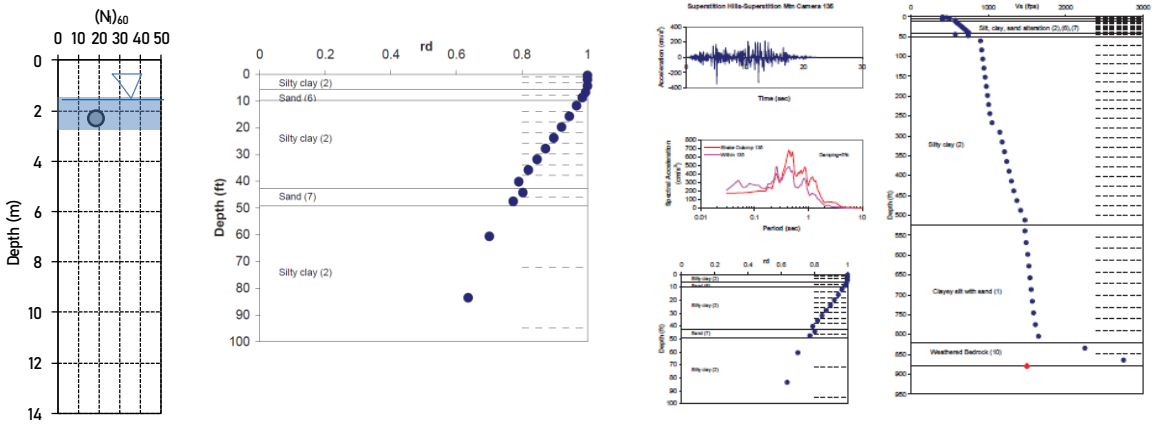
EQ Page Shake Map

https://earthquake.usgs.gov/earthquakes/eventpage/ci628016/executive



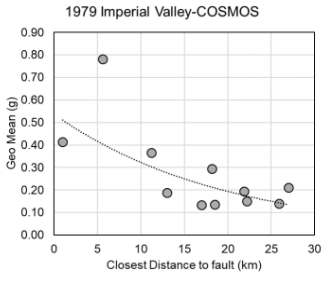


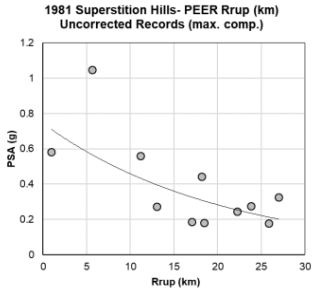
Cetin (2000)



	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		FC	silt	clay	D50
R4	*2.3*	*7.3*		*11*	*1.74*	*0.87*	*18.8*	sand (SM)	*18.0*	*17.0*	*1.0*	*0.1*
						Mean:	18.8		18.0	17.0	1.0	0.100
						St. Dev.	2.0	assigned	8.6	8.3	2.3	0.050

Case number:	121
Earthquake:	Superstition Hills
Magnitude:	6.54 (Mw)
Location:	River Park C
References:	Youd and Bennett (1983), Bennett et al (1981), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface manifastation of liquefaction
GPS LAT	32.96954267
GPS LONG	-115.5532487
Liq. layer consist of:	SP
Geological Unit:	Holocene fluvial deposits
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "The Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much as 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The principal rivers are the Alamo and New Rivers along which many sand boils were developed on fluvial deposits. River Park Site is ~30 km from the epicenter of the earthquake. PGA's values of 0.46 and 0.16 g were recorded at Parachute (15 kms southwest) and Brawley (~8 kms east) stations, respectively. Site response analysis result suggest a PGA value of 0.19 g. ASTM D1586-67 procedures were followed for SPT tests. 10" outside diameter hollow-stem auger was used with Safe-T Driver and safety hammer. Energy ratio ~68 % SPT blowcounts were taken in 1979 and 1981." SMS rupture distances noted by COSMOS and PEER are slightly different than what is determined by this study. SMS data is downloaded from COSMOS, a local PGA model is contstructed and the PGA selection seems correct. The fault parameters and the fault surface rupture is obtained from Hudnutt et al (1989), USGS. Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).





Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes

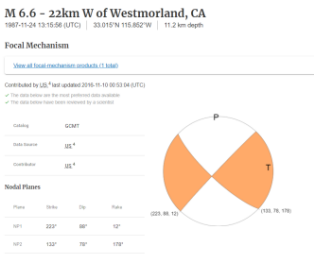
Summary of Input Data

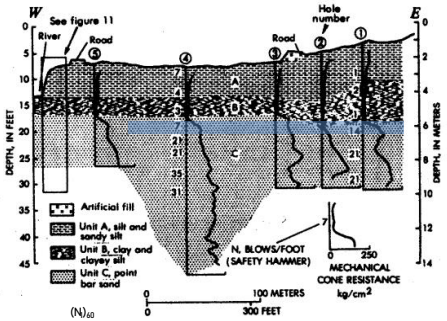
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?		No	No	No	No
Data Class		A	-	A	A
d_{crtc} range (m)		3.4 - 5.2		3.4 - 5.2	4.0 - 5.2
d_{crt} (m)		4.3	4.3	4.3	4.6
GWT (m)		0.3 ± 0.2	0.3	0.3 ± 0.1	0.3 ± 0.1
γ_{moist} (kN/m^3)		14.1 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)		17.3 ± 0.6	-	18.1 ± 0.5	18.1 ± 0.5
σ_v (kPa)		73.0 ± 5.9	83.2	76.6 ± 5.8	82.2 ± 4.2
σ_v' (kPa)		34.0 ± 3.5	45.1	37.6 ± 3.2	40.2 ± 2.7
a_{max} (g)		0.190 ± 0.020	0.19	0.190 ± 0.029	0.190 ± 0.029
r_d		0.97 ± 0.025	0.95	0.93 ± 0.025	0.93 ± 0.032
CSR		0.235 ± 0.031	0.218	0.234 ± 0.037	0.235 ± 0.037
M_w		6.70	6.54	6.54	6.54
D_{50}		0.150 ± 0.008	-	0.142 ± 0.020	0.142 ± 0.020
% Fines		18.0 ± 3.0	18	13.2 ± 4.4	13.2 ± 4.4
% PI		-	-	-	NAV
N		12.3 ± 4.7	11	12.4 ± 4.9	18.7 ± 4.1
C_R		0.86	0.85	0.86	0.87
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.13	1.13	1.13	1.13
C_N		1.68	1.44	1.64	1.59
$(N_1)_{60}$		20.2 ± 7.7	15.2	19.9 ± 7.8	29.5 ± 6.5
V_{s30m} (m/s)		-	-	-	NAV
V_{s12m} (m/s)		160.0	-	160.0	NOT LISTED

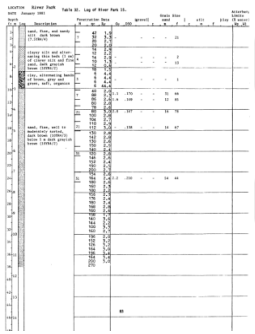
EVENT PARAMETERS

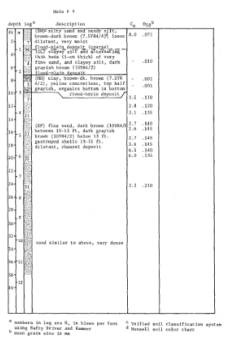
Superstition Hills	Hypocentral Depth (km): 9	Hudnutt et al (1989), USGS
Magnitude: 6.54	Length (km): 20	
Fault Type: strike slip	Z_{tor} (km): 0	R_{rup} (km): 14.5
Dip: 90	Width (km): -	R_{jb} (km): 14.5

Nov 24, 1987, 1:16 PM
EQ Page Shake Map
https://earthquake.usgs.gov/earthquakes/eventpage/ci628016/executive









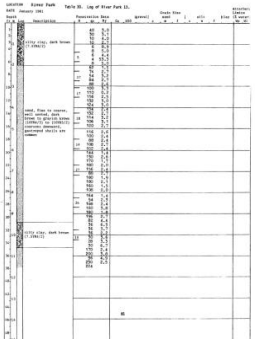
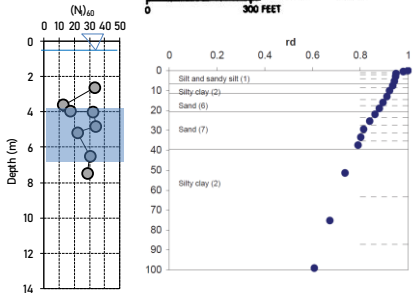


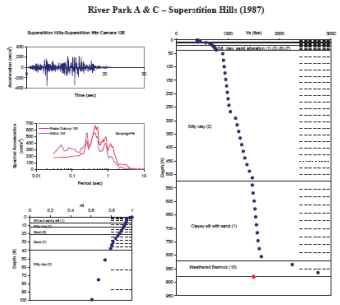
FIG. 12.—Bore-Hole Log Showing Index Properties of Soil Layers at River Park

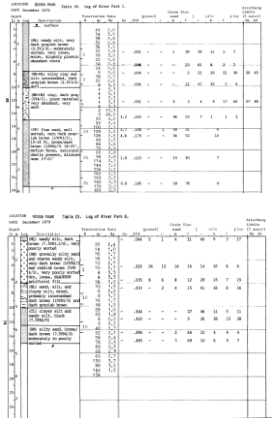
Cetin (2000)



	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
BH-13	2.6	8.5		17	2.00	0.87	33.7	sand
BH-4	3.6	11.8		7	1.78	0.90	12.7	***SP (probably MH transision hence excluded)***
BH-6	3.96	13.0		10	1.70	0.91	17.5	***SM-CL boundary hence excluded***
BH-4	***4***	***17.0***		***21***	***1.50***	***0.91***	***32.3***	SP
BH-4	***4.8***	***15.7***		***21***	***1.55***	***0.92***	***34.1***	SP
BH-1	***5.18***	***17.0***		***14***	***1.50***	***0.93***	***22.0***	SP
BH-1	6.5	21.3		21	1.35	0.94	30.2	SP
BH-1	7.5	24.6		21	1.26	0.95	28.5	SP
						Mean:	29.5	
						St. Dev.	6.5	

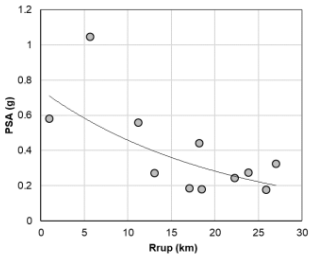
Depth (m)	FC	sand	silt	clay	D50	
3.3	12	88	9	3	0.110	BH-4
3.5	13	87	11	2	0.120	BH-4
3.9	11	88	9	2	0.135	BH-4
4.4	11	89	10	1	0.140	BH-4
4.6	10	90	9	1	0.145	BH-4
5.1	10	90	10	0	0.145	BH-4
5.2	9	91	9	0	0.180	BH-1
5.2	14	86	14	0	0.170	BH-1
5.3	13	87	10	3	0.145	BH-4
5.7	18	82	14	4	0.140	BH-4
6.0	24	76	20	4	0.135	BH-4
6.4	7	93	7	0	0.115	BH-1
7.8	6	94	6	0	0.145	BH-1
Mean:	13.2	86.7	11.4	1.8	0.142	
St. Dev.	4.4	4.3	3.4	1.5	0.020	





Case number:	122
Earthquake:	1987 Superstition Hills
Magnitude:	6.54 (Mw)
Location:	Wildlife B
References:	Bennett et al. (1984) and Fear et al. (1995), Bierschwale. (1984), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Site has liquefied. Pore pressure ratios exceeded 1
GPS LAT	33.0976
GPS LONG	-115.5306
Liq. layer consist of:	Silty Sand
Geological Unit:	Holocene floodplain
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much ad 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The site is very closely monitored. Strong ground motion seismometers were installed at the surface and at 6.7 m depth. Piezometers were installed almost at every meter along the potentially liquefiable layer of thickness 4 m. A: very loose and very soft interbedded micaceous sandy silt, silt and clayey silts (0-2.5 m) flood plain deposits B: very loose to loose moderately sorted sandy silt (2.5-6.8m); point bar deposits C: silty clay (medium to very stiff) and clayey silt (medium to stiff); lacustrine deposit. PGA was recorded at the surface and at 6.7 m depth as 0.2 and 0.17g respectively. The epicentral distance is 30.2 km. Site response analyses results estimate PGA in two direction as 0.18 g and 0.23 g geometric mean of which is 0.205 g. Energy ratio ~68 %"

Rjb and Rrup is taken from PEER.



Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	A	-	A	A
d_{cr1c} range (m)	-	2.7 - 6.7	-	2.7 - 6.7	2.7 - 7.0
d_{cr1} (m)	-	4.7	4.6	4.7	4.9
GWT (m)	-	0.9 ± 0.3	1.2	0.9 ± 0.1	1.2 ± 0.1
γ_{moist} (kN/m^3)	-	14.1 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	15.7 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-	73.0 ± 10.7	87.2	86.4 ± 12.6	87.9 ± 13.7
σ_v' (kPa)	-	35.5 ± 5.3	54.1	49.0 ± 6.3	52.0 ± 6.8
a_{max} (g)	-	0.180 ± 0.005	0.206	0.205 ± 0.031	0.205 ± 0.010
r_d	-	0.84 ± 0.035	0.94	0.82 ± 0.035	0.82 ± 0.034
CSR	-	0.202 ± 0.021	0.216	0.192 ± 0.031	0.184 ± 0.014
M_w	-	6.60	6.54	6.54	6.54
D_{50}	-	0.090 ± 0.005	-	0.109 ± 0.038	0.089 ± 0.012
% Fines	-	40.0 ± 3.0	30	26.2 ± 7.6	27.4 ± 9.0
% PI	-	-	-	-	0
N	-	7.8 ± 3.5	7.1	7.9 ± 3.5	8.0 ± 3.5
C_R	-	0.88	0.95	0.88	0.92
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.13	1.13	1.13	1.13
C_N	-	1.64	1.36	1.44	1.40
$(N_1)_{60}$	-	12.8 ± 5.7	10.3	11.3 ± 5.0	11.6 ± 5.1
V_{s30m} (m/s)	-	-	-	-	179.0
V_{s12m} (m/s)	-	160.0	-	160.0	131.0

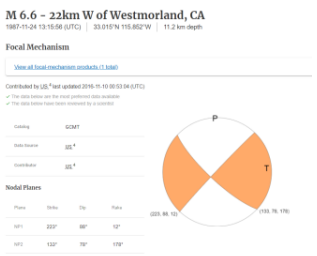
EVENT PARAMETERS

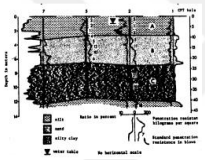
1987 Superstition Hills	Hypocentral Depth (km): 9	Hudnutt et al (1989), USGS
Magnitude: 6.54	Length (km): 20	PEER
Fault Type: strike slip	Z_{tor} (km): 0	R_{up} (km): 23.9
Dip: 90	Width (km): -	R_{jb} (km): 23.9

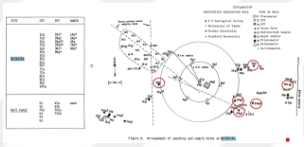
Nov 24, 1987, 1:16 PM

EQ Page Shake Map

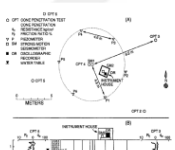
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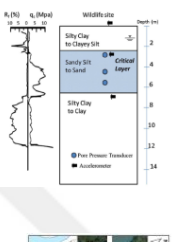


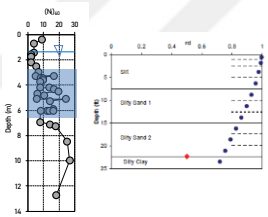


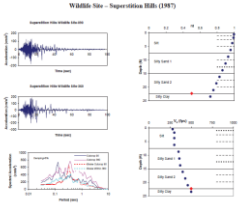


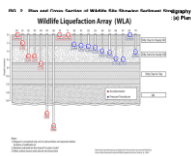
Cetin (2000)

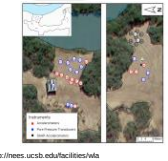




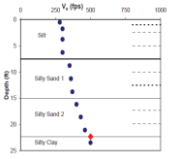








http://nees.ucsb.edu/facilities/wla



Cetin 2000
Probably Cetin 2000 used SASW results in his site response anaysis

	Depth (m)	Depth (ft)	CSR	N	C_N	C_E	$(N1)_{60}$	
A	0.40	1.3		5	2.00	0.80	9.1	silt, ML
	0.69	2.3		2	2.00	0.81	3.7	silty to silty sand
	1.45	4.8		2	2.00	0.84	3.8	clayey silt
B	*1.58*	*5.2*		*1*	*2.00*	*0.85*	*1.9*	*silty clay, ML*
A	*1.75*	*5.8*		*1*	*2.00*	*0.85*	*1.9*	silt
	1.75	*5.8*		*1*	*2.00*	*0.85*	*1.9*	silt
	2.21	*7.3*		*1*	*1.90*	*0.86*	*1.9*	silt
C	2.50	8.2		3	1.82	0.87	5.4	sandy silt, ML
	2.97	*9.8*		*4*	*1.70*	*0.88*	*6.8*	*sandy silt*
B	*3.28*	*10.8*		*3*	*1.64*	*0.89*	*5.0*	*sand to silty sand*
	3.28	*10.8*		*10*	*1.64*	*0.89*	*16.6*	*sand to silty sand*
C	*3.40*	*11.2*		*5*	*1.61*	*0.89*	*8.2*	*sand, SM*
	3.48	*11.4*		*6*	*1.60*	*0.90*	*9.8*	*silty sand*
	3.58	*11.8*		*6*	*1.58*	*0.90*	*9.7*	*silty sand*
	3.73	*12.3*		*5*	*1.56*	*0.90*	*8.0*	*very fine sand*
B	*4.19*	*13.8*		*5*	*1.49*	*0.91*	*7.7*	*sand to silty sand*
	4.19	*13.8*		*9*	*1.49*	*0.91*	*13.8*	*sand to silty sand*
	4.33	*14.2*		*11*	*1.47*	*0.91*	*16.7*	*sand, SM*
	4.50	*14.8*		*13*	*1.44*	*0.92*	*19.5*	*very fine sand*
	4.70	*15.4*		*4*	*1.42*	*0.92*	*5.9*	*silty sand*
	4.80	*15.8*		*7*	*1.40*	*0.92*	*10.3*	*silty sand*
B	*5.11*	*16.8*		*4*	*1.37*	*0.93*	*5.7*	*sand to silty sand*
	5.11	*16.8*		*17*	*1.37*	*0.93*	*24.4*	*sand to silty sand*
	5.26	*17.3*		*10*	*1.35*	*0.93*	*14.2*	*very fine sand*
	5.91	*19.4*		*12*	*1.28*	*0.94*	*16.4*	*silty sand*
B	*6.02*	*19.8*		*9*	*1.27*	*0.94*	*12.2*	*sand to silty sand*
	6.02	*19.8*		*10*	*1.27*	*0.94*	*13.5*	*silty sand*
	6.02	*19.8*		*12*	*1.27*	*0.94*	*16.3*	*sand to silty sand*
	6.02	*19.8*		*6*	*1.27*	*0.94*	*8.1*	*silty sand*
	6.93	*22.8*		*6*	*1.20*	*0.95*	*7.7*	*sand, SM*
	7.12	23.4		11	1.18	0.95	14.0	clayey silt
	7.24	23.8		14	1.17	0.95	17.7	silty sand
	8.46	27.8		21	1.09	0.96	25.1	silty clay, CH
	9.98	32.8		24	1.02	0.97	26.9	clayey silt, MH
	12.73	41.8		18	0.91	0.98	18.2	silt, ML
					Mean:		11.6	
					St. Dev.		5.1	

	Depth (ft)	FC	Sand	Silt	Clay	D_{50}		wn	wl	PI	LI
sandy silt, ML	0.6	82.0	18.0	72.0	10.0	0.046	2Ng1				
silt ML	1.3	99.0	1.0	87.0	12.0	0.015	2Ng1	32.0			
silt	4.3	98.0	2.0	76.0	22.0	0.011	2Ng1	28.0			
silt ML	4.7	93.0	7.0	76.0	17.0	0.038	2Ng1	31.0	30.0	5.0	1.6
silty clay ML	5.2	99.0	1.0	41.0	58.0	0.003	2Ng1	33.0	38.0	11.0	0.4
silt ML	7.5	89.0	11.0	76.0	13.0	0.034	2Ng1				
sandy silt ML	8.2	70.0	30.0	66.0	4.0	0.052	2Ng1				
silty sand ML	***10.5***	***34.0***	***66.0***	***34.0***	***0.0***	***0.076***	***2Ng1***				
sand SM	***11.2***	***17.0***	***83.0***	***17.0***	***0.0***	***0.096***	***2Ng1***				
silty sand SM	***13.5***	***27.0***	***73.0***	***26.0***	***1.0***	***0.090***	***2Ng1***				
sand SM	***14.2***	***20.0***	***80.0***	***20.0***	***0.0***	***0.100***	***2Ng1***				
silty sand SM	***18.3***	***33.0***	***67.0***	***29.0***	***4.0***	***0.082***	***2Ng1***				
sand SM	***22.8***	***18.0***	***82.0***	***17.0***	***1.0***	***0.102***	***2Ng1***				
silty clay CH	27.8	100.0	0.0	34.0	66.0	0.002	2Ng1	26.0	64.0	26.0	-0.5
clayey silt MH	32.8	100.0	0.0	57.0	43.0	0.005	2Ng1	24.0	57.0	22.0	-0.5
silt ML	41.8	100.0	1.0	84.0	16.0	0.026	2Ng1	24.0	30.0	4.0	-0.5
clayey silt, SYR 4/2, (CL-ML)	1.3	87.0	13.0	69.0	18.0	0.020	3Ag	27.0	26.0	5.0	1.2
clayey silt, 5Y 4.5/1	3.0	89.0	11.0	89.0	0.0		3Ag	31.0			
silt, 5Y 4.5/1	3.5	97.0	3.0	75.0	22.0	0.016	3Ag				
silt, 5Y 4.5/1, (CL-ML)	4.5	98.0	2.0	78.0	20.0	0.020	3Ag	43.0	28.0	6.0	3.5
sandy silt, 2.5Y 3/2, (ML)	5.8	56.0	44.0	44.0	12.0	0.056	3Ag	28.0			
silt, 2.5Y 3/2, (CL)	7.3	96.0	4.0	78.0	18.0	0.025	3Ag	34.0	30.0	9.0	1.6
sandy silt, 10YR 4/2, ML	9.0	63.0	37.0	53.0	10.0	0.056	3Ag				
sandy silt, 10YR 4/2, ML	9.5	56.0	44.0	46.0	10.0	0.057	3Ag				
silty sand, 10YR 4/2, SM	***11.4***	***31.0***	***69.0***	***26.0***	***5.0***	***0.086***	***3Ag***				
sand, 10YR 4/2, (SM)	***13.5***	***22.0***	***78.0***	***19.0***	***3.0***	***0.095***	***3Ag***				
silty sand, 10YR 4/2, SM	***15.0***	***26.0***	***74.0***	***23.0***	***3.0***	***0.088***	***3Ag***				
silty sand, 10YR 4/2, SM	***18.0***	***31.0***	***69.0***	***26.0***	***5.0***	***0.086***	***3Ag***				
silty sand, 10YR 3/3,SM	***19.5***	***49.0***	***51.0***	***43.0***	***6.0***	***0.063***	***3Ag***				
sand, 10YR 3/3, (SM)	***21.0***	***21.0***	***79.0***	***18.0***	***3.0***	***0.109***	***3Ag***				
clayey silt, 10YR 4/2, CL	22.8	96.0	4.0	66.0	30.0	0.012	3Ag	30.0	36.0	16.0	0.6
clayey silt, 10YR 4/2	24.5	97.0	3.0	71.0	26.0	0.013	3Ag	30.0			
silty clay, SYR 4/2	25.5	97.0	3.0	41.0	56.0	0.003	3Ag	28.0			
silty clay, SYR 4/2	27.5	99.0	1.0	28.0	71.0	0.001	3Ag	29.0			
clay, SYR 4/2, (CH)	30.0	98.0	2.0	23.0	75.0	0.001	3Ag	27.0	68.0	41.0	0.0
silty clay, SYR 4/2	33.0	98.0	2.0	29.0	69.0	0.002	3Ag	28.0			
clay, SYR 4/2, (CH)	36.0	99.0	1.0	11.0	88.0	0.001	3Ag	26.0	68.0	39.0	-0.1
silty clay, SYR 4/2	37.0	92.0	8.0	26.0	66.0	0.002	3Ag	31.0			
silt, (ML)	40.0	88.0	12.0	75.0	13.0	0.046	3Ag	26.0			
clayey silt	41.0	98.0	2.0	56.0	42.0	0.007	3Ag	25.0			
silt, 5Y 4/2, (ML)	44.0	97.0	3.0	79.0	18.0	0.023	3Ag	27.0	28.0	4.0	1.0
silt, 5Y 4/2, (ML)	46.5	96.0	4.0	86.0	10.0	0.030	3Ag	28.0			
clayey silt, 10YR 3.5/2	49.0	88.0	12.0	74.0	14.0	0.028	3Ag	30.0			
silt, 10YR 3.5/2, (ML)	51.5	96.0	4.0	84.0	12.0	0.022	3Ag	31.0			
silt, 10YR 3.5/2, (ML)	53.3	95.0	5.0	82.0	13.0	0.028	3Ag	29.0			
sandy silt, 10YR 3.5/2,	56.0	85.0	15.0	71.0	14.0	0.034	3Ag				
sandy silt, 10YR 3.5/2,	58.0	66.0	34.0	56.0	10.0	0.050	3Ag				
silty clay, SYR 4/2	58.8	95.0	5.0	31.0	64.0	0.002	3Ag				
silty sand, SYR 4/3, (SM)	59.5	49.0	51.0	39.0	10.0	0.063	3Ag				
clayey silt, SYR 4/2.5	61.0	94.0	6.0	66.0	28.0	0.015	3Ag	24.0			
clayey silt, SYR 4/2.5	62.5	97.0	3.0	73.0	24.0	0.018	3Ag	28.0			
sand, (SM)	66.0	14.0	86.0	14.0		0.114	3Ag				
silty sand, 7. SYR 4/2, (SM)	68.0	34.0	66.0	28.0	6.0	0.088	3Ag				
silty sand, 7. SYR 4/2, (SM)	70.0	53.0	47.0	41.0	12.0	0.056	3Ag				
silt, 7. SYR 4/2, (ML)	72.0	96.0	4.0	82.0	14.0	0.023	3Ag	31.0			
clayey silt, 7. SYR 4/2	73.0	96.0	4.0	69.0	27.0	0.013	3Ag	31.0			
clayey silt, SYR 4/2.5, (CL)	74.5	95.0	5.0	61.0	34.0	0.009	3Ag	31.0	33.0	12.0	0.8
clayey silt, SYR 4/2.5	76.5	90.0	10.0	61.0	29.0	0.013	3Ag				
sandy silt, (ML)	78.0	80.0	20.0	66.0	14.0	0.041	3Ag	24.0			
silty sand, (SM)	80.0	29.0	71.0	23.0	6.0	0.088	3Ag				
clayey silt	82.0	85.0	15.0	65.0	20.0	0.036	3Ag	25.0			
silty clay, 7. SYR 4/2	83.0	96.0	4.0	42.0	54.0	0.003	3Ag	33.0			
clayey silt, 7. SYR 4/2	84.0	99.0	1.0	59.0	40.0	0.010	3Ag	27.0			
silty clay, 7. SYR 4/2, (CH)	85.0	99.0	1.0	39.0	60.0	0.002	3Ag	32.0	51.0	27.0	0.3
silty clay, 7. SYR 4/2	86.5	98.0	2.0	48.0	50.0	0.004	3Ag	35.0			
Mean:	27.4	72.6	24.8	2.6	0.089						
St. Dev.	9.0	9.0	7.8	2.2	0.012						

	Depth (m)	N	
1Ns silt	1.75	1	A
1Ns sand to silt	3.28	3	B
1Ns sand to silt	4.19	5	B
1Ns sand to silt	5.11	4	B
1Ns sand to silt	6.02	9	B
2Ng1 silt, ML	0.40	5	A
2Ng1 silty clay, M	1.58	1	B
2Ng1 sandy silt, I	2.50	3	C
2Ng1 sand, SM	3.40	5	C
2Ng1 sand, SM	4.33	11	
2Ng1 sand, SM	6.93	6	
2Ng1 silty clay, C	8.46	21	
2Ng1 clayey silt,	9.98	24	
2Ng1 silt, ML	12.73	18	
2Ng2 silty sand	3.58	6	
2Ng2 silty sand	4.80	7	
2Ng2 silty sand	6.02	10	
2Ng2 silty sand	7.24	14	
2Ng3 silty sand	3.48	6	
2Ng3 silty sand	4.70	4	
2Ng3 silty sand	5.91	12	
2Ng3 clayey silt	7.12	11	
3Ns silt	1.75	1	
3Ns sand to silt	3.28	10	
3Ns sand to silt	4.19	9	
3Ns sand to silt	5.11	17	
3Ns sand to silt	6.02	12	
5Ng silty to silty	0.69	2	
5Ng clayey silt	1.45	2	
5Ng silt	2.21	1	
5Ng sandy silt	2.97	4	
5Ng very fine sa	3.73	5	
5Ng very fine sa	4.50	13	
5Ng very fine sa	5.26	10	
5Ng silty sand	6.02	6	

Crosshole

Depth (m)	Vs (m/s)
0.79	93.25
1.59	97.35
2.43	102.43
3.10	109.46
3.81	127.47
4.50	130.11
5.33	131.28
6.03	135.88
6.97	156.80
8.19	139.65
9.41	149.82
0.79	93.50
1.63	93.93
2.35	103.65
3.07	117.27
3.78	117.47
4.66	124.49
5.38	124.94
5.96	140.52

SASW

Depth (m)		Vs (m/s)	ickness (m	time (s)
0.00	0.25	86.45	0.25	0.003
0.25	0.88	86.90	0.63	0.007
0.88	1.19	96.64	0.31	0.003
1.19	1.84	109.54	0.65	0.006
1.84	2.41	102.67	0.57	0.006
2.41	3.37	109.20	0.96	0.009
3.37	3.91	105.51	0.54	0.005
3.91	4.63	110.59	0.72	0.007
4.63	4.90	116.18	0.26	0.002
4.90	5.46	118.83	0.56	0.005
5.46	6.05	126.12	0.59	0.005
6.05	6.69	133.64	0.65	0.005
6.69	6.91	164.13	0.22	0.001
6.91	8.22	170.15	1.31	0.008
8.22	8.50	163.54	0.28	0.002
8.50	9.78	172.01	1.28	0.007
9.78	10.28	184.17	0.50	0.003
10.28	11.94	186.03	1.66	0.009
		V_{s12m} (m/s):		131.0

Case number:	123
Earthquake:	Loma Prieta
Magnitude:	6.93 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Alameda Bay Farm Island (Dike Location)
References:	Mitchell et al. (1994), Kayen et al (1998), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface manifestation of liquefaction.
GPS LAT	37.738863
GPS LONG	-122.25834
Liq. layer consist of:	sand
Geological Unit:	artificial fill, site was improved by vibraflotation
Site Response Anlaysis:	No
Comments:	Mitchell et al. (1994), "In-situ test results from four Loma Prieta Earthquake liquefaction sites: SPT, CPT, DMT and Shear Wave Velocity". Kayen et al. (1998), "Site was improved by vibraflotation." Cetin (2000) "Located immediately north of Oakland International Airport Most of the western part of Bay Farm Island consists of sandy hydraulic fill, underlain by bay mud and deeper stiffer soil. Considerable liquefaction occurred at the northwest corner and at points along the west edge of the fill. Soil liquefaction in the northern part of the island was largely confined to artificially fill land. Numerous sand boils~ 3m in diameter erupted in Harbor Bay Plaza area. Fill in the perimeter dike area was densified by vibroflotation. Densification prevented soil liquefaction of the western-perimeter dike. Complex stratigraphy of thin (<1m thick) interbeds of sand and finer material A layer of noncohesive sand and silty sand at 2-3 m. Below this layer to 6.5 m is a set of interlayered deposits. PGA is recorded as 0.27 & 0.21g at the Alameda Naval Air Station seismogram which is located on a 152 m deep soil site. Measurements performed after the earthquake. Depth to water table is given as 2-3 m in Kayen et al (1998). However, in Mitchell et al it was given as 5.5 m. P-wave plots suggests a water depth of 5.5 m."
	https://earthquake.usgs.gov/earthquakes/eventpage/nc216859/executive
	Vs12m is calculated as 181 m/s based on Vs data given by the original reference.
	PI is assigned as 0 since FC=7%.
	Kayen et al. (1998) "Standard penetration tests (SPT) were performed in shallow 10-cm (4 in.)-diameter uncased rotary-wash boreholes drilled with CME model 450 and 750 drill rigs, following the guidelines of the American Society for Testing and Materials (1984). SPT-energy calibrations, using the stresswave method (Farrar, 1991), were made on a CME model 450 drill rig to adjust the field-measured standard penetration resistance, N, to a normalized 60-percent-hammer-efficiency blowcount, (N1)^60)."
Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	No	No	No	No
Data Class	-	B	-	B	B
d_{crc} range (m)	-	6.0 - 7.0		6.0 - 7.0	6.0 - 7.0
d_{crL} (m)	-	6.5	6.5	6.5	6.5
GWT (m)	-	3.0 ± 0.9	3	3.0 ± 0.1	3.0 ± 0.1
γ_{moist} (kN/m^3)	-	18.9 ± 0.6	-	18.9 ± 0.5	20.0 ± 0.5
γ_{sat} (kN/m^3)	-	19.6 ± 0.6	-	19.6 ± 0.5	21.5 ± 0.5
σ_v (kPa)	-	125.6 ± 4.4	125.3	125.6 ± 3.9	135.5 ± 4.2
σ_v' (kPa)	-	91.2 ± 8.9	91.2	91.2 ± 2.9	101.1 ± 3.0
a_{max} (g)	-	0.240 ± 0.024	0.24	0.240 ± 0.036	0.240 ± 0.036
r_d	-	0.95 ± 0.087	0.92	0.99 ± 0.087	0.88 ± 0.087
CSR	-	0.205 ± 0.034	0.198	0.212 ± 0.037	0.185 ± 0.033
M_w	-	7.00	6.93	6.93	6.93
D_{50}	-	0.280 ± 0.020	-	0.280 ± 0.050	0.280 ± 0.050
% Fines	-	7.0 ± 2.0	7	7.0 ± 2.0	7.0 ± 8.6
% PI	-	-	-	-	0
N	-	37.1 ± 1.6	37	37.1 ± 1.7	37.2 ± 2.0
C_R	-	0.94	0.95	0.94	0.94
C_S	-	1.30	1.30	1.30	1.30
C_B	-	1.00	1.00	1.00	1.00
C_E	-	0.92	0.92	0.92	0.92
C_N	-	1.03	1.03	1.06	1.00
$(N_1)_{60}$	-	42.6 ± 1.8	43.3	43.8 ± 2.0	41.9 ± 2.2
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	231.6	-	248.4	181.0

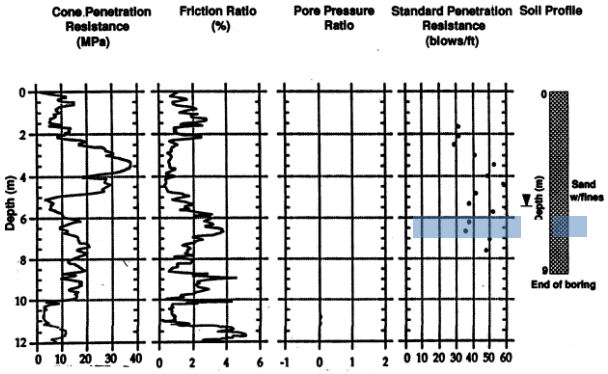
EVENT PARAMETERS

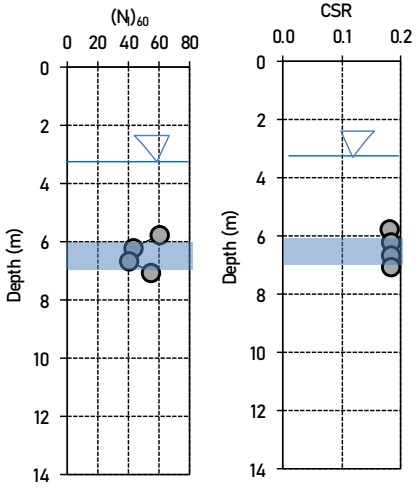
1989 Loma Prieta Earthquake — USGS, Graves and Pitarka (2004), Toprak et al. (1999), Holzer et al. (1998)

Magnitude: 6.93

Fault Type: reverse-obliqu — Z_{tor} (km): 3.85 — R_{rup} (km): -

Dip: 70 — Width (km): 20 — R_{jb} (km): 68.0

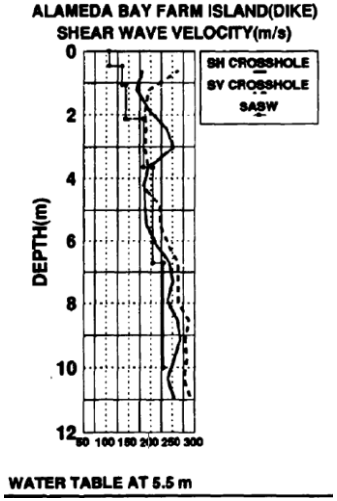




Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
5.75	18.9	0.183	52	1.05	0.93	60.8	sand
6.2	***20.3***	***0.184***	***38***	***1.02***	***0.94***	***43.4***	sand
6.65	***21.8***	***0.185***	***36***	***0.99***	***0.95***	***40.3***	sand
7.05	23.1	0.185	50	0.97	0.95	55.0	sand
					Mean:	41.9	
					St. Dev.	2.2	

Depth (m)	Vs (m/s)	time (s)	
1.2	169	0.007	
1.8	194	0.003	
2.4	235	0.003	
3.1	252	0.002	
3.7	194	0.003	
4.3	186	0.003	
4.9	187	0.003	
5.5	190	0.003	
6.1	211	0.003	
6.7	243	0.003	
7.3	251	0.002	
7.9	239	0.003	
8.5	260	0.002	
9.2	268	0.002	
9.8	253	0.002	
10.4	239	0.003	**Vs,12m (m/s)**
11.0	253	0.006	219

Depth (m)	Vs (m/s)	time (s)	
0.6	132	0.005	
1.2	134	0.005	
1.8	143	0.004	
2.4	136	0.004	
3.1	115	0.005	
3.7	99	0.006	
4.3	92	0.007	
4.9	109	0.006	
5.5	101	0.006	
6.1	123	0.005	
6.7	128	0.005	
7.3	120	0.005	
7.9	238	0.003	
8.5	250	0.002	
9.2	272	0.002	
9.8	240	0.003	
10.4	192	0.003	**Vs,12m (m/s)**
11.0	191	0.009	143



Case number:	124
Earthquake:	Loma Prieta
Magnitude:	6.93 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Farris Farm Site
References:	Holzer et al. (1994), Cetin (2000), Cetin et al (204, 2018)
Nature of Failure:	Lateral spread near the Pajaro River. South of the river ~0.2 m high head scarp
GPS LAT	36.910221
GPS LONG	-121.745251
Liq. layer consist of:	SM
Geological Unit:	Composed of younger and older hol
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "Lateral spread near the Pajaro River. South of the river ~0.2 m high head scarp which could be followed for 1.7 km. Maximum horizontal displacement of ~30 cm just west of the study area. Sand boils along the area affected by lateral spreading. Eyewitnesses reported that sediment-laden water flowed gently from vents on the lateral spread during and until 20 minuntes after the earthquake. Located at the south side of the Pajara River at Clint Miller Farms near Watsonville, CA. Composed of younger and older holocene fluvial deposits. The upper 4-6 m of the younger flood-plain deposits is silty and contains only a few thin sand layers. In the depth interval from 4.6-9.1, sand percentages range 67-100. This layer includes most of the liquefied layer. Average fines content of the sandy layers if 15%, ranging from 22 % at Miller Farm to 8% at Farris Farm. The depth to the water table was ~4.6 m 10 days after the main shock. PGA is recorded in a four-story building 1km west of Miller Farm as 0.39 g. In Open File Report 95-663, Holzer et al., the PGA was given as 0.53g. Watsonville region was shaken at MMI scale of 8.(~ 0.25-0.5 g ?). The earthquake specific attenuation-relationship suggests for alluvium sites at 4.6 miles (closest distance to the fault) ~0.5-0.65 g. PGA was recorded as 0.36 g at Watsonville. Based on site response analyses results a PGA of 0.37 g was adopted for the analyses. Strong ground motion lasted ~ 6 seconds. SPT performed after the earthquake"
	The critical layer is selected as the sub-layer within the 5 m thick silty sand layer. The CPT data also supports this sublayering. Hence the layer is represented with one single SPTN is accepted.
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	5.0 - 7.0	-	5.0 - 7.0	5.0 - 7.0
d_{crt} (m)	-	6.0	6.0	6.0	6.0
GWT (m)	-	4.5 ± 0.9	4.5	4.5 ± 0.1	4.5 ± 0.1
γ_{moist} (kN/m^3)	-	14.1 ± 1.3	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	14.9 ± 1.3	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-	86.2 ± 7.8	106.3	99.2 ± 6.7	99.2 ± 6.7
σ_v' (kPa)	-	71.5 ± 10.3	92.2	84.5 ± 3.8	84.5 ± 3.8
a_{max} (g)	-	0.370 ± 0.050	0.37	0.370 ± 0.056	0.370 ± 0.056
r_d	-	0.90 ± 0.020	0.93	0.95 ± 0.020	0.95 ± 0.041
CSR	-	0.280 ± 0.049	0.259	0.268 ± 0.041	0.268 ± 0.043
M_w	-	7.00	6.93	6.93	6.93
D_{50}	-	0.200 ± 0.020	-	0.200 ± 0.050	0.113 ± 0.050
% Fines	-	8.0 ± 2.0	8	8.0 ± 2.0	21.0 ± 8.6
% PI	-	-	-	-	NAV
N	-	9.0 ± 2.1	9	9.0 ± 1.7	9.0 ± 1.7
C_R	-	0.92	0.95	0.92	0.94
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.13	1.13	1.13	1.13
C_N	-	1.16	1.05	1.10	1.10
$(N_1)_{60}$	-	10.9 ± 2.5	10.2	10.3 ± 2.0	10.5 ± 2.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	185.9	185.9

EVENT PARAMETERS

1989 Loma Prieta Earthquake — USGS, Graves and Pitarka (2004), Toprak et al. (1999), Holzer et al. (1998)

Magnitude: 6.93

Fault Type: reverse-obliqu — Z_{tor} (km): 3.85 — R_{rup} (km): -

Dip: 70 — Width (km): 20 — R_{jb} (km): 6.6

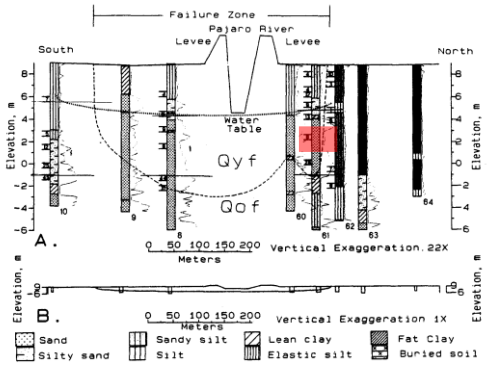
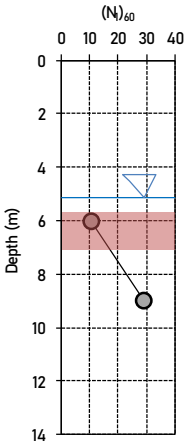
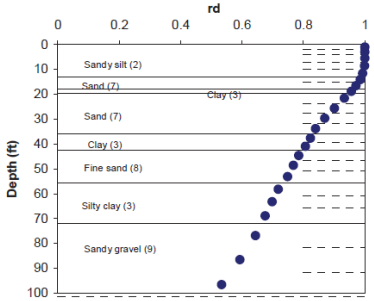
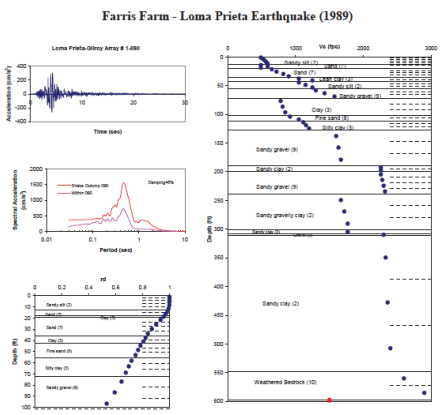


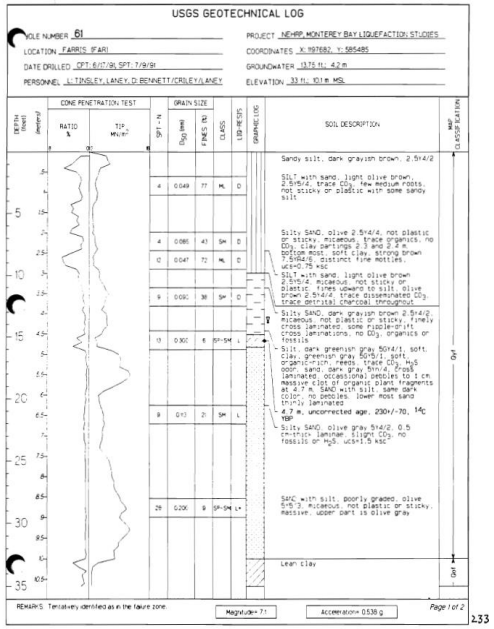
Table 2. Index properties of subsurface and surface samples

SITE	DEPTH (FT)	DEPTH RANGE	SPT N	G	S	M	C	D50 mm	Cu	USC	Name	Wn	LL	PI	LI	ACT
FAR59	10.3	10–11.5		0	1	53	46	0.006		CL	Lean CLAY	37	47	23	0.6	0.9
FAR59	11.0	10–11.5	4	0	11	69	20	0.031	19.0	CL	Lean CLAY	35	33	10	1.2	1.0
FAR59	13.4	13–14.5		0	83	14	3	0.113	2.8	SM	Silty SAND	27				
FAR59	14.2	13–14.5	5	0	70	25	5	0.097	5.4	SM	Silty SAND	34				
FAR59	16.6	16–17.5		0	75	18	7	0.113	9	SM	Silty SAND					
FAR59	17.3	16–17.5	9	0	94	6		0.159	1.9	SP–SM	SAND w/M	32				
FAR59	21.0	20–21.5	16	0	95	5		0.205	2.1	SP–SM	SAND w/M	26				
FAR59	26.0	25–26.5	21	0	93	7		0.205	2.4	SP–SM	SAND w/M	25				
FAR59	30.3	30–31.5		0	93	7		0.200	2.3	SP–SM	SAND w/M	24				
FAR59	31.1	30–31.5	16	0	90	10		0.190	3.5	SP–SM	SAND w/M	24				
FAR61–1	3.0	2–3.5		0	23	73	4	0.049	3.8	ML	SILT w/S		26	9	−0.2	
FAR61–2	3.1	2–3.5	4									15				
FAR61–4	7.5	6.5–8		0	57	37	6	0.085	7	SM	silty SAND					
FAR61–3	7.6	6.5–8	4									34				
FAR61–5	8.6	8–9.5										26				
FAR61–6	8.8	8–9.5	12	0	28	61	11	0.047	10	ML	SILT w/S					
FAR61–7	11.3	11–12.5										28				
FAR61–8	12.0	11–12.5	9	0	62	31	7	0.090	5	SM	silty SAND					
FAR61–9	14.7	14.5–16										38				
FAR61–10	15.7	14.5–16	13	2	92	6		0.300	3	SP–SM	SAND with/m					
FAR61–14	21.1	20.5–22										25				
FAR61–15	21.5	20.5–22	9	0	79	18	3	0.113	2.2	SM	silty SAND					
FAR61–16	28.6	28–29.5										23				
FAR61–17	29.0	28–29.5	28	0	91	9		0.200	2.7	SP–SM	SAND with/m					
FAR62–1	3.0	2–3.5		0	2	48	50	0.005		CH	Fat CLAY	28	57	30		0.9
FAR62–2	3.1	2–3.5	10									28				
FAR62–4	6.0	5–6.5		0	4	66	30	0.019		ML	SILT		36	9	0.4	0.5
FAR62–3	6.0	5–6.5	3									31				
FAR62–7	12.9	12.5–14		0	5	60	35	0.014		ml	Silt					
FAR62–6	13.0	12.5–14										41				
FAR62–5	13.4	12.5–14										42				
FAR62–10	13.4	12.5–14		0	2	72	26	0.014	9.5	ML	SILT					
FAR62–9	13.9	12.5–14										40				
FAR62–11	13.9	12.5–14	1	0	5	55	40	0.007		ml	Silt					
FAR62–13	16.5	15.5–17	6	0	1	49	50	0.005		MH	Elastic SILT		53	21	0.1	0.7
FAR62–22	30.1	30–31.5										30				









Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	Gravel	Sand	Silt	Clay	FC	D50	USCS
6	***19.7***		***9***	***1.10***	***0.94***	***10.5***	***0.00***	***79.00***	***18.00***	***3.00***	***21.00***	***0.113***	***SM***
9	29.5		28	0.95	0.97	29.3	0.00	91.00	9.00	0.00	9.00	0.200	SP-SM
					Mean:	10.5	0.0	79.0	18.0	3.0	21.0	0.113	
					St. Dev.	2.0	5.9	2.0	8.3	2.3	8.6	0.050	assigned

Case number:	125
Earthquake:	Loma Prieta
Magnitude:	6.93 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Port of Richmond (Hall Avenue)
References:	Mitchell et al. (1994), Kayen et al (1998), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface evidence of liquefaction was observed at Hall Avenue. However,
GPS LAT	37.91028 between depths of about 1.5-3.5 m, the sampler sank under its own weight
GPS LONG	-122.35939 in a layer of very soft silty clay.
Liq. layer consist of:	silt/very fine silty sand
Geological Unit:	uncompacted sandy hydraulic fill
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "Mitchell et al. (1994), Insitu test results from four Loma Prieta Earthquake liquefaction sites: SPT, CPT, DMT and Shear Wave Velocity. Kayen et al. (1998), Soil Liquefaction in the East Bay during the earthquake The site is close to POR 2-3-4 (~ 1 km) by the Hall Street. No surface evidence of liquefaction was observed at Hall Avenue. However, between depths of about 1.5-3.5 m, the sampler sank under its own weight in a layer of very soft silty clay. The site is close to POR 2-3-4 (~ 1 km) by the Hall Street. The site represents the most distant point, approximately 85 km north of the rupture zone The liquefaction zone overlies deposits of soft bay mud, underlain by deeper deposits of stiffer, overconsolidated noncohesive and cohesive soils Up to 0.8 m depth the soil is characterized by oxidized, tan-brown crusted silty sand. 0.8-1.8 m oxidized tan-brown silty sand. 1.8-4.1 m oxidized tan-brown sandy clay to reduced sandy clay.4.1-7.8 m, is a hydraulic fill layer of olive-gray fine-silty sand containing shell fragments. The thick deposits amplified the level of ground motion at the site PGA was estimated as 0.18 g by performing a site response analysis (SHAKE) using the input motion from Richmond City Hall (PGA=0.13g) by Kayen et al. Based on site response analyses results, a PGA of 0.14 was adopted. Depth to water table in Kayen et al. (1998) was reported as 2.5 m contrary to 3.5 m reported in Mitchell et al. (1994)"
	Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
	Kayen et al. (1998) "Standard penetration tests (SPT) were performed in shallow 10-cm (4 in.)-diameter uncased rotary-wash boreholes drilled with CME model 450 and 750 drill rigs, following the guidelines of the American Society for Testing and Materials (1984). SPT-energy calibrations, using the stresswave method (Farrar, 1991), were made on a CME model 450 drill rig to adjust the field-measured standard penetration resistance, N, to a normalized 60-percent-hammer-efficiency blowcount, (N1)^60)."
Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	No	No	No	No
Data Class	-	A	-	A	A
d_{crtc} range (m)	-	3.5 - 5.8	-	3.5 - 5.8	3.5 - 5.8
d_{crt} (m)	-	4.6	4.6	4.6	4.6
GWT (m)	-	3.5 ± 0.6	3.5	3.5 ± 0.1	3.5 ± 0.1
γ_{moist} (kN/m^3)	-	14.1 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.1 ± 0.5	18.1 ± 0.5
σ_v (kPa)	-	68.2 ± 6.8	75.2	75.5 ± 7.0	75.5 ± 7.0
σ_v' (kPa)	-	57.2 ± 5.7	64.2	64.4 ± 3.6	64.4 ± 3.6
a_{max} (g)	-	0.140 ± 0.013	0.14	0.140 ± 0.021	0.140 ± 0.021
r_d	-	0.72 ± 0.013	0.95	0.72 ± 0.013	0.72 ± 0.033
CSR	-	0.075 ± 0.011	0.102	0.077 ± 0.012	0.077 ± 0.012
M_w	-	7.00	6.93	6.93	6.93
D_{50}	-	0.090 ± 0.010	-	0.090 ± 0.050	0.090 ± 0.050
% Fines	-	30.0 ± 7.0	30	30.0 ± 2.0	30.0 ± 8.6
% PI	-	-	-	-	NAV
N	-	4.6 ± 3.2	4.6	4.6 ± 3.2	4.7 ± 3.3
C_R	-	0.88	0.95	0.88	0.92
C_S	-	1.10	1.10	1.10	1.10
C_B	-	1.00	1.00	1.00	1.00
C_E	-	0.92	0.92	0.92	0.92
C_N	-	1.30	1.28	1.26	1.26
$(N_1)_{60}$	-	5.3 ± 3.7	5.7	5.1 ± 3.6	5.4 ± 3.8
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

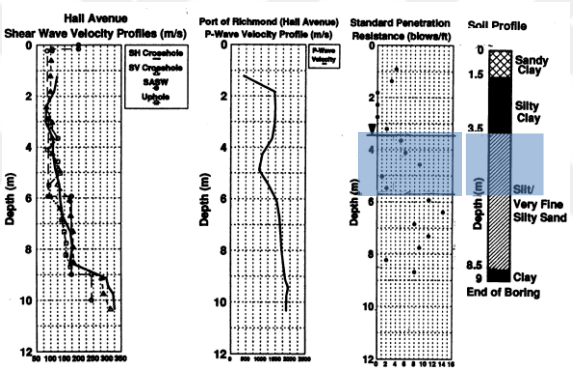
EVENT PARAMETERS

1989 Loma Prieta Earthquake USGS, Graves and Pitarka (2004), Toprak et al. (1999), Holzer et al. (1998)

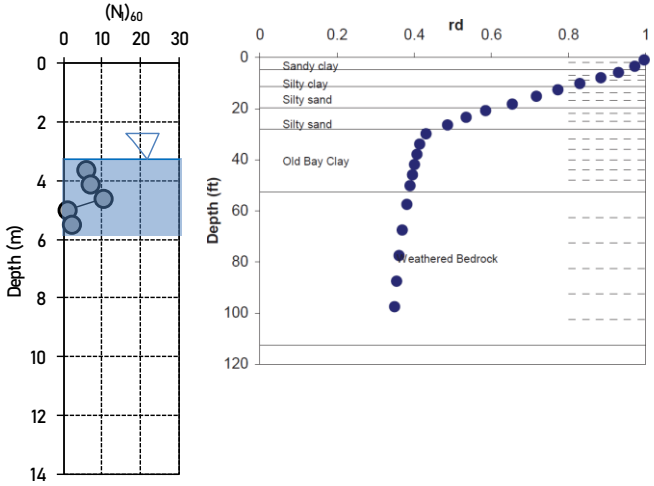
Magnitude: 6.93

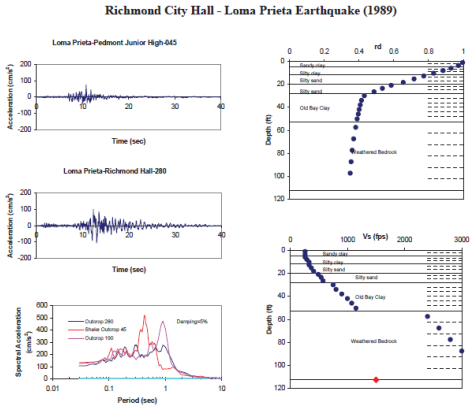
Fault Type: reverse-obliqu Z_{tor} (km): 3.85 R_{rup} (km): -

Dip: 70 Width (km): 20 R_{jb} (km): 89.0



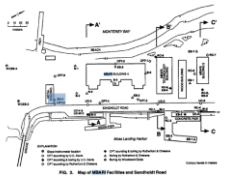
Cetin (2000)





Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
3.65	*12.0*		*5*	*1.34*	*0.90*	*6.1*	silt/very fine silty sand
4.15	*13.6*		*6*	*1.30*	*0.91*	*7.1*	silt/very fine silty sand
4.6	*15.1*		*9*	*1.26*	*0.92*	*10.5*	silt/very fine silty sand
5	*16.4*		*1*	*1.23*	*0.92*	*1.1*	silt/very fine silty sand
5.5	*18.0*		*2*	*1.19*	*0.93*	*2.2*	silt/very fine silty sand
					Mean:	5.4	
					St. Dev.	3.8	

Case number:	126
Earthquake:	Loma Prieta
Magnitude:	6.93 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	MBARI Facilities Building 3 EB-1
References:	Boulanger et al. (1996), Cetin (2000), Cetin et al (2004, 2018), NGL
Nature of Failure:	Extensive ground deformations were observed along Sandholdt Road,
GPS LAT	36.80296 including the portion alongside the MBARI facilities. Cracks parallel to the front
GPS LONG	-121.787617 line. Away from Sandholdt Road, surface evidence of liquefaction appeared to
Liq. layer consist of:	poorly graded sand with interlayers occur in localized areas.
Geological Unit:	Holocene deposit
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "Boulanger et al. (1996), Liquefaction at Moass Landing During Loma Prieta Earthquake. Located on Monterey Bay about midway between the cities of Santa Cruz and Monterey, CA. The MBARI facilities include three main buildings and a pier located along Sandholt Road on the Moss Landing spit. Historical shoreline suggest that the shoreline in the vicinity of the site has fluctuated significantly. Shallower soil strata may have been deposited recently. The area is underlain by Holocene deposits consisting of relatively thick sands offshore and estuarine and fluvial deposits onshore, up to about 60-m deep. The Moss Landing spit is underlain by littoral soils comprising eolian, fluvial, estuarine, and beach deposits of gravel, sand, silt, and clay deposited in a shoreline environment within the zone of tidal fluctuation. Pleistocene and miocene deposits extend to a depth of ~2000 m The site is underlain by an 8-12 m thick layer of poorly graded sand with interlayers of gravelly sand and sandy gravel in its lower portion and occasional thin layers of clayey silt throughout. PGA was recorded in a four-story building 8km from rupture plane as 0.39 g (alluvial site). Also San Juan Bautista seismographic station, ~20 km from the rupture plane recorded 0.15 g (stiff alluvium). The Moss Landing area is located ~21 km from the rupture plane. Due to deep alluvium which is soft near the surface, PGA at the site was predicted in the range of 0.2-0.3g. Based on site response analyses results, a PGA value of 0.24 g was adopted. EB-1 and EB-5 are ~50ft apart. Difficult to choose a representative SPT value SPT performed after the earthquake"
	Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
	Boulanger et al. (1995) "SPT performed with rotary wash borings with energy measurments. dEnergy ratios of 75% were measured for a central mine equipment (CME) trip hammer. Energy ratios of 60% were estimated for a cat-head and rope system." N60 values were provided by the same study. Hence ER is used as 60%.
Gravel Content (%):	poorly graded sand with interlayers of gravelly sand (content unkown)
CPT available:	Yes
Vs available:	No



Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	No	No	No	No
Data Class	-	B	-	B	B
d_{cric} range (m)	-	2.0 - 3.0	-	2.0 - 3.0	2.0 - 3.0
d_{cri} (m)	-	2.5	2.0	2.5	2.5
GWT (m)	-	2.0 ± 0.3	2	2.0 ± 0.1	2.0 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	18.9 ± 0.6	-	19.6 ± 0.5	19.6 ± 0.5
σ_v (kPa)	-	39.4 ± 3.6	35.1	44.5 ± 3.4	44.5 ± 3.4
σ_v' (kPa)	-	34.5 ± 2.7	35.1	39.6 ± 2.0	39.6 ± 2.0
a_{max} (g)	-	0.240 ± 0.025	0.28	0.240 ± 0.036	0.240 ± 0.036
r_d	-	0.99 ± 0.007	0.99	0.99 ± 0.007	0.99 ± 0.019
CSR	-	0.180 ± 0.024	0.179	0.174 ± 0.027	0.174 ± 0.027
M_w	-	7.00	6.93	6.93	6.93
D_{50}	-	0.600 ± 0.100	-	0.600 ± 0.050	0.600 ± 0.050
% Fines	-	1.0 ± 2.0	1	1.0 ± 2.0	1.0 ± 8.6
% PI	-	-	-	-	0
N	-	20.9 ± 3.1	18	18.5 ± 1.6	16.4 ± 1.4
C_R	-	0.69	0.80	0.77	0.87
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.00	1.00	1.00	1.00
C_N	-	1.67	1.57	1.60	1.60
$(N_1)_{60}$	-	23.9 ± 3.5	22.6	22.9 ± 2.0	22.9 ± 2.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

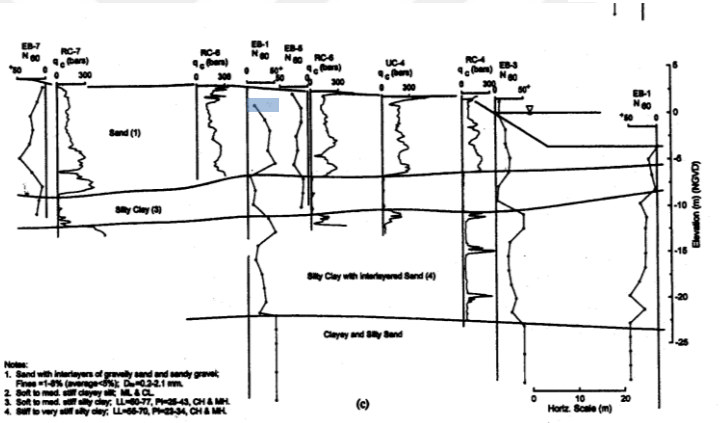
EVENT PARAMETERS

1989 Loma Prieta Earthquake USGS, Graves and Pitarka (2004), Toprak et al. (1999), Holzer et al. (1998)

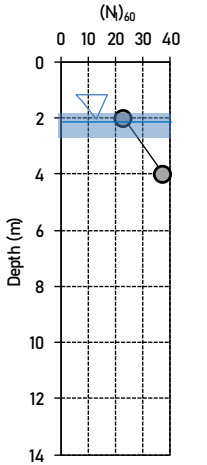
Magnitude: 6.93

Fault Type: reverse-obliqu Z_{tor} (km): 3.85 R_{rup} (km): -

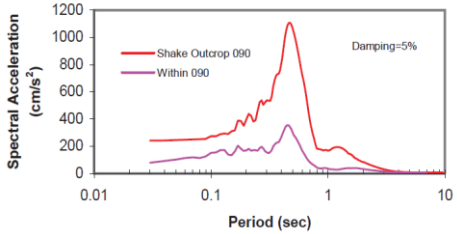
Dip: 70 Width (km): 20 R_{jb} (km): 18.0

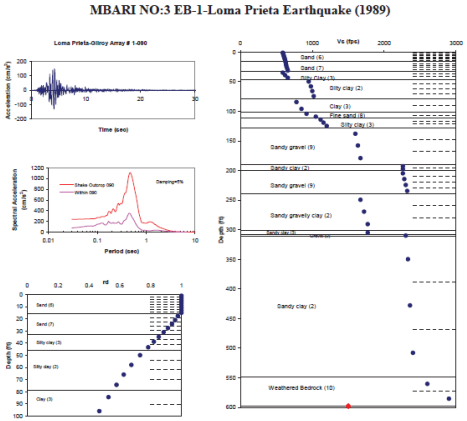


Boulanger et al (1995) provided N1,60 values
Boulanger et al (1997) provided N60 values



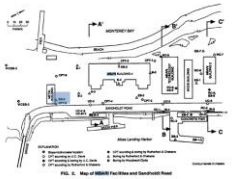
CSR is estimated by site response by Cetin (2000)





Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
2	***6.6***		***18***	***1.71***	***0.74***	***22.9***	Sand (1)
4	13.1		32	1.37	0.85	37.2	
					Mean:	22.9	
					St. Dev.	2.0	assigned

Case number:	127
Earthquake:	Loma Prieta
Magnitude:	6.93 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	MBARI Facilities Building 3 EB-5
References:	Boulanger et al. (1996), Cetin (2000), Cetin et al (2004, 2018), NGL
Nature of Failure:	Extensive ground deformations were observed along Sandholdt Road,
GPS LAT	36.80292 including the portion alongside the MBARI facilities. Cracks parallel to the front
GPS LONG	-121.787434 line. Away from Sandholdt Road, surface evidence of liquefaction appeared to
Liq. layer consist of:	poorly graded sand with interlayers of gravelly sand occur in localized areas.
Geological Unit:	Holocene deposits
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "Located on Monterey Bay about midway between the cities of Santa Cruz and Monterey, CA. The MBARI facilities include three main buildings and a pier located along Sandholt Road on the Moss Landing spit. Historical shoreline suggest that the shoreline in the vicinity of the site has fluctuated significantly. Shallower soil strata may have been deposited recently. The area is underlain by Holocene deposits consisting of relatively thick sands offshore and estuarine and fluvial deposits onshore, up to about 60-m deep. The Moss Landing spit is underlain by littoral soils comprising eolian, fluvial, estuarine, and beach deposits of gravel, sand, silt, and clay deposited in a shoreline environment within the zone of tidal fluctuation. Pleistocene and miocene deposits extend to a depth of ~2000 m The site is underlain by an 8-12 m thick layer of poorly graded sand with interlayers of gravelly sand and sandy gravel in its lower portion and occasional thin layers of clayey silt throughout. PGA is recorded in a four-story building 8km from rupture plane as 0.39 g which is underlain by alluvium. Also San Juan Bautista seismogram, ~20 km from the rupture plane recorded 0.15 g (stiff alluvium). The Moss Landing area is located ~21 km from the rupture plane. Due to deep alluvium which is soft near the surface, PGA at the site is predicted between 0.2-0.3 g. Based on site response analyses results, PGA is adopted as 0.27 g, slightly higher than the value adopted by authors of the source document (0.25 g) EB-1 and EB-5 are ~50ft apart. SPT performed before the earthquake."
	Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
	Boulanger et al. (1995) "SPT performed with rotary wash borings with energy measurments. dEnergy ratios of 75% were measured for a central mine equipment (CME) trip hammer. Energy ratios of 60% were estimated for a cat-head and rope system." N60 values were provided by the same study. Hence ER is used as 60%
Gravel Content (%):	poorly graded sand with interlayers of gravelly sand (content unkown)
CPT available:	Yes
Vs available:	No



Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	No	No	No	No
Data Class	-	A	-	A	A
d_{crtc} range (m)	-	1.8 - 6.4	-	1.8 - 6.4	1.8 - 6.4
d_{cr1} (m)	-	4.1	3.4	4.1	4.1
GWT (m)	-	1.8 ± 0.3	1.8	1.8 ± 0.1	1.8 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	18.1 ± 0.6	-	19.6 ± 0.5	19.6 ± 0.5
σ_v (kPa)	-	68.6 ± 14.0	63.2	76.5 ± 15.2	76.5 ± 15.2
σ_v' (kPa)	-	46.0 ± 6.9	47.1	53.9 ± 7.7	53.9 ± 7.7
a_{max} (g)	-	0.270 ± 0.025	0.28	0.270 ± 0.041	0.270 ± 0.041
r_d	-	0.99 ± 0.007	0.97	0.99 ± 0.007	0.99 ± 0.030
CSR	-	0.240 ± 0.033	0.235	0.247 ± 0.040	0.247 ± 0.040
M_w	-	7.00	6.93	6.93	6.93
D_{50}	-	0.600 ± 0.100	-	0.600 ± 0.050	0.600 ± 0.050
% Fines	-	1.0 ± 2.0	1	1.0 ± 2.0	1.0 ± 8.6
% PI	-	-	-	-	0
N	-	15.1 ± 2.8	12	15.2 ± 2.8	15.2 ± 2.2
C_R	-	0.86	0.85	0.86	0.91
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.00	1.00	1.00	1.00
C_N	-	1.44	1.46	1.37	1.37
$(N_1)_{60}$	-	18.7 ± 3.5	14.9	17.8 ± 3.3	19.0 ± 2.8
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	160.0	NOT LISTED

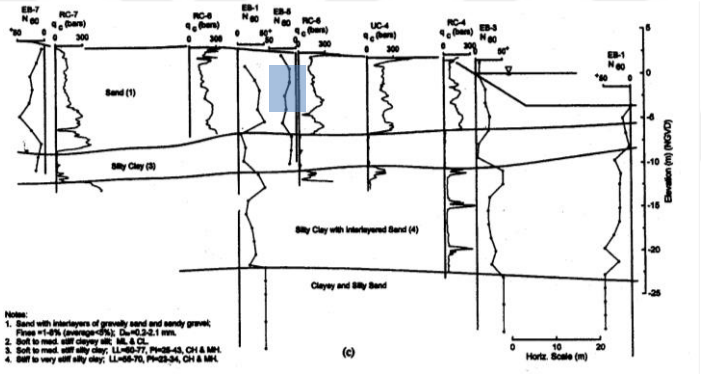
EVENT PARAMETERS

1989 Loma Prieta Earthquake USGS, Graves and Pitarka (2004), Toprak et al. (1999), Holzer et al. (1998)

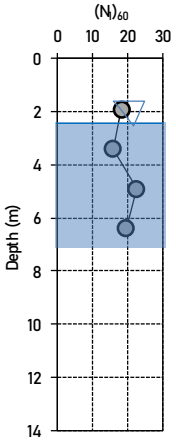
Magnitude: 6.93

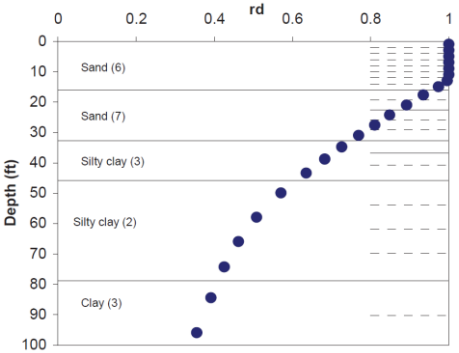
Fault Type: reverse-obliqu Z_{tor} (km): 3.85 R_{rup} (km): -

Dip: 70 Width (km): 20 R_{jb} (km): 18.0

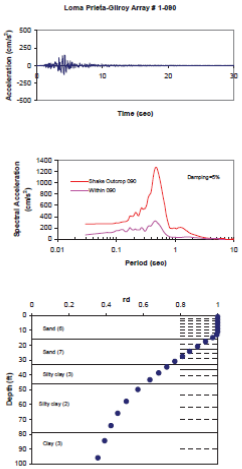


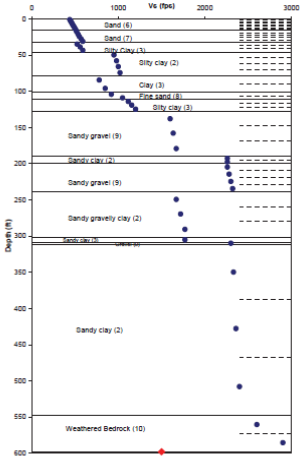
Boulanger et al (1995) provided N1,60 values
Boulanger et al (1997) provided N60 values





MBARI NO:3 EB-5-Loma Prieta Earthquake (1989)





Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
1.9	*6.2*		*12*	*1.78*	*0.86*	*18.2*	Sand (1)
3.4	*11.2*		*12*	*1.47*	*0.89*	*15.8*	Sand (1)
4.9	*16.1*		*19*	*1.28*	*0.92*	*22.5*	Sand (1)
6.4	*21.0*		*18*	*1.15*	*0.94*	*19.6*	Sand (1)
					Mean:	19.0	
					St. Dev.	2.8	

Sand (1): "poorly graded sand with interlayers of gravelly sand and sandy gravel in its lower portion and occasional thin layers of clayey silt throughout" (Boulanger et al. 1997)

Case number:	128
Earthquake:	Loma Prieta
Magnitude:	6.93 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Miller Farm CMF 10
References:	Bennett and Tinsley (1995), Cetin (2000), Cetin et al (2004, 2018), NGL Project
Nature of Failure:	Lateral spread, slide, and sand boils.
GPS LAT	36.9063126
GPS LONG	-121.7440785
Liq. layer consist of:	SM
Geological Unit:	younger and older holocene fluvial deposits
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "Located at the east of Watsonville, Monterey. Both SPT and CPT test were performed. Surface samples were taken. Grain size characteristices were given in detail. Usually SPT's were made 3-5 ft away from the CPT boreholes to obtain samples. SPT procedures followed the guidelines outlined in D1586-67 (ASTM). Hollow-stem augers (10" outside diameter, 4" inside diameter with split liners) 140 lb "inhole sampling hammer dropped at 30" height by "Safe-T-Driver" hoist. The overall efficiency of the hammer-hoist system is 68 %. Undisturbed samples were taken using thin-walled Shelby tubes. PGA is recorded in a four-story building 1km west of Miller Farm as 0.39 g In Open File Report 95-663, Holzer et al., the PGA was given as 0.53 g. Watsonville region was shaken at MMI scale of 8.(~ 0.25-0.50 g ?). The earthquake specific attenuation-relationship suggests for alluvium sites at 4.6 miles (closest distance to the fault) ~0.50-0.65 g. A PGA value of 0.36 g was recorded at Watsonville Based on site response analyses results, a PGA value of 0.46 is adopted. Strong ground motion lasted ~ 6 seconds.CMF3-5-8-10 are ~ 1000 ft apart. The SPT blowcount 26 at depth ~8m was eliminated due to high CPT tip resistance at that depth. Unlikely to be liquefied? SPT performed after the earthquake."
	Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	No	No	No
Data Class	-	B	-	B	B
d_{critic} range (m)	-	7.0 - 10.0	-	7.0 - 10.0	7.0 - 10.0
d_{cr1} (m)	-	8.5	8.4	8.5	8.5
GWT (m)	-	3.0 ± 0.3	3	3.0 ± 0.1	3.0 ± 0.1
γ_{moist} (kN/m^3)	-	14.1 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	14.9 ± 0.6	-	19.6 ± 0.5	19.6 ± 0.5
σ_v (kPa)	-	124.8 ± 8.5	158.4	160.2 ± 10.3	160.2 ± 10.3
σ_v' (kPa)	-	70.8 ± 5.5	105.3	106.2 ± 5.8	106.2 ± 5.8
a_{max} (g)	-	0.410 ± 0.050	0.39	0.410 ± 0.062	0.410 ± 0.062
r_d	-	0.88 ± 0.024	0.89	0.88 ± 0.024	0.88 ± 0.055
CSR	-	0.370 ± 0.056	0.338	0.354 ± 0.054	0.354 ± 0.058
M_w	-	7.00	6.93	6.93	6.93
D_{50}	-	0.150 ± 0.020	-	0.134 ± 0.026	0.134 ± 0.026
% Fines	-	20.0 ± 3.0	20	20.0 ± 2.0	20.0 ± 8.6
% PI	-	-	-	-	NAV
N	-	18.4 ± 2.7	19	18.3 ± 3.2	18.4 ± 8.3
C_R	-	0.99	0.95	0.99	0.96
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.13	1.13	1.13	1.13
C_N	-	1.16	0.99	0.98	0.98
$(N_1)_{60}$	-	24.0 ± 3.5	20.2	20.1 ± 3.5	19.6 ± 8.9
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

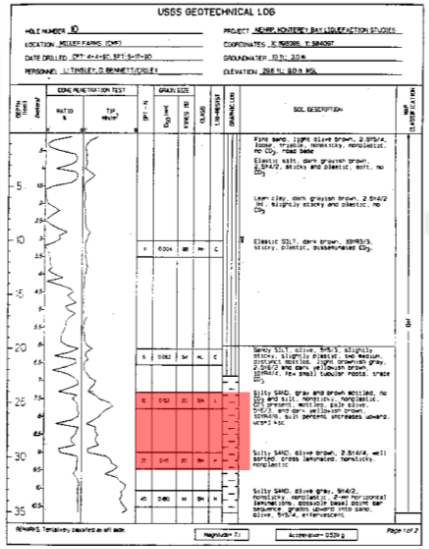
EVENT PARAMETERS

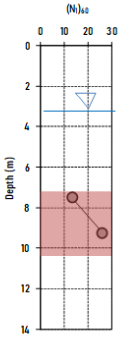
1989 Loma Prieta Earthquake — USGS, Graves and Pitarka (2004), Toprak et al. (1999), Holzer et al. (1998)

Magnitude: 6.93

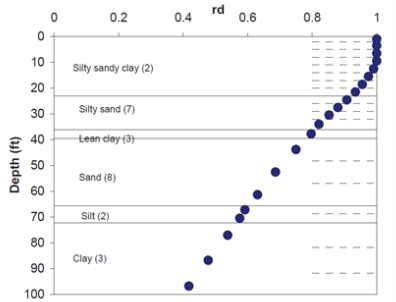
Fault Type: reverse-obliqu — Z_{tor} (km): 3.85 — R_{rup} (km): -

Dip: 70 — Width (km): 20 — R_{jb} (km): 6.8

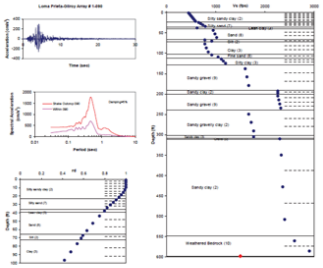




Cetin (2000)



Miller Farm CMF 10 - Loma Prieta Earthquake (1989)



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC %	D50	Gravel	Sand	Silt	Clay	USCS
7.5	*24.6*		*12*	*1.03*	*0.95*	*13.3*	*20.0*	*0.152*	*0*	*80*	*15*	*5*	*SM*
9.25	*30.3*		*25*	*0.95*	*0.97*	*25.9*	*20.0*	*0.115*	*0*	*80*	*17*	*3*	*SM*
					Mean:	19.6	20.0	0.134	0.0	80.0	16.0	4.0	
					St. Dev.	8.9	8.6	0.026	5.9	2.0	1.4	1.4	

Case number:	129
Earthquake:	Loma Prieta
Magnitude:	6.93 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Miller Farm CMF 3
References:	Bennett and Tinsley (1995), Cetin (2000), Cetin et al (2004, 2018), NGL
Nature of Failure:	Lateral spread, slide, and sand boils.
GPS LAT	36.9078755
GPS LONG	-121.7375061
Liq. layer consist of:	SM
Geological Unit:	younger and older holocene fluvial deposits
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "Located at the east of Watsonville, Monterey. Both SPT and CPT test were performed. Surface samples were taken. Grain size characteristices were given in detail. Usually SPT's were made 3-5 ft away from the CPT boreholes to obtain samples. SPT procedures followed the guidelines outlined in D1586-67 (ASTM). Hollow-stem augers (10" outside diameter, 4" inside diameter with split liners) 140 lb "inhole sampling hammer dropped at 30" height by "Safe-T-Driver" hoist. The overall efficiency of the hammer-hoist system is 68 %. Undisturbed samples were taken using thin-walled Shelby tubes. PGA is recorded in a four-story building 1km west of Miller Farm as 0.39 g In Open File Report 95-663, Holzer et al., the PGA was given as 0.53 g. Watsonville region was shaken at MMI scale of 8.(~ 0.25-0.50 g ?). The earthquake specific attenuation-relationship suggests for alluvium sites at 4.6 miles (closest distance to the fault) ~0.50-0.65 g. A PGA value of 0.36 g was recorded at Watsonville. Based on site response analyses results, a PGA value of 0.46 is adopted. Strong ground motion lasted ~ 6 seconds. CMF3-5-8-10 are ~ 1000 ft apart. The SPT blowcount 26 at depth ~8m was eliminated due to high CPT tip resistance at that depth. Unlikely to be liquefied? SPT performed after the earthquake."
	Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	A	-	A	A
d_{crtc} range (m)	-	5.8 - 7.5	-	5.8 - 7.5	5.8 - 7.5
d_{crt} (m)	-	6.6	6.2	6.6	6.6
GWT (m)	-	5.7 ± 0.9	4.9	5.7 ± 0.1	5.7 ± 0.1
γ_{moist} (kN/m^3)	-	14.1 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	17.3 ± 0.6	-	19.6 ± 0.5	19.6 ± 0.5
σ_v (kPa)	-	96.8 ± 6.9	114.3	116.9 ± 6.4	116.9 ± 6.4
σ_v' (kPa)	-	87.7 ± 7.4	101.3	107.9 ± 4.0	107.9 ± 4.0
a_{max} (g)	-	0.460 ± 0.050	0.39	0.460 ± 0.069	0.460 ± 0.069
r_d	-	0.83 ± 0.019	0.92	0.83 ± 0.019	0.83 ± 0.044
CSR	-	0.263 ± 0.041	0.252	0.269 ± 0.041	0.269 ± 0.043
M_w	-	7.00	6.93	6.93	6.93
D_{50}	-	0.120 ± 0.010	-	0.120 ± 0.034	0.120 ± 0.034
% Fines	-	27.0 ± 5.0	32	27.3 ± 11.9	27.3 ± 11.9
% PI	-	-	-	-	NAV
N	-	10.4 ± 3.7	9.2	10.3 ± 3.7	10.6 ± 3.8
C_R	-	0.94	0.95	0.94	0.95
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.13	1.13	1.13	1.13
C_N	-	1.05	1.00	0.97	0.97
$(N_1)_{60}$	-	11.6 ± 4.1	9.9	10.7 ± 3.8	11.0 ± 3.9
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

EVENT PARAMETERS

1989 Loma Prieta Earthquake USGS, Graves and Pitarka (2004), Toprak et al. (1999), Holzer et al. (1998)

Magnitude: 6.93

Fault Type: reverse-obliqu Z_{tor} (km): 3.85 R_{rup} (km): -

Dip: 70 Width (km): 20 R_{jb} (km): 6.3

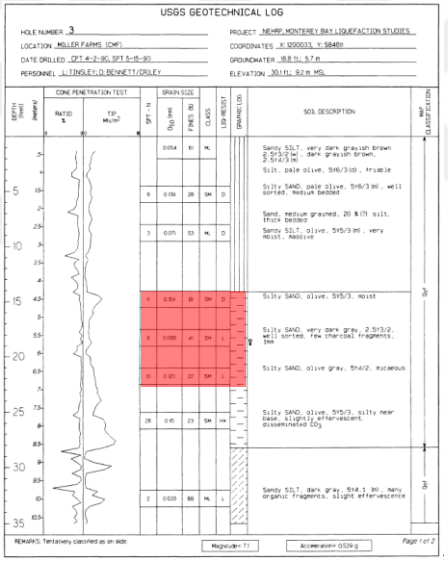
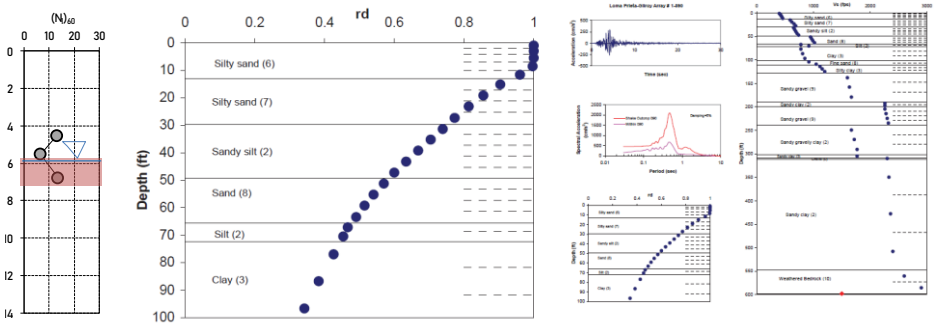


Table 2. Index properties of subsurface and surface samples

SITE	DEPTH (FT)	DEPTH RANGE	SPT N	G	S	M	C	D50 mm	Cu	USC	Name	Wn	LL	PI	LI	ACT
CLINT MILLER FARMS (CMF)																
CMF1-1	1.5	auger		0	13	52	35	0.011		ML	SILT		44	16		0.7
CMF1-2	3.0	2-3.5	6	0	34	53	13	0.048	17	ML	Sandy SILT	20	28	1	-7.5	0.1
CMF1-3	6.5	6-7.5		0	9	79	12	0.038	12	ML	SILT	29				
CMF1-4	7.3	6-7.5	6	0	3	53	44	0.007		mh	elastic silt					
CMF1-5	11.0	10-11.5	17	0	2	30	68	0.002		MH	Elastic SILT	35	68	32	0	0.7
CMF1-6	16.0	15-16.5	3	0	30	60	10	0.051	12	ML	Sandy silt	31	27	2	3.2	0.4
CMF1-7	26.0	25-26.5	3	0	2	85	13	0.027	8	ML	SILT	31	32	5	0.9	0.8
CMF1-8	36.0	35-36.5	16	0	66	26	8	0.120	16	SM	Silty SAND	27				
CMF1-9	49.5	48.5-50	23	0	84	13	3	0.277	13	SM	Silty SAND	25				
CMF2-1	3.0	2-3.5	5	0	42	44	14	0.060	27	ML	Sandy SILT					
CMF2-2	6.0	5-6.5	6	0	22	69	9	0.047	9	ML	SILT with sand	26	26	0		
CMF2-3	13.5	12.5-14	2	0	25	53	22	0.024		ML	SILT with sand	23	28	4	-0.2	0.3
CMF2-4	23.0	22-23.5	3	0	5	84	11	0.036	10	ML	SILT	35	31	1	4.9	0.2
CMF2-5	35.0	34-35.5	23	0	62	26	12	0.103	31	SM	Silty SAND	28				
CMF3-1	1.0	auger		0	39	45	16	0.054	42	ML	Sandy SILT		24	0		
CMF3-2	5.5	4.5-6	6	0	72	19	9	0.139	26	SM	Silty SAND	7				
CMF3-3	9.0	8-9.5	3	0	47	45	8	0.071	10	ML	Sandy SILT	26	23	0		
CMF3-4	15.0	14-15.5	11	0	81	12	7	0.154	16	SM	Silty SAND	28				
CMF3-5	18.5	17.5-19	6	0	59	36	5	0.086	6.5	SM	Silty SAND	29				
CMF3-7	22.0	21-22.5	13	0	78	17	5	0.120	3.9	SM	Silty SAND	28				
CMF3-8	26.0	25-26.5	26	0	77	20	3	0.115	3.6	SM	Silty SAND	24				
CMF3-9	33.0	32-33.5	2	0	34	52	14	0.033	19	ML	Sandy SILT	33	29	6	1.7	1.0
CMF3-10	46.0	45-46.5	23	0	70	22	8	0.133	20	SM	Silty SAND	29				
CMF3-12	50.0	49-50.5	30	7	81	12		0.360		SM	Silty SAND	25				
CMF3-13	55.0	54-55.5	50	4	85	11		0.430	9	SW-SM	SAND with silt	23				
CMF5-1	6.0	5-6.5	7	0	50	43	7	0.076	14	SM	silty SAND	24				
CMF5-2	11.0	10-11.5	27	0	90	10		0.223	3.3	SP-SM	SAND with silt	12				
CMF5-3	14.0	13-14.5	15	0	90	10		0.244	3.8	SP-SM	SAND with silt	25				
CMF5-4	16.8	16-17.5		0	9	79	12	0.042	15	ML	SILT					
CMF5-5	17.5	16-17.5	5	0	84	14	2	0.146	3.3	SM	silty SAND	23				
CMF5-6	23.0	22-23.5	20	0	87	13		0.185	4.3	SM	silty SAND	22				
CMF5-7	34.5	33.5-35	24	0	91	9		0.230	3.4	SP-SM	SAND with silt	24				

Cetin (2000)

Miller Farm CMF 3 - Loma Prieta Earthquake (1989)



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC %	D_{50} (mm)	Gravel	Sand	Silt	Clay	USCS
4.5	*14.8*		*11*	*1.14*	*0.92*	*13.0*	*19.0*	*0.154*	*0*	*81*	*12*	*7*	SM
5.5	*18.0*		*6*	*1.03*	*0.93*	*6.5*	*41.0*	*0.086*	*0*	*59*	*36*	*5*	SM
6.75	*22.1*		*13*	*0.96*	*0.95*	*13.5*	*22.0*	*0.120*	*0*	*78*	*17*	*5*	SM
					Mean:	11.0	27.3	0.120	0.0	72.7	21.7	5.7	
					St. Dev.	3.9	11.9	0.034	5.9	11.9	12.7	1.2	

Case number:	130
Earthquake:	Loma Prieta
Magnitude:	6.93 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Miller Farm CMF 5
References:	Bennett and Tinsley (1995), Cetin (2000), Cetin et al (2004, 2018), NGL Project
Nature of Failure:	Lateral spread, slide, and sand boils.
GPS LAT	36.907471
GPS LONG	-121.7407732
Liq. layer consist of:	SM
Geological Unit:	younger and older holocene fluvial deposits
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "Located at the east of Watsonville, Monterey. Both SPT and CPT test were performed. Surface samples were taken. Grain size characteristices were given in detail. Usually SPT's were made 3-5 ft away from the CPT boreholes to obtain samples. SPT procedures followed the guidelines outlined in D1586-67 (ASTM). Hollow-stem augers (10" outside diameter, 4" inside diameter with split liners) 140 lb "inhole sampling hammer dropped at 30" height by "Safe-T-Driver" hoist. The overall efficiency of the hammer-hoist system is 68 %. Undisturbed samples were taken using thin-walled Shelby tubes. PGA is recorded in a four-story building 1km west of Miller Farm as 0.39 g. In Open File Report 95-663, Holzer et al., the PGA was given as 0.53 g. Watsonville region was shaken at MMI scale of 8.(~ 0.25-0.50 g ?). The earthquake specific attenuation-relationship suggests for alluvium sites at 4.6 miles (closest distance to the fault) ~0.50-0.65 g. A PGA value of 0.36 g was recorded at Watsonville. Based on site response analyses results, a PGA value of 0.41g is adopted. Strong ground motion lasted ~ 6 seconds. CMF3-5-8-10 are ~ 1000 ft apart. SPT performed after the earthquake."
	Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?		Yes	Yes	Yes	Yes
Data Class		B	-	B	B
d_{crtc} range (m)		5.5 - 8.5		5.5 - 8.5	5.5 - 8.5
d_{crt} (m)		7.0	7.0	7.0	7.0
GWT (m)		4.7 ± 0.3	4.7	4.7 ± 0.1	4.7 ± 0.1
γ_{moist} (kN/m^3)		15.7 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)		18.1 ± 0.6	-	19.6 ± 0.5	19.6 ± 0.5
σ_v (kPa)		115.7 ± 9.7	130.3	134.1 ± 10.1	134.1 ± 10.1
σ_v' (kPa)		93.1 ± 5.8	108.3	111.5 ± 5.6	111.5 ± 5.6
a_{max} (g)		0.410 ± 0.050	0.39	0.410 ± 0.062	0.410 ± 0.062
r_d		0.90 ± 0.016	0.91	0.90 ± 0.016	0.90 ± 0.047
CSR		0.290 ± 0.039	0.28	0.288 ± 0.044	0.288 ± 0.047
M_w		7.00	6.93	6.93	6.93
D_{50}		0.185 ± 0.020	-	0.185 ± 0.050	0.185 ± 0.050
% Fines		13.0 ± 2.0	13	13.0 ± 2.0	13.0 ± 8.6
% PI		-	-	-	NAV
N		20.0 ± 3.2	20	20.0 ± 1.9	20.0 ± 1.9
C_R		0.95	0.95	0.95	0.95
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.13	1.13	1.13	1.13
C_N		1.02	0.97	0.95	0.95
$(N_1)_{60}$		21.9 ± 3.5	20.9	20.6 ± 2.0	20.5 ± 2.0
V_{s30m} (m/s)		-	-	-	NAV
V_{s12m} (m/s)		160.0	-	160.0	NOT LISTED

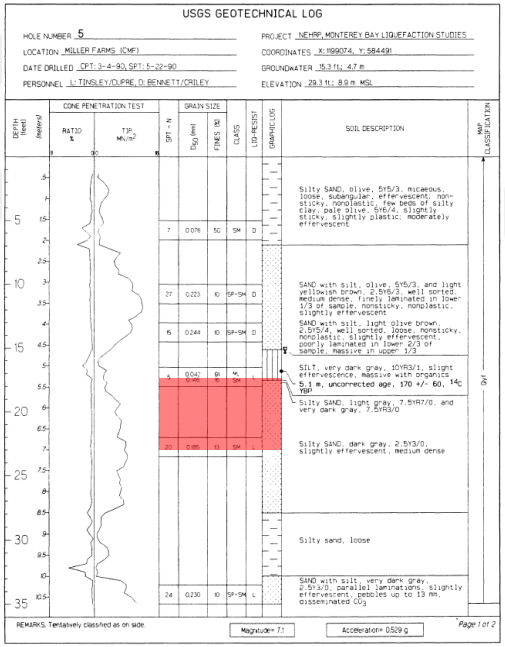
EVENT PARAMETERS

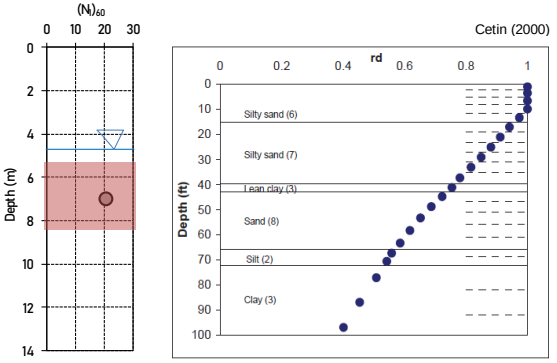
1989 Loma Prieta Earthquake — USGS, Graves and Pitarka (2004), Toprak et al. (1999), Holzer et al. (1998)

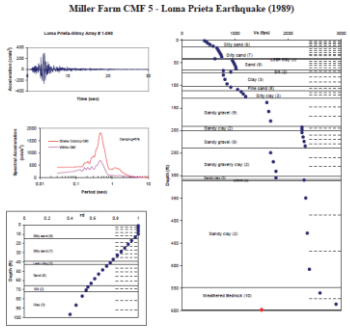
Magnitude: 6.93

Fault Type: reverse-obliqu — Z_{tor} (km): 3.85 — R_{rup} (km): -

Dip: 70 — Width (km): 20 — R_{jb} (km): 6.6







Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	Gravel	Sand	Silt	Clay	USCS	FC %	D_{50} (mm)
7	*23.0*		*20*	*0.95*	*0.95*	*20.5*	*0.0*	*87.0*	*13.0*	*0.0*	*SM*	*13*	*0.185*
					Mean:	20.5	0.0	87.0	13.0	0.0		13.0	0.185
					St. Dev.	2.0	5.9	2.0	8.3	2.3		8.6	0.050

Case number:	131
Earthquake:	Loma Prieta
Magnitude:	6.93 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Miller Farm CMF 8
References:	Bennett and Tinsley (1995), Cetin (2000), Cetin et al (2004, 2018), NGL
Nature of Failure:	Lateral spread, slide, and sand boils.
GPS LAT	36.9082916
GPS LONG	-121.7444089
Liq. layer consist of:	SM
Geological Unit:	younger and older holocene fluvial deposits
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "Located at the east of Watsonville, Monterey. Both SPT and CPT test were performed. Surface samples were taken. Grain size characteristices were given in detail. Usually SPT's were made 3-5 ft away from the CPT boreholes to obtain samples. SPT procedures followed the guidelines outlined in D1586-67 (ASTM). Hollow-stem augers (10" outside diameter, 4" inside diameter with split liners) 140 lb "inhole sampling hammer dropped at 30" height by "Safe-T-Driver" hoist. The overall efficiency of the hammer-hoist system is 68 %. Undisturbed samples were taken using thin-walled Shelby tubes. PGA is recorded in a four-story building 1km west of Miller Farm as 0.39 g. In Open File Report 95-663, Holzer et al., the PGA was given as 0.53 g. Watsonville region was shaken at MMI scale of 8 (~ 0.25-0.50 g ?). The earthquake specific attenuation-relationship suggests for alluvium sites at 4.6 miles (closest distance to the fault) ~0.50-0.65 g. A PGA value of 0.36 g was recorded at Watsonville Based on site response analyses results, a PGA value of 0.46 g is adopted. Strong ground motion lasted ~ 6 seconds. CMF3-5-8-10 are ~ 1000 ft apart. SPT performed after the earthquake."
	Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	5.0 - 8.0	-	5.0 - 8.0	5.0 - 8.0
d_{crt} (m)	-	6.5	6.0	6.5	6.5
GWT (m)	-	4.9 ± 0.3	4.4	4.9 ± 0.1	4.9 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	15.7 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-	98.5 ± 8.5	111.3	107.4 ± 9.8	107.4 ± 9.8
σ_v' (kPa)	-	82.8 ± 5.2	95.2	91.7 ± 5.2	91.7 ± 5.2
a_{max} (g)	-	0.460 ± 0.050	0.39	0.460 ± 0.069	0.460 ± 0.069
r_d	-	0.73 ± 0.013	0.93	0.73 ± 0.013	0.73 ± 0.044
CSR	-	0.250 ± 0.032	0.274	0.256 ± 0.040	0.256 ± 0.043
M_w	-	7.00	6.93	6.93	6.93
D_{50}	-	0.200 ± 0.030	-	0.203 ± 0.085	0.203 ± 0.085
% Fines	-	15.0 ± 2.0	25	15.5 ± 2.1	15.5 ± 2.1
% PI	-	-	-	-	NAV
N	-	9.0 ± 0.9	8.8	9.0 ± 0.9	9.0 ± 1.8
C_R	-	0.94	0.95	0.94	0.94
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.13	1.13	1.13	1.13
C_N	-	1.08	1.03	1.05	1.05
$(N_1)_{60}$	-	10.3 ± 1.0	9.8	10.0 ± 1.0	10.1 ± 2.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

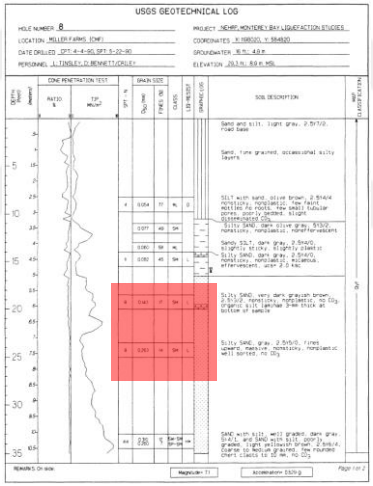
EVENT PARAMETERS

1989 Loma Prieta Earthquake — USGS, Graves and Pitarka (2004), Toprak et al. (1999), Holzer et al. (1998)

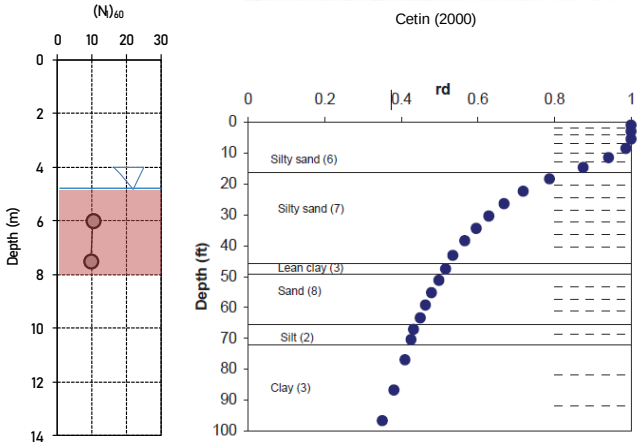
Magnitude: 6.93

Fault Type: reverse-obliqu — Z_{tor} (km): 3.85 — R_{rup} (km): -

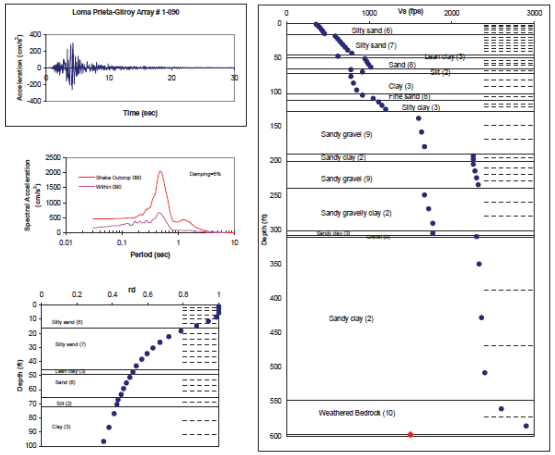
Dip: 70 — Width (km): 20 — R_{jb} (km): 6.8



Cetin (2000)



Miller Farm CMF 8 - Loma Prieta Earthquake (1989)



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	D50	Gravel	Sand	Silt	Clay	USCS
6	*19.7*		*9*	*1.08*	*0.94*	*10.3*	*17.0*	*0.143*	*0*	*83*	*13*	*4*	*SM*
7.5	*24.6*		*9*	*1.00*	*0.95*	*9.8*	*14.0*	*0.263*	*0*	*86*	*14*	*0*	*SM*
					Mean:	10.1	15.5	0.203	0.0	84.5	13.5	2.0	
					St. Dev.	2.0	2.1	0.1	5.9	2.1	0.7	2.8	

Case number:	132
Earthquake:	Loma Prieta
Magnitude:	6.93 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Port of Oakland (POO7-2)
References:	Mitchell et al. (1994), Kayen et al. (1998), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Significant settlements (max ~ 30 cm.) occurred over most of the fill.
GPS LAT	37.8043 — Significant lateral spreading along most of the fill, causing longitudinal fissures.
GPS LONG	-122.3395 — A 10 m diameter. 0.3 m high sand boil was observed in the paved container
Liq. layer consist of:	clean sand — south of the C.F.S. Building near Berth 38.
Geological Unit:	artificial fill
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "Mitchell et al. (1994), Insitu test results from four Loma Prieta Earthquake liquefaction sites: SPT, CPT, DMT and Shear Wave Velocity Kayen et al. (1998), Soil Liquefaction in the East Bay during the earthquake. Located immediately south of the San Francisco - Oakland Bay Bridge. Most of the surface fills at the Port of Oakland were hydraulically placed to sea level, above which a combination of hydraulic fill and dumped fill was placed. A relatively thick asphalt was laid on top of the unimproved fill. Underlain by 180 m of stiffer Pleistocene glacial and interglacial deposits. Upper 3-4 m, surface layer of high penetration resistance; below this layer lies a looser deposits of marine sand. Liquefaction appears to have occurred in the depth range of 4-8 m. PGA is recorded as 0.29 & 0.27g at the Oakland Outer Harbor seismogram which is located on a 155 m deep soil site. PGA is estimated as 0.22 g based on site response analyses results. Measurements performed after the earthquake. The POO7-2 and POO7-3 are approximately 15 m apart."
	Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
	PI is assigned as 0 since FC=3%
	Kayen et al. (1998) "Standard penetration tests (SPT) were performed in shallow 10-cm (4 in.)-diameter uncased rotary-wash boreholes drilled with CME model 450 and 750 drill rigs, following the guidelines of the American Society for Testing and Materials (1984). SPT-energy calibrations, using the stresswave method (Farrar, 1991), were made on a CME model 450 drill rig to adjust the field-measured standard penetration resistance, N, to a normalized 60-percent-hammer-efficiency blowcount, (N1)^60)."
Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	A	-	A	A
d_{crtc} range (m)	-	5.5 - 6.8		5.5 - 6.8	5.5 - 6.8
d_{crt} (m)	-	6.2	6.3	6.2	6.2
GWT (m)	-	3.0 ± 0.6	3	3.0 ± 0.1	3.0 ± 0.1
γ_{moist} (kN/m^3)	-	18.1 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	18.1 ± 0.6	-	19.6 ± 0.5	19.6 ± 0.5
σ_v (kPa)	-	111.4 ± 4.8	121.3	118.7 ± 4.7	118.7 ± 4.7
σ_v' (kPa)	-	80.4 ± 6.8	89.2	87.7 ± 3.1	87.7 ± 3.1
a_{max} (g)	-	0.220 ± 0.010	0.28	0.220 ± 0.033	0.220 ± 0.033
r_d	-	0.95 ± 0.018	0.92	0.86 ± 0.018	0.86 ± 0.042
CSR	-	0.165 ± 0.014	0.229	0.166 ± 0.025	0.166 ± 0.026
M_w	-	7.00	6.93	6.93	6.93
D_{50}	-	0.300 ± 0.030	-	0.300 ± 0.050	0.300 ± 0.050
% Fines	-	3.0 ± 1.0	3	3.0 ± 2.0	3.0 ± 8.6
% PI	-	-	-	-	0
N	-	12.7 ± 3.0	14.4	12.7 ± 3.1	12.8 ± 3.0
C_R	-	0.93	0.95	0.93	0.94
C_S	-	1.10	1.10	1.10	1.10
C_B	-	1.00	1.00	1.00	1.00
C_E	-	0.92	0.92	0.92	0.92
C_N	-	1.09	1.11	1.08	1.08
$(N_1)_{60}$	-	13.0 ± 3.1	15.4	12.8 ± 3.1	13.0 ± 3.1
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

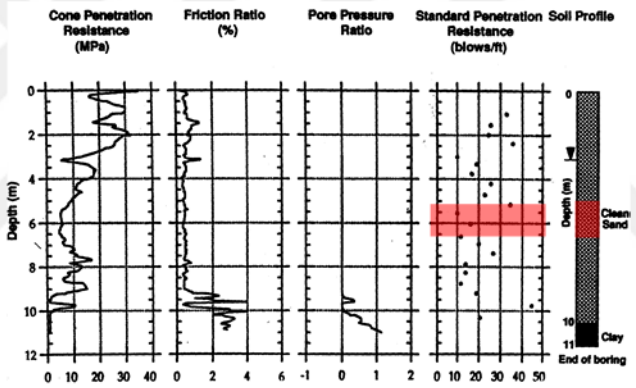
EVENT PARAMETERS

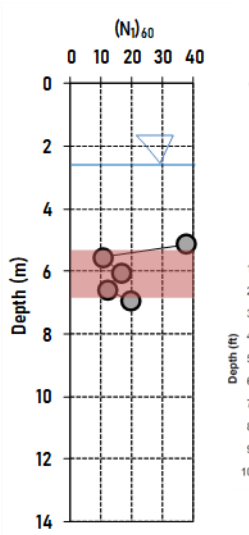
1989 Loma Prieta Earthquake — USGS, Graves and Pitarka (2004), Toprak et al. (1999), Holzer et al. (1998)

Magnitude: 6.93

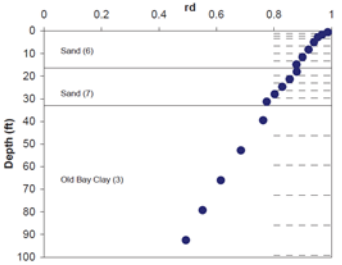
Fault Type: reverse-obliqu — Z_{tor} (km): 3.85 — R_{rup} (km): -

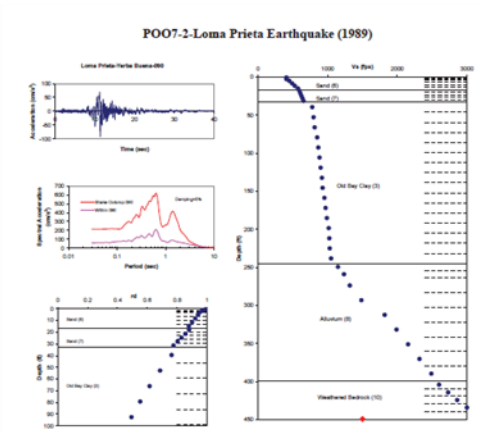
Dip: 70 — Width (km): 20 — R_{jb} (km): 77.5





CSR is estimated by site response by Cetin (2000)





Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
5.15	16.9		35	1.14	0.93	37.3	clean sand
5.55	***18.2***		***10***	***1.11***	***0.93***	***10.5***	clean sand
6.05	***19.8***		***16***	***1.08***	***0.94***	***16.4***	clean sand
6.6	***21.7***		***12***	***1.05***	***0.95***	***12.0***	clean sand
6.95	22.8		20	1.03	0.95	19.7	clean sand
					Mean:	13.0	
					St. Dev.	3.1	

Case number:	133
Earthquake:	Loma Prieta
Magnitude:	6.93 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Port of Oakland (POO7-3)
References:	Mitchell et al. (1994), Kayen et al. (1998), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Significant settlements (max ~ 30 cm.) occurred over most of the fill.
GPS LAT	37.8043 — Significant lateral spreading along most of the fill, causing longitudinal fissures
GPS LONG	-122.3395 — A 10 m diameter. 0.3 m high sand boil was observed in the paved container
Liq. layer consist of:	clean sand — south of the C.F.S. Building near Berth 38.
Geological Unit:	artificial fill — Muddy sand unit at depths 5-7 m
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "Mitchell et al. (1994), Insitu test results from four Loma Prieta Earthquake liquefaction sites: SPT, CPT, DMT and Shear Wave Velocity Kayen et al. (1998), Soil Liquefaction in the East Bay during the earthquake Located immediately south of the San Francisco - Oakland Bay Bridge. Most of the surface fills at the Port of Oakland were hydraulically placed to sea level, above which a combination of hydraulic fill and dumped fill was placed. A relatively thick asphalt was laid on top of the unimproved fill Underlain by 180 m of stiffer Pleistocene glacial and interglacial deposits Upper 3-4 m, surface layer of high penetration resistance; Below this layer lies a looser deposits of marine sand. Borehole is characterized by high N values (~21) for the entire submerged soil profile, except for a muddy-sand unit between 5-7m depth. Liquefied? PGA is recorded as 0.29 & 0.27g at the Oakland Outer Harbor seismogram which is located on a 155 m deep soil site. PGA is estimated as 0.22 g based on site response analyses results. Measurements performed after the earthquake. The POO7-2 and POO7-3 are approximately 15 m apart. The SPT blowcount (~22) at depth ~6.6 m does not appear on the borelog excel spreadsheet given in Appedix of Mitchell et al. Eliminated for the analysis."
	SPT values were updated in Cetin et al (2018), it is again updated to be the same as given Cetin (2000).
	Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
	PI is assigned as 0 since FC=5%
	Kayen et al. (1998) "Standard penetration tests (SPT) were performed in shallow 10-cm (4 in.)-diameter uncased rotary-wash boreholes drilled with CME model 450 and 750 drill rigs, following the guidelines of the American Society for Testing and Materials (1984). SPT-energy calibrations, using the stresswave method (Farrar, 1991), were made on a CME model 450 drill rig to adjust the field-measured standard penetration resistance, N, to a normalized 60-percent-hammer-efficiency blowcount, (N1)^60)."
Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

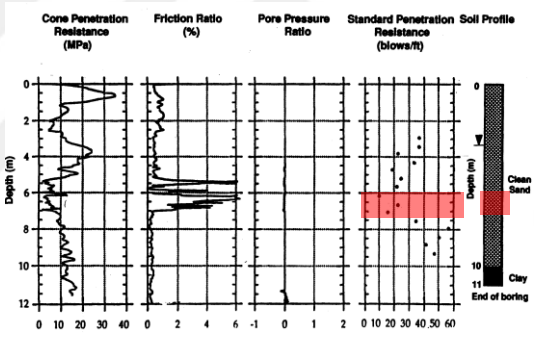
Summary of Input Data

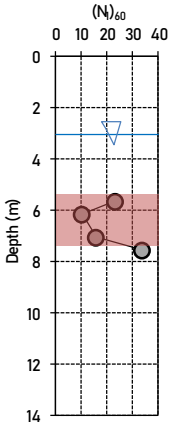
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	marginal	Yes	Yes
Data Class	-	B	-	A	A
d_{crtc} range (m)	-	6.0 - 7.0		5.0 - 7.0	5.0 - 7.0
d_{crt} (m)	-	6.5	6.3	6.0	6.0
GWT (m)	-	3.0 ± 0.3	3	3.0 ± 0.1	3.0 ± 0.1
γ_{moist} (kN/m^3)	-	18.1 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	18.1 ± 0.6	-	19.6 ± 0.5	19.6 ± 0.5
σ_v (kPa)	-	117.7 ± 4.2	121.3	115.7 ± 6.9	115.7 ± 6.9
σ_v' (kPa)	-	83.3 ± 4.4	89.2	86.3 ± 3.9	86.3 ± 3.9
a_{max} (g)	-	0.220 ± 0.010	0.28	0.220 ± 0.033	0.220 ± 0.033
r_d	-	0.83 ± 0.018	0.92	0.83 ± 0.018	0.83 ± 0.041
CSR	-	0.164 ± 0.011	0.229	0.159 ± 0.024	0.159 ± 0.025
M_w	-	7.00	6.93	6.93	6.93
D_{50}	-	0.320 ± 0.020	-	0.320 ± 0.050	0.320 ± 0.050
% Fines	-	5.0 ± 1.0	3	5.0 ± 2.0	5.0 ± 6.4
% PI	-	-	-	-	0
N	-	13.0 ± 4.0	16	16.2 ± 6.4	15.9 ± 6.2
C_R	-	0.94	0.95	0.92	0.94
C_S	-	1.10	1.10	1.10	1.10
C_B	-	1.00	1.00	1.00	1.00
C_E	-	0.92	0.92	0.92	0.92
C_N	-	1.07	1.10	1.09	1.09
$(N_1)_{60}$	-	13.2 ± 4.1	17	16.4 ± 6.5	16.3 ± 6.4
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

EVENT PARAMETERS

1989 Loma Prieta Earthquake — USGS, Graves and Pitarka (2004), Toprak et al. (1999), Holzer et al. (1998)

Magnitude: 6.93
Fault Type: reverse-obliqu — Z_{tor} (km): 3.85 — R_{rup} (km): -
Dip: 70 — Width (km): 20 — R_{jb} (km): 77.5





In Cetin et al 2018 SPT data was errounously edited now it is fixed.

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
5.65	*18.5*		*22*	*1.11*	*0.93*	*22.9*
6.15	*20.2*		*10*	*1.08*	*0.94*	*10.2*
7.05	*23.1*		*16*	*1.03*	*0.95*	*15.7*
7.55	24.8		35	1.00	0.95	33.7
					Mean:	16.3
					St. Dev.	6.4

Case number:	134
Earthquake:	Loma Prieta
Magnitude:	6.93 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Port of Richmond (POR-2&3&4)
References:	Mitchell et al. (1994), Kayen et al. (1998), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Four large and a dozen smaller sand boils vented fine sand and silty sand
GPS LAT	37.91028
GPS LONG	-122.35939
Liq. layer consist of:	silt and silty sand
Geological Unit:	uncompacted sandy hydraulic fill
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "Mitchell et al. (1994), Insitu test results from four Loma Prieta Earthquake liquefaction sites: SPT, CPT, DMT and Shear Wave Velocity Kayen et al. (1998), Soil Liquefaction in the East Bay during the earthquake The site represents the most distant point, approximately 85 km north of the rupture zone. The liquefaction zone overlies deposits of soft bay mud, underlain by deeper deposits of stiffer, overconsolidated noncohesive and cohesive soils. Up to 0.8 m depth the soil is characterized by oxidized, tan-brown crusted silty sand. 0.8-1.8 m oxidized tan-brown silty sand. 1.8-4.1 m oxidized tan-brown sandy clay to reduced sandy clay.4.1-7.8 m, is a hydraulic fill layer of olive-gray fine-silty sand containing shell fragments. The thick deposits amplified the level of ground motion at the site. At adjacent sites (POR-3 & 4) SPT, CPT and shear wave velocity tests were performed. POR-2 &3&4 are aprroximately 10-15m apart. Correlated? PGA is estimated as 0.18 g by performing a site response analysis (SHAKE) using the input motion from Richmond City Hall (PGA=0.13g ~2km) by Kayen et al. Based on site response analyses results performed by using the recording scaled to the geometric mean of the two orthonormal components. PGA is estimated as 0.15. The SPT blowcount ~11 is eliminated due to unrepresentative nature of it. Depth to water table in Kayen et al. (1998) is reported as 2.5 m contrary to 3.5 m reported in Mitchell et al. (1994)."
	Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
	Kayen et al. (1998) "Standard penetration tests (SPT) were performed in shallow 10-cm (4 in.)-diameter uncased rotary-wash boreholes drilled with CME model 450 and 750 drill rigs, following the guidelines of the American Society for Testing and Materials (1984). SPT-energy calibrations, using the stresswave method (Farrar, 1991), were made on a CME model 450 drill rig to adjust the field-measured standard penetration resistance, N, to a normalized 60-percent-hammer-efficiency blowcount, (N1)^60)."
Gravel Content (%):	8.00
CPT available:	No
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	A	-	A	A
d_{crtc} range (m)	-	4.0 - 5.8		4.0 - 5.8	4.0 - 5.8
d_{crt} (m)	-	4.9	5.9	4.9	4.9
GWT (m)	-	3.5 ± 0.3	3.5	3.5 ± 0.1	3.5 ± 0.1
γ_{moist} (kN/m^3)	-	13.4 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	14.1 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
σ_v (kPa)	-	66.6 ± 4.9	97.2	79.3 ± 5.5	79.3 ± 5.5
σ_v' (kPa)	-	52.9 ± 3.9	73.2	65.6 ± 3.0	65.6 ± 3.0
a_{max} (g)	-	0.150 ± 0.013	0.18	0.150 ± 0.023	0.150 ± 0.023
r_d	-	0.71 ± 0.017	0.93	0.78 ± 0.017	0.78 ± 0.034
CSR	-	0.090 ± 0.010	0.142	0.092 ± 0.014	0.092 ± 0.015
M_w	-	7.00	6.93	6.93	6.93
D_{50}	-	0.090 ± 0.010	-	0.090 ± 0.050	0.090 ± 0.050
% Fines	-	50.0 ± 5.0	50	50.0 ± 2.0	50.0 ± 8.6
% PI	-	-	-	-	NAV
N	-	3.2 ± 1.0	4.3	3.2 ± 1.0	3.1 ± 1.0
C_R	-	0.89	0.95	0.89	0.92
C_S	-	1.10	1.10	1.10	1.10
C_B	-	1.00	1.00	1.00	1.00
C_E	-	0.92	0.92	0.92	0.92
C_N	-	1.35	1.27	1.24	1.24
$(N_1)_{60}$	-	3.8 ± 1.2	5.1	3.5 ± 1.1	3.6 ± 1.1
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

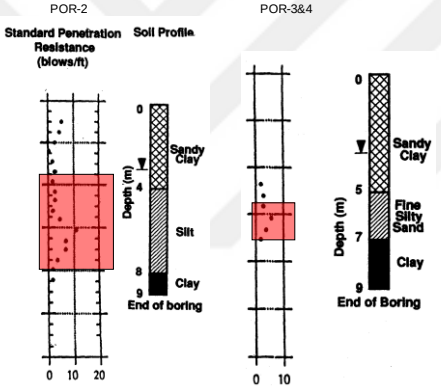
EVENT PARAMETERS

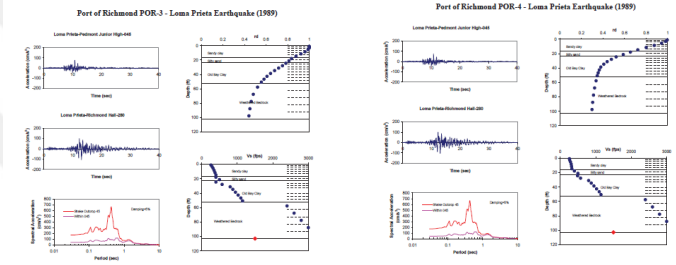
1989 Loma Prieta Earthquake — USGS, Graves and Pitarka (2004), Toprak et al. (1999), Holzer et al. (1998)

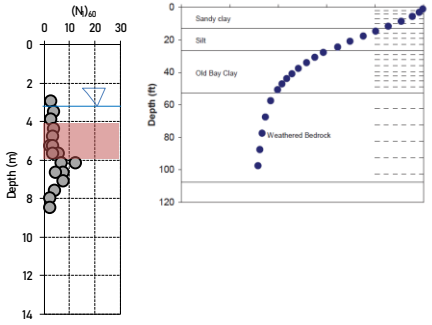
Magnitude: 6.93

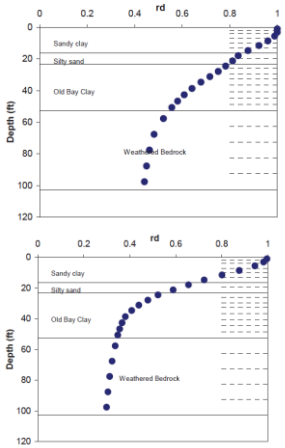
Fault Type: reverse-obliqu — Z_{tor} (km): 3.85 — R_{rup} (km): -

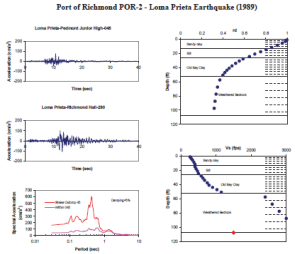
Dip: 70 — Width (km): 20 — R_{jb} (km): 89.0











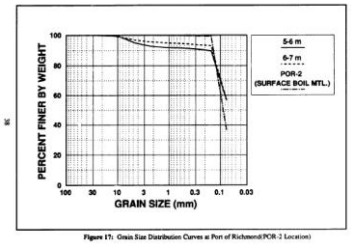


Figure 17: Grain Size Distribution Curves at Port of Richmond(POR-2 Location)

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		
2.95	9.7		2	1.48	0.88	2.6	POR-2	sandy clay
3.45	11.3		3	1.37	0.90	3.7	POR-2	sandy clay
3.85	12.6		2	1.33	0.90	2.4	POR-2	sandy clay
4.35	*14.3*		*3*	*1.29*	*0.91*	*3.5*	*POR-2*	silt
4.75	*15.6*		*3*	*1.26*	*0.92*	*3.5*	*POR-2*	silt
5.25	*17.2*		*2*	*1.22*	*0.93*	*2.3*	*POR-2*	silt
5.25	*17.2*		*3*	*1.22*	*0.93*	*3.4*	*POR-3&4*	Fine silty SAND
5.65	*18.5*		*5*	*1.19*	*0.93*	*5.6*	*POR-2*	silt
5.65	*18.5*		*3*	*1.19*	*0.93*	*3.4*	*POR-3&4*	Fine silty SAND
6.15	20.2		11	1.16	0.94	12.1	POR-2	silt
6.15	20.2		6	1.16	0.94	6.6	POR-3&4	Fine silty SAND
6.65	21.8		7	1.14	0.95	7.6	POR-2	silt
6.65	21.8		4	1.14	0.95	4.3	POR-3&4	Fine silty SAND
7.05	23.1		7	1.11	0.95	7.5	POR-2	silt
7.55	24.8		4	1.09	0.95	4.2	POR-2	silt
7.95	26.1		2	1.07	0.96	2.1	POR-2	silt
8.45	27.7		2	1.05	0.96	2.0	POR-2	silt
					Mean:	3.6		
					St. Dev.	1.1		

Depth (m)			
0	*4*	*sandy clay*	*POR-2*
4	*8*	*silt*	
8	*9*	*CLAY*	
0	*5*	*sandy clay*	*POR-3&4*
5	*7*	*Fine silty SAND*	
7	*9*	*CLAY*	

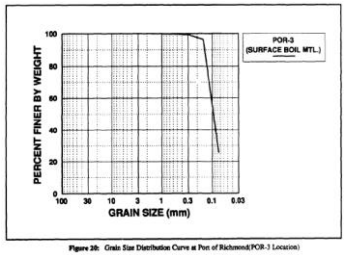


Figure 20: Grain Size Distribution Curve at Port of Richmond(POR-3 Location)

Case number:	135
Earthquake:	Loma Prieta
Magnitude:	6.93 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Sandholdt Road UC-B10
References:	Boulanger et al. (1996), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Extensive ground deformations were observed along Sandholdt Road,
GPS LAT	36.800944 including the portion alongside the MBARI facilities. Cracks parallel to the front
GPS LONG	-121.788075 line. Away from Sandholdt Road, surface evidence of liquefaction appeared to
Liq. layer consist of:	sand with interlayers of gravelly sand and sandy gravel occur in localized areas.
Geological Unit:	Holocene deposit
Site Response Anlaysis:	rd is estimated from event-specific site response analysis.
Comments:	Cetin (2000) "Located on Monterey Bay about midway between the cities of Santa Cruz and Monterey, CA. The MBARI facilities include three main buildings and a pier located along Sandholt Road on the Moss Landing spit. Historical shoreline suggest that the shoreline in the vicinity of the site has fluctuated significantly. Shallower soil strata may have been deposited recently. The area is underlain by Holocene deposits consisting of relatively thick sands offshore and estuarine and fluvial deposits onshore, up to about 60-m deep. The Moss Landing spit is underlain by littoral soils comprising eolian, fluvial, estuarine, and beach deposits of gravel, sand, silt, and clay deposited in a shoreline environment within the zone of tidal fluctuation. Pleistocene and miocene deposits extend to a depth of ~2000 m The site is underlain by an 8-12 m thick layer of poorly graded sand with interlayers of gravelly sand and sandy gravel in its lower portion and occasional thin layers of clayey silt throughout. PGA is recorded in a four-story building 8km from rupture plane as 0.39 g which is underlain by alluvium. Also San Juan Bautista seismogram, ~20 km from the rupture plane recorded 0.15 g (stiff alluvium). The Moss Landing area is located ~21 km from the rupture plane. Due to deep alluvium which is soft near the surface, PGA at the site is predicted in the range of 0.2-0.3 g. PGA is chosen for the analysis as 0.26 g almost identical with the value chosen by the authors of the source document (0.25 g) ~30 ft away from 30 degree 15' slope. SPT performed after the earthquake."

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	B	-	A	A
d_{crtc} range (m)	-	1.8 - 3.7	-	2.4 - 4.0	2.4 - 4.0
d_{crt} (m)	-	2.7	3.0	3.2	3.2
GWT (m)	-	1.7 ± 0.3	1.8	1.7 ± 0.1	1.7 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-	42.5 ± 5.3	55.1	57.8 ± 4.9	57.8 ± 4.9
σ_v' (kPa)	-	32.1 ± 3.5	43.1	43.1 ± 2.7	43.1 ± 2.7
a_{max} (g)	-	0.260 ± 0.025	0.28	0.260 ± 0.039	0.260 ± 0.039
r_d	-	0.99 ± 0.008	0.97	0.99 ± 0.008	0.99 ± 0.024
CSR	-	0.230 ± 0.032	0.226	0.224 ± 0.035	0.224 ± 0.035
M_w	-	7.00	6.93	6.93	6.93
D_{50}	-	0.800 ± 0.100	-	0.800 ± 0.050	0.800 ± 0.050
% Fines	-	2.0 ± 2.0	2	2.0 ± 2.0	2.0 ± 8.6
% PI	-	-	-	-	NAV
N	-	9.5 ± 0.6	9.5	9.2 ± 3.8	9.2 ± 3.9
C_R	-	0.79	0.85	0.81	0.89
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.25	1.25	1.25	1.25
C_N	-	1.73	1.52	1.53	1.53
$(N_1)_{60}$	-	16.1 ± 1.0	15.3	14.3 ± 5.9	15.7 ± 6.7
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

EVENT PARAMETERS

1989 Loma Prieta Earthquake USGS, Graves and Pitarka (2004), Toprak et al. (1999), Holzer et al. (1998)

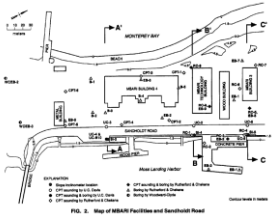
Magnitude: 6.93

Fault Type: reverse-obliqu Z_{tor} (km): 3.85 R_{rup} (km): -

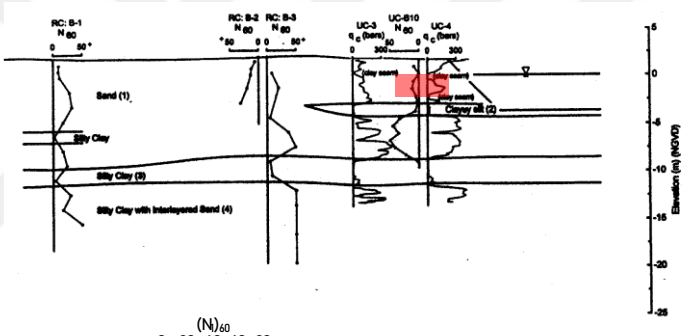
Dip: 70 Width (km): 20 R_{jb} (km): 18.0

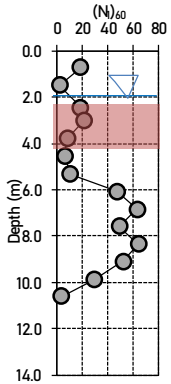
Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).

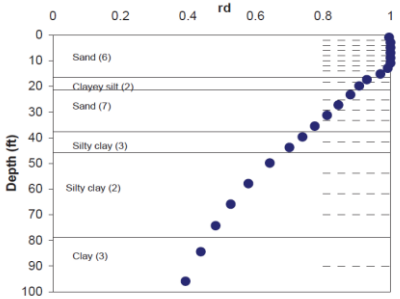
Boulanger et al. (1995) "SPT performed with rotary wash borings with energy measurments. Energy ratios of 75% were measured for a central mine equipment (CME) trip hammer. Energy ratios of 60% were estimated for a cat-head and rope system. CME-750 drill rig, CME 623 N (140-pound) automatic trip hammer, Rotary wash. " N60 values were provided by the same study. N60 values were digitized. CE is calculated as 1.25 by Idriss and Boulanger (2010) which corresponds to 75 % energy. Either digitized N60 values can be used directly and ER can be taken as 60% or N60 values can be backcalculated with ER=75% and CE can be calculated with ER as 75%. Both will give same result. As Idriss and Boulanger (2010) provided CE as 1.25



Gravel Content (%):	sand with interlayers of gravelly sand and sandy gravel (content unkonwn)
CPT available:	Yes
Vs available:	Yes







Boulanger et al (1995) provided N1,60 values
Boulanger et al (1997) provided N60 values

C_E
1.25
*Energy ratios of 75% were measured
*N60 values were provided by Boulanger et al. (1995)

N60	N
9	7
1	1
10	***8***
12	***10***
5	***4***
4	3
7	6
33	26
46	37
37	30
50	40
42	34
24	19
3	2

N values were back calculated.

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
0.7	2.4		9	2.00	0.82	*18.4*	sand with interlayers of gravelly sand and sandy gravel Fines=1-8%, D50=0.2-2.1 mm
1.5	4.9		1	1.99	0.84	*2.1*	sand with interlayers of gravelly sand and sandy gravel Fines=1-8%, D50=0.2-2.1 mm
2.4	***8.0***		***10***	***1.67***	***0.87***	***18.2***	sand with interlayers of gravelly sand and sandy gravel Fines=1-8%, D50=0.2-2.1 mm
3.0	***9.9***		***12***	***1.56***	***0.89***	***20.8***	sand with interlayers of gravelly sand and sandy gravel Fines=1-8%, D50=0.2-2.1 mm
3.8	***12.4***		***5***	***1.45***	***0.90***	***8.2***	sand with interlayers of gravelly sand and sandy gravel Fines=1-8%, D50=0.2-2.1 mm
4.5	14.9		4	1.36	0.92	*6.2*	clayey silt
5.3	17.5		7	1.28	0.93	*10.4*	clayey silt
6.1	19.9		33	1.21	0.94	*46.9*	sand with interlayers of gravelly sand and sandy gravel Fines=1-8%, D50=0.2-2.1 mm
6.9	22.5		46	1.15	0.95	*62.9*	sand with interlayers of gravelly sand and sandy gravel Fines=1-8%, D50=0.2-2.1 mm
7.6	24.8		37	1.11	0.96	*48.9*	sand with interlayers of gravelly sand and sandy gravel Fines=1-8%, D50=0.2-2.1 mm
8.4	27.4		50	1.06	0.96	*63.9*	sand with interlayers of gravelly sand and sandy gravel Fines=1-8%, D50=0.2-2.1 mm
9.1	29.8		42	1.03	0.97	*52.1*	sand with interlayers of gravelly sand and sandy gravel Fines=1-8%, D50=0.2-2.1 mm
9.9	32.4		24	0.99	0.97	*28.9*	sand with interlayers of gravelly sand and sandy gravel Fines=1-8%, D50=0.2-2.1 mm
10.6	34.8		3	0.96	0.98	*3.5*	silty clay
					Mean:	15.7	
					St. Dev.	6.7	

Case number:	136
Earthquake:	Loma Prieta
Magnitude:	6.93 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	San Francisco Oakland Bay Bridge (SFOBB-1&2)
References:	Mitchell et al. (1994), Kayen et al. (1998)
Nature of Failure:	Significant settlements (max ~ 40 cm.) occurred over most of the mole.
GPS LAT	37.824
GPS LONG	-122.314
Liq. layer consist of:	clean sand
Geological Unit:	fill
Site Response Anlaysis:	Yes

In some places differential settlements produced hummocky surface with permanent waves as large as 15 cm in amplitude.

Significant lateral spreading along most of the fill, causing longitudinal fissures.

Comments: Cetin (2000) "Mitchell et al. (1994), Insitu test results from four Loma Prieta Earthquake liquefaction sites: SPT, CPT, DMT and Shear Wave Velocity Kayen et al. (1998), Soil Liquefaction in the East Bay during the earthquake Significant settlements (max ~ 40 cm.) occurred over most of the mole. In some places differential settlements produced hummocky surface with permanent waves as large as 15 cm in amplitude. Significant lateral spreading along most of the fill, causing longitudinal fissures. Many of the fissures exuded fine to silty sand. Numerous sand boils erupted along the median strip of the roadway. Fissure width openings ~7-8 cm and exhibited maximum differential vertical offset of 3-5 cm. The San Francisco- Oakland Bay Bridge mole (peninsula-approach fill) is located at immediate south of Emeryville. SFOBB-1 was drilled at the easternmost end of the Toll Plaza Parking lot. No piezocone pore-pressure generation during cone penetration until bay mud was reached at 15 m depth. 0-2.8 m depth, moderately dense surface crust; 2.8-4.5 m interbedded sequence of cohesionless silty sand and cohesive clay. Between 4.5 to 7.5 m lies cohesionless material with low qc values ~5MPa. Drill rod and hammer sank under their own weight at 6.6 m depth. PGA is recorded as 0.29 & 0.27 at the Oakland Outer Harbor seismogram which is located on a 155 m deep soil site. PGA is estimated as 0.25 g based on site response analyses results. The average of recorded and site response based estimated PGA values was adopted. Depth to water table in Kayen et al. (1998) is reported as 2.0 m contrary to 3.0 m reported in Mitchell et al. (1994). Measurements performed after the earthquake. The measurements could be correlated with SFOBB-2."



Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).

Kayen et al. (1998) "Standard penetration tests (SPT) were performed in shallow 10-cm (4 in.)-diameter uncased rotary-wash boreholes drilled with CME model 450 and 750 drill rigs, following the guidelines of the American Society for Testing and Materials (1984). SPT-energy calibrations, using the stresswave method (Farrar, 1991), were made on a CME model 450 drill rig to adjust the field-measured standard penetration resistance, N, to a normalized 60-percent-hammer-efficiency blowcount, (N1)^60)."

Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	A	-	A	A
d_{crtc} range (m)	-	5.5 - 7.0		5.5 - 7.0	5.5 - 7.0
d_{crt} (m)	-	6.3	6.3	6.3	6.3
GWT (m)	-	3.0 ± 0.3	3	3.0 ± 0.1	3.0 ± 0.1
γ_{moist} (kN/m^3)	-	18.9 ± 0.8	-	18.9 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	18.9 ± 0.6	-	19.6 ± 0.5	19.6 ± 0.5
σ_v (kPa)	-	118.1 ± 5.7	118.3	120.7 ± 5.3	120.7 ± 5.3
σ_v' (kPa)	-	86.2 ± 4.9	86.2	88.7 ± 3.3	88.7 ± 3.3
a_{max} (g)	-	0.270 ± 0.010	0.27	0.270 ± 0.041	0.270 ± 0.041
r_d	-	0.77 ± 0.013	0.92	0.79 ± 0.013	0.79 ± 0.042
CSR	-	0.190 ± 0.010	0.222	0.189 ± 0.029	0.189 ± 0.030
M_w	-	7.00	6.93	6.93	6.93
D_{50}	-	0.280 ± 0.010	-	0.280 ± 0.050	0.280 ± 0.050
% Fines	-	8.0 ± 3.0	8	8.0 ± 2.0	8.0 ± 8.6
% PI	-	-	-	-	0
N	-	7.5 ± 2.0	7.5	7.5 ± 2.0	7.9 ± 3.2
C_R	-	0.93	0.95	0.93	0.94
C_S	-	1.20	1.20	1.20	1.20
C_B	-	1.00	1.00	1.00	1.00
C_E	-	0.92	0.92	0.92	0.92
C_N	-	1.06	1.10	1.07	1.07
$(N_1)_{60}$	-	8.1 ± 2.2	8.6	8.2 ± 2.2	8.8 ± 3.5
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

EVENT PARAMETERS

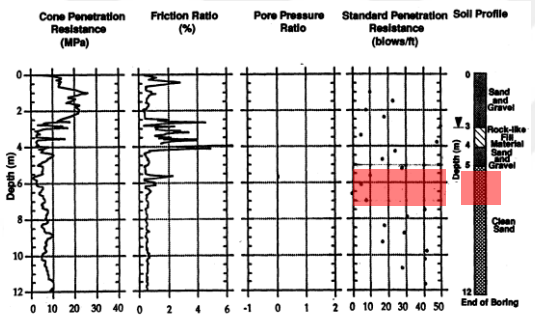
1989 Loma Prieta Earthquake — USGS, Graves and Pitarka (2004), Toprak et al. (1999), Holzer et al. (1998)

Magnitude: 6.93

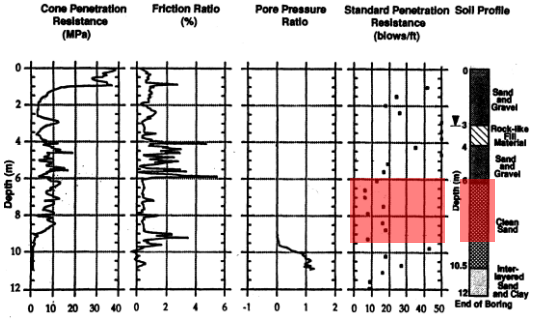
Fault Type: reverse-obliqu — Z_{tor} (km): 3.85 — R_{rup} (km): -

Dip: 70 — Width (km): 20 — R_{jb} (km): 78.7

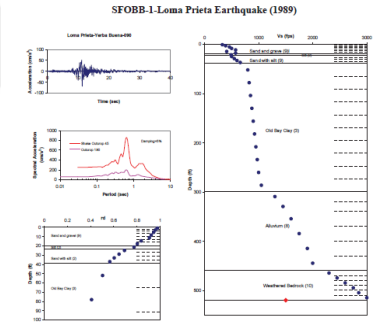
Cetin (2000)

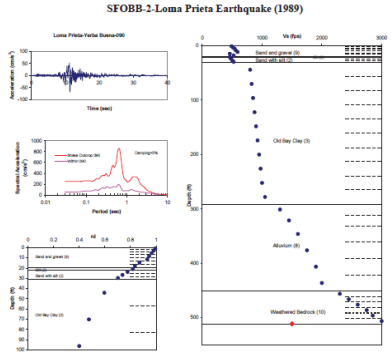


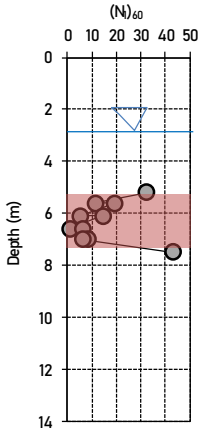
SFOBB-1

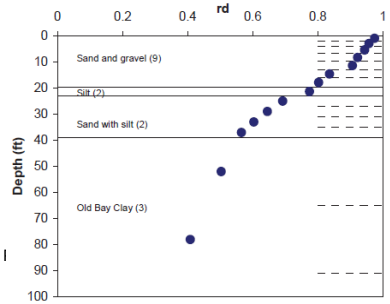


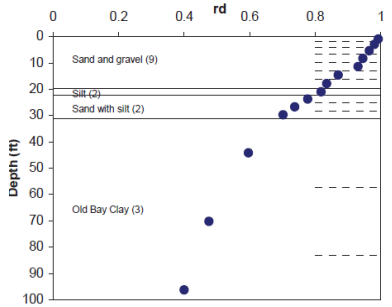
SFOBB-2











Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$			
5.2	17.1		28	1.14	0.93	32.5	SFOBB-1		clean sand
5.6	***18.4***		***10***	***1.11***	***0.93***	***11.4***	***SFOBB-1***		clean sand
5.6	18.4		17	1.11	0.93	19.4	SFOBB-2	Gravel?	clean sand
6.1	***20.0***		***5***	***1.08***	***0.94***	***5.6***	***SFOBB-1***		clean sand
6.1	***20.0***		***13***	***1.08***	***0.94***	***14.5***	***SFOBB-2***		clean sand
6.6	21.7		1	1.05	0.95	1.1	SFOBB-1	outlier exclude	clean sand
6.6	***21.7***		***6***	***1.05***	***0.95***	***6.5***	***SFOBB-2***		clean sand
7	***23.0***		***8***	***1.03***	***0.95***	***8.6***	***SFOBB-1***		clean sand
7	***23.0***		***6***	***1.03***	***0.95***	***6.4***	***SFOBB-2***		clean sand
7.5	24.6		41	1.00	0.95	43.2	SFOBB-1		clean sand
					Mean:	8.8			
					St. Dev.	3.5			

Case number:	137
Earthquake:	Loma Prieta
Magnitude:	6.93 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Moss Landing State Beach UC-B1
References:	Boulanger et al. (1996), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefaction-induced lateral spreading caused extensive damage to the access road. The tide gate was destroyed due to liquefaction flow slide. Road surface slumping about 1.3 m. Lateral spreading were roughly 0.3-0.6 m horizontal with vertical offset up to 0.3 m. Sand boils and ground cracks on the north side of the access road.
GPS LAT	36.8167
GPS LONG:	-121.789345
Liq. layer consist of:	sand
Geological Unit:	Holocene deposit
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "Boulanger et al. (1996), Liquefaction at Moass Landing During Loma Located on Monterey Bay about midway between the cities of Santa Cruz and Monterey, CA. The area is underlain by Holocene deposits consisting of relatively thick sands offshore and estuarine and fluvial deposits onshore, up to about 60-m deep. The Moss Landing spit is underlain by littoral soils comprising eolian, fluvial, estuarine, and beach deposits of gravel, sand, silt, and clay deposited in a shoreline environment within the zone of tidal fluctuation. Pleistocene and miocene deposits extend to a depth of ~2000 m. The upper 8-10 m of soils encountered were poorly graded, clean sands to gravelly sands having no more than 3 % fines. Underlying the sands was a complex sequence of interlayered clay, sand, and gravelly sand. PGA is recorded in a four-story building 8km from rupture plane as 0.39 g which is underlain by alluvium. Also San Juan Bautista seismogram, ~20 km from the rupture plane recorded 0.15 g (stiff alluvium). The Moss Landing area is located ~21 km from the rupture plane. Due to deep alluvium which is soft near the surface, PGA at the site is predicted between 0.2-0.3g PGA adopted for the analysis based on site response analyses results (~0.29 g) is slightly higher than the value suggested by the authors of the source document. SPT performed after the earthquake."
	Boulanger et al. (1995) "SPT performed with rotary wash borings with energy measurments. Energy ratios of 75% were measured for a central mine equipment (CME) trip hammer. Energy ratios of 60% were estimated for a cat-head and rope system. CME-750 drill rig, CME 623 N (140-pound) automatic trip hammer, Rotary wash. " N60 values were provided by the same study. N60 values were digitized. CE is calculated as 1.25 by Idriss and Boulanger (2010) which corresponds to 75 % energy. Either digitized N60 values can be used directly and ER can be taken as 60% or N60 values can be backcalculated with ER=75% and CE can be calculated with ER as 75%. Both will give same result. As Idriss and Boulanger (2010) provided CE as 1.25
Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	A	-	A	A
d_{crtc} range (m)	-	1.8 - 3.7	-	1.8 - 3.7	1.8 - 3.7
d_{crt} (m)	-	2.7	3.4	2.7	2.7
GWT (m)	-	1.8 ± 0.3	1.8	1.8 ± 0.1	1.8 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	15.7 ± 0.6	-	19.6 ± 0.5	19.6 ± 0.5
σ_v (kPa)	-	41.6 ± 5.0	61.2	49.5 ± 6.2	49.5 ± 6.2
σ_v' (kPa)	-	32.4 ± 3.5	46.1	40.3 ± 3.3	40.3 ± 3.3
a_{max} (g)	-	0.290 ± 0.025	0.28	0.290 ± 0.044	0.290 ± 0.044
r_d	-	0.95 ± 0.010	0.97	0.95 ± 0.010	0.95 ± 0.021
CSR	-	0.240 ± 0.032	0.234	0.220 ± 0.035	0.220 ± 0.035
M_w	-	7.00	6.93	6.93	6.93
D_{50}	-	0.260 ± 0.100	-	0.260 ± 0.050	0.260 ± 0.050
% Fines	-	2.0 ± 2.0	1	1.7 ± 0.6	1.7 ± 0.6
% PI	-	-	-	-	0
N	-	5.0 ± 0.9	6.3	5.1 ± 0.9	4.4 ± 1.3
C_R	-	0.79	0.85	0.79	0.88
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.25	1.25	1.25	1.25
C_N	-	1.72	1.53	1.59	1.59
$(N_1)_{60}$	-	8.5 ± 1.6	10.3	7.9 ± 1.4	7.6 ± 2.3
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

EVENT PARAMETERS

1989 Loma Prieta Earthquake — USGS, Graves and Pitarka (2004), Toprak et al. (1999), Holzer et al. (1998)

Magnitude: 6.93

Fault Type: reverse-obliqu — Z_{tor} (km): 3.85 — R_{rup} (km): -

Dip: 70 — Width (km): 20 — R_{jb} (km): 17.0

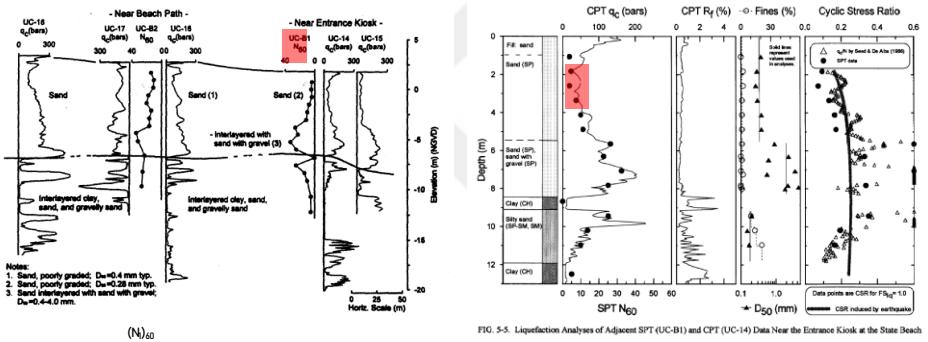
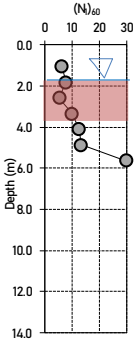
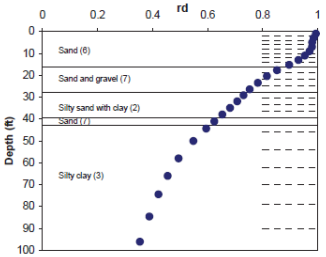
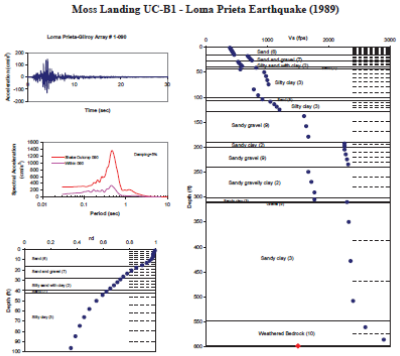


FIG. 5-5. Liquefaction Analyses of Adjacent SPT (UC-B1) and CPT (UC-14) Data Near the Entrance Kiosk at the State Beach





Boulanger et al (1995) provided N60 values



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
1.1	3.5		3	2.00	0.83	6.2	0.0	sand
1.8	*6.0*		*4*	*1.80*	*0.85*	*7.7*	*2.0*	*sand*
2.6	*8.5*		*3*	*1.61*	*0.87*	*5.3*	*2.0*	*sand*
3.4	*11.0*		*6*	*1.48*	*0.89*	*9.9*	*1.0*	*sand*
4.1	13.5		8	1.37	0.91	12.5	1.0	sand
4.9	16.0		9	1.29	0.92	13.3	1.0	sand
5.6	18.5		21	1.21	0.93	29.7	1.0	sand
					Mean:	7.6	1.7	
					St. Dev.	2.3	0.6	

C_E
1.25

*Energy ratios of 75% were measured
*N60 values were provided by Boulanger et al. (1995) Figure 5-5

N60	N
4	3
5	4
4	3
8	6
10	8
11	9
26	21
22	18
32	26
25	20
0	0
25	20
14	11
10	8
5	4

N values were back calculated.

Case number:	138
Earthquake:	Loma Prieta
Magnitude:	6.93 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Moss Landing State Beach UC-B2
References:	Boulanger et al. (1996), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefaction-induced lateral spreading caused extensive damage to the access road. The tide gate was destroyed due to liquefaction flow slide. Road surface slumping about 1.3 m. Lateral spreading were roughly 0.3-0.6 m horizontal with vertical offset up to 0.3 m. Sand boils and ground cracks on the north side of the access road.
GPS LAT	36.815103
GPS LONG	-121.790268
Liq. layer consist of:	sand
Geological Unit:	Holocene deposit
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "Boulanger et al. (1996), Liquefaction at Moss Landing During Loma Prieta Earthquake. Located on Monterey Bay about midway between the cities of Santa Cruz and Monterey, CA. The area is underlain by Holocene deposits consisting of relatively thick sands offshore and estuarine and fluvial deposits onshore, up to about 60-m deep. The Moss Landing spit is underlain by littoral soils comprising eolian, fluvial, estuarine, and beach deposits of gravel, sand, silt, and clay deposited in a shoreline environment within the zone of tidal fluctuation. Pleistocene and miocene deposits extend to a depth of ~2000 m. The upper 8-10 m of soils encountered were poorly graded, clean sands to gravelly sands having no more than 3 % fines. Underlying the sands was a complex sequence of interlayered clay, sand, and gravelly sand. PGA is recorded in a four-story building 8km from rupture plane as 0.39 g which is underlain by alluvium. Also San Juan Bautista seismogram, ~20 km from the rupture plane recorded 0.15 g (stiff alluvium). The Moss Landing area is located ~21 km from the rupture plane. Due to deep alluvium which is soft near the surface, PGA at the site is predicted between 0.2-0.3g Based on site response analyses results, a PGA value of 0.24 g is adopted which is slightly lower than the value suggested by the authors of the source document (0.25 g). SPT performed after the earthquake."
	Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
	Boulanger et al. (1995) "SPT performed with rotary wash borings with energy measurments. Energy ratios of 75% were measured for a central mine equipment (CME) trip hammer. Energy ratios of 60% were estimated for a cat-head and rope system. CME-750 drill rig, CME 623 N (140-pound) automatic trip hammer, Rotary wash. " N60 values were provided by the same study. N60 values were digitized. CE is calculated as 1.25 by Idriss and Boulanger (2010) which corresponds to 75 % energy. Either digitized N60 values can be used directly and ER can be taken as 60% or N60 values can be backcalculated with ER=75% and CE can be calculated with ER as 75%. Both will give same result. As Idriss and Boulanger (2010) provided CE as 1.25
Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	A	-	A	A
d_{crit} range (m)	-	2.7 - 6.7	-	2.7 - 6.7	2.7 - 6.7
d_{crt} (m)	-	4.7	4.9	4.7	4.7
GWT (m)	-	2.7 ± 0.3	2.6	2.7 ± 0.1	2.7 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	19.6 ± 0.5	19.6 ± 0.5
σ_v (kPa)	-	76.0 ± 11.1	90.2	90.8 ± 13.1	90.8 ± 13.1
σ_v' (kPa)	-	56.5 ± 5.6	67.2	71.4 ± 6.8	71.4 ± 6.8
a_{max} (g)	-	0.240 ± 0.025	0.28	0.240 ± 0.036	0.240 ± 0.036
r_d	-	0.99 ± 0.013	0.95	0.99 ± 0.013	0.99 ± 0.033
CSR	-	0.210 ± 0.028	0.229	0.197 ± 0.031	0.197 ± 0.032
M_w	-	7.00	6.93	6.93	6.93
D_{50}	-	0.400 ± 0.100	-	0.400 ± 0.050	0.400 ± 0.050
% Fines	-	1.0 ± 2.0	1	1.0 ± 2.0	1.0 ± 8.6
% PI	-	-	-	-	0
N	-	13.3 ± 1.7	12.8	13.3 ± 1.8	13.1 ± 2.2
C_R	-	0.88	0.95	0.88	0.92
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.25	1.25	1.25	1.25
C_N	-	1.30	1.20	1.19	1.19
$(N_1)_{60}$	-	19.0 ± 2.5	18.4	17.4 ± 2.4	17.9 ± 3.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

EVENT PARAMETERS

1989 Loma Prieta Earthquake — USGS, Graves and Pitarka (2004), Toprak et al. (1999), Holzer et al. (1998)

Magnitude: 6.93

Fault Type: reverse-obliqu — Z_{tor} (km): 3.85 — R_{rup} (km): -

Dip: 70 — Width (km): 20 — R_{jb} (km): 17.0

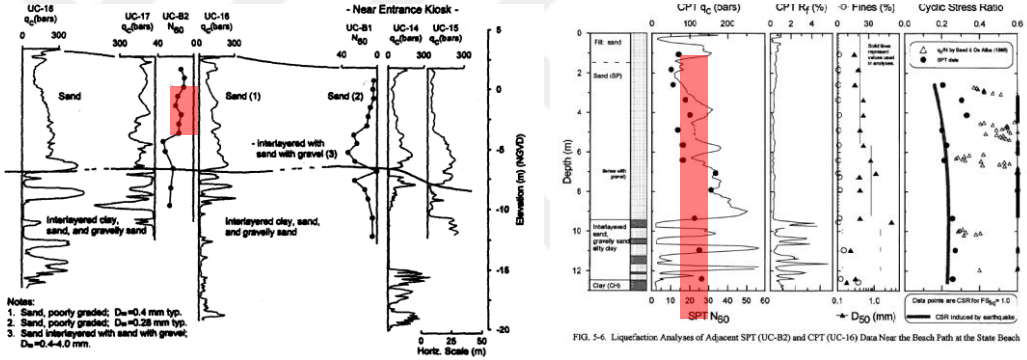
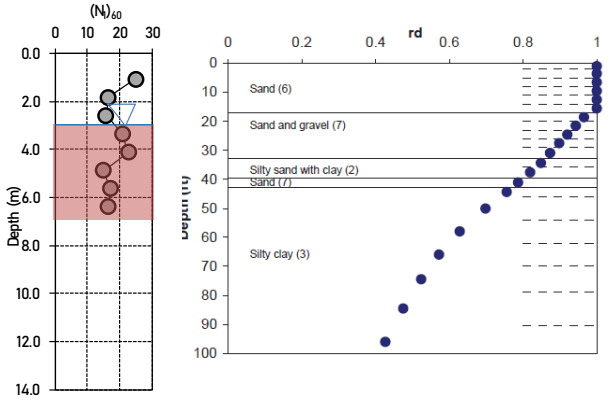
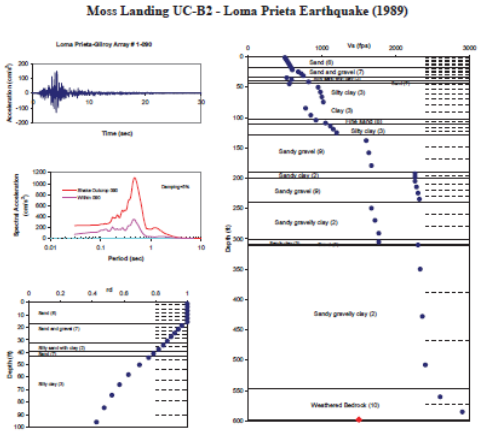


FIG. 5-6. Liquefaction Analyses of Adjacent SPT (UC-B2) and CPT (UC-16) Data Near the Beach Path at the State Beach





Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
1.1	3.5		12	2.00	0.83	24.9	sand
1.8	6.0		9	1.71	0.85	16.5	sand
2.6	*8.5*		*10*	*1.44*	*0.87*	*15.7*	sand
3.4	*11.0*		*14*	*1.33*	*0.89*	*20.7*	sand
4.1	*13.5*		*16*	*1.25*	*0.91*	*22.7*	sand
4.9	*16.0*		*11*	*1.18*	*0.92*	*15.0*	sand
5.6	*18.5*		*13*	*1.12*	*0.93*	*17.0*	sand
6.4	*21.0*		*13*	*1.08*	*0.94*	*16.5*	sand
					Mean:	17.9	
					St. Dev.	3.0	

C_E
1.25

*Energy ratios of 75% were measured
*N60 values were provided by Boulanger et al. (1995) Figure 5-6
N values were back calculated.

N60	N
15	12
11	9
12	10
18	14
20	16
14	11
16	13
16	13

Case number:	139
Earthquake:	Loma Prieta
Magnitude:	6.93 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Treasure Island Naval Station
References:	De Alba et al. (1994), Rollins and Mchood (1994), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface evidence of liquefaction; however significant change in frequency
GPS LAT	37.825137 content of the ground motion after 15 s. compared to the recorded motion at 322 ft.
GPS LONG	-122.374141
Liq. layer consist of:	SM
Geological Unit:	fill
Site Response Anlaysis:	Yes
Comments:	De Alba et al. (1994), "Deep Instrumentation Array at the Treasure Island Naval Station"
	Rollins and Mchood (1994), "Ground Response on Treasure Island"
	Cetin (2000) "Treasure Island is a 400-acre manmade island immediately northwest of the rock outcrop on Yerba Buena Island in San Francisco Bay. The original surface soils included a shallow-water sandbar or spit extending northwestward from Yerba Buena Island, and soft silty clay known as bay mud surrounding the sandbar to the north and east. Approximately 65% of the island was built on the sandbar and the rest on the bay mud. Treasure Island was constructed by hydraulic and clamshell dredging. A perimeter rock dike was built in two to four stages on a bed of coarse sand placed over bay mud. The structure is essentially an upstream-constructed hydraulic fill. The soils on Treasure Island may be grouped into four broad categories: fill, native shoal sand, recent bay sedimentary deposits, and older bay sedimentary deposits. Both the fill and native shoal sand consists predominantly of sand and varying amounts of clay, silt and gravel; however, the fill is somewhat looser. The depth and thickness of soil layers vary significantly around the island. The thickness of the fill and native shoal sand ranges from 10.7 m at the south end to 15.2 m in the north. The depth of recent bay sedimentary deposits ranges from 10.7 m in the south. Bedrock elevation has been confirmed at a depth of 85 m. PGA is recorded on Yerba Buena Island as 0.06 and 0.03 g (rock outcrop) and 0.16 and 0.11 g onTreasure Island. A PGA value of 0.18 g is adopted based on site response analyses results. Depth to water table is reported as 1.5 m."
	Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
	C_E by IB 2010 is adapted as no information regarding hammer energy was found in the original document. Other Loma Prieta sites had energy measurements hence Idriss and Boulanger (2010) selection was used considering they may information regarding hammer energy.
Gravel Content (%):	0.00
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	A	-	A	A
d_{cr1c} range (m)	-	1.5 - 9.0	-	1.5 - 9.0	1.5 - 9.0
d_{cr1} (m)	-	5.3	6.5	5.3	5.3
GWT (m)	-	1.5 ± 0.6	1.5	1.5 ± 0.0	1.5 ± 0.0
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.1 ± 0.5	18.1 ± 0.5
σ_v (kPa)	-	85.6 ± 20.8	116.3	91.5 ± 22.7	91.5 ± 22.7
σ_v' (kPa)	-	48.8 ± 10.4	67.2	54.7 ± 10.5	54.7 ± 10.5
a_{max} (g)	-	0.180 ± 0.010	0.16	0.180 ± 0.027	0.180 ± 0.027
r_d	-	0.88 ± 0.012	0.92	0.88 ± 0.012	0.88 ± 0.036
CSR	-	0.160 ± 0.027	0.165	0.172 ± 0.028	0.172 ± 0.029
M_w	-	7.00	6.93	6.93	6.93
D_{50}	-	0.170 ± 0.030	-	0.170 ± 0.050	0.170 ± 0.050
% Fines	-	20.0 ± 4.0	20	20.0 ± 2.0	21.7 ± 14.1
% PI	-	-	-	-	NAV
N	-	4.8 ± 2.9	4.3	5.1 ± 3.0	5.1 ± 3.2
C_R	-	0.90	0.95	0.90	0.93
C_S	-	1.10	1.10	1.10	1.10
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.13	1.13	1.13	1.13
C_N	-	1.40	1.24	1.36	1.36
$(N_1)_{60}$	-	7.6 ± 4.6	6.4	7.7 ± 4.6	8.0 ± 5.1
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

EVENT PARAMETERS

1989 Loma Prieta Earthquake USGS, Graves and Pitarka (2004), Toprak et al. (1999), Holzer et al. (1998)

Magnitude: 6.93

Fault Type: reverse-obliqu Z_{tor} (km): 3.85 R_{rup} (km): -

Dip: 70 Width (km): 20 R_{jb} (km): 80.8

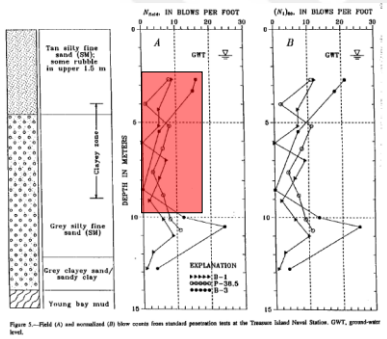


Figure 5.—Field (A) and normalized (B) blow counts from standard penetration tests at the Treasure Island Naval Station. GWT, ground-water level.

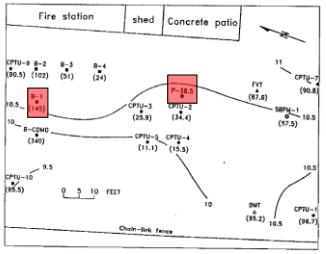
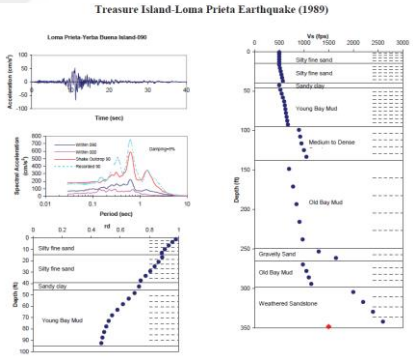


Figure 4.—Area near fire station at the Treasure Island Naval Station, showing locations of inplace borehole tests: B, accelerometer boring; CPTU, piezocone; DMT, dilatometer; FVT, field vane; SBPM, self-boring pressuremeter. Standard penetration tests were also performed in boreholes B–1, B–3, and P–38.5. Curved lines, contours of elevation of ground surface (in feet above mean lower low water). Numbers in parentheses indicate exploration depth (in feet). CDMG, California Division of Mines and Geology.



	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
P-38.5	*2.7*	*8.9*		*8*	*1.74*	*0.88*	*15.2*	SM
P-38.5	*4*	*13.1*		*1*	*1.51*	*0.91*	*1.7*	SM
P-38.5	*5.2*	*17.1*		*8*	*1.37*	*0.93*	*12.6*	SM
P-38.5	*6.4*	*21.0*		*6*	*1.26*	*0.94*	*8.9*	SM
P-38.5	*7.6*	*24.9*		*3*	*1.17*	*0.96*	*4.2*	SM
P-38.5	*8.8*	*28.9*		*6*	*1.10*	*0.97*	*7.9*	SM
P-38.5	10.15	33.3		8	1.03	0.97	10.0	SM
P-38.5	10.65	34.9		11	1.01	0.98	13.5	SM
						Mean:	8.4	
						St. Dev.	5.1	

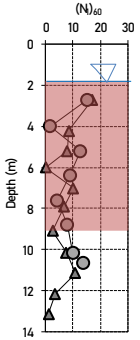
Depth (m)	FC (%)
2.4	*12.0*
6.1	*16.0*
7.3	*26.0*
Mean:	18.0
St. Dev.	7.2

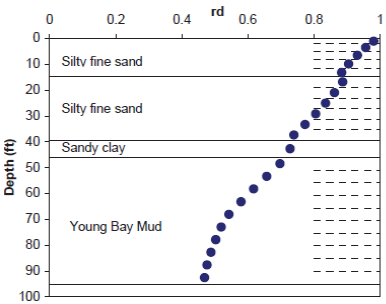
	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
B-1	*2.7*	*8.9*		*9*	*1.74*	*0.88*	*17.1*	SM
B-1	*4.2*	*13.8*		*5*	*1.49*	*0.91*	*8.4*	SM
B-1	*5.2*	*17.1*		*5*	*1.37*	*0.93*	*7.9*	SM
B-1	*6*	*19.7*		*0*	*1.29*	*0.94*	*0.0*	SM
B-1	*7*	*23.0*		*7*	*1.21*	*0.95*	*10.0*	SM
B-1	*7.9*	*25.9*		*5*	*1.15*	*0.96*	*6.9*	SM
B-1	*9.1*	*29.9*		*2*	*1.08*	*0.97*	*2.6*	SM
B-1	10.15	33.3		6	1.03	0.97	7.5	SM
B-1	11.15	36.6		9	0.99	0.98	10.9	SM
B-1	12.15	39.9		3	0.95	0.98	3.5	SM
B-1	13.15	43.1		1	0.92	0.99	1.1	clayey sand/sandy clay
						Mean:	7.6	
						St. Dev.	5.5	

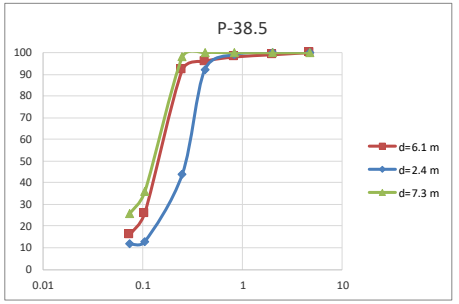
Depth (m)	FC (%)
2.4	*6.0*
4.0	*24.0*
5.8	*46.0*
9.8	13.0
10.7	8.0
Mean:	25.3
St. Dev.	20.0

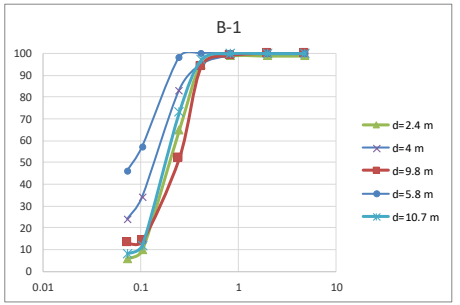
Mean:	8.0
St. Dev.	5.1

Mean:	21.7
St. Dev.	14.1









Case number:	140
Earthquake:	Loma Prieta
Magnitude:	6.93 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Woodward Marine UC-B4
References:	Boulanger et al. (1995, 1997), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefaction-induced ground spreading was evident across much of the site. Along the shoreline, jetty piles were displaced horizontally, and the boat ramp and adjacent asphalt pavement experienced cracking and settlement. Several cracks up to 5 cm wide. The oil and gas tanks settled and tilted 1-6o. Gray coarse to medium grained sand was vented through some of the cracks. Sand dikes were traced from the ground surface to a depth of about 0.8 m through a gravelly sand and gray, medium-grained sand to a gray silty sand.
GPS LAT	36.805448
GPS LONG	-121.786238
Liq. layer consist of:	sand and gravel fill, interlayerd sand
Geological Unit:	Holocene deposit
Site Response Anlaysis:	Yes
Comments:	Boulanger et al. (1996), "Liquefaction at Moss Landing During Loma Prieta Earthquake" Cetin et al. (2018) "Located on Salomon Way off Sandholdt Road near the northern end of the Moss Landing spit and along the South Harbor. The Woodward Marine facilities include a boat launch ramp, fuel service dock and oil and gas storage tanks. The Moss Landing spit is underlain by littoral soils comprising eolian, fluvial, estuarine, and beach deposits of gravel, sand, silt, and clay deposited in a shoreline environment within the zone of tidal fluctuation. Pleistocene and miocene deposits extend to a depth of ~2000 m. A ~1m thick layer of sandy fill blankets the site. By the shoreline, the fill is underlain by a roughly 2.2 m thick layer of sand and silty sand. By the fuel tanks, the fill is underlain by a 1-2 m thick layer of soft silty sand, sandy silt and silt. This soft layer of silty sand to silt is underlain by a thin zone of sand which appears similar to the sand encountered at similar depths near the shoreline. These materials are underlain by a ~ 2m thick layer of denser sand. Beneath this layer, there is a layer of high plasticity clay with interlayers of dense silty sand and sand. PGA is recorded in a four-story building 8 km from rupture plane as 0.39 g which is underlain by alluvium. Also Sab Juan Bautista seismogram, ~20 km from the rupture plane recorded 0.15 g (stiff alluvium). The Moss Landing area is located ~21 km from the rupture plane. Due to deep alluvium which is soft near the surface, PGA at the site is predicted between 0.2-0.3 g. PGA is chosen for the analysis as 0.25 g same as the value chosen by the authors of the source document. Also site response analyses results supported this conclusion. SPT performed after the earthquake." Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000). Boulanger et al. (1995) "SPT performed with rotary wash borings with energy measurments. dEnergy ratios of 75% were measured for a central mine equipment (CME) trip hammer. Energy ratios of 60% were estimated for a cat-head and rope system." N60 values were provided by the same study. Hence ER is used as 60%.
Gravel Content (%):	content unkown
CPT available:	Yes
Vs available:	Yes

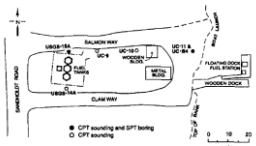


FIG. 11. Map of Woodward Marine Site

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	B	-	A	A
d_{crtc} range (m)	-	1.0 - 2.5	-	1.0 - 2.5	1.0 - 2.5
d_{crt} (m)	-	1.8	1.8	1.8	1.8
GWT (m)	-	1.0 ± 0.3	1	1.0 ± 0.1	1.0 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	15.7 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-	26.8 ± 4.0	32.1	31.5 ± 4.8	31.5 ± 4.8
σ_v' (kPa)	-	19.4 ± 3.2	25.1	24.1 ± 2.5	24.1 ± 2.5
a_{max} (g)	-	0.250 ± 0.025	0.28	0.250 ± 0.038	0.250 ± 0.038
r_d	-	0.99 ± 0.005	0.99	0.99 ± 0.005	0.99 ± 0.014
CSR	-	0.200 ± 0.043	0.233	0.210 ± 0.034	0.210 ± 0.035
M_w	-	7.00	6.93	6.93	6.93
D_{50}	-	0.100 ± 0.050	-	0.100 ± 0.050	0.100 ± 0.050
% Fines	-	35.0 ± 5.0	35	35.0 ± 2.0	35.0 ± 8.6
% PI	-	-	-	-	NAV
N	-	6.7 ± 0.2	6.7	5.8 ± 0.2	5.8 ± 0.2
C_R	-	0.72	0.80	0.72	0.85
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.00	1.00	1.00	1.00
C_N	-	2.00	1.70	2.00	2.00
$(N_1)_{60}$	-	9.7 ± 0.3	9.1	8.3 ± 0.3	9.8 ± 0.3
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

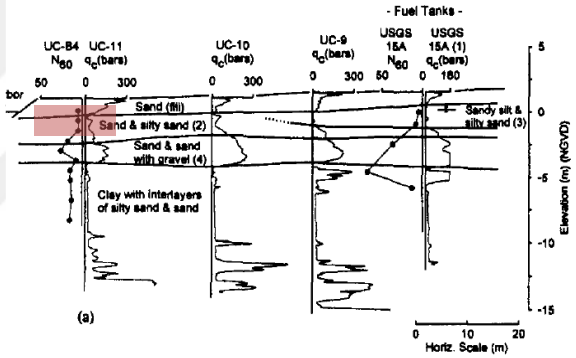
EVENT PARAMETERS

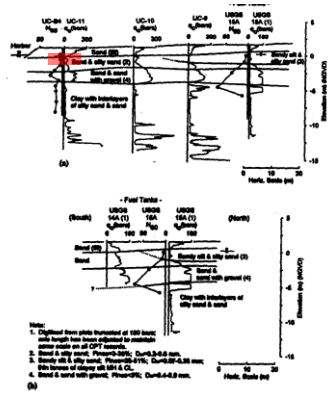
1989 Loma Prieta Earthquake — USGS, Graves and Pitarka (2004), Toprak et al. (1999), Holzer et al. (1998)

Magnitude: 6.93

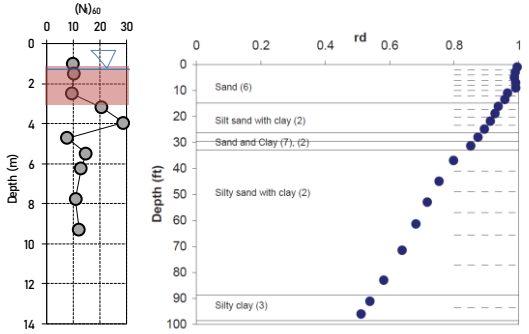
Fault Type: reverse-obliqu — Z_{tor} (km): 3.85 — R_{rup} (km): -

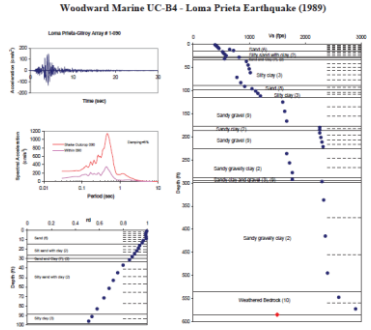
Dip: 70 — Width (km): 20 — R_{jb} (km): 17.4





Cetin (2000)





Boulanger et al (1995) provided N1,60 values
Boulanger et al (1997) provided N60 values

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
1	***3.3***		***6***	***2.00***	***0.83***	***9.9***	sand and gravel fill
1.5	***4.9***		***6***	***2.00***	***0.84***	***10.1***	sand and silty sand
2.5	***8.2***		***6***	***1.81***	***0.87***	***9.5***	sand and silty sand
3.2	10.5		14	1.65	0.89	20.6	sand and sand with gravel
3.96	13.0		21	1.52	0.91	28.8	sand and sand with gravel
4.72	15.5		6	1.41	0.92	7.8	sand and sand with gravel
5.48	18.0		12	1.32	0.93	14.8	clay with interlayers of silty sand and sand
6.25	20.5		11	1.25	0.94	12.9	clay with interlayers of silty sand and sand
7.77	25.5		10	1.14	0.96	10.9	clay with interlayers of silty sand and sand
9.29	30.5		12	1.05	0.97	12.2	clay with interlayers of silty sand and sand
					Mean:	9.8	
					St. Dev.	0.3	

* Actual energy ratio is reported as 75 %, however it is corrected to 60% in the source document

Case number:	141
Earthquake:	Loma Prieta
Magnitude:	6.93 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	General Fish
References:	Boulanger et al. (1995, 1997), Ilgac (2015), Cetin et al (2018)
Nature of Failure:	"The Site of General Fish Company experienced minor lateral movements. Ground cracks and some cracks in the buildings
GPS LAT	36.800989 (up to 8 cm) were observed. A significant ground crack was observed at the location of EB-5 borehole.
GPS LONG	-121.788479 Lateral movement of the site was tottally estimated as 5-7.5 cm." (Barminski 1993)
Liq. layer consist of:	sand with interlayers of gravelly sand and sandy gravel
Geological Unit:	Holocene deposit
Site Response Anlaysis:	No
Comments:	It is stated that the site is somewhere near to existing metal building.
	In original document it is stated that "the General Fish Company building were
	constructed of wood but the details are not known". Boulanger et.al. (1995)
	The site consists of 8-12 m of poorly graded sand (FC=5%; 1-8%, D_{50}=0.20-2.1 mm) with some interlayers.
	For SI-2 inclinometer D_{50}=0.40-0.70 mm. Sand layer is underlained by clay layer of low plasticity (ML and CL).
	The magnitude of the Loma Prieta is given by USGS equal to 6.9. The acceleration value is recommended
	by Boulanger (1995) 0.20-0.30 g. In Cetin et al 2004 it is taken as 0.25 g. However in Idriss and Boulanger 2010 study it is taken as
	In Boulanger et.al (1997) it is stated that "a peak horizantal acceleration of about 0.25 g is a reasonable estimate for evalua
	effects of soil behavior during the 1989 Loma Prieta earthquake at Moss Landing .In Cetin 2004 a_{max} is taken as 0.25 g.
	"The SPT were performed by Rutherford and Chekene (1988,1993) by Taber Consultans using a Concore rig. A fish tail bit w
	drilling. SPT testes were performed by using a safety hammer, a cathead and rope system with 2 wraps of the rope around
	and a 5-cm-outside diameter split spoon sampler with room for liners. A few samples were obtained using a California split
	sampler (6.3-cm outside-diameter). Energy measurements for this rig
	and the procedures while drilling at shallow depth in soft clay on
	another profect indicated an average energy ratio of 65%.Given
	the differences in energy ratios that may arise from different
	operators and soil conditions it seems reasonable to conclude that
	the blow counts reported by R&C (1988,1993) can be essentially taken
	as N_{60} values." Boulanger et.al. (1995).
	In Boulanger et.al (1995) borehole x-axis was named as $N_{1,60}$, In
	Boulanger et.al (1997) x-axis named as N_{60}. In this study these values
	are taken as N_{60} values. GWT is taken as 1.7 m.
	There exist ambiguity in Boulanger et.al (1995)
	1. FC data is missing. The data is given in the output section
	on a graph however since the ground level information is missing
	it is unclear in which depth these fines content can be assigned.
	In the text in Boulanger et.al (1995) it is stated that "The site consists of
	8-12 m of poorly graded sand (FC=5%; 1-8%, D50=0.20-2.1 mm)
	with some interlayers. In this study FC=5% is taken for all depths.
	Sea depth is 3 m. B1 is located 28 m away from sea, B2 is located
	69 m away from sea and B3 is located 71 m away from sea. Thus, the site is a free field. PI is
	assigned as 0 since FC=5%.
	Boulanger et al. (1995) "SPT performed with rotary wash borings with energy measurments. dEnergy ratios of 75% were measured for a central mine equipment (CME) trip hammer. Energy ratios of 60% were estimated for a cat-head and rope system." N60 values were provided by the same study. Hence ER is used as 60%.
Gravel Content (%):	sand with interlayers of gravelly sand and sandy gravel (content unkown)
CPT available:	Yes
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	No	No	No
Data Class	-	-	-	B	B
d_{crtc} range (m)	-	-	-	1.5 - 2.5	1.7 - 2.5
d_{cr1} (m)	-	-	2.5	2.0	2.1
GWT (m)	-	-	1.4	1.7 ± 0.0	1.7 ± 0.0
γ_{moist} (kN/m^3)	-	-	-	17.3 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	-	45.1	36.0 ± 3.4	40.4 ± 3.1
σ_v' (kPa)	-	-	35.1	32.5 ± 1.9	36.2 ± 1.8
a_{max} (g)	-	-	0.28	0.250 ± 0.075	0.250 ± 0.075
r_d	-	-	0.98	0.99 ± 0.007	0.99 ± 0.007
CSR	-	-	0.232	0.179 ± 0.054	0.180 ± 0.054
M_w	-	-	6.93	6.93	6.93
D_{50}	-	-	-	0.550 ± 0.050	0.550 ± 0.050
% Fines	-	-	5	5.0 ± 2.0	5.0 ± 8.6
% PI	-	-	-	-	0
N	-	-	16.9	11.5 ± 2.3	12.1 ± 2.5
C_R	-	-	0.80	0.74	0.86
C_S	-	-	1.00	1.00	1.00
C_B	-	-	1.00	1.00	1.00
C_E	-	-	1.00	1.00	1.00
C_N	-	-	1.58	1.77	1.67
$(N_1)_{60}$	-	-	21.4	15.1 ± 3.0	17.5 ± 3.6
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	210.3	210.3

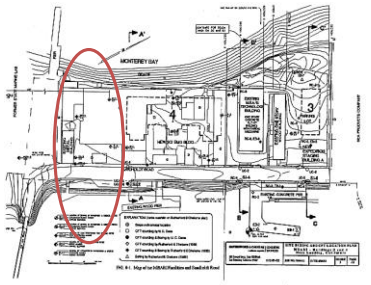
EVENT PARAMETERS

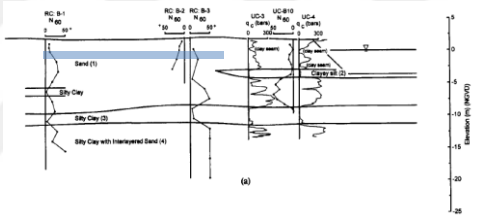
1989 Loma Prieta Earthquake USGS, Graves and Pitarka (2004), Toprak et al. (1999), Holzer et al. (1998)

Magnitude: 6.93

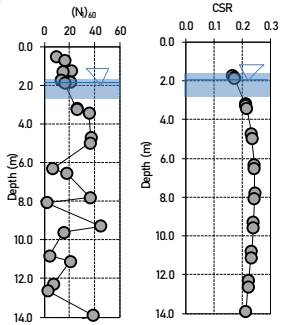
Fault Type: reverse-obliqu Z_{tor} (km): 3.85 R_{rup} (km): -

Dip: 70 Width (km): 20 R_{jb} (km): 18.0





Boulanger et al (1995) provided N1,60 values
Boulanger et al (1997) provided N60 values



	GWT	Borehole elevation	
CPT-5(1992)	1.5	7.20	B3
CPT-6(1992)	1.7	6.70	B1
UC-3	1.7	6.60	B2
UC-4	1.8	5.20	EB5
B-2	1.7		
B-3	1.7		
B-1	1.6		
Mean:	1.7		
St. Dev.	0.1		

Notes:
1. Sand with interlayers of gravelly sand and sandy gravel; Fines =1-8% (average<5%); D_{50}=0.2-2.1 mm.
2. Soft to med. stiff clayey silt; ML & CL.
3. Soft to med. stiff silty clay; LL=50-77, PI=25-43, CH & MH.
4. Stiff to very stiff silty clay; LL=55-70, PI=23-34, CH & MH.

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	Borehole	Soil Type	
0.5	1.64	NA	6	2.00	0.81	9.7	5.0	**B2**	Sand(1)	
0.7	2.33	NA	10	2.00	0.82	16.3	5.0	**B1**	Sand(1)	
1.2	***4.04***	***NA***	***13***	***2.00***	***0.83***	***21.7***	***5.0***	***B2***	***Sand(1)***	sand with interlayers of gravelly sand and sandy gravel
1.3	***4.33***	***NA***	***9***	***2.00***	***0.84***	***15.1***	***5.0***	***B1***	***Sand(1)***	
1.7	***5.71***	***0.165***	***9***	***1.77***	***0.85***	***13.6***	***5.0***	***B3***	***Sand(1)***	
1.8	***6.04***	***0.169***	***14***	***1.74***	***0.85***	***20.8***	***5.0***	***B2***	***Sand(1)***	
1.9	***6.20***	***0.172***	***11***	***1.73***	***0.86***	***16.3***	***5.0***	***B1***	***Sand(1)***	
3.2	10.50	0.210	20	1.45	0.89	25.9	5.0	**B2**	Sand(1)	
3.3	10.70	0.211	20	1.44	0.89	25.7	5.0	**B3**	Sand(1)	
3.4	11.29	0.215	28	1.42	0.89	35.5	5.0	**B1**	Sand(1)	
4.7	15.49	0.232	32	1.25	0.92	36.9	5.0	**B2**	Sand(1)	
5.0	16.37	0.234	32	1.23	0.92	36.3	5.0	**B1**	Sand(1)	
6.3	20.70	0.241	6	1.12	0.94	6.3	5.0	**B3**	Sand(1)	
6.5	21.42	0.242	17	1.10	0.94	17.6	5.0	**B1**	Sand(1)	
7.8	25.59	0.243	37	1.02	0.96	36.1	5.0	**B3**	Sand(1)	
8.1	26.51	0.242	2	1.00	0.96	1.9	5.0	**B1**	Silty Clay	
9.3	30.48	0.239	49	0.94	0.97	44.8	5.0	**B3**	Sand(1)	
9.6	31.50	0.238	17	0.93	0.97	15.4	5.0	**B1**	Sand(1)	
10.8	35.50	0.231	5	0.88	0.98	4.3	5.0	**B3**	Silty Clay (3)	
11.1	36.48	0.230	24	0.87	0.98	20.5	5.0	**B1**	Sand(1)	
12.3	40.35	0.222	9	0.83	0.98	7.4	5.0	**B3**	Silty Clay (3)	
12.6	41.47	0.220	4	0.82	0.98	3.2	5.0	**B1**	Silty Clay (3)	
13.9	45.60	0.213	50	0.79	0.99	38.9	5.0	**B3**	Silty Clay with interlayered Sand(4)	
14.2	46.59	0.211	30	0.78	0.99	23.1	5.0	**B1**	Silty Clay with interlayered Sand(4)	
15.8	51.67	0.204	18	0.74	0.99	13.3	5.0	**B1**	Silty Clay with interlayered Sand(4)	
17.3	56.63	0.199	50	0.71	0.99	35.4	5.0	**B1**	Silty Clay with interlayered Sand(4)	
					Mean:	17.5	5.0			
					St. Dev.	3.6	8.6	**assigned**		

C_N is not greater than 2.0 hence included

Case number:	142
Earthquake:	Loma Prieta
Magnitude:	6.93 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Marine Laboratory B-1 & B-2
References:	Boulanger et al. (1995, 1997), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefaction-induced lateral spreadi Buildings spread 1-1.3 m at the ground surface. Fine grained clayey silt boil
GPS LAT	36.799942 in the voleyball court near the southeaast of the site.
GPS LONG	-121.789322
Liq. layer consist of:	beach sand
Geological Unit:	Holocene deposit
Site Response Anlaysis:	Yes
Comments:	Boulanger et al. (1996), "Liquefaction at Moass Landing During Loma Prieta Earthquake" Cetin et al. (2018) "Located on the Moss Landing spit, just south of the timber bridge. The facilities consisted of one- and two-story, woodframe structures and oil and gas storage tanks. The Moss Landing spit is underlain by littoral soils comprising eolian, fluvial, estuarine, and beach deposits of gravel, sand, silt, and clay deposited in a shoreline environment within the zone of tidal fluctuation. Pleistocene and miocene deposits extend to a depth of ~2000 m. The clayey silt stratum beneath the east side is 1.5-3 m thick, and is interbedded between dune and beach sands. PGA was recorded in a four-story building 8 km from rupture plane as 0.39 g (alluvial site). Also San Juan Bautista seismographic station, ~20 km from the rupture plane recorded 0.15 g (stiff alluvium). The Moss Landing area is located ~21 km from the rupture plane. Due to deep alluvium which is soft near the surface, PGA at the site is predicted between 0.2-0.3g Based on site response analyses results, a PGA value of 0.24 g was adopted for these studies SPT performed after the earthquake."
	Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
	PI is assigned as 0 since FC=3%.
	Marine Laboratory B-1 & B-2 were two seperate case histories. However they are merged in this study as they are 100 ft apart and the critical layer is the same beach sand. Those case histories are statistically dependent. As a result merged. rd and amax are estimated as the average values of the two site repsonse analysis performed by Cetin (2000) for B-1 and B-2. Critical layer is updated as 2-6 m to cover the beach sand (digitized from the figure 13, Boulanger et al 1995). rd is read from Cetin (2000) as 0.99 for 13 ft depth.
	Boulanger et al. (1995) "SPT performed with rotary wash borings with energy measurments. dEnergy ratios of 75% were measured for a central mine equipment (CME) trip hammer. Energy ratios of 60% were estimated for a cat-head and rope system." N60 values were provided by the same study. Hence ER is used as 60%.
Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Marine Laboratory B-1 & B-2 are two seperate case histories.	Marine Laboratory B-1 & B-2 are two seperate case histories.	Marine Laboratory B-1 & B-2 are two seperate case histories.	Yes
Data Class	-				A
d_{crtc} range (m)	-				2.0 - 6.0
d_{crt} (m)	-				4.0
GWT (m)	-				2.5 ± 0.1
γ_{moist} (kN/m^3)	-				17.3 ± 0.5
γ_{sat} (kN/m^3)	-				19.6 ± 0.5
σ_v (kPa)	-				73.0 ± 13.2
σ_v' (kPa)	-				57.7 ± 6.7
a_{max} (g)	-				0.250 ± 0.038
r_d	-				0.99 ± 0.029
CSR	-				0.203 ± 0.034
M_w	-				6.93
D_{50}	-				0.800 ± 0.050
% Fines	-				3.0 ± 8.6
% PI	-				0
N	-				10.5 ± 1.4
C_R	-				0.91
C_S	-				1.00
C_B	-				1.00
C_E	-				1.00
C_N	-				1.33
$(N_1)_{60}$	-				12.6 ± 1.7
$V_{s,30m}$ (m/s)	-				NAV
V_{s12m} (m/s)	-				NOT LISTED

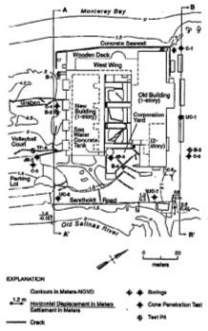
EVENT PARAMETERS

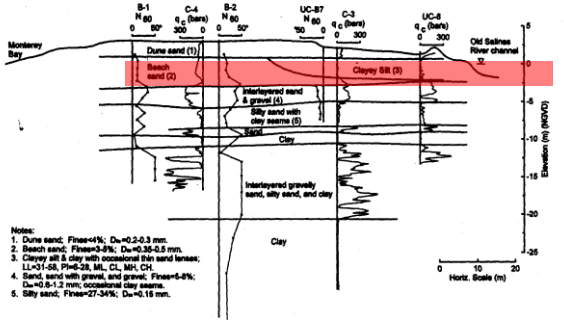
1989 Loma Prieta Earthquake — USGS, Graves and Pitarka (2004), Toprak et al. (1999), Holzer et al. (1998)

Magnitude: 6.93

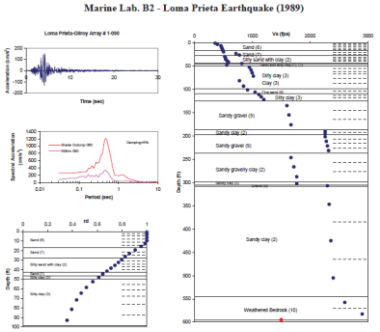
Fault Type: reverse-obliqu — Z_{tor} (km): 3.85 — R_{rup} (km): -

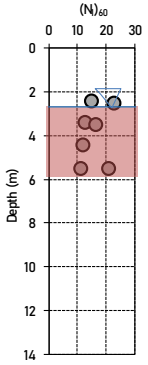
Dip: 70 — Width (km): 20 — R_{jb} (km): 18.2



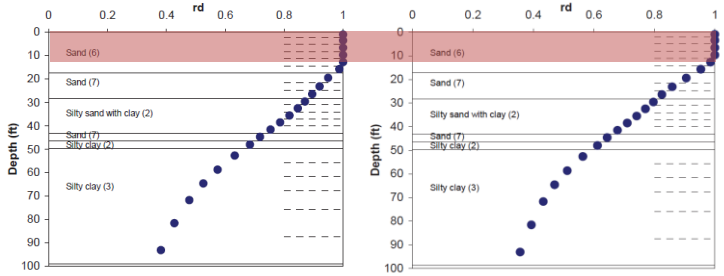


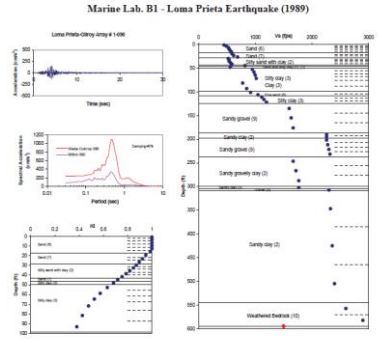
Boulanger et al (1995) provided N1,60 values
Boulanger et al (1997) provided N60 values





Cetin (2000)





	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
B-1	*2.4*	*7.9*		*11*	*1.56*	*0.87*	*15.0*	beach sand (2)
B-1	*3.4*	*11.2*		*10*	*1.40*	*0.89*	*12.5*	beach sand (2)
B-1	*4.4*	*14.4*		*10*	*1.28*	*0.91*	*11.7*	beach sand (2)
B-1	*5.5*	*18.0*		*10*	*1.18*	*0.93*	*11.0*	beach sand (2)
						Mean:	12.6	
						St. Dev.	1.7	

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		
B-2	2.5	8.2		17	1.54	0.87	22.8	beach sand (2)	***outlier***
B-2	*3.5*	*11.5*		*13*	*1.39*	*0.90*	*16.2*	beach sand (2)	
B-2	5.5	18.0		19	1.18	0.93	20.9	beach sand (2)	***outlier***
						Mean:	16.2		
						St. Dev.	2.0		

	GWT (m)
B-1	2.4
B-2	2.5
Mean:	2.5
St. Dev.	0.1

B-1 & B-2

Mean:	13.3
St. Dev.	2.2

Case number:	144
Earthquake:	Loma Prieta
Magnitude:	6.93 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Marine Laboratory F1-F7
References:	Boulanger et al. (1995, 1997), Ilgac (2015), Cetin et al (2018)
Nature of Failure:	"The MLML facilities damaged beyond repair by liquefaction-induced lateral spreading and differential settlement of the site.
GPS LAT	36.799942 The survey data shows that the building spread 1 to 1.3 m at the ground surface.
GPS LONG	-121.789322 Severe cracking occured in the foundation and slab." Boulanger et.al. (1995)
Liq. layer consist of:	sand
Geological Unit:	Holocene deposit
Site Response Anlaysis:	No
Comments:	Boulanger et al. (1995), "Liquefaction at Moss Landing During Loma Prieta Earthquake" Cetin et al (2018) "MLML consist of two building and a west wing surrounding a courtuyard. The northern building is one and two storey wood frame structure founded on spread footings. The southern one and the west wing were one storey wood frame and shear wall structure with concrete slab-on-grade floors. The eastern part of southern building was founded on 0.4 m diameter cast in place concrete piers up to 5.5 m deep. Field investigations were perfomed by WCC (1990) and UC Davis. Additional data were obtained from Fugro (1980). B1,B2,B3 belongs to Woodward-Clyde Consultants (1990) There exist two additional cases: Marine Lab B1 and B2. SPT were performed using a CME automatic trip hammer and a safety hammer with a cathead and rope system. The sampler was a standard 5 cm outside diameter split spoon with room for liners. Sample taken with the liners omitted. Energy hammer ratios were estimated as 63% and 75% for the safety hammer and automatic trip hammer systems. Fugro's boreholes located 80 m away from the site. "SPT hammers were of two types: a rope around the cathead "donut" hammer provided by drillers (total weigth of 225 ponds)i and a "free-fall", mechanical trip hammer (total weigth of 210 pounds) manufactured by Pilcon Engineering. Sampling spoon were newly constructed following ASTM-guidlines with the exception that space for liners was provided, but liners were not used. " (Fugro Inc.) In Boulanger et. al. 1995 UCB-6-12 and F1-6 were used.However UCB 6-12 boreholes were unavailable. From Boulanger et. al. 1995 it can be inferred that these boreholes are CPT logs. Therefore F1-7 logs are used in Marine Laboratory F1-F7 site."
	Boulanger et al. (1995) "SPT performed with rotary wash borings with energy measurments. Energy ratios of 75% were measured for a central mine equipment (CME) trip hammer. Energy ratios of 60% were estimated for a cat-head and rope system." N60 values were provided by the same study. Energy hammer ratios were estimated as 63% and 75% for the safety hammer and automatic trip hammer systems.
Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

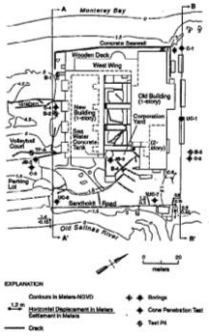


FIG. 9-1. Map of the Moss Landing Marine Laboratory (MLML) Site

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	Yes	Yes	Yes
Data Class	-	-	-	B	B
d_{crtc} range (m)	-	-	-	3.5 - 5.6	3.5 - 5.6
d_{crt} (m)	-	-	5.3	4.6	4.6
GWT (m)	-	-	1.5	1.5 ± 0.0	1.5 ± 0.0
γ_{moist} (kN/m^3)	-	-	-	18.9 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	-	102.3	88.8 ± 7.2	91.7 ± 7.5
σ_v' (kPa)	-	-	64.2	58.8 ± 3.9	61.7 ± 4.2
a_{max} (g)	-	-	0.28	0.250 ± 0.075	0.250 ± 0.075
r_d	-	-	0.94	0.99 ± 0.007	0.99 ± 0.007
CSR	-	-	0.27	0.243 ± 0.073	0.239 ± 0.072
M_w	-	-	6.93	6.93	6.93
D_{50}	-	-	-	0.425 ± 0.075	0.425 ± 0.075
% Fines	-	-	3	3.0 ± 1.4	3.0 ± 1.4
% PI	-	-	-	-	0
N	-	-	12	13.8 ± 4.7	13.8 ± 4.6
C_R	-	-	0.95	0.87	0.92
C_S	-	-	1.00	1.00	1.00
C_B	-	-	1.00	1.00	1.00
C_E	-	-	1.25	1.25	1.25
C_N	-	-	1.23	1.31	1.28
$(N_1)_{60}$	-	-	17.6	19.8 ± 6.7	20.2 ± 6.7
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	237.7	237.7

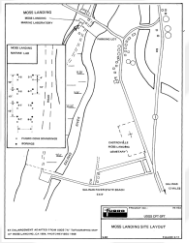
EVENT PARAMETERS

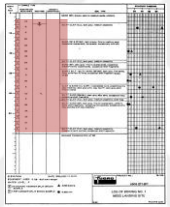
1989 Loma Prieta Earthquake USGS, Graves and Pitarka (2004), Toprak et al. (1999), Holzer et al. (1998)

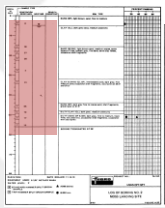
Magnitude: 6.93

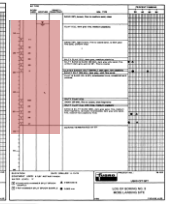
Fault Type: reverse-obliqu Z_{tor} (km): 3.85 R_{rup} (km): -

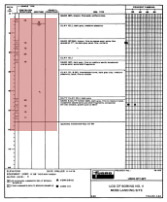
Dip: 70 Width (km): 20 R_{jb} (km): 18.2

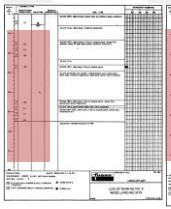


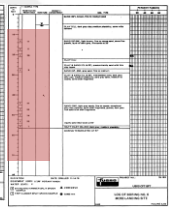


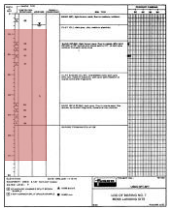


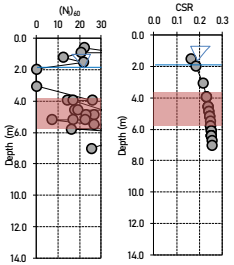












depth (m)	FC	D50 (mm)
1.5-2.5	4%	0.20-0.30
3.0-6.0	3-5%	0.35-0.50

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	Borehole	Soil Type	Hammer Type
0.6	2.0	NA	13	2.00	0.81	*22.2*	-	S-1	sand	S
0.9	3.0	NA	22	2.00	0.82	*38.0*	-	S-7	sand	S
0.9	3.0	NA	10	2.00	0.82	*20.6*	-	T-4	sand	T
1.2	4.0	NA	6	2.00	0.83	*12.5*	2	T-2	sand	T
1.5	5.0	0.162	11	1.88	0.84	*21.8*	-	T-5	sand	T
2.0	6.5	0.184	0	1.74	0.86	*0.0*	-	S-1	silty clay	S
3.0	10.0	0.215	0	1.50	0.89	*0.0*	-	S-1	silty clay	S
4.0	13.0	0.231	20	1.36	0.91	*25.8*	12	S-1	silty clay	S
4.0	***13.0***	***0.231***	***11***	***1.36***	***0.91***	***14.2***	***-***	***S-3***	***sand***	***S***
4.0	***13.0***	***0.231***	***11***	***1.36***	***0.91***	***16.9***	***-***	***T-6***	***sand***	***T***
4.6	***15.0***	***0.239***	***25***	***1.28***	***0.92***	***30.9***	***2.0***	***S-7***	***sand***	***S***
4.6	***15.0***	***0.239***	***12***	***1.28***	***0.92***	***17.6***	***4.0***	***T-4***	***sand***	***T***
4.6	***15.0***	***0.239***	***13***	***1.28***	***0.92***	***19.1***	***-***	***T-5***	***sand***	***T***
4.9	***16.0***	***0.242***	***22***	***1.25***	***0.92***	***26.6***	***-***	***S-1***	***sand***	***S***
4.9	***16.0***	***0.242***	***16***	***1.25***	***0.92***	***23.0***	***-***	***T-2***	***sand***	***T***
5.2	***17.0***	***0.245***	***19***	***1.22***	***0.93***	***22.5***	***-***	***S-3***	***sand***	***S***
5.2	***17.0***	***0.245***	***12***	***1.22***	***0.93***	***16.9***	***-***	***T-4***	***sand***	***T***
5.2	***17.0***	***0.245***	***5***	***1.22***	***0.93***	***7.1***	***-***	***T-6***	***sand***	***T***
5.5	***18.0***	***0.247***	***23***	***1.19***	***0.93***	***26.8***	***-***	***S-7***	***sand***	***S***
5.8	19.0	0.250	65	1.16	0.94	*74.3*	-	S-1	sand	S
5.8	19.0	0.250	27	1.16	0.94	*36.8*	-	T-2	sand	T
5.8	19.0	0.250	12	1.16	0.94	*16.3*	-	T-5	sand	T
6.1	20.0	0.251	44	1.14	0.94	*49.5*	-	S-3	sand	S
6.1	20.0	0.251	28	1.14	0.94	*37.5*	8	T-6	sand	T
6.4	21.0	0.253	42	1.12	0.94	*46.4*	-	S-1	sand	S
6.4	21.0	0.253	57	1.12	0.94	*63.0*	3	S-7	sand	S
6.4	21.0	0.253	26	1.12	0.94	*34.2*	-	T-4	sand	T
6.4	21.0	0.253	30	1.12	0.94	*39.5*	-	T-5	sand	T
6.7	22.0	0.255	25	1.09	0.95	*32.4*	-	T-2	sand	T
7.0	23.0	0.256	24	1.07	0.95	*25.7*	-	S-3	silty clay	S
					Mean:	20.2	3.0			
					St. Dev.	6.7	1.4			

Case number:	145
Earthquake:	Loma Prieta
Magnitude:	6.93 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	MBARI N0.4-B4B5EB2EB3
References:	Boulanger et al. (1995), Ilgac (2015), Cetin et al (2018)
Nature of Failure:	"Ground cracks were mapped at a few spots toward the eastern side of the current site of Building 4 and the lot on
GPS LAT	36.80296 its south side" Boulanger et. al. 1997
GPS LONG	-121.787617
Liq. layer consist of:	sand
Geological Unit:	Holocene deposit
Site Response Anlaysis:	No
Comments:	Boulanger et al. (1995), "Liquefaction at Moass Landing During Loma Prieta Earthquake" Cetin et al. (2018) "The MBARI facilities include three main buildings and a pier located along Sandholt Road on the Moss Landing spit. Construction of No.4 building started in 1994. B4, B5, EB2, EB3 is used for the liquefaction analysis by Boulanger et. al. 1995. However in Cetin 2014 B5 and EB3 was used due to fact that B4 borehole data was unavailable and from EB-3 borehole data consists of silty clay layers. The site consists of 8-12 m of poorly graded sand (FC=5%; 1-8%, D50=0.20-2.1 mm) with some interlayers. For SI-2 inlinometer D50=0.40-0.70 mm. Sand layer is underlained by clay layer of low plasticity (ML and CL). The magnitude of the Loma Prieta is given by USGS equal to 6.9. The acceleration value is recommended by Boulanger (1995) 0.20-0.30 g. In Cetin 2004 it is taken as 0.25 g. However in Boulanger 2010 study it is taken as 0.28 g. "The SPT were performed by Rutherford and Chekene (1988,1993) by Taber Consultans using a Concore rig. A fish tail bit was used for drilling. SPT testes were performed by using a safety hammer, a cathead and rope system with 2 wraps of the rope around the cathead and a 5-cm-outside diameter split spoon sampler with room for liners. A few samples were obtained using a California split spoon sampler (6.3-cm outside-diameter). Energy measurements for this rig and the procedures while drilling at shallow depth in soft clay on another profectindicated an average anergy ratio of 65%.Given the differences in energy ratios that may arise from different opertaors and soil conditionsi it seems reasonable to conclude that the blow counts reported by R&C (1988,1993) can be essentially taken as N60 values." Boulanger et.al. (1995) From B5 water table is located at 2.3 m depth and from EB3 it is located at 1.6 m. An average value of 1.95 m is assigned as ground water table for the site. FC data is missing. The FC data is given in the output section in Boulanger 1995 on a graph however since the ground level information is missing it is unclear in which depth these fines content can be assigned. In the text in Boulanger et.al (1995) it is stated that "The site consists of 8-12 m of poorly graded sand (FC=5%; 1-8%, D50=0.20-2.1 mm) with some interlayers. In this study FC=5% is taken for all depths. Sea depth is 3 m. B4 is located 59 m away from sea, EB3 is located 33 m away from sea and EB2 is located 84 m away from sea. Thus, the site is a free field." Boulanger et al. (1995) "SPT performed with rotary wash borings with energy measurments. dEnergy ratios of 75% were measured for a central mine equipment (CME) trip hammer. Energy ratios of 60% were estimated for a cat-head and rope system." N60 values were provided by the same study. Hence ER is used as 60%.
Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	No	No	No
Data Class	-	-	-	B	B
$d_{crt.}$ range (m)	-	-	-	2.4 - 7.7	2.4 - 7.7
d_{crt} (m)	-	-	3.4	5.1	5.1
GWT (m)	-	-	1.9	2.0 ± 0.5	2.0 ± 0.5
γ_{moist} (kN/m^3)	-	-	-	18.9 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	19.6 ± 0.5	21.5 ± 0.5
σ_v (kPa)	-	-	62.2	97.9 ± 17.5	103.7 ± 19.2
σ_v' (kPa)	-	-	48.1	67.5 ± 9.9	73.3 ± 11.1
a_{max} (g)	-	-	0.28	0.250 ± 0.075	0.250 ± 0.075
r_d	-	-	0.97	0.98 ± 0.007	0.98 ± 0.035
CSR	-	-	0.231	0.230 ± 0.072	0.224 ± 0.070
M_w	-	-	6.93	6.93	6.93
D_{50}	-	-	-	0.550 ± 0.150	0.550 ± 0.150
% Fines	-	-	5	5.0 ± 2.0	5.0 ± 8.6
% PI	-	-	-	-	0
N	-	-	18	23.6 ± 5.5	24.4 ± 5.1
C_R	-	-	0.85	0.89	0.92
C_S	-	-	1.00	1.00	1.00
C_B	-	-	1.00	1.00	1.00
C_E	-	-	1.00	1.00	1.00
C_N	-	-	1.38	1.23	1.18
$(N_1)_{60}$	-	-	21.2	25.8 ± 6.0	26.5 ± 5.5
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	216.4	216.4

EVENT PARAMETERS

1989 Loma Prieta Earthquake USGS, Graves and Pitarka (2004)

Magnitude: 6.93

Fault Type: reverse-obliqu Z_{tor} (km): 3.85 R_{rup} (km): -

Dip: 70 Width (km): 20 R_{jb} (km): 17.8

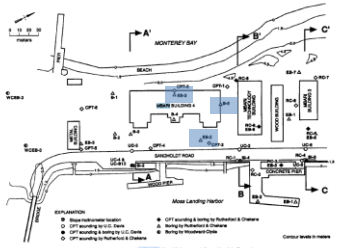


FIG. 2. Map of MBARI Facilities and Sandholdt Road

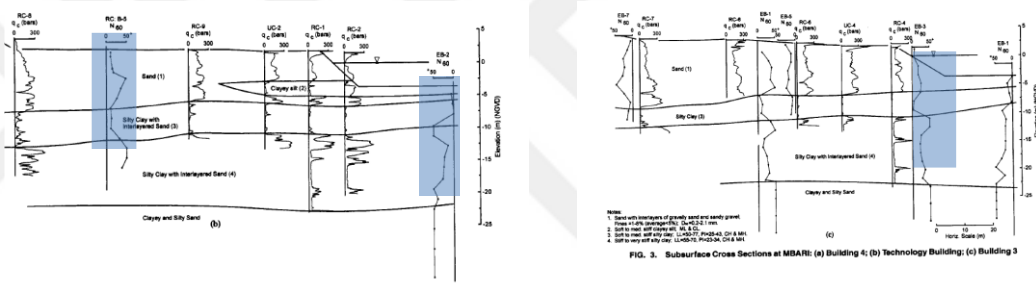
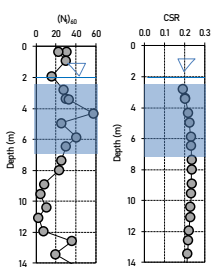


FIG. 3. Subsurface Cross Sections at MBARI: (a) Building 4; (b) Technology Building; (c) Building 3

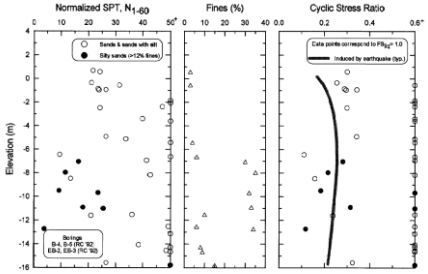


GWT

EB3	1.61	m
B5	2.3	m
Mean:	2.0	
St. Dev.	0.5	

For SI-2 inclonometer

D_{50} (mm) 0.4-0.7mm 1-8%
Poorly graded sand
D_{50} (mm) 0.21-2.1mm



Boulanger et al (1995) provided N1,60 values
Boulanger et al (1997) provided N60 values

FIG. 8-8. Liquefaction Analysis of SPT Data at the MBARI Building No. 4

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	Borehole	Soil Type
0.34	1.12	NA	19	2.00	0.80	*30.4*	*5.0*	B5	sand
0.34	1.12	NA	14	2.00	0.80	*22.4*	*5.0*	EB3	sand
0.92	3.02	NA	18	2.00	0.82	*29.6*	*5.0*	B5	sand
1.92	***6.30***	***NA***	***11***	***1.67***	***0.86***	***15.8***	***5.0***	***EB3***	***sand***
2.79	***9.15***	***0.189***	***21***	***1.47***	***0.88***	***27.2***	***5.0***	***B5***	***sand***
3.39	***11.12***	***0.203***	***24***	***1.37***	***0.89***	***29.5***	***5.0***	***B5***	***sand***
3.43	***11.25***	***0.203***	***27***	***1.37***	***0.89***	***33.0***	***5.0***	***EB3***	***sand***
4.33	14.21	0.217	50	1.25	0.91	*57.1*	*5.0*	B5	sand
4.96	***16.27***	***0.223***	***23***	***1.19***	***0.92***	***25.2***	***5.0***	***EB3***	***sand***
5.87	19.26	0.230	39	1.11	0.94	*40.4*	*5.0*	B5	sand
6.47	***21.23***	***0.233***	***30***	***1.06***	***0.94***	***30.1***	***5.0***	***EB3***	***sand***
7.38	***24.21***	***0.235***	***26***	***1.00***	***0.95***	***24.9***	***5.0***	***B5***	***sand***
7.99	26.21	0.235	25	0.97	0.96	*23.3*	*5.0*	EB3	silty clay
8.9	29.20	0.234	9	0.93	0.97	*8.0*	*5.0*	B5	sand
9.54	31.30	0.232	5	0.90	0.97	*4.4*	*5.0*	EB3	silty clay
10.38	34.06	0.229	12	0.86	0.97	*10.1*	*5.0*	B5	silty clay2
11.06	36.29	0.226	3	0.84	0.98	*2.5*	*5.0*	EB3	silty clay
11.93	39.14	0.221	9	0.81	0.98	*7.2*	*5.0*	B5	silty clay2
12.58	41.27	0.218	46	0.79	0.98	*35.9*	*5.0*	EB3	silty clay2
13.43	44.06	0.213	25	0.77	0.99	*19.0*	*5.0*	B5	silty clay2
14.08	46.19	0.210	49	0.75	0.99	*36.4*	*5.0*	EB3	silty clay2
14.96	49.08	0.205	50	0.73	0.99	*36.2*	*5.0*	B5	silty clay3
15.58	51.12	0.202	20	0.72	0.99	*14.2*	*5.0*	EB3	silty clay2
16.49	54.10	0.199	38	0.70	0.99	*26.4*	*5.0*	B5	silty clay3
17.16	56.30	0.197	16	0.69	0.99	*10.9*	*5.0*	EB3	silty clay2
17.98	58.99	0.195	26	0.67	0.99	*17.4*	*5.0*	B5	silty clay3
18.66	61.22	0.194	17	0.66	1.00	*11.2*	*5.0*	EB3	silty clay2
20.17	66.17	0.192	19	0.64	1.00	*12.0*	*5.0*	EB3	silty clay2
21.68	71.13	0.191	23	0.61	1.00	*14.1*	*5.0*	EB3	silty clay2
23.21	76.15	0.190	17	0.60	1.00	*10.1*	*5.0*	EB3	silty clay2
24.77	81.27	0.190	35	0.58	1.00	*20.2*	*5.0*	EB3	silty clay2
					Mean:	26.5	5.0		
					St. Dev.	5.5	8.6	*assigned*	

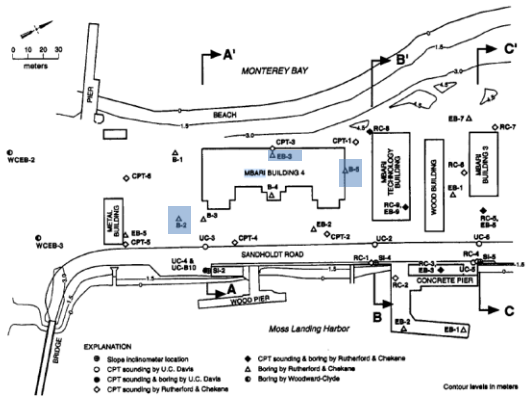


FIG. 2. Map of MBARI Facilities and Sandholdt Road

Case number:	146
Earthquake:	Loma Prieta
Magnitude:	6.93 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Miller Farm Site
References:	Holzer et al. (1994), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Lateral spread near the Pajaro River. South of the river ~0.2 m high head scarp
GPS LAT	36.906692 which could be followed for 1.7 km. Maximum horizontal displacement of
GPS LONG	-121.740992 ~30 cm just west of the study area. Sand boils along the area affected by
Liq. layer consist of:	silty sand and sandy silt lateral spreading. Eyewitnesses reported that sediment-laden water flowed
Geological Unit:	younger and older holocene fluvial d gently from vents on the lateral spread during and until 20 minuntes after the earthquake
Site Response Anlaysis:	Yes
Comments:	Holzer et al. (1994), "Observed and predicted ground deformation-Miller Farm lateral spread, Watsonville, California."

Cetin (2000) "Located at the south side of the Pajara River at Clint Miller Farms near Watsonville, CA. Composed of younger and older holocene fluvial deposits. The upper 4-6 m of the younger flood-plain deposits is silty and contains only a few thin sand layers. In the depth interval from 4.6-9.1, sand percentages range from 67-100. This layer includes most of the liquefied layer. Average fines content of the sandy layers if 15%, ranging from 22 % at Miller Farm to 8% at Farris Farm. The depth to the water table was 4.6 m 10 days after the main shock. PGA is recorded in a four-story building 1km west of Miller Farm as 0.39 g. In Open File Report 95-663, Holzer et al., the PGA was given as 0.53 g. Watsonville region was shaken at MMI scale of 8.(~ 0.25-0.50 g ?) The earthquake specific attenuation-relationship suggests for alluvium sites at 4.6 miles (closest distance to the fault) ~0.50-0.65 g. A PGA value of 0.36 g was recorded at Watsonville. Based on site response analyses results, a PGA value of 0.42 is adopted. Strong ground motion lasted ~ 6 seconds. SPT performed after the earthquake."

Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).

No information regarding SPT hammer type provided.

Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	Yes	-	Yes	Yes
Data Class	-	B	-	A	A
d_{crtc} range (m)	-	4.0 - 8.0	-	4.0 - 8.0	4.0 - 8.0
d_{crt} (m)	-	6.0	-	6.0	6.0
GWT (m)	-	4.0 ± 0.3	-	4.0 ± 0.1	4.0 ± 0.1
γ_{moist} (kN/m^3)	-	14.1 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	14.9 ± 0.6	-	19.6 ± 0.5	19.6 ± 0.5
σ_v (kPa)	-	86.6 ± 10.4	-	108.7 ± 13.3	108.7 ± 13.3
σ_v' (kPa)	-	67.0 ± 5.2	-	89.0 ± 6.9	89.0 ± 6.9
a_{max} (g)	-	0.420 ± 0.050	-	0.420 ± 0.063	0.420 ± 0.063
r_d	-	0.84 ± 0.017	-	0.90 ± 0.017	0.90 ± 0.041
CSR	-	0.320 ± 0.043	-	0.300 ± 0.048	0.300 ± 0.049
M_w	-	7.00	-	6.93	6.93
D_{50}	-	0.160 ± 0.020	-	0.160 ± 0.050	0.160 ± 0.050
% Fines	-	22.0 ± 3.0	-	22.0 ± 2.0	22.0 ± 8.6
% PI	-	-	-	-	NAV
N	-	8.0 ± 3.5	-	8.0 ± 3.4	8.0 ± 3.2
C_R	-	0.92	-	0.92	0.94
C_S	-	1.00	-	1.00	1.00
C_B	-	1.00	-	1.00	1.00
C_E	-	1.13	-	1.13	1.13
C_N	-	1.20	-	1.07	1.07
$(N_1)_{60}$	-	10.0 ± 4.4	-	8.9 ± 3.8	9.0 ± 3.6
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

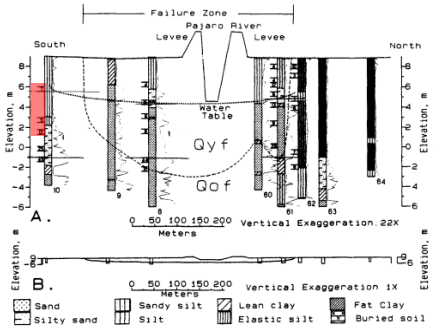
EVENT PARAMETERS

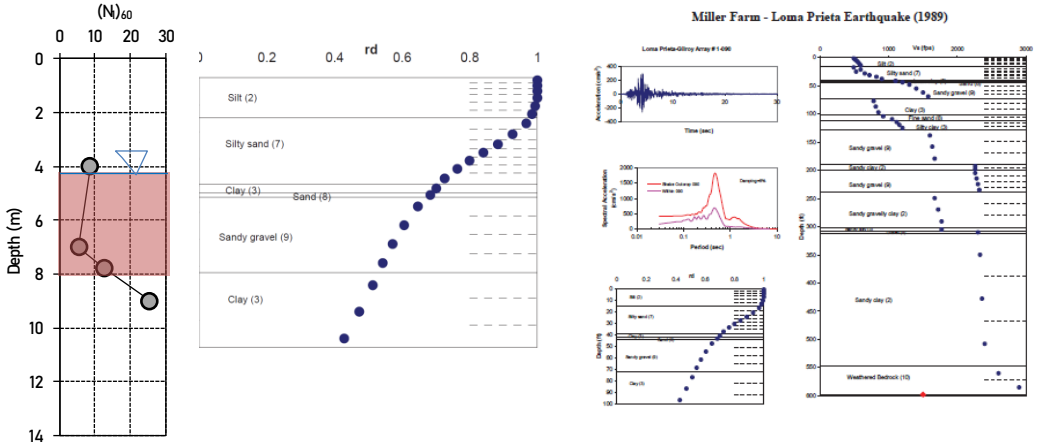
1989 Loma Prieta Earthquake USGS, Graves and Pitarka (2004), Toprak et al. (1999), Holzer et al. (1998)

Magnitude: 6.93

Fault Type: reverse-obliqu Z_{tor} (km): 3.85 R_{rup} (km): -

Dip: 70 Width (km): 20 R_{jb} (km): 6.6





Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$			Vs,est (m/s)
4	*13.1*		*7*	*1.21*	*0.91*	*8.7*		silt	160
7	*23.0*		*5*	*1.01*	*0.95*	*5.5*	HOLZER	sandy silt	169
7.8	*25.6*		*12*	*0.98*	*0.96*	*12.7*	HOLZER	silty sand	200
9	29.5		25	0.93	0.97	25.3	HOLZER	silty sand	233
					Mean:	9.0			
					St. Dev.	3.6			

Case number:	352
Earthquake:	1989 Loma Prieta Earthquake
Magnitude:	6.93 (Mw) Pacific Earthquake Engineering Research Center: NGA Database
Location:	Alameda Strong Motion Station
References:	Youd and Carter 2003, Gibbs et al (1992), Carlisle and Rollins (1994), Greenfield (2017), NGL Project, Bozorgnia et al 2014, Greenfield 2018
GPS LAT	37.785748
GPS LONG	-122.309346
Liq. layer consist of:	Sand
Geological Unit:	Fill
Site Response Anlaysis:	No
Nature of Failure:	Youd and Carter (2003) indicate that sand boils and ground settlement were observed at ANAS following the Loma Pri
Comments:	The station has recorded 1989 Loma Prieta earthquake. Acceleration time is history is available digitally. Fines content is not available. The fill is classified as SP which can be concluded as FC 0-5 %. PGA is reported as 0.229 g by Greenfield (2018). Greenfield (2018) reported the critical layer as 2.5 m with a drainage path of 0.5 m. The station is located on an artificial fill. Greenfeld 2018 reported that the station is "founded on Merritt Sand hydraulic fill. … the thickness of the fill 4-5m on average…". Vs30 is reported as 190 m/s by NGA West 2 as indicated by Greenfield (2018). Field investigation data are available in Carlisle and Rollins (1994) report and Gibbs et al. (1992). Gibbs et al (1992) performed SPT using ASTM D1586. Carlisle and Rollins (1994) "Alameda Naval Air Station, a soft-soil site, Field testing included cone-penetration tests, standard penetration tests, and shear-wave-velocity logging, using both downhole methods and a seismic cone penetrometer.ANAS consists primarily of shale and graywacke sandstone.ANAS was constructed between 1939 and 1940 by placing dredged Merritt Sand from nearby channels over the shallow estuarine mud, using hydraulic-filling techniques. The fill was placed behind a hand-stacked rockfill seawall that enclosed an area of about 2 mi2 (5.2 km2) (Rogers and Figuers, 1991).To define the soil profile at ANAS, a test borehole (BYU1, fig. 1) was drilled to bedrock immediately east of building 23, which houses the two seismographs. A simplified diagram of the soil profile, based on logging by Thomas E. Fumal of the U.S. Geological Survey, is shown in figure 4…." The PGA is recorded as 0.237 g at the station however liquefaction was observed at the station. As part of the protocol it is necessary to use PGApredicted that had not liquefied hence PGA is taken as 0.25 g. No information regarding the SPT hammer provided in the document.
Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.4 - 4.5
d_{crt} (m)	-	-	-	-	3.5
GWT (m)	-	-	-	-	2.4 ± 0.1
g_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
g_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
s_v (kPa)	-	-	-	-	67.0 ± 7.3
s_v' (kPa)	-	-	-	-	56.7 ± 4.0
a_{max} (g)	-	-	-	-	0.250 ± 0.013
r_d	-	-	-	-	0.85 ± 0.051
CSR	-	-	-	-	0.163 ± 0.015
M_w	-	-	-	-	6.93
D_{50}	-	-	-	-	NAV
% Fines	-	-	-	-	<10 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	13.3 ± 1.3
C_R	-	-	-	-	0.90
C_S	-	-	-	-	1.30
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.00
C_N	-	-	-	-	1.34
$(N_1)_{60}$	-	-	-	-	20.7 ± 2.0
V_{s30m} (m/s)	-	-	-	-	190.0
V_{s12m} (m/s)	-	-	-	-	128.8

EVENT PARAMETERS

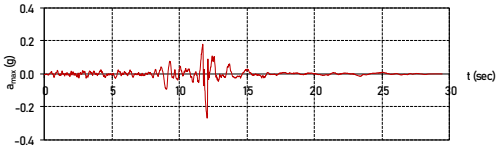
1989 Loma Prieta Earthquake — USGS, Graves and Pitarka (2004), Toprak et al. (1999), Holzer et al. (1998)

Magnitude: 6.93
Fault Type: reverse-obliqu — Z_{tor} (km): 3.85 — R_{rup} (km): 71.0
Dip: 70 — Width (km): 20 — R_{jb} (km): 74.0

ACCELERATION TIME HISTORY

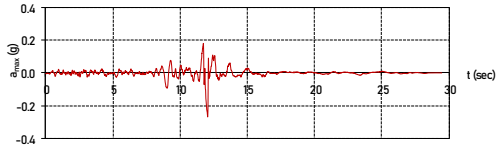
Full Record

N_{H1}	2.8
N_{H2}	4.6
N_{gm}	3.5
PGA_{H1}	0.268
PGA_{H2}	0.209
PGA	0.237
M_w	6.93
$M_{w,cycle}$	error low cycle



Untill Liquefaction

$N_{H1,L}$	2.5
$N_{H2,L}$	4.0
$N_{gm,L}$	3.2
PGA_{H1}	0.268
PGA_{H2}	0.209
PGA_L	0.237
$M_{w,eq}$	error low cycle
t_L	12.4



Carlisle and Rollins (1994)

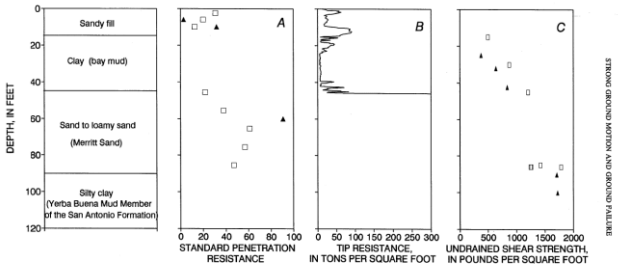
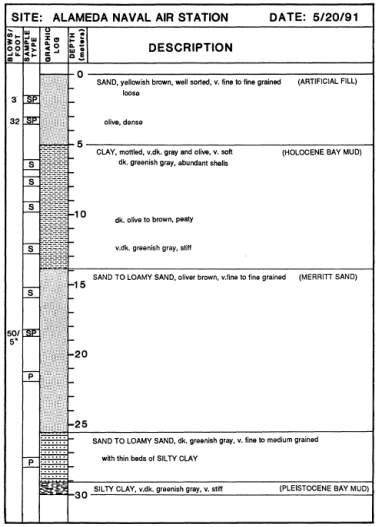


Figure 6.—Standard penetration resistance (A), tip resistance (B), and undrained shear strength (C) versus depth at Alameda Naval Air Station. Squares, averages of data of Harding Lawson Associates (1984); triangles, downhole measurements in borehole BYU1 (fig. 1).

Gibbs et al 1992



Greenfield (2017)

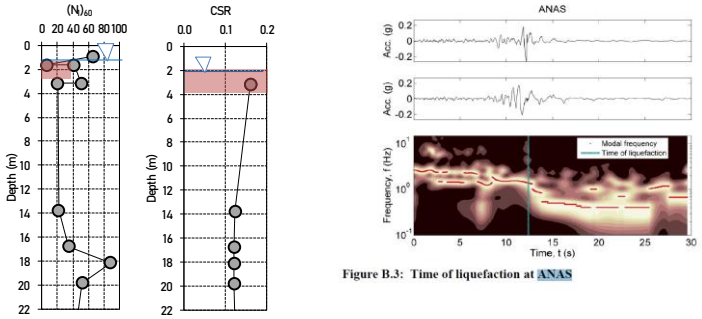


Figure B.3: Time of liquefaction at ANAS

Carlisle and Rollins (1994)
**The fill is composed of Merritt Sand. Merritt sand is poorly graded fine sand containing less than 10% silt.*

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	Soil Type	Energy	
BH2	0.9	3.0	NA	31	2.00	0.82	66.3	Sandy fill	*1*	
BH1	1.7	5.4	NA	3	1.80	0.85	6.0	SAND, yellowish brown, well sorted, v. fine to fine grained loose (ARTIFICIAL FILL)	*2*	
BH2	1.7	5.4	NA	21	1.80	0.85	41.8	Sandy fill	*1*	
BH1	3.2	10.3	0.160	32	1.38	0.89	50.9	SAND, yellowish brown, well sorted, v. fine to fine grained loose (ARTIFICIAL FILL)	*2*	***outlier***
BH2	***3.2***	***10.3***	***0.160***	***13***	***1.38***	***0.89***	***20.7***	***Sandy fill***	***1***	
BH2	13.8	45.1	0.123	22	0.78	0.99	22.0	Sand to loamy sand (Merritt Sand)	*1*	
BH2	16.8	55.1	0.121	38	0.71	0.99	34.9	Sand to loamy sand (Merritt Sand)	*1*	
BH1	18.2	59.5	0.120	100	0.69	0.99	88.8	SAND TO LOAMY SAND, oliver [sic] brown, v.fine to fine grained (MERRITT SAND)	*2*	
BH2	19.9	65.1	0.121	61	0.66	1.00	52.1	Sand to loamy sand (Merritt Sand)	*1*	
BH2	22.9	75.0	0.121	57	0.62	1.00	45.7	Sand to loamy sand (Merritt Sand)	*1*	
BH2	25.9	85.0	0.122	47	0.58	1.00	35.6	Sand to loamy sand (Merritt Sand)	*1*	
						Mean:	20.7			
						St. Dev.	2.0			

1 Composite average from Carlisle and Rollins (1994)
2 Assumed energy based on descriptions 60%

Youd and Carter (2003) "Similar to Treasure Island, the fill beneath ANAS is uncompacted and susceptible to liquefaction"

Case number:	150
Earthquake:	1993 Kushiro-Oki
Magnitude:	7.8 (M_{jma}), 7.6 (M_w)
Location:	Quay Wall Site A
References:	lai et al (1994), Cetin (2000),Cetin et al (2004, 2018)
Nature of Failure:	Settlement and lateral movement of quay wall couple of meters.
GPS LAT	42.985814
GPS LONG	144.368416
Liq. layer consist of:	gravelly and fine sand layers
Geological Unit:	reclaimed from the sea by filling the sand dredged from the nearby sea
Site Response Anlaysis:	No
Comments:	Cetin (2000) "On January 15, 1993, an earthquake of magnitude 7.8 in JMA scale hit a northern island of Japan called Hokkaido. The epicenter was located 15 km south of Kushiro City. Kushiro Port was shaken with a peak horizontal acceleration of 0.47 and 0.34g. The earthquake caused liquefaction of untreated backfill sand at the port, resulting in damage to many of the quay walls. The extent of the damage was generally moderate; the displacements of the quay walls were less than about 5% of the water depth in front of the quay walls. In contrast, the quay walls having the backfill sand compacted as measures against liquefaction survived the earthquake without damage. Kushiro Port is developed at the estuary of the Kushiro River. Most of the port area has been reclaimed from the sea by filling the sand dredged from the nearby sea. The natural ground along the former beach line is of sand dune origin being dense with SPT N values of about 50. The fill above the original ground gradually increases its thickness from none at the former beach line to about 10 m at the southern end of the piers in the West Port District. SPT was conducted before the earthquake."

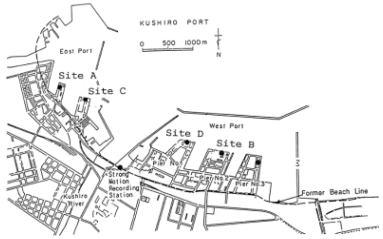


Fig. 2 Plan of Kushiro Port
143



Gravel Content (%):	NAV
CPT available:	No
Vs available:	-

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	A	-	A	A
d_{crtc} range (m)	-	4.0 - 6.5		4.0 - 6.5	2.4 - 7.3
d_{crt} (m)	-	5.3	5.2	5.3	4.9
GWT (m)	-	2.0 ± 0.3	2	2.0 ± 0.1	2.0 ± 0.1
γ_{moist} (kN/m^3)	-	16.5 ± 0.6	-	16.5 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	17.3 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	89.4 ± 7.6	100.3	97.0 ± 8.4	97.2 ± 16.8
σ_v' (kPa)	-	57.4 ± 4.8	68.2	65.1 ± 4.5	68.9 ± 8.9
a_{max} (g)	-	0.400 ± 0.040	0.4	0.400 ± 0.060	0.410 ± 0.061
r_d	-	0.94 ± 0.073	0.96	0.96 ± 0.073	0.99 ± 0.068
CSR	-	0.380 ± 0.053	0.366	0.372 ± 0.063	0.372 ± 0.064
M_w	-	8.00	7.60	7.60	7.60
D_{50}	-	0.340 ± 0.070	-	0.340 ± 0.050	0.340 ± 0.050
% Fines	-	2.0 ± 1.0	2	2.0 ± 2.0	2.0 ± 8.6
% PI	-	-	-	-	0
N	-	11.7 ± 2.9	11.7	11.7 ± 2.9	11.4 ± 2.8
C_R	-	0.93	0.95	0.93	0.94
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.29	1.21	1.25	1.21
$(N_1)_{60}$	-	17.1 ± 4.2	16.4	16.5 ± 4.1	17.6 ± 4.4
V_{s30m} (m/s)	-	-	-	-	193.6
V_{s12m} (m/s)	-	204.2	-	204.2	237.7

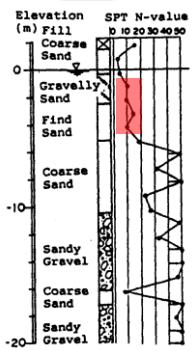
EVENT PARAMETERS

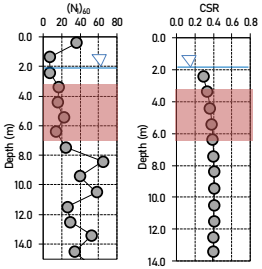
1993 Kushiro-Oki

Magnitude: 7.60

Fault Type: subduction | Z_{tor} (km): - | R_{rup} (km): -

Dip: - | Width (km): - | R_{jb} (km): -





Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
0.4	1.3	NA	16.0	2.00	0.84	36.6	Fill
1.4	4.4	NA	3.0	2.00	0.87	7.1	Coarse Sand
2.4	**8.0**	**0.293**	**4.0**	**1.55**	**0.89**	**7.5**	**Coarse Sand at the boundary of GWT probably**
3.4	***11.1***	***0.334***	***10.0***	***1.39***	***0.91***	***17.3***	***Gravelly Sand*** **not fully saturated very thin layer under water**
4.4	***14.5***	***0.362***	***10.0***	***1.26***	***0.93***	***16.0***	***Gravelly Sand***
5.4	***17.8***	***0.382***	***15.0***	***1.16***	***0.94***	***22.5***	***Fine Sand***
6.4	***21.0***	***0.394***	***10.0***	***1.09***	***0.95***	***14.2***	***Fine Sand***
7.5	24.4	0.403	18.0	1.03	0.96	24.3	Coarse Sand
8.4	27.6	0.408	50.0	0.97	0.97	64.5	Coarse Sand
9.4	30.9	0.410	32.0	0.93	0.97	39.5	Coarse Sand
10.5	34.4	0.409	49.0	0.89	0.98	58.1	Coarse Sand
11.5	37.7	0.406	23.0	0.85	0.98	26.3	Coarse Sand
12.5	41.0	0.402	27.0	0.82	0.99	29.8	Coarse Sand
13.4	44.0	0.396	49.0	0.79	0.99	52.6	Sandy Gravel
14.5	47.7	0.389	33.0	0.77	0.99	34.2	Sandy Gravel
15.4	50.6	0.383	51.0	0.75	0.99	51.6	Sandy Gravel
16.3	53.6	0.377	51.0	0.73	0.99	50.3	Sandy Gravel
17.4	57.2	0.372	47.0	0.70	1.00	45.1	Sandy Gravel
18.4	60.4	0.368	7.0	0.69	1.00	6.5	Coarse Sand
19.4	63.6	0.365	51.0	0.67	1.00	46.6	Sandy Gravel
					Mean:	17.6	
					St. Dev.	4.4	

Case number:	151
Earthquake:	1993 Kushiro-Oki
Magnitude:	7.8 (M_{jma}), 7.6 (M_w)
Location:	Quay Wall Site D
References:	Iai et al (1994), Cetin (2000),Cetin et al (2004, 2018)
Nature of Failure:	No surface evidence of liquefaction
GPS LAT	42.99431
GPS LONG	144.33899
Liq. layer consist of:	Coarse Sand mixed with Gravel and fine sand
Geological Unit:	reclaimed from the sea by filling the sand dredged from the nearby sea
Site Response Anlaysis:	No
Comments:	Cetin (2000) "On January 15, 1993, an earthquake of magnitude 7.8 in JMA scale hit a northern island of Japan called Hokkaido. The epicenter was located 15 km south of Kushiro City. Kushiro Port was shaken with a peak horizontal acceleration of 0.47 and 0.34g. The earthquake caused liquefaction of untreated backfill sand at the port, resulting in damage to many of the quay walls. The extent of the damage was generally moderate; the displacements of the quay walls were less than about 5% of the water depth in front of the quay walls. In contrast, the quay walls having the backfill sand compacted as measures against liquefaction survived the earthquake without damage. Kushiro Port was developed at the estuary of the Kushiro River. Most of the port area has been reclaimed from the sea by filling the sand dredged from the nearby sea. The natural ground along the former beach line is of sand dune origin being dense with SPT N values of about 50. The fill above the original ground gradually increases its thickness from none at the former beach line to about 10 m at the southern end of the piers in the West Port District. SPT was conducted before the earthquake. The Site had been improved by sand compaction piles."

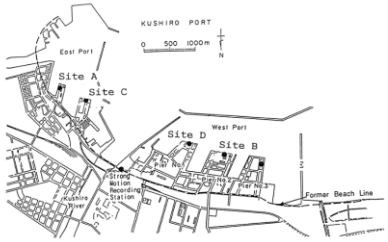


Fig. 2 Plan of Kushiro Port
143

Gravel Content (%):	NAV
CPT available:	No
Vs available:	-

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	No	No	No	No
Data Class	-	B	-	B	A
d_{crtc} range (m)	-	7.5 - 14.0		7.5 - 14.0	6.2 - 10.3
d_{crt} (m)	-	10.8	10.8	10.8	8.3
GWT (m)	-	1.6 ± 0.3	1.6	1.6 ± 0.1	1.6 ± 0.1
γ_{moist} (kN/m^3)	-	17.3 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	18.9 ± 0.6	-	19.6 ± 0.5	21.5 ± 0.5
σ_v (kPa)	-	200.6 ± 21.3	208.5	210.4 ± 21.8	173.7 ± 15.1
σ_v' (kPa)	-	110.7 ± 11.7	118.3	120.4 ± 11.6	108.4 ± 8.7
a_{max} (g)	-	0.400 ± 0.040	0.4	0.400 ± 0.060	0.410 ± 0.061
r_d	-	0.79 ± 0.134	0.89	0.88 ± 0.134	0.99 ± 0.107
CSR	-	0.373 ± 0.075	0.408	0.398 ± 0.086	0.423 ± 0.079
M_w	-	8.00	7.60	7.60	7.60
D_{50}	-	0.340 ± 0.070	-	0.340 ± 0.050	0.340 ± 0.050
% Fines	-	0.0 ± 1.0	0	0.0 ± 2.0	0.0 ± 8.6
% PI	-	-	-	-	0
N	-	26.8 ± 3.2	26.8	26.7 ± 3.1	25.2 ± 3.6
C_R	-	1.00	1.00	1.00	0.97
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	0.93	0.95	0.92	0.97
$(N_1)_{60}$	-	30.3 ± 3.6	30.9	29.8 ± 3.5	32.2 ± 4.6
V_{s30m} (m/s)	-	-	-	-	193.6
V_{s12m} (m/s)	-	217.9	-	217.9	271.3

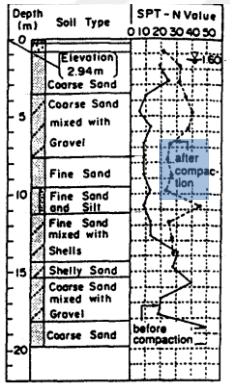
EVENT PARAMETERS

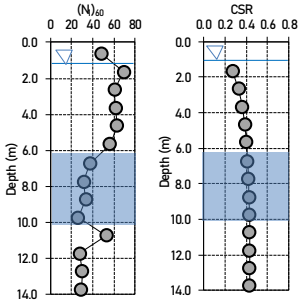
1993 Kushiro-Oki

Magnitude: 7.60

Fault Type: subduction Z_{tor} (km): - R_{rup} (km): -

Dip: - Width (km): - R_{jb} (km): -





Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N_1)_{60}$	
0.7	2.1	NA	21.0	2.00	0.84	48.5	Coarse Sand
1.7	5.4	0.271	32.0	1.82	0.87	69.4	Coarse Sand
2.7	8.7	0.331	32.0	1.54	0.90	60.6	Coarse Sand
3.7	12.0	0.365	36.0	1.37	0.92	61.7	Coarse Sand mixed with Gravel
4.7	15.3	0.386	40.0	1.24	0.93	63.2	Coarse Sand mixed with Gravel
5.7	18.5	0.401	38.0	1.14	0.94	56.1	Coarse Sand mixed with Gravel
6.8	***22.1***	***0.413***	***27.0***	***1.06***	***0.96***	***37.3***	Coarse Sand mixed with Gravel
7.8	***25.4***	***0.420***	***24.0***	***1.00***	***0.96***	***31.5***	Fine Sand
8.8	***28.7***	***0.426***	***27.0***	***0.94***	***0.97***	***33.8***	Fine Sand
9.8	***32.0***	***0.430***	***22.0***	***0.90***	***0.98***	***26.4***	Fine Sand and Silt
10.8	35.3	0.432	46.0	0.86	0.98	52.9	gravel? Fine Sand and Silt
11.8	38.5	0.433	25.0	0.82	0.98	27.7	Fine Sand mixed with Shells
12.8	41.8	0.432	28.0	0.79	0.99	30.0	Fine Sand mixed with Shells
13.8	45.1	0.430	28.0	0.77	0.99	29.0	Fine Sand mixed with Shells
					Mean:	32.2	
					St. Dev.	4.6	

Case number:	368
Earthquake:	1993 Kushiro-Oki earthquake
Magnitude:	7.8
Location:	Kushiro Port
References:	Iai et al. (1995), Greenfield (2017, 2018), Sasatani (1996), Kayen (2008), Cetin et al. (2004, 2018), Cetin (2000), NGL Proje
Nature of Failure:	Liquefaction of the backfill sand of quay walls; displacements of quay walls.
GPS LAT:	42.999 Sudden change in the response of ground after 30 seconds.
GPS LONG:	144.355
Liq. layer consist of:	Sand
Geological Unit:	man-made fill
Site Response Anlaysis:	No
Comments:	Greenfield (2018) "..The recording array included accelerographs at the ground surface and at a depth of 77 m. 42.999 and 144.355. Kushiro Port (Kushiro-G) recorded ground motions are provided by PARI. The recording array included accelerographs at the ground surface and at a depth of 77 m...The test results indicate the average shear wave velocity in the upper 30 m of the site, Vs30, is about 290 m/s. An approximately 3 m-tall seawall and levee separate the site from the Kushiro River....The investigations described by Iai et al. are referred to as Sites No. 1 through 5...Sasatani (1996) indicates up to 8 m of very loose to loose sand fill was placed at the west side of Kushiro Port, but no descriptions of the thickness of fill at the location of Kushiro-G have been provided....The Site Plan (Figure 1) from Iai et al. refers to the PARI boring as Site No. 1...Sand (Fill): Based on three gradation tests, the sand fill has a median diameter, D50, between 0.6 to 0.8 mm and contains between 4% to 16% fine-grained particles. Areas of the sand fill may, therefore, be silty. Cyclic triaxial tests were performed on samples of the sand fill from boring B-5. These tests indicate liquefaction, defined by 5% double-amplitude shear strain, is triggered after 15 cycles of loading with cyclic stress ratios between 0.18 and 0.28..." The PGA is recorded as 0.41 g and the site is liquefied. Based on the database protocol, it is necessary to use PGApredicted that had not liquefied. However based on the recordings, it became apparent that the site has liquefied 28th second, considering the level of PGA as 0.40 g, PGA was considered not to be affacted by liquefaction hence it is used as 0.41 g.

Cetin (2000) "On January 15, 1993, an earthquake of magnitude 7.8 in JMA scale hit a northern island of Japan called Hokkaido. The epicenter was located 15 km south of Kushiro City. Kushiro Port was shaken with a peak horizontal acceleration of 0.47 and 0.34g. The earthquake caused liquefaction of untreated backfill sand at the port, resulting in damage to many of the quay walls. The extent of the damage was generally moderate; the displacements of the quay walls were less than about 5% of the water depth in front of the quay walls. In contrast, the quay walls having the backfill sand compacted as measures against liquefaction survived the earthquake without damage. Kushiro Port has been developed at the estuary of the Kushiro River. Most of the port area has been reclaimed from the sea by filling the sand dredged from the nearby sea. The natural ground along the former beach line is of sand dune origin being dense with SPT N values of about 50. The fill above the original ground gradually increases its thickness from none at the former beach line to about 10 m at the southern end of the piers in the West Port District. SPT was conducted before the earthquake."



Gravel Content (%):	<5
CPT available:	No
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	B	-	A	A
d_{crtc} range (m)	-	19.0 - 22.0		1.6 - 5.6	2.0 - 5.5
d_{crt} (m)	-	20.5	3.8	3.6	3.8
GWT (m)	-	1.6 ± 0.3	2	2.0 ± 0.1	2.0 ± 0.1
γ_{moist} (kN/m^3)	-	17.3 ± 0.6	-	17.3 ± 0.5	17.7 ± 0.5
γ_{sat} (kN/m^3)	-	18.9 ± 0.6	-	19.6 ± 0.5	18.6 ± 0.5
σ_v (kPa)	-	384.9 ± 15.2	65.2	66.1 ± 13.2	68.1 ± 11.0
σ_v' (kPa)	-	199.2 ± 13.0	47.1	50.4 ± 6.7	50.9 ± 5.4
a_{max} (g)	-	0.400 ± 0.040	0.47	0.400 ± 0.060	0.410 ± 0.020
r_d	-	0.47 ± 0.149	0.98	0.99 ± 0.053	0.99 ± 0.055
CSR	-	0.234 ± 0.079	0.41	0.338 ± 0.059	0.352 ± 0.034
M_w	-	8.00	7.60	7.60	7.60
D_{50}	-	0.150 ± 0.070	-	0.350 ± 0.050	0.350 ± 0.050
% Fines	-	10.0 ± 3.0	5	5.0 ± 2.0	5.0 ± 8.6
% PI	-	-	-	-	0
N	-	8.5 ± 2.2	17.4	16.9 ± 2.0	15.8 ± 1.1
C_R	-	1.00	0.85	0.87	0.92
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.30	1.22	1.37
C_N	-	0.69	1.35	1.42	1.41
$(N_1)_{60}$	-	7.2 ± 1.9	25.9	25.4 ± 3.0	28.0 ± 1.9
V_{s30m} (m/s)	-	-	-	-	279.2
V_{s12m} (m/s)	-	204.2	-	231.6	222.4

EVENT PARAMETERS

1993 Kushiro-Oki earthquake
Magnitude: 7.60
Fault Type: subduction Z_{tor} (km): - R_{rup} (km): 100.0
Dip: - Width (km): - R_{jb} (km): -

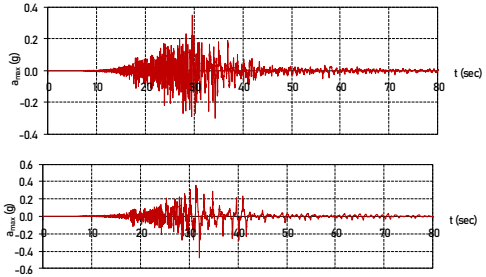
ACCELERATION TIME HISTORY

Full Record

N_{H1}	10.6
N_{H2}	22.7
N_{gm}	15.5
PGA_{H1}	0.479
PGA_{H2}	0.351
PGA	0.410
M_w	7.6
$M_{w,cycle}$	4.8

Untill Liquefaction

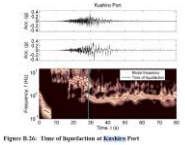
$N_{H1,L}$	14.3
$N_{H2,L}$	22.0
$N_{gm,L}$	17.7
PGA_{H1}	0.275
PGA_{H2}	0.269
PGA_L	0.272
$M_{w,eq}$	8.7
t_L	28.8

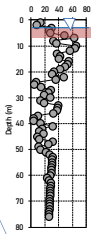


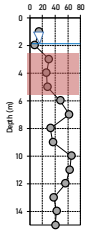
	Depth (m)	Depth (ft)	rd	CSR	N	C_N	C_E	$(N1)_{60}$		
above GWT	1	3.3	0.998	NA	6	2.00	0.86	14.0	Sand	PARI
above GWT	2	6.6	0.996	0.265	4	1.69	0.88	8.2	Sand	PARI
	3	***9.8***	***0.992***	***0.323***	***16***	***1.52***	***0.90***	***30.0***	***Sand***	***PARI***
	4	***13.1***	***0.987***	***0.360***	***15***	***1.38***	***0.92***	***26.1***	***Sand***	***PARI***
	5	***16.4***	***0.981***	***0.386***	***17***	***1.28***	***0.94***	***27.9***	***Sand***	***PARI***
	6	19.7	0.972	0.403	31	1.20	0.95	48.1	Gravelly sand	PARI
	7	23.0	0.961	0.414	42	1.13	0.96	62.1	Gravelly sand	PARI
	8	26.2	0.947	0.420	23	1.07	0.97	32.5	Gravelly sand	PARI
	9	29.5	0.929	0.422	27	1.02	0.97	36.6	Gravelly sand	PARI
	10	32.8	0.908	0.421	50	0.98	0.98	65.3	Gravelly sand	PARI
	11	36.1	0.884	0.417	50	0.94	0.98	63.0	Gravelly sand	PARI
	12	39.4	0.859	0.410	46	0.91	0.99	56.1	Gravelly sand	PARI
	13	42.7	0.833	0.402	32	0.87	0.99	37.8	Gravelly sand	PARI
	14	45.9	0.808	0.395	37	0.85	0.99	42.4	Gravelly sand	PARI
	15	49.2	0.786	0.387	36	0.82	0.99	40.1	Gravelly sand	PARI
	16	52.5	0.767	0.381	50	0.80	0.99	54.2	Gravelly sand	PARI
	17	55.8	0.751	0.375	50	0.78	0.99	52.8	Gravelly sand	PARI
	18	59.1	0.738	0.371	48	0.76	1.00	49.5	Gravelly sand	PARI
	19	62.3	0.729	0.369	42	0.74	1.00	42.3	Gravelly sand	PARI
	20	65.6	0.722	0.367	34	0.72	1.00	33.5	Gravelly sand	PARI
	21	68.9	0.717	0.366	32	0.71	1.00	30.8	Gravelly sand	PARI
	22	72.2	0.712	0.365	50	0.69	1.00	47.2	Gravelly sand	PARI
	23	75.5	0.708	0.364	39	0.68	1.00	36.1	Silt	PARI
	24	***78.7***	***0.703***	***0.363***	***8***	***0.66***	***1.00***	***7.3***	***Silt***	***PARI***
	25	***82.0***	***0.699***	***0.362***	***6***	***0.65***	***1.00***	***5.3***	***Sand***	***PARI***
	26	85.3	0.694	0.361	17	0.64	1.00	14.9	Sand	PARI
	27	88.6	0.689	0.359	34	0.63	1.00	29.2	Sand	PARI
	28	91.9	0.685	0.358	30	0.62	1.00	25.3	Sand	PARI
	29	95.1	0.680	0.356	23	0.61	1.00	19.1	Sand	PARI
	30	98.4	0.676	0.355	34	0.60	1.00	27.8	Sand	PARI
	31	101.7	0.671	0.353	17	0.59	1.00	13.7	Sand	PARI
	32	105.0	0.666	0.351	24	0.58	1.00	19.1	Sand	PARI
	33	108.3	0.662	0.350	50	0.57	1.00	39.1	Sand	PARI
	34	111.5	0.657	0.348	50	0.56	1.00	38.6	Sand	PARI
	35	114.8	0.653	0.346	50	0.56	1.00	38.0	Sand	PARI
	36	118.1	0.648	0.344	43	0.55	1.00	32.3	Sand	PARI
	37	***121.4***	0.643	0.342	***14***	***0.54***	***1.00***	***10.4***	***Silt***	PARI
	38	***124.7***	0.639	0.340	***6***	***0.54***	***1.00***	***4.4***	***Silt***	PARI
	39	***128.0***	0.634	0.338	***6***	***0.53***	***1.00***	***4.3***	***Silt***	PARI
	40	131.2	0.630	0.336	19	0.52	1.00	13.6	Sand	PARI
	41	134.5	0.625	0.334	45	0.52	1.00	31.8	Sand	PARI
	42	137.8	0.620	0.332	23	0.51	1.00	16.1	Sand	PARI
	43	141.1	0.616	0.330	17	0.50	1.00	11.7	Sand	PARI
	44	**144.4**	0.611	0.328	**26**	**0.50**	**1.00**	**17.7**	**Silt**	PARI
	45	**147.6**	0.607	0.326	**14**	**0.49**	**1.00**	**9.5**	**Silt**	PARI
	46	150.9	0.602	0.324	18	0.49	1.00	12.0	Sandy gravel	PARI
	47	154.2	0.598	0.321	48	0.48	1.00	31.7	Sandy gravel	PARI
	48	157.5	0.593	0.319	38	0.48	1.00	24.9	Sandy gravel	PARI
	49	160.8	0.588	0.317	17	0.47	1.00	11.0	Sandy gravel	PARI
	50	164.0	0.584	0.315	21	0.47	1.00	13.5	Sandy gravel	PARI
	51	167.3	0.579	0.313	34	0.47	1.00	21.6	Sandy gravel	PARI
	52	170.6	0.575	0.310	43	0.46	1.00	27.1	Sand	PARI
	53	173.9	0.570	0.308	50	0.46	1.00	31.2	Sand	PARI
	54	177.2	0.565	0.306	50	0.45	1.00	30.9	Sand	PARI
	55	180.4	0.561	0.304	50	0.45	1.00	30.7	Sand	PARI
	56	183.7	0.556	0.301	50	0.44	1.00	30.4	Sand	PARI
	57	187.0	0.552	0.299	50	0.44	1.00	30.1	Sand	PARI
	58	190.3	0.547	0.297	50	0.44	1.00	29.9	Sand	PARI
	59	193.6	0.542	0.294	50	0.43	1.00	29.6	Sand	PARI
	60	196.9	0.538	0.292	47	0.43	1.00	27.6	Sand	PARI
	61	200.1	0.533	0.290	40	0.43	1.00	23.3	Sand	PARI
	62	203.4	0.529	0.287	45	0.42	1.00	26.0	Sand	PARI
	63	206.7	0.524	0.285	50	0.42	1.00	28.7	Sand	PARI
	64	210.0	0.519	0.283	50	0.42	1.00	28.5	Sand	PARI
	65	213.3	0.515	0.280	50	0.41	1.00	28.3	Sand	PARI
	66	216.5	0.510	0.278	50	0.41	1.00	28.1	Sand	PARI
	67	219.8	0.506	0.276	50	0.41	1.00	27.9	Sand	PARI
	68	223.1	0.501	0.273	50	0.40	1.00	27.7	Sand	PARI
	69	226.4	0.496	0.271	50	0.40	1.00	27.5	Sand	PARI
	70	229.7	0.492	0.268	50	0.40	1.00	27.3	Sand	PARI
	71	232.9	0.487	0.266	50	0.40	1.00	27.1	Sand	PARI
	72	236.2	0.483	0.264	50	0.39	1.00	26.9	Sand	PARI
	73	239.5	0.478	0.261	50	0.39	1.00	26.7	Sand	PARI
	74	242.8	0.474	0.259	50	0.39	1.00	26.6	Sand	PARI
	75	246.1	0.469	0.256	50	0.39	1.00	26.4	Sand	PARI
	76	249.3	0.464	0.254	50	0.38	1.00	26.2	Sand	PARI
							Mean:	28.0		
							St. Dev.	1.9		

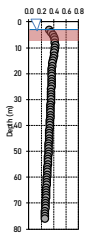
Cetin (2000) selected this layer. Greenfield (2017) selected dcrt as 2.3 m

Greenfield (2017)



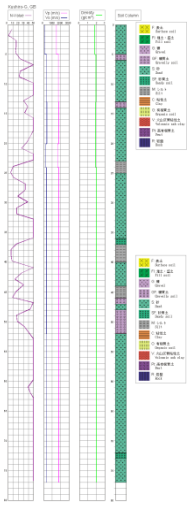


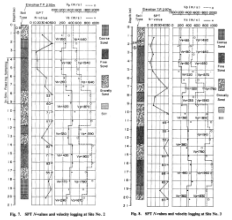


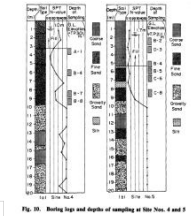


PARI

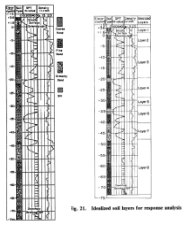
After 1993 Kushiro oki the same site is liquefied and It was noted as "Liquefaction of the backfill sand of quay walls; displacements of quay walls," by Iai et al. (1994). Hence the above backfill sand kept as critical layer. The PI of this silt layer is unknown. CSR is decreased at deeper layers







Site no 1



B-2

Depth	Fines
1.15	***16.4***
2.15	***4.2***
2.15	***4.5***
3.15	***5.1***
3.15	***55.6***
4.15	***15.6***
5.15	***7.1***
6.15	10.5
6.15	6.2
7.15	10.2
Mean:	15.5
St. Dev.	18.4

Case number:	152
Earthquake:	1994 Northridge Earthquake
Magnitude:	6.7 (M_w)
Location:	Balboa Blv. Unit C
References:	Bennett et al. (1998), Holzer et al (1999), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Cracks and lateral spread
GPS LAT	34.28122
GPS LONG	-118.5027
Liq. layer consist of:	Silty Sand (ML)
Geological Unit:	Holocene age alluvials
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "The Northridge Earthquake of January 17, 1994 caused widespread ground deformations on the gently sloping alluvial fan surface of the San Fernando Valley. The San Fernando Valley is a structural valley in southern California, which is filled with up to 4500 m of Tertiary sedimentary rock and alluvial sediment. Holocene age alluvial gravels, sands, and finer sediment with an aggregate thickness ranging from ~8-12 m immediately underlie the gently sloping valley floor. The alluvium was deposited by sediment-laden floodwaters that flowed out of the surrounding mountain canyons. The Balboa Boulevard site is on the northern margin of the San Fernando Valley where a 5 km long belt defined by a complex pattern of ground cracks formed in the Granada and Mission Hills. Ground cracks in most of the belt developed in Holocene alluvium on a gentle south-sloping surface. The site is underlain by Holocene silty sand to lean clay that ranges in thickness from 8-10 m. The uppermost unit, A, is less than 1 m thick and consists of fill and reworked sandy silt and lean clay with sand. The upper part of the primary Holocene section, unit B, consists of sheet flood and debris flow deposits and the lower part unit C, consists of fluvial deposits. The locations of maximum compression and extension correlate closely with where the water table falls below the base of the Holocene fluvial unit C. The part of unit C below water table has an average fines content of 52% and clay content of 18 %. Only 8 SPTs in unit C are below water table. Unit D is much coarser grained but is still very silty. Average fines content is 48%. 44 SPT's in unit D. PGA was recorded as 0.83 and 0.47g 2.3 km east of the study site at Los Angles Department of Water and Power Rinaldi Receiving station. Other nearby recorded PGA's were as high as 0.94 g; contoured regional maps of peak acceleration imply a value of 0.85 g. Site response analyses results suggests a value of 0.7 g."
	https://earthquake.usgs.gov/earthquakes/eventpage/ci3144585/executive
	https://earthquake.usgs.gov/earthquakes/eventpage/ci3144585/map
	Rupture distance is determined based on the fault plane derived from aftershock distribution by Hauksson et al (1995).
	SPT borehole data is redigitized. FC and D50 is slightly updated.
	Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
Gravel Content (%):	8.00
CPT available:	Yes
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	A	-	B	B
d_{crtc} range (m)	-	8.3 - 9.8		8.3 - 9.8	8.3 - 9.8
d_{crt} (m)	-	9.0	8.5	9.0	9.0
GWT (m)	-	7.2 ± 0.6	7.2	7.2 ± 0.1	7.2 ± 0.1
γ_{moist} (kN/m^3)	-	17.3 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	19.6 ± 0.6	-	19.6 ± 0.5	19.6 ± 0.5
σ_v (kPa)	-	160.2 ± 6.9	156.4	160.2 ± 6.0	160.2 ± 6.0
σ_v' (kPa)	-	142.5 ± 7.0	143.4	142.5 ± 4.4	142.5 ± 4.4
a_{max} (g)	-	0.693 ± 0.060	0.84	0.693 ± 0.104	0.693 ± 0.104
r_d	-	0.71 ± 0.005	0.87	0.71 ± 0.005	0.71 ± 0.058
CSR	-	0.357 ± 0.035	0.428	0.360 ± 0.054	0.360 ± 0.062
M_w	-	6.70	6.69	6.70	6.70
D_{50}	-	0.110 ± 0.020	-	0.099 ± 0.040	0.112 ± 0.041
% Fines	-	43.0 ± 13.0	50	48.0 ± 15.0	39.8 ± 12.7
% PI	-	-	-	-	NAV
N	-	19.9 ± 4.3	13.6	19.9 ± 4.2	19.9 ± 4.3
C_R	-	1.00	1.00	1.00	0.97
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.13	1.13	1.13	1.13
C_N	-	0.82	0.86	0.84	0.84
$(N_1)_{60}$	-	18.5 ± 4.0	13.1	19.0 ± 4.0	18.4 ± 4.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

EVENT PARAMETERS

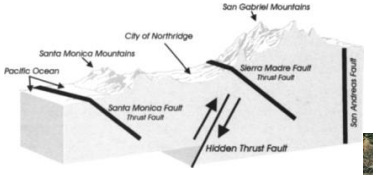
1994 Northridge Earthquake — Jan 17, 1994, 12:31 PM

Magnitude: 6.70 — Hauksson et al (1995), Wald and Heaton (1994)

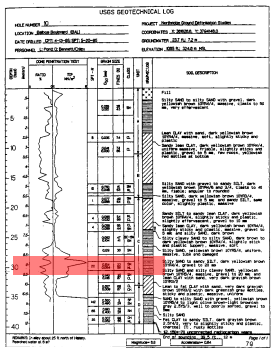
Fault Type: thrust fault — Z_{tor} (km): did not rupture surfac — R_{rup} (km): -

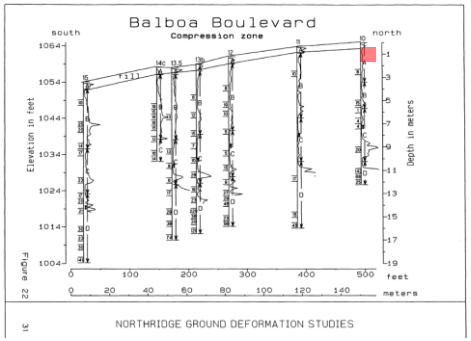
Dip: 35 to the south- — Width (km): 20 — R_{jb} (km): 0

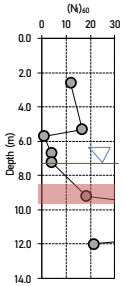
https://www.sciencedirect.com/topics/engineering/northridge-earthquake

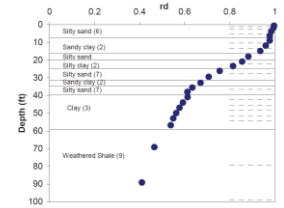


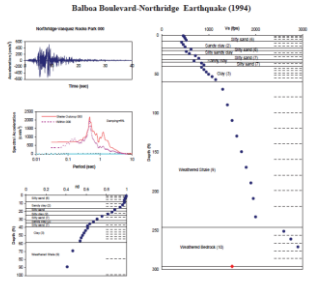












Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
2.6	8.5		8	1.50	0.87	11.9	CL
5.3	17.4		15	1.05	0.93	16.6	SM-ML
5.7	18.7		1	1.01	0.93	1.1	SM-CL
6.7	22.0		4	0.94	0.95	4.0	ML-CL
7.2	23.6		4	0.90	0.95	3.9	CL-SM
9.2	***30.2***		***20***	***0.84***	***0.97***	***18.4***	***SM-ML***
11.0	36.1		142	0.79	0.98	124.5	SP-SM
11.5	37.7		68	0.78	0.98	58.9	SM
12.0	39.4		25	0.77	0.98	21.4	CH-ML
					Mean:	18.4	
					St. Dev.	4.0	

above GWT

given in the source document

Depth (m)	G	S	M	C	D50	USCS	PI	FC (%)
2.6	0	26	55	19	0.035	CL	-	74
5.3	4	33	48	15	0.048	ML	-	63
5.7	1	45	36	18	0.066	CL	7.0	54
6.7	0	31	48	21	0.032	CL	15.0	69
7.2	7	49	36	8	0.099	SM	-	44
8.1	***2***	***62***	***24***	***12***	***0.129***	***SM***	***-***	***36***
8.9	***0***	***77***	***17***	***6***	***0.154***	***SM***	***-***	***23***
9.0	***1***	***48***	***41***	***10***	***0.072***	***ML***	***-***	***51***
9.2	***8***	***38***	***42***	***12***	***0.064***	***ML***	***-***	***54***
9.3	***5***	***60***	***21***	***14***	***0.140***	***SM***	***-***	***35***
9.4	3	49	32	16	0.082	SC-SM	5	48
9.5	2	55	32	11	0.093	CL	-	43
9.6	0	13	60	27	0.016	CL	26	87
9.7	0	19	47	34	0.016	CL	-	81
9.8	1	19	45	35	0.016	CL	-	80
9.9	0	20	42	38	0.012	CL	-	80
11.0	17	55	20	8	0.049	SM	-	28
11.5	20	54	17	9	0.040	SM	-	26
12.0	0	35	51	14	0.052	ML	-	65
Mean:	3.2	57.0	29.0	10.8	0.112			39.8
St. Dev.	3.3	14.8	11.7	3.0	0.041			12.7

Case number:	***153***
Earthquake:	1994 Northridge Earthquake
Magnitude:	6.7 (Mw)
Location:	Potrero Canyon Unit C
References:	Bennett et al. (1998), Holzer et al (1999), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Cracks and lateral spread
GPS LAT	34.39443
GPS LONG	-118.6624
Liq. layer consist of:	SM
Geological Unit:	Potrero Canyon is a narrow 5 km long E-W valley incised into Pliocene sedimentary rock on the north flank of the Santa Su
Site Response Anlaysis:	No
Comments:	Cetin (2000) "The Northridge Earthquake of January 17, 1994 caused widespread ground deformations on the gently sloping alluvial fan surface of the San Fernando Valley. The San Fernando Valley is a structural valley in southern California, which is filled with up to 4500 m of Tertiary sedimentary rock and alluvial sediment. Holocene age alluvial gravels, sands, and finer sediment with an aggregate thickness ranging from ~8-12 m immediately underlie the gently sloping valley floor. The alluvium was deposited by sediment-laden floodwaters that flowed out of the surrounding mountain canyons. Potrero Canyon is a narrow 5 km long E-W valley incised into Pliocene sedimentary rock on the north flank of the Santa Susana Mountains. Although it is about 22 km NNW of the epicenter of the Northridge earthquake, it is near the up dip projection of the seismogenic rupture surface. Ground failure in Potrero Canyon consisted of two zones of ground cracks along the north and south edges of the valley. Cracks formed in alluvium at or near the contact between the valley fill and the Pliocene bedrock forming the adjacent valley walls. Horizontal displacements across ground cracks were at least 10 cm. The Valley is underlain by fine grained Holocene sediment, units A and C, most of which is below the water table. Depth to groundwater was about 2.5 m. The uppermost unit, A, is a homogeneous lean clay to silt with an average thickness of 2.7 m. The remainder of Holocene section, unit C, consists of lean clay to sandy silt with lenses of silt and silty sand, C1. The Holocene sediment rests on dense silty sand, which may either Pleistocene or part of Pliocene Pico Formation, unit D. The average fines and clay contents for unit C are 57 and 11 % respectively. PGA was recorded as 0.43 and 0.37g 3.8 km east of the study site at NWS. Contoured regional maps of peak acceleration imply a value of 0.35 g" https://earthquake.usgs.gov/earthquakes/eventpage/ci3144585/executive https://earthquake.usgs.gov/earthquakes/eventpage/ci3144585/map Rupture distance is determined based on the fault plane derived from aftershock distribution by Hauksson et al (1995). Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
Gravel Content (%):	7.50
CPT available:	Yes
Vs available:	No

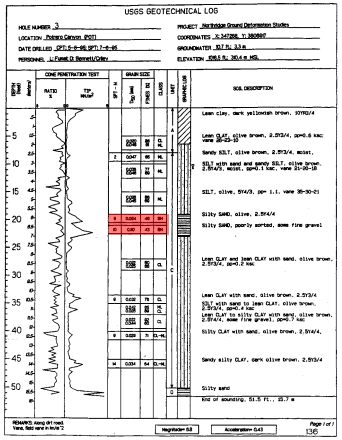


Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	A	-	B	B
d_{crtc} range (m)	-	6.0 - 7.0		6.0 - 7.0	6.0 - 7.0
d_{crt} (m)	-	6.5	7.1	6.5	6.5
GWT (m)	-	3.3 ± 0.3	2	3.3 ± 0.1	3.3 ± 0.9
γ_{moist} (kN/m^3)	-	17.3 ± 0.6	-	17.3 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	19.6 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	120.2 ± 4.4	139.3	120.2 ± 3.9	118.0 ± 5.9
σ_v' (kPa)	-	88.7 ± 4.0	88.2	88.7 ± 2.8	86.5 ± 5.1
a_{max} (g)	-	0.399 ± 0.040	0.43	0.399 ± 0.120	0.399 ± 0.120
r_d	-	0.72 ± 0.087	0.91	0.79 ± 0.087	0.79 ± 0.087
CSR	-	0.254 ± 0.041	0.32	0.279 ± 0.089	0.281 ± 0.093
M_w	-	6.70	6.69	6.70	6.70
D_{50}	-	0.100 ± 0.020	-	0.102 ± 0.011	0.102 ± 0.011
% Fines	-	37.0 ± 5.0	64	44.5 ± 2.1	44.5 ± 2.1
% PI	-	-	-	-	NAV
N	-	9.5 ± 0.6	7.4	9.5 ± 0.6	9.6 ± 0.5
C_R	-	0.94	0.95	0.94	0.94
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.13	1.13	1.13	1.13
C_N	-	1.04	1.07	1.07	1.08
$(N_1)_{60}$	-	10.5 ± 0.7	8.5	10.8 ± 0.7	11.1 ± 0.6
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

EVENT PARAMETERS

1994 Northridge Earthquake		Jan 17, 1994, 12:31 PM	
Magnitude: 6.70		Hauksson et al (1995), Wald and Heaton (1994)	
Fault Type: thrust fault	Z_{tor} (km): did not rupture surfac		R_{rup} (km): -
Dip: 35 to the south	Width (km): 20		R_{jb} (km): 0



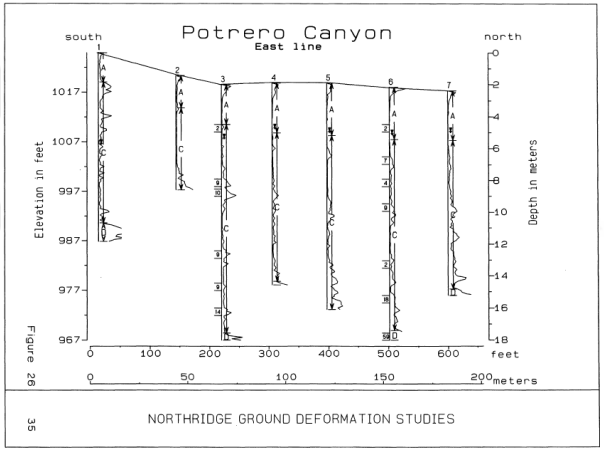
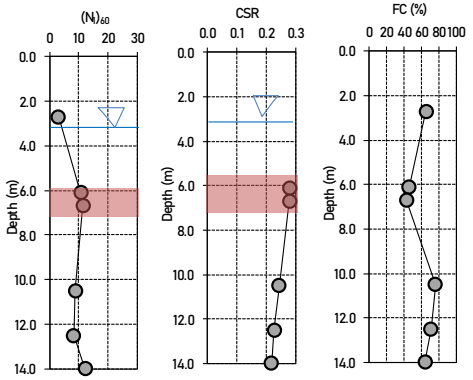


Figure 26

35



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC (%)	D50 (mm)	Gravel	Sand	Silt	Clay	PI	USCS
2.7	8.9	NA	2	1.55	0.88	3.1	65	0.047	0	35	51	14	6	CL-ML
6.1	***20.0***	***0.281***	***9***	***1.11***	***0.94***	***10.6***	***46***	***0.094***	***10***	***44***	***37***	***9***	***-***	***SM***
6.7	***22.0***	***0.280***	***10***	***1.07***	***0.95***	***11.5***	***43***	***0.110***	***5***	***52***	***38***	***7***	***-***	***SM***
10.5	34.4	0.244	9	0.88	0.98	8.8	76	0.032	0	24	57	19	6	ML
12.5	41.0	0.226	9	0.82	0.98	8.2	71	0.029	0	29	53	18	6	CL-ML
14.0	45.9	0.218	14	0.78	0.99	12.2	64	0.034	0	36	46	18	4	CL-ML
					Mean:	11.1	44.5	0.102	7.5	48.0	37.5	8.0		
					St. Dev.	0.6	2.1	0.011	3.5	5.7	0.7	1.4		

GWT measurements were taken from NGL database

GWT (m)	Date
3.3	7/6/95, 12:00 AM
2.8	7/7/95, 12:00 AM
3.3	7/8/95, 12:00 AM
2	7/9/95, 12:00 AM
5.6	5/8/95, 12:00 AM
3.3	5/8/95, 12:00 AM
2.7	5/9/95, 12:00 AM
3	5/9/95, 12:00 AM
2.8	5/9/95, 12:00 AM
2.5	5/9/95, 12:00 AM
3.3	5/9/95, 12:00 AM
2.6	5/10/95, 12:00 AM
2.5	5/10/95, 12:00 AM
2.2	5/10/95, 12:00 AM
2	5/10/95, 12:00 AM
Mean:	2.9
St. Dev.	0.9

Case number:	154
Earthquake:	1994 Northridge Earthquake
Magnitude:	6.7 (Mw)
Location:	Wynne Ave. Unit C1
References:	Bennett et al. (1998)
Nature of Failure:	Cracks and lateral spread
GPS LAT	34.21982
GPS LONG	-118.53006
Liq. layer consist of:	SM
Geological Unit:	Holocene and Pleistocene alluvial deposits
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "The Northridge Earthquake of January 17, 1994 caused widespread ground deformations on the gently sloping alluvial fan surface of the San Fernando Valley. The San Fernando Valley is a structural valley in southern California, which is filled with up to 4500 m of Tertiary sedimentary rock and alluvial sediment. Holocene age alluvial gravels, sands, and finer sediment with an aggregate thickness ranging from ~8-12 m immediately underlie the gently sloping valley floor.The alluvium was deposited by sediment-laden floodwaters that flowed out of the surrounding mountain canyons. The Wynne Ave. site is located couple of kms north east from the epicenter. Ground failure at the Wynne Ave. site consisted of an 150 m long by 12 m wide down dropped block. Vertical offset across cracks ranged from 100-200 mm. Groundwater beneath the failure zone was was at a depth of about 4.3 m. The site is underlain by 2 m of silty sand and sandy lean clay, unit A, which in turn is underlain by 12-14 m of Holocene sandy silt to lean clay, unit B and C. Unit B consists of multiple fining upward sequences of overbank and sheetflood deposits that were deposited in a flood basin between major distributary flood channels. Unit C, which is texturally comparable to B, is distinguished by the presence of lenticular sand layers. Immediately beneath the failure, two sand layers are intercalated in unit C at depths of 6 and 10 m. The shallower sand layer, C1, is about 2 m thick. Deeper sand layer C2, is 1.5 thick. Both layers have average fines and clay content of 38 and 11 %. PGA was recorded as 0.47 and 0.36g 1.7 km south-east of the study site at NRG. Contoured regional maps of peak acceleration imply a value of 0.50 g. Site response based estimation of PGA is 0.54 g." https://earthquake.usgs.gov/earthquakes/eventpage/ci3144585/executive https://earthquake.usgs.gov/earthquakes/eventpage/ci3144585/map Rupture distance is determined based on the fault plane derived from aftershock distribution by Hauksson et al (1995). Vs12m is needed to estimate rd hence CSR values. Vs12m was not calculated by Cetin (2000). Because site response analysis performed for this case history, rd is calculated directly from these analysis. However 160 m/s was written for all the case histories where site response analysis were performed. As a result, we do not know the Vs12m values for those sites. But Vs profiles are given in the next page as presented by Cetin (2000).
Gravel Content (%):	4.67
CPT available:	Yes
Vs available:	No

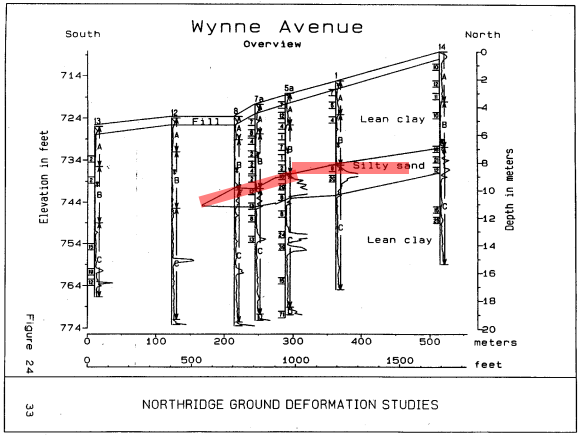


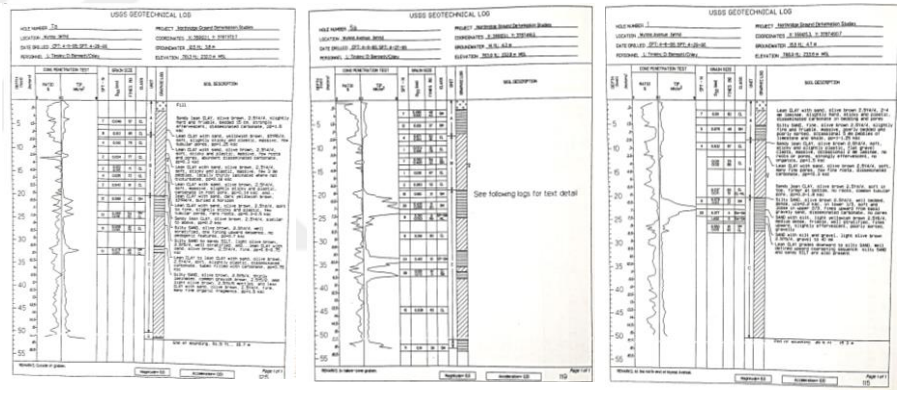
Summary of Input Data

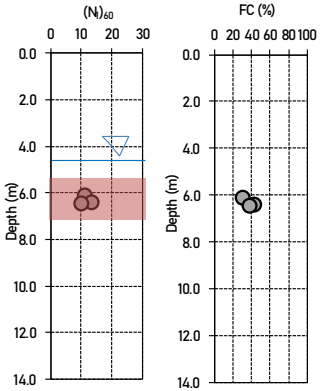
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	A	-	A	A
d_{crit} range (m)	-	5.8 - 6.8	-	5.8 - 6.8	5.8 - 6.8
d_{crt} (m)	-	6.3	6.7	6.3	6.3
GWT (m)	-	4.3 ± 0.3	4.3	4.2 ± 0.5	4.2 ± 0.5
γ_{moist} (kN/m^3)	-	17.3 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	19.6 ± 0.6	-	19.6 ± 0.5	19.6 ± 0.5
σ_v (kPa)	-	112.9 ± 4.5	129.3	113.2 ± 4.1	113.2 ± 4.1
σ_v' (kPa)	-	93.7 ± 4.1	105.3	92.7 ± 4.5	92.7 ± 4.5
a_{max} (g)	-	0.540 ± 0.040	0.51	0.540 ± 0.081	0.540 ± 0.081
r_d	-	0.86 ± 0.040	0.91	0.86 ± 0.040	0.86 ± 0.042
CSR	-	0.350 ± 0.034	0.39	0.369 ± 0.061	0.369 ± 0.061
M_w	-	6.70	6.69	6.70	6.70
D_{50}	-	0.153 ± 0.100	-	0.106 ± 0.037	0.127 ± 0.031
% Fines	-	38.0 ± 23.0	33	42.4 ± 8.9	37.3 ± 6.0
% PI	-	-	-	-	4
N	-	10.3 ± 1.5	11	10.3 ± 1.5	10.3 ± 1.5
C_R	-	0.93	0.95	0.93	0.94
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.13	1.13	1.13	1.13
C_N	-	1.01	0.98	1.05	1.05
$(N_1)_{60}$	-	11.0 ± 1.6	11.6	11.4 ± 1.7	11.5 ± 1.7
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	160.0	-	160.0	NOT LISTED

EVENT PARAMETERS

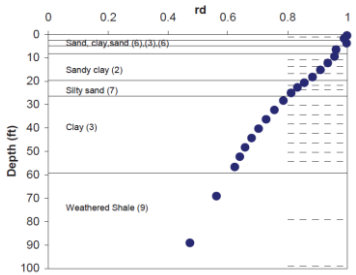
1994 Northridge Earthquake		Jan 17, 1994, 12:31 PM	
Magnitude: 6.70		Hauksson et al (1995), Wald and Heaton (1994)	
Fault Type: thrust fault	Z_{tor} (km): did not rupture surfac		R_{rup} (km): -
Dip: 35 to the south	Width (km): 20		R_{jb} (km): 0

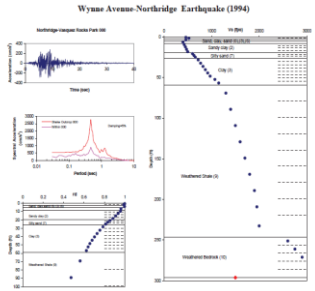






Cetin (2000)





	BH-7a	BH-5a	BH-1a
ground level	3.84	3.12	**2.13**
water depth	7.51	7.34	**6.74**
	3.67	4.22	4.61 ft

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
6.1	*20.0*		*10*	*1.06*	*0.94*	*11.2*	BH-5a
6.4	*21.0*		*12*	*1.04*	*0.94*	*13.3*	BH-7a
6.5	*21.2*		*9*	*1.04*	*0.94*	*10.0*	BH-1a
					Mean:	11.5	
					St. Dev.	1.7	

Gravel	Sand	Silt	Clay	D_{50} (mm)	USCS	PI	FC
8	*61*	*21*	*10*	*0.16*	*SM*	*-*	*31*
0	*57*	*32*	*11*	*0.098*	*SM*	*0*	*43*
6	*56*	*24*	*14*	*0.123*	*SM*	*8*	*38*
4.7	58.0	25.7	11.7	0.127		4.0	37.3
4.2	2.6	5.7	2.1	0.031		5.7	6.0

Case number:	155
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	7.2 (M_L), 6.9 (M_w)
Location:	Ashiyama A (Mountain Sand 1)
References:	Shibata et al. (1996), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	From the cracks in roads, building foundations, and around utility poles, massive amounts of sand were ejected. Many two-story houses tilted and settled differentially. However, this site is located in the non-liquefied zone.
GPS LAT	34.719486
GPS LONG	135.307744
Liq. layer consist of:	sand
Geological Unit:	reclaimed land
Site Response Anlaysis:	No
Comments:	Cetin (2000) "On January 17, 1995, an earthquake of magnitude 7.2 (Richter scale) struck the southern part of Hyogo Prefecture. Sand boils and liquefied, ejected soil were observed art numerous sites, mainly in the coastal areas of Hyogo and Osaka Prefectures. In particular, massive liquefaction was observed on man-made islands and inland areas with high ground water tables. The reclaimed island known as Ashiyahama was reclamed by Hyogo Prefecture using mainly Masado, weathered and decomposed low plasticity, low cohesion, high permeability, erodible granite. The reclamation of Ashiyahama began in 1969 and completed in 1975. An alluvial clay layer of 3-5 m in thickness was deposited just beneath the old sea level, and the total thickness of the reclamation is 13-15 m. The fill material used was mainly debris from mountainside construction sites, but also a marine sand layer having an N value of ~10 exists about 5 m below the ground surface. The erupted sand has the characteristics of marine sand layer. In the vicinity of the site, PGA was recorded as 0.3-0.4g at liquefied sites and 0.6-0.8 g at non-liquefied sites. The PGA value of 0.326g, was recorded at Uozakihama, which is 2-3 km south-west of Ashiyahama. A PGA value of 0.4 g was adopted. The average Japanese SPT SPT borehole data is redigitzed. Case histories Ashiyama A (Marine Sand) and Mountain Sand were two case histories in Cetin (2000). This is against statistically independent assumption hence case 156 is excluded. Vs12m is updated based on Vs-SPT correlations. https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive
Gravel Content (%):	10.00
CPT available:	No
Vs available:	No



Fig. 11. Liquefaction zone in Ashiyahama



Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	No	No	No	No
Data Class	-	A	-	B	B
d_{crtc} range (m)	-	3.5 - 6.9	-	3.5 - 6.9	3.5 - 6.9
d_{crt} (m)	-	5.2	5.2	5.2	5.2
GWT (m)	-	3.5 ± 0.3	3.5	3.5 ± 0.1	3.5 ± 0.1
γ_{moist} (kN/m^3)	-	16.5 ± 0.6	-	17.3 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	18.1 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	88.7 ± 10.6	97.2	94.1 ± 11.3	101.2 ± 11.8
σ_v' (kPa)	-	72.0 ± 5.9	80.2	77.4 ± 5.9	84.5 ± 6.4
a_{max} (g)	-	0.400 ± 0.050	0.4	0.400 ± 0.080	0.400 ± 0.080
r_d	-	0.89 ± 0.072	0.94	0.94 ± 0.072	0.98 ± 0.072
CSR	-	0.286 ± 0.047	0.295	0.297 ± 0.065	0.306 ± 0.067
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	0.126 ± 0.025	-	0.126 ± 0.050	0.126 ± 0.050
% Fines	-	18.0 ± 4.0	18	18.0 ± 2.0	18.0 ± 8.6
% PI	-	-	-	-	NAV
N	-	16.6 ± 5.4	16.6	16.6 ± 5.3	16.0 ± 4.2
C_R	-	0.93	0.95	0.93	0.94
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.16	1.10	1.15	1.10
$(N_1)_{60}$	-	21.6 ± 7.1	21.1	21.5 ± 6.8	22.5 ± 5.9
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	185.9	-	192.0	231.6

EVENT PARAMETERS

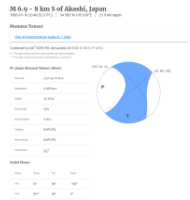
1995 Hyogoken-Nambu

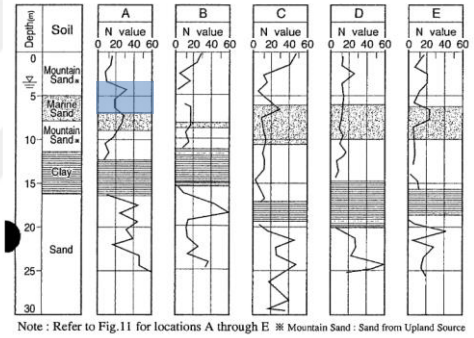
Magnitude: 6.90 — Yoshida et al (1996)

Fault Type: strike-slip — Z_{tor} (km): 0 — R_{rup} (km): 4.3

Dip: 85 — Width (km): 16 — R_{jb} (km): 4.3

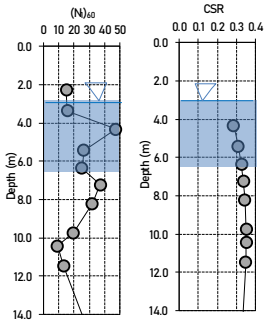






Note : Refer to Fig.11 for locations A through E ※ Mountain Sand : Sand from Upland Source

Fig. 10(a). Geological section of Ashiyahama (sites where *N* values were measured are described in Fig. 11)



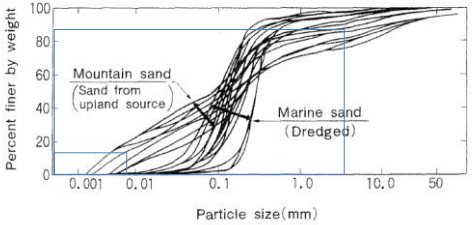


Fig. 10(b). Particle size distribution curve

The total thickness of the reclamation is 13 to 15 m.

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
0.5	1.5	NA	16	2.00	0.84	36.7	Mountain sand
1.5	5.0	NA	14	1.88	0.87	31.3	Mountain sand
2.3	7.5	NA	8	1.53	0.89	14.9	Mountain sand
3.4	***11.0***	***NA***	***10***	***1.26***	***0.91***	***15.8***	Mountain sand
4.3	14.2	0.285	32	1.16	0.93	47.2	Gravel ? Mountain sand
5.4	***17.8***	***0.311***	***19***	***1.08***	***0.94***	***26.4***	Mountain sand
6.4	***20.9***	***0.327***	***19***	***1.02***	***0.95***	***25.3***	Mountain sand
7.2	23.7	0.337	29	0.98	0.96	37.2	Marine sand
8.2	27.0	0.345	26	0.93	0.97	32.0	Marine sand
9.7	32.0	0.351	17	0.87	0.98	19.8	Mountain sand
10.4	34.2	0.351	8	0.85	0.98	9.1	Mountain sand
11.5	37.6	0.349	12	0.82	0.98	13.2	Mountain sand
17.5	57.4	0.316	45	0.68	1.00	41.8	Sand
18.4	60.4	0.313	25	0.67	1.00	22.8	Sand
19.4	63.5	0.311	44	0.65	1.00	39.2	Sand
					Mean:	22.5	
					St. Dev.	5.9	

Depth (m)		
0	7	Mountain Sand
7	8	Marine Sand
8	12.3	Mountain Sand
12.3	16.5	Clay
16.5	30	Sand

Case number:	158
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	7.2 (M_L), 6.9 (M_w)
Location:	Ashiyama E (Marine Sand)
References:	Shibata et al. (1996), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	From the cracks in roads, building foundations, and around utility poles,
GPS LAT	34.718377 massive amounts of sand were ejected. Many two-story houses tilted and
GPS LONG	135.314172 settled differentially.
Liq. layer consist of:	Marine Sand
Geological Unit:	reclaimed land
Site Response Anlaysis:	No
Comments:	Cetin (2000) "On January 17, 1995, an earthquake of magnitude 7.2 (Richter scale) struck the southern part of Hyogo Prefecture. Sand boils and liquefied, ejected soil were observed at numerous sites, mainly in the coastal areas of Hyogo and Osaka Prefectures. In particular, massive liquefaction was observed on man-made islands and inland areas with high ground water tables. The reclaimed island known as Ashiyahama was reclamed by Hyogo Prefecture using mainly Masado, weathered and decomposed low plasticity, low cohesion, high permeability, erodible granite. The reclamation of Ashiyahama began in 1969 and completed in 1975. An alluvial clay layer of 3-5 m in thickness was deposited just beneath the old sea level, and the total thickness of the reclamation is 13-15 m. The fill material used was mainly debris from mountainside construction sites, but also a marine sand layer having an N value of ~10 exists about 5 m below the ground surface. The erupted sand has the characteristics of marine sand layer. In the vicinity of the site, PGA was recorded as 0.3-0.4g at liquefied sites and 0.6-0.8 g at non-liquefied sites. The PGA value of 0.326g, was recorded at Uozakihama, which is 2-3 km south-west of Ashiyahama. A PGA value of 0.4 g was adopted. The average Japanese SPT energy ratio of 73% is used."

Ashiyama (Mountain Sand) is excluded since there are two seperate case histories liquefied in Cetin (2000): Mountain sand and marine sand

It is against statistically independent assumption.

The original document states that "The sand which erupted from the ground surface was the marine sand."

Additionally Site C & D are located far away from Site E which is on the liq. Area.

However it is ambigious that Site C and D liquefied from the map below.

As a result only Site E is taken as a liquefied case history from Ashiyama.



Gravel Content (%):	5.00
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Ashiyama CDE (Marine Sand) and (Mountain Sand) were two seperate case histories.	Yes	Yes	Yes
Data Class	-		-	B	B
$d_{crt,c}$ range (m)	-		-	7.5 - 10.0	7.4 - 10.0
d_{crt} (m)	-		8.8	8.8	8.7
GWT (m)	-		3.5	3.5 ± 0.0	3.5 ± 0.0
γ_{moist} (kN/m^3)	-		-	17.3 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-		-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-		166.4	164.0 ± 8.7	173.4 ± 9.4
σ_v' (kPa)	-		115.3	112.4 ± 5.1	122.3 ± 5.6
a_{max} (g)	-		0.4	0.400 ± 0.080	0.400 ± 0.080
r_d	-		0.88	0.74 ± 0.113	0.92 ± 0.112
CSR	-		0.331	0.281 ± 0.071	0.339 ± 0.079
M_w	-		6.90	6.90	6.90
D_{50}	-		-	0.185 ± 0.050	0.185 ± 0.050
% Fines	-		2	2.0 ± 2.0	2.0 ± 8.6
% PI	-		-	-	0
N	-		10.9	10.9 ± 2.6	10.8 ± 3.1
C_R	-		1.00	1.00	0.97
C_S	-		1.00	1.00	1.00
C_B	-		1.00	1.00	1.00
C_E	-		1.22	1.22	1.37
C_N	-		0.94	0.95	0.91
$(N_1)_{60}$	-		12.5	12.6 ± 3.0	13.1 ± 3.8
V_{s30m} (m/s)	-		-	-	NAV
V_{s12m} (m/s)	-		-	170.7	219.5

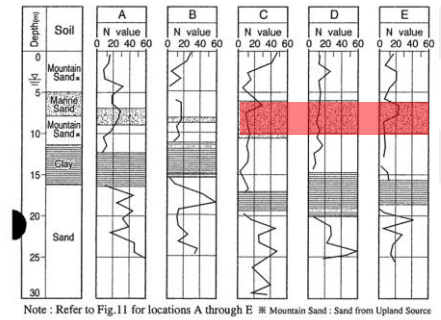
EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 4.8

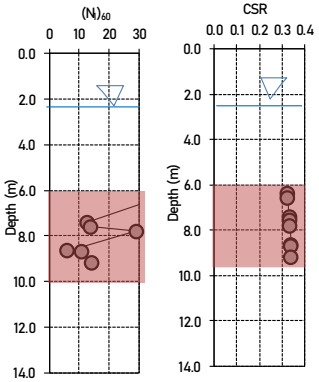
Dip: 85 Width (km): 16 R_{jb} (km): 4.8



Note : Refer to Fig.11 for locations A through E ※ Mountain Sand : Sand from Upland Source

Fig. 10(a). Geological section of Ashiyahama (sites where *N* values were measured are described in Fig. 11)

The sand which erupted from the ground surface was the marine sand.

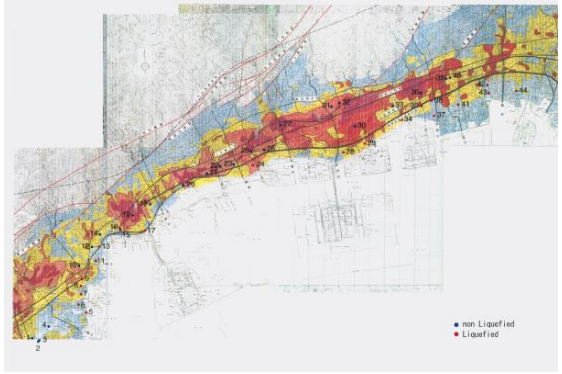




	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		
SITE C	***6.4***	***21.0***	***0.322***	***29.0***	***1.02***	***0.95***	***38.6***	***Marine Sand***	outlier
Site E	***6.6***	***21.6***	***0.325***	***23.0***	***1.01***	***0.95***	***30.3***	***Marine Sand***	outlier
SITE C	***7.4***	***24.3***	***0.333***	***10.0***	***0.97***	***0.96***	***12.7***	***Marine Sand***	
SITE D	***7.6***	***24.9***	***0.334***	***11.0***	***0.96***	***0.96***	***13.9***	***Marine Sand***	
Site E	***7.8***	***25.6***	***0.335***	***23.0***	***0.95***	***0.96***	***28.8***	***Marine Sand***	outlier
Site E	***8.7***	***28.4***	***0.339***	***5.0***	***0.91***	***0.97***	***6.1***	***Marine Sand***	
SITE D	***8.7***	***28.6***	***0.339***	***9.0***	***0.91***	***0.97***	***10.9***	***Marine Sand***	
SITE C	***9.2***	***30.2***	***0.339***	***12.0***	***0.89***	***0.97***	***14.2***	***Marine Sand***	
SITE D	***9.6***	***31.5***	***0.339***	***14.0***	***0.88***	***0.98***	***16.4***	***Marine Sand***	
SITE C	***9.9***	***32.4***	***0.339***	***15.0***	***0.87***	***0.98***	***17.4***	***Marine Sand***	
						Mean:	13.1		
						St. Dev.	3.8		

Case number:	159
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	7.2 (M_L), 6.9 (M_w)
Location:	Kobe No : 1
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Non-liquefied
GPS LAT	34.654346
GPS LONG	135.158047
Liq. layer consist of:	Sand and Gravel
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is updated based Vs-SPTN correlations. https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	Sand and gravel (content unkown)
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	5.0 - 7.0	-	5.0 - 7.0	5.0 - 7.0
d_{crt} (m)	-	6.0	5.8	6.0	6.0
GWT (m)	-	2.4 ± 0.3	2.4	2.4 ± 0.1	2.4 ± 0.1
γ_{moist} (kN/m^3)	-	16.5 ± 0.6	-	18.9 ± 0.5	20.0 ± 0.5
γ_{sat} (kN/m^3)	-	18.1 ± 0.6	-	21.2 ± 0.5	21.5 ± 0.5
σ_v (kPa)	-	105.0 ± 6.6	113.3	122.0 ± 7.4	125.7 ± 7.5
σ_v' (kPa)	-	69.1 ± 4.6	80.2	86.1 ± 4.4	89.9 ± 4.5
a_{max} (g)	-	0.400 ± 0.060	0.4	0.400 ± 0.080	0.400 ± 0.080
r_d	-	0.93 ± 0.082	0.93	0.99 ± 0.082	1.00 ± 0.082
CSR	-	0.368 ± 0.066	0.345	0.365 ± 0.079	0.362 ± 0.079
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	4.0 ± 1.5	3	3.5 ± 4.9	3.5 ± 4.9
% PI	-	-	-	-	0
N	-	42.3 ± 2.3	42.1	42.4 ± 2.5	42.5 ± 3.1
C_R	-	0.95	0.95	0.95	0.95
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.18	1.07	1.09	1.06
$(N_1)_{60}$	-	57.7 ± 3.2	52	53.2 ± 3.2	58.6 ± 4.3
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	213.4	-	259.1	278.9

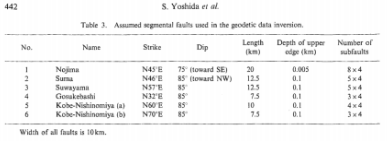
EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 — Yoshida et al (1996)

Fault Type: strike-slip — Z_{tor} (km): 0 — R_{rup} (km): 4.3

Dip: 85 — Width (km): 16 — R_{jb} (km): 4.3



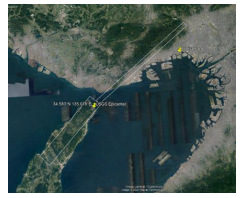
442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N53°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

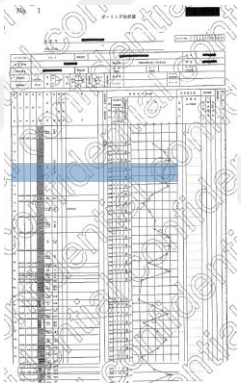
Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



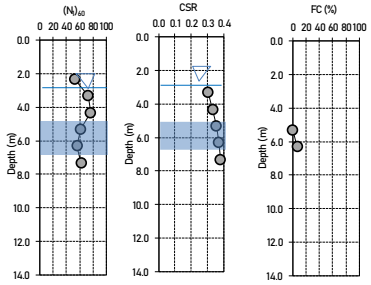






Personal Communication Prof. Tokimatsu (2000)

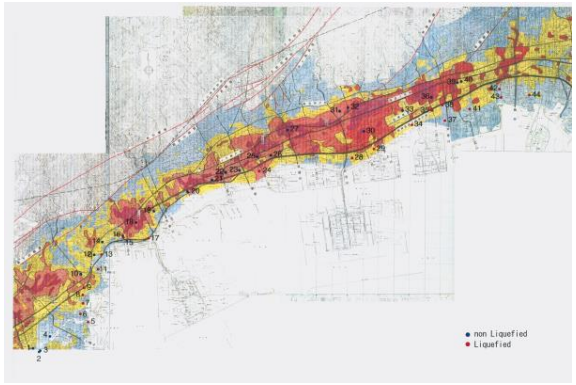
No.	1		stC0989									
ACC=	400		non-liquefied							STDEV of corrected N		0.16
W.T=	2.35									Average of corrected N		51.17
	tf/m3	tf/m2	tf/m2									
DEPTH(m)	Density	SV	SVD	Nvalue	C_N	C_R	C_S	C_E	C_K	Corrected N	F.C.	Soil quality
5.8	1.8	10.51	7.55	43	0.85	1	1	1.22	1.15	51.26	0.00	
6.3		12.61	8.65	42	0.95	1	1	1.22	1.07	51.08	0.07	



Depth (m)	Depth (ft)	CSR	N	C_N	C_S	$(N1)_{60}$	FC	
2.3	7.5	NA	29.0	1.49	0.89	52.4	-	sand and gravel
3.3	10.8	0.301	44.0	1.32	0.91	72.3	-	sand and gravel
4.3	14.1	0.331	50.0	1.21	0.93	76.3	-	sand and gravel
5.3	***17.4***	***0.351***	***43.0***	***1.12***	***0.94***	***61.6***	***0.0***	sand and gravel
6.3	***20.7***	***0.367***	***41.0***	***1.04***	***0.95***	***55.6***	***7.0***	sand and gravel
7.3	24.0	0.378	48.0	0.98	0.96	61.9	-	sand and gravel
					Mean:	58.6	3.5	
					St. Dev.	4.3	4.9	

Case number:	160
Earthquake:	1995 Hypgoken-Nambu
Magnitude:	7.2 (M_L), 6.9 (M_w)
Location:	Kobe No : 2
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface manifestation of liquefaction
GPS LAT	34.653123 Coordiantes were taken from NGL
GPS LONG	135.16011
Liq. layer consist of:	Sand and Gravel
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments (it can be fill?)
Site Response Anlaysis:	No
Comments:	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	Sand and gravel (content unkown)
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	5.0 - 12.0		5.0 - 12.0	2.9 - 12.0
d_{crt} (m)	-	8.5	5.8	8.5	7.4
GWT (m)	-	2.9 ± 0.3	2.4	2.9 ± 0.1	2.9 ± 0.1
γ_{moist} (kN/m^3)	-	16.5 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	18.1 ± 0.6	-	21.2 ± 0.5	21.5 ± 0.5
σ_v (kPa)	-	149.4 ± 21.5	113.3	173.9 ± 25.0	152.9 ± 32.9
σ_v' (kPa)	-	94.3 ± 10.7	80.2	118.8 ± 13.7	108.1 ± 18.0
a_{max} (g)	-	0.400 ± 0.060	0.4	0.400 ± 0.080	0.400 ± 0.080
r_d	-	0.83 ± 0.110	0.93	0.98 ± 0.110	0.99 ± 0.098
CSR	-	0.341 ± 0.071	0.345	0.373 ± 0.086	0.363 ± 0.083
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	15.0 ± 5.0	3	14.8 ± 11.5	14.8 ± 11.5
% PI	-	-	-	-	NAV
N	-	34.8 ± 7.8	42.1	35.2 ± 8.1	34.6 ± 8.2
C_R	-	1.00	0.95	1.00	0.96
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.01	1.07	0.92	0.97
$(N_1)_{60}$	-	42.7 ± 9.6	52	39.6 ± 9.1	44.1 ± 10.5
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	207.3	-	259.1	259.1

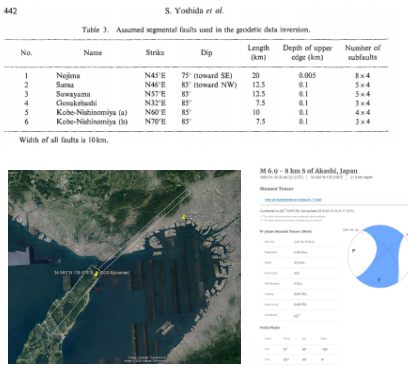
EVENT PARAMETERS

1995 Hypgoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 1.8

Dip: 85 Width (km): 16 R_{jb} (km): 1.8



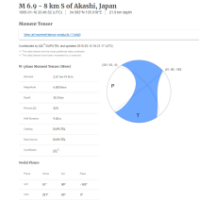
442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

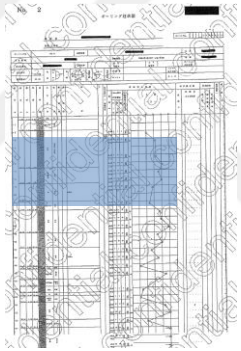
No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N40°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gionkuhashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive

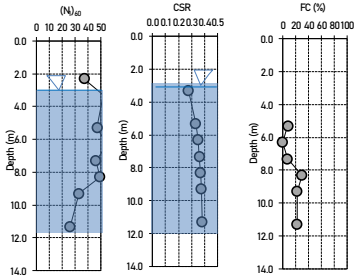






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No.	2	kt00996								
ACC=	400	non-liquefied	△					STDEV of corrected N		9.49
W.T=	2.89							Average of corrected N		38.47
	tf/m3	tf/m2	tf/m2							
DEPTH(m)	Density	SV	SVD	Nvalue	C_R	C_S	C_B	C_E	C_N	Corrected N	F.C.	Soil quality
2.3		10.18	7.77	33	0.85	1	1	1.22	1.18	38.82	0.88	
3.3		12.28	9.37	41	0.80	1	1	1.22	1.05	50.45	0.00	
4.3		14.28	9.57	36	0.95	1	1	1.22	2.01	42.00	0.07	
5.3		16.23	10.57	40	0.95	1	1	1.22	0.98	44.59	0.33	
6.3		18.18	11.77	21	0.95	1	1	1.22	0.92	24.92	0.22	
7.3		20.08	13.07	14	1.10	1	1	1.22	0.90	21.05	0.22	



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
2.3	7.5	NA	20.0	1.53	0.89	37.2	-	SAND and gravel
3.3	***10.8***	***0.277***	***32.0***	***1.31***	***0.91***	***52.0***	**-**	SAND and gravel
5.3	***17.4***	***0.332***	***33.0***	***1.11***	***0.94***	***46.9***	***8.0***	SAND and gravel
6.3	***20.7***	***0.349***	***41.0***	***1.04***	***0.95***	***55.2***	***0.0***	SAND and gravel
7.3	***24.0***	***0.361***	***36.0***	***0.98***	***0.96***	***46.2***	***7.0***	N/A, could not translate description
8.3	***27.2***	***0.370***	***40.0***	***0.93***	***0.97***	***49.1***	***30.0***	N/A, could not translate description
9.3	***30.5***	***0.376***	***28.0***	***0.88***	***0.97***	***33.0***	***22.0***	SAND
11.3	***37.1***	***0.381***	***24.0***	***0.81***	***0.98***	***26.2***	***22.0***	N/A, could not translate description
					Mean:	44.1	14.8	
					St. Dev.	10.5	11.5	

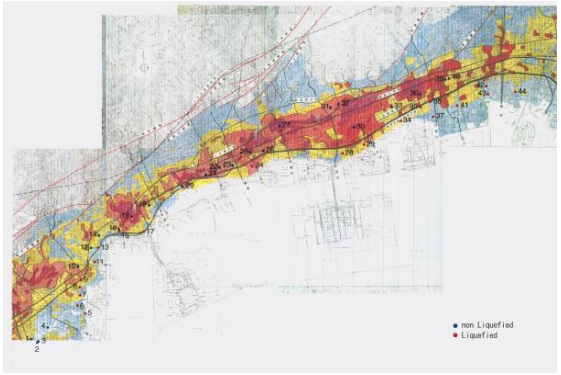
Case number:	161
Earthquake:	1995 Hypgoken-Nambu
Magnitude:	7.2 (M_L), 6.9 (M_w)
Location:	Kobe No : 3
References:	Kobe City Office, Construction Engineering Research Institute (1999)
Nature of Failure:	No surface manifestation of liquefaction
GPS LAT	34.653388 Coordiantes were taken from NGL
GPS LONG	135.160517
Liq. layer consist of:	Sand and Gravel
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	

https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





#2 and #3 are very close but have different soil profiles



Gravel Content (%):	Sand and gravel (content unkown)
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	3.5 - 7.5		3.5 - 7.5	3.5 - 7.6
d_{crt} (m)	-	5.5	5.8	5.5	5.6
GWT (m)	-	2.5 ± 0.3	2.5	2.5 ± 0.1	2.5 ± 0.1
γ_{moist} (kN/m^3)	-	16.5 ± 0.6	-	15.7 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	18.1 ± 0.6	-	21.2 ± 0.5	21.5 ± 0.5
σ_v (kPa)	-	95.7 ± 12.3	109.3	103.1 ± 14.3	109.1 ± 14.9
σ_v' (kPa)	-	66.2 ± 6.5	77.2	73.7 ± 7.9	79.1 ± 8.3
a_{max} (g)	-	0.400 ± 0.060	0.4	0.400 ± 0.080	0.400 ± 0.080
r_d	-	0.91 ± 0.076	0.93	0.99 ± 0.076	0.99 ± 0.076
CSR	-	0.343 ± 0.063	0.344	0.362 ± 0.078	0.356 ± 0.077
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	4.0 ± 1.0	3	3.3 ± 2.2	3.3 ± 2.2
% PI	-	-	-	-	0
N	-	39.5 ± 5.2	40	39.5 ± 5.5	38.2 ± 5.9
C_R	-	0.94	0.95	0.94	0.94
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.20	1.08	1.17	1.13
$(N_1)_{60}$	-	54.2 ± 7.2	49.8	52.8 ± 7.4	55.8 ± 8.6
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	198.1	-	259.1	259.1

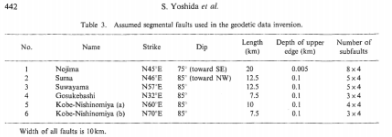
EVENT PARAMETERS

1995 Hypgoken-Nambu

Magnitude: 6.90 — Yoshida et al (1996)

Fault Type: strike-slip — Z_{tor} (km): 0 — R_{rup} (km): 1.8

Dip: 85 — Width (km): 16 — R_{jb} (km): 1.8



442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

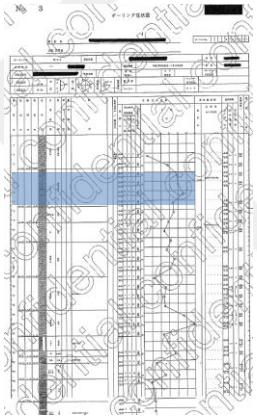
Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



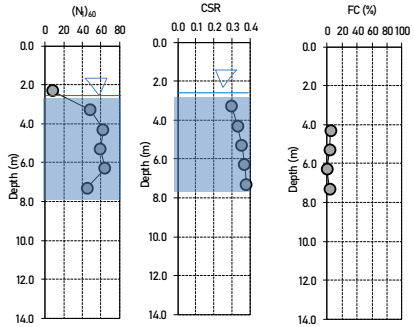






Personal Communication Prof. Tokimatsu (2000)

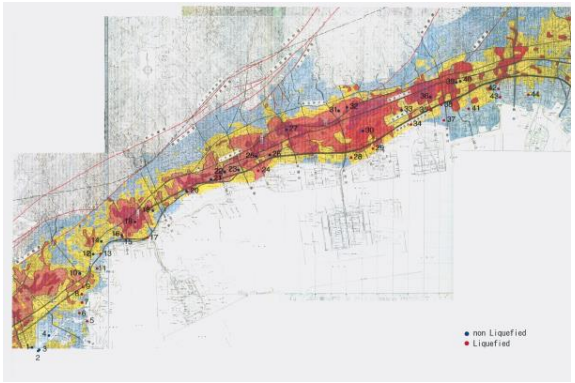
No.	3		ks03034									
AGC=	400		non-liquefied							STDEV of corrected N		7.35
W.T=	2.5									Average of corrected N		48.66
	tf/m3	tf/m2	tf/m2									
DEPTH(m)	Density	SV	SVD	Nvalue	C_R	C_S	C_B	C_E	C_N	Corrected N	F.C.	Soil quality
4.0		7.99	6.15	36	0.85	1	1	1.22	1.27	51.40	0.05	
5.1		10.09	7.29	40	0.85	1	1	1.22	1.17	48.58	0.04	
6.3		12.15	8.38	46	0.85	1	1	1.22	1.09	58.20	0.00	
7.3		14.29	9.41	34	0.85	1	1	1.22	1.03	40.47	0.04	



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
2.3	7.5	NA	4.0	1.60	0.89	7.8		sand
3.3	***10.8***	***0.298***	***28.0***	***1.39***	***0.91***	***48.3***		sand
4.3	***14.1***	***0.330***	***39.0***	***1.26***	***0.93***	***62.0***	***5.0***	SAND and gravel
5.3	***17.4***	***0.352***	***40.0***	***1.15***	***0.94***	***59.4***	***4.0***	SAND and gravel
6.3	***20.7***	***0.367***	***46.0***	***1.07***	***0.95***	***64.3***	***0.0***	SAND and gravel
7.3	***24.0***	***0.378***	***34.0***	***1.01***	***0.96***	***45.1***	***4.0***	SAND and gravel
					Mean:	55.8	3.3	
					St. Dev.	8.6	2.2	

Case number:	162
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	7.2 (M_L), 6.9 (M_w)
Location:	Kobe No : 4
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface manifestation of liquefaction
GPS LAT	34.657901 Coordiantes were taken from NGL
GPS LONG	135.163688
Liq. layer consist of:	Sand and Gravel
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments (fill??)
Site Response Anlaysis:	No
Comments:	Vs12m is updated basedn Vs-SPTN correlations.
	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	Sand and gravel (content unkown)
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	3.0 - 6.5		3.0 - 5.5	3.0 - 6.5
d_{crt} (m)	-	4.8	4.3	4.3	4.8
GWT (m)	-	2.1 ± 0.3	2.1	2.1 ± 0.1	2.1 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	17.3 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	19.6 ± 0.5	21.5 ± 0.5
σ_v (kPa)	-	76.9 ± 9.9	76.2	78.8 ± 8.3	97.0 ± 12.7
σ_v' (kPa)	-	50.4 ± 5.2	54.1	57.2 ± 4.4	70.5 ± 7.1
a_{max} (g)	-	0.400 ± 0.060	0.4	0.400 ± 0.080	0.400 ± 0.080
r_d	-	0.90 ± 0.067	0.95	0.99 ± 0.061	1.00 ± 0.067
CSR	-	0.358 ± 0.066	0.35	0.354 ± 0.075	0.357 ± 0.076
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	4.0 ± 1.0	1	1.3 ± 2.3	1.3 ± 2.3
% PI	-	-	-	-	0
N	-	28.4 ± 3.5	25.8	27.8 ± 3.0	28.4 ± 2.6
C_R	-	0.91	0.95	0.90	0.93
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.38	1.23	1.33	1.20
$(N_1)_{60}$	-	43.5 ± 5.3	36.6	40.4 ± 4.4	43.5 ± 4.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	182.9	-	228.6	265.2

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 1.6

Dip: 85 Width (km): 16 R_{jb} (km): 1.6

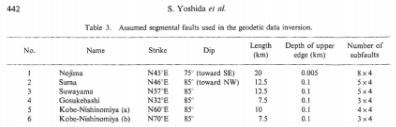

442 S. Yoshida *et al.*

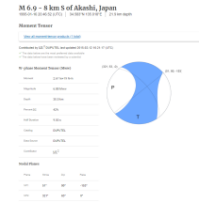
Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Sama	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gonakehashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

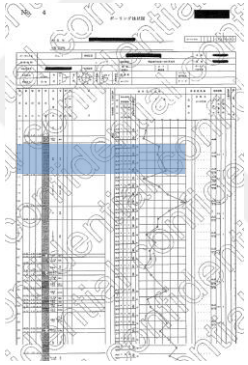
Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



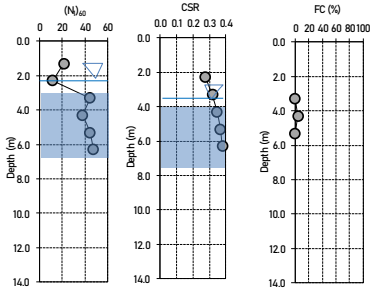






Personal Communication Prof. Tokimatsu (2000)

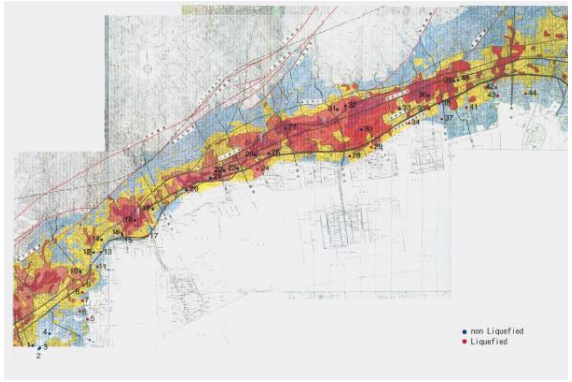
No.	4		kx20034						STDEV of corrected N	2.36
ACC=	400		non-liquefied						Average of corrected N	36.03
W.T=	2.05									
	tf/m3	tf/m2	tf/m2							
DEPTH(m)	Density	SV	SVD	Nvalue	C_E	C_B	C_R	C_N	Corrected N	F.C.	Soil quality
3.3		5.61	4.38	26	0.75	1	1	1.22	1.51	38.02	0.00	
4.3		7.71	5.45	24	0.85	1	1	1.22	1.33	33.57	0.00	
5.3		9.81	6.39	30	0.85	1	1	1.22	1.25	33.40	0.00	



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
1.3	4.3	NA	9.0	2.00	0.86	21.3	-	clay
2.3	7.5	0.275	6.0	1.56	0.89	11.4	-	-
3.3	***10.8***	***0.319***	***26.0***	***1.38***	***0.91***	***44.6***	***0.0***	sand and gravel
4.3	***14.1***	***0.347***	***24.0***	***1.25***	***0.93***	***38.0***	***4.0***	sand and gravel
5.3	***17.4***	***0.366***	***30.0***	***1.15***	***0.94***	***44.3***	***0.0***	sand and gravel
6.3	***20.7***	***0.380***	***34.0***	***1.07***	***0.95***	***47.3***	***-***	sand and gravel
					Mean:	43.5	1.3	
					St. Dev.	4.0	2.3	

Case number:	163
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	7.2 (M_L), 6.9 (M_w)
Location:	Kobe No : 5
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Surface manifestation of liquefaction
GPS LAT	34.661722 Coordiantes were taken from NGL
GPS LONG	135.177354
Liq. layer consist of:	Sand and Gravel
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments (fill??)
Site Response Anlaysis:	No
Comments:	Vs12m is updated basedn Vs-SPTN correlations. https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	Sand and gravel (content unkown)
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	6.5 - 11.0		6.5 - 11.0	6.8 - 11.8
d_{crt} (m)	-	8.8	8.9	8.8	9.3
GWT (m)	-	3.0 ± 0.3	3	3.0 ± 0.1	3.0 ± 0.1
γ_{moist} (kN/m^3)	-	17.3 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	18.1 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-	156.1 ± 14.2	173.4	160.6 ± 14.5	171.0 ± 16.1
σ_v' (kPa)	-	99.8 ± 7.9	116.3	104.3 ± 7.5	109.3 ± 8.3
a_{max} (g)	-	0.350 ± 0.045	0.35	0.350 ± 0.070	0.350 ± 0.070
r_d	-	0.71 ± 0.113	0.88	0.70 ± 0.113	0.75 ± 0.118
CSR	-	0.252 ± 0.053	0.298	0.244 ± 0.063	0.267 ± 0.068
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	2.0 ± 1.0	1	1.3 ± 2.5	1.3 ± 2.5
% PI	-	-	-	-	0
N	-	5.8 ± 1.3	5.4	5.8 ± 1.3	6.0 ± 1.4
C_R	-	1.00	1.00	1.00	0.97
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	0.98	0.92	0.99	0.96
$(N_1)_{60}$	-	6.9 ± 1.6	6.1	7.0 ± 1.6	7.7 ± 1.8
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	182.9	-	160.0	176.8

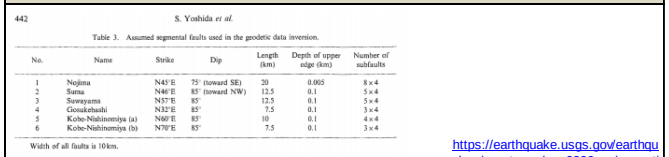
EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 2.0

Dip: 85 Width (km): 16 R_{jb} (km): 2.0



442 S. Yoshida *et al.*

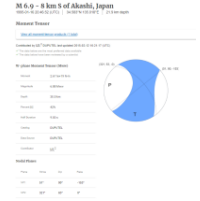
Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N45°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

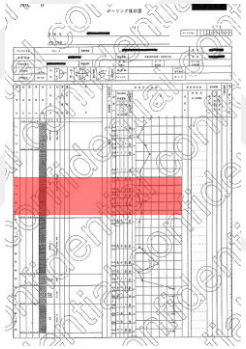
Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



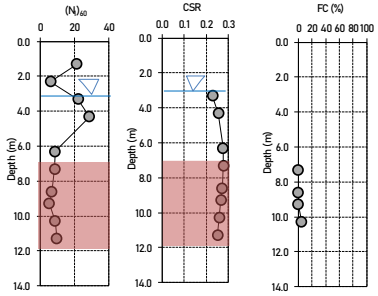






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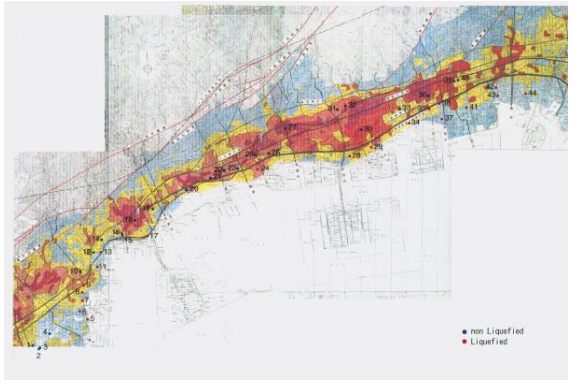
No.	5	kt0990							STDEV of corrected N	1.46
ACC=	350	liquefied							Average of corrected N	5.97
W.T=	3.02									
	tf/m3	tf/m2								
DEPTH(m)	Density	SV	SVD	Nvalue	C_R	C_1	C_E	C_N	Corrected N	F.C.	Soil quality
7.51		14.37	10.03	6	0.95	1	1	1.22	1.00	6.98	0.00	
8.605		17.09	11.51	5	0.95	1	1	1.22	0.93	5.40	0.00	
9.315		18.59	12.29	4	0.95	1	1	1.22	0.90	4.18	0.00	
10.8		20.65	13.37	7	1.00	1	1	1.22	0.96	7.39	0.00	



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
1.3	4.3	NA	9.0	2.00	0.86	21.3		Coarse SAND (based on approximate translation)
2.3	7.5	NA	3.0	1.60	0.89	5.8		Coarse SAND (based on approximate translation)
3.3	10.8	0.228	13.0	1.36	0.91	22.0		Coarse SAND (based on approximate translation)
4.3	14.1	0.254	18.0	1.26	0.93	28.7		SAND and GRAVEL
6.3	20.7	0.276	6.0	1.11	0.95	8.7		SAND and GRAVEL
7.3	***24.0***	***0.277***	***6.0***	***1.06***	***0.96***	***8.3***	***0.0***	SAND and GRAVEL
8.6	***28.2***	***0.272***	***5.0***	***0.99***	***0.97***	***6.6***	***0.0***	SAND and GRAVEL
9.3	***30.5***	***0.267***	***4.0***	***0.96***	***0.97***	***5.1***	***0.0***	SAND and GRAVEL
10.3	***33.8***	***0.259***	***7.0***	***0.93***	***0.98***	***8.7***	***5.0***	SAND and GRAVEL
11.3	***37.1***	***0.251***	***8.0***	***0.89***	***0.98***	***9.6***		SAND and GRAVEL
					Mean:	7.7	1.3	
					St. Dev.	1.8	2.5	

Case number:	164
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	7.2 (M_L), 6.9 (M_w)
Location:	Kobe No : 6
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface manifestation of liquefaction.
GPS LAT	34.664261 ***Coordiantes were taken from NGL***
GPS LONG	135.174646
Liq. layer consist of:	Unkown
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is updated basedn Vs-SPTN correlations.
	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	Unkown
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	No	No	No
Data Class	-	A	-	B	B
d_{crtc} range (m)	-	4.3 - 7.3		4.3 - 7.3	4.3 - 7.3
d_{crt} (m)	-	5.8	5.9	5.8	5.8
GWT (m)	-	2.3 ± 0.3	2.3	2.3 ± 0.1	2.3 ± 0.1
γ_{moist} (kN/m^3)	-	17.3 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	18.1 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	103.2 ± 9.4	107.3	112.4 ± 10.0	115.7 ± 10.5
σ_v' (kPa)	-	68.8 ± 5.6	72.2	78.0 ± 5.4	81.3 ± 5.8
a_{max} (g)	-	0.400 ± 0.060	0.4	0.400 ± 0.080	0.400 ± 0.080
r_d	-	0.84 ± 0.079	0.93	0.89 ± 0.079	0.96 ± 0.079
CSR	-	0.328 ± 0.061	0.36	0.332 ± 0.073	0.357 ± 0.078
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	25.0 ± 3.0	21	24.7 ± 9.2	24.7 ± 9.2
% PI	-	-	-	-	NAV
N	-	16.8 ± 2.9	13.4	16.7 ± 3.0	16.8 ± 3.5
C_R	-	0.95	0.95	0.95	0.95
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.18	1.15	1.14	1.12
$(N_1)_{60}$	-	22.7 ± 3.9	17.8	21.9 ± 3.9	24.2 ± 5.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	176.8	-	176.8	216.4

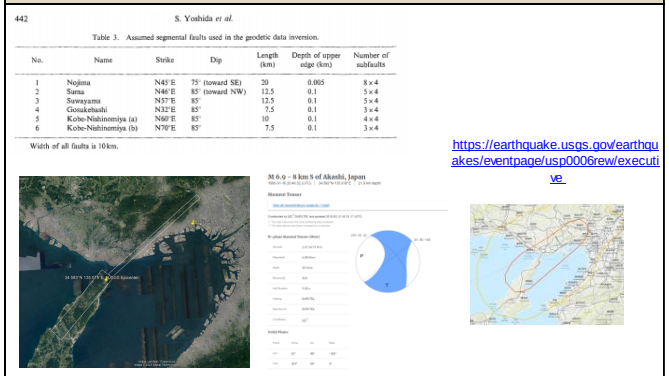
EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 1.6

Dip: 85 Width (km): 16 R_{jb} (km): 1.6



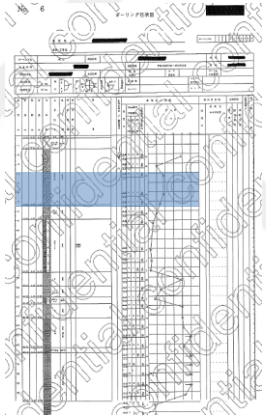
442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

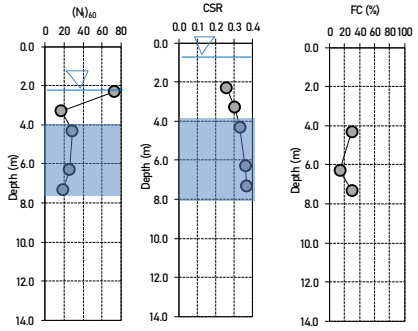
Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



Personal Communication Prof. Tokimatsu (2000)

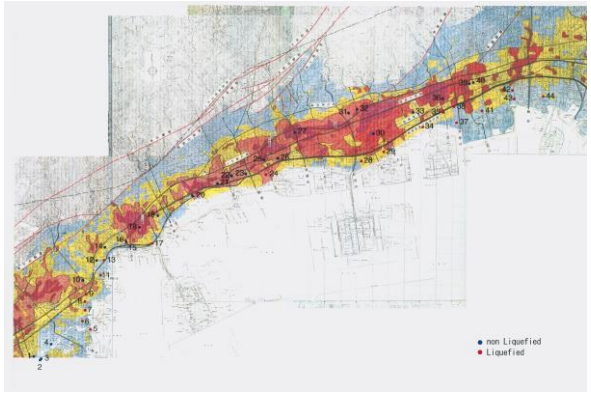
No.	6		kt00998							STDEV of corrected N		3.85
ACC=	400		liquefied							Average of corrected N		21.81
W.T=	2.3											
	tf/m3	tf/m2	tf/m2									
DEPTH(m)	Density	SV	SVD	Nvalue	C_R	C_S	C_E	C_B	C_N	Corrected N	F.C.	Soil quality
4.3		7.66	5.86	18	0.85	1	1	1.22	1.31	24.33	0.80	
6.3		11.76	7.76	18	0.95	1	1	1.22	1.14	23.68	0.14	
7.3		13.71	8.71	14	0.95	1	1	1.22	1.07	17.38	0.30	



Depth (m)	Depth (ft)	CSR	N	C_N	C_B	$(N1)_{60}$	FC	
2.3	7.5	0.258	39.0	1.53	0.89	72.5		-
3.3	10.8	0.303	10.0	1.37	0.91	17.0		-
4.3	***14.1***	***0.332***	***18.0***	***1.25***	***0.93***	***28.5***	***30.0***	-
6.3	***20.7***	***0.362***	***18.0***	***1.08***	***0.95***	***25.3***	***14.0***	-
7.3	***24.0***	***0.368***	***14.0***	***1.02***	***0.96***	***18.8***	***30.0***	-
					Mean:	24.2	24.7	
					St. Dev.	5.0	9.2	

Case number:	165
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	7.2 (M_L), 6.9 (M_w)
Location:	Kobe No : 7
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Surface manifestation of liquefaction
GPS LAT	34.667342 Coordiantes were taken from NGL
GPS LONG	135.175643
Liq. layer consist of:	Sand and Gravel
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is updated basedn Vs-SPTN correlations.
	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	Sand and gravel (content unkown)
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	A	-	B	B
$d_{crit.}$ range (m)	-	4.3 - 8.3		1.8 - 3.8	3.2 - 3.8
d_{crt} (m)	-	6.3	3.3	2.8	3.5
GWT (m)	-	3.2 ± 0.3	3.2	3.2 ± 0.1	3.2 ± 0.1
γ_{moist} (kN/m^3)	-	17.3 ± 0.6	-	17.3 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	18.1 ± 0.6	-	18.9 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	111.6 ± 12.4	62.2	47.9 ± 6.5	66.3 ± 2.7
σ_v' (kPa)	-	80.8 ± 6.8	60.2	51.5 ± 3.5	63.2 ± 2.0
a_{max} (g)	-	0.400 ± 0.060	0.4	0.400 ± 0.080	0.400 ± 0.080
r_d	-	0.81 ± 0.085	0.93	0.99 ± 0.043	0.99 ± 0.051
CSR	-	0.293 ± 0.056	0.314	0.239 ± 0.052	0.271 ± 0.056
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	0.0 ± 0.0	0	0.0 ± 2.0	0.0 ± 8.6
% PI	-	-	-	-	0
N	-	21.5 ± 1.3	8	15.6 ± 5.5	14.1 ± 5.0
C_R	-	0.96	0.85	0.84	0.91
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.09	1.32	1.40	1.27
$(N_1)_{60}$	-	27.3 ± 1.7	10.9	22.3 ± 7.9	22.3 ± 7.9
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	176.8	-	205.7	231.6

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 1.4

Dip: 85 Width (km): 16 R_{jb} (km): 1.4

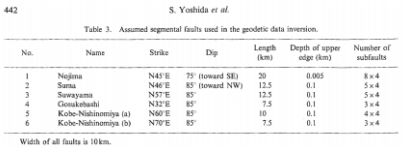

442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

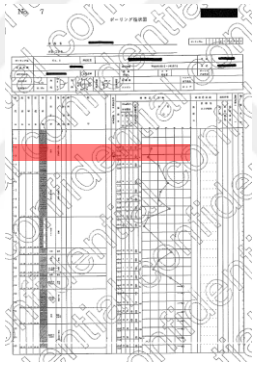
Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



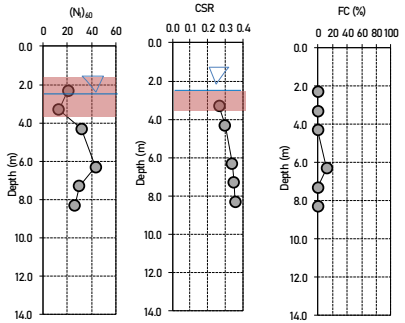






Personal Communication Prof. Tokimatsu (2000)

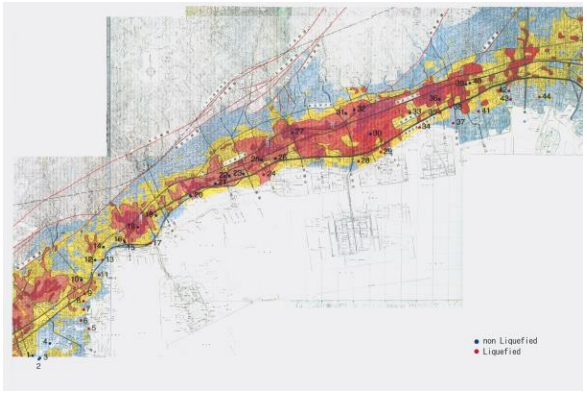
No.	7		kt00991						STDEV of corrected N		1.86
ACC=	400		liquefied						Average of corrected N		24.68
W.T=	3.16										
	tf/m3	tf/m2	tf/m2								
DEPTH(m)	Density	SV	SVD	Nvalue	C_R	C_S	C_B	C_E	C_N	Corrected N	F.C.	Soil quality
4.3		8.40	7.26	21	0.85	1	1	1.22	1.17	25.56	0.00	
6.3		12.60	9.46	32	0.95	1	1	1.22	1.03	38.14	0.12	
7.3		14.70	10.56	23	0.95	1	1	1.22	0.97	25.94	0.00	
8.3		16.80	11.66	21	0.95	1	1	1.22	0.93	22.54	0.00	



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC		
2.3	***7.5***	***NA***	***11.0***	***1.53***	***0.89***	***20.4***	***0.0***	interpreted	SAND and GRAVEL
3.3	***10.8***	***0.264***	***8.0***	***1.29***	***0.91***	***12.8***	***0.0***	interpreted	SAND and very thin sat layer
4.3	14.1	0.297	21.0	1.19	0.93	31.6	0.0		SAND and GRAVEL
6.3	20.7	0.337	32.0	1.04	0.95	43.3	12.0	outlier	-
7.3	24.0	0.348	23.0	0.99	0.96	29.8	0.0		-
8.3	27.2	0.355	21.0	0.94	0.97	26.1	0.0		-
					Mean:	16.6	0.0		
					St. Dev.	5.4	8.6	assigned	

Case number:	166
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	7.2 (M_L), 6.9 (M_w)
Location:	Kobe No : 8
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Surface manifestation of liquefaction
GPS LAT	34.669858 Coordiantes were taken from NGL
GPS LONG	135.175292
Liq. layer consist of:	coarse SAND with gravel
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is updated basedn Vs-SPTN correlations. https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	coarse sand with gravel (content unkown)
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	A	-	B	B
d_{crtc} range (m)	-	4.0 - 6.0		4.0 - 6.0	3.0 - 6.3
d_{cr1} (m)	-	5.0	5.0	5.0	4.6
GWT (m)	-	3.0 ± 0.3	3	3.0 ± 0.1	3.0 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	19.6 ± 0.5	19.6 ± 0.5
σ_v (kPa)	-	80.4 ± 6.0	85.2	86.8 ± 6.8	78.9 ± 10.9
σ_v' (kPa)	-	60.2 ± 4.2	65.2	66.7 ± 3.7	62.7 ± 5.7
a_{max} (g)	-	0.500 ± 0.075	0.5	0.500 ± 0.100	0.500 ± 0.100
r_d	-	0.89 ± 0.070	0.94	0.96 ± 0.070	0.99 ± 0.065
CSR	-	0.386 ± 0.069	0.402	0.407 ± 0.087	0.403 ± 0.088
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	0.0 ± 0.0	0	0.0 ± 2.0	0.0 ± 8.6
% PI	-	-	-	-	0
N	-	17.3 ± 2.0	17.4	17.4 ± 2.0	17.5 ± 2.0
C_R	-	0.92	0.95	0.92	0.93
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.26	1.20	1.23	1.27
$(N_1)_{60}$	-	24.5 ± 2.9	24.1	24.0 ± 2.8	28.3 ± 3.3
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	182.9	-	205.7	231.6

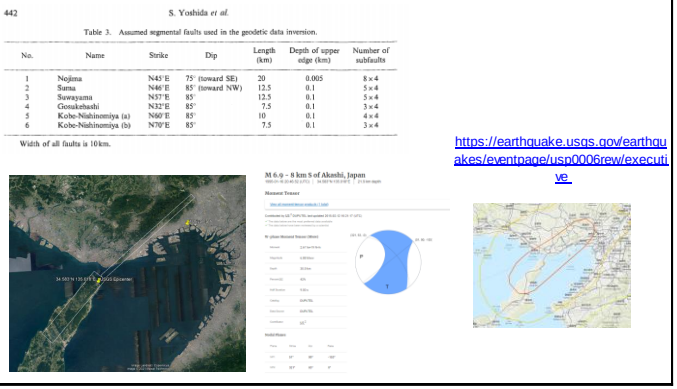
EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 1.2

Dip: 85 Width (km): 16 R_{jb} (km): 1.2



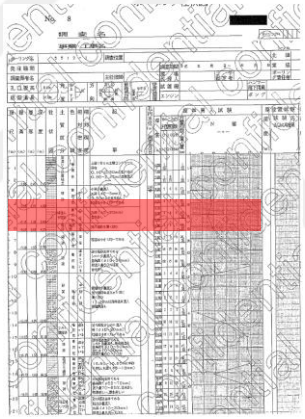
442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

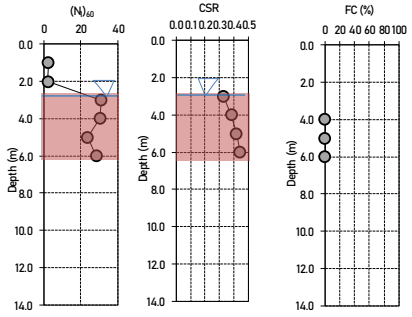
No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



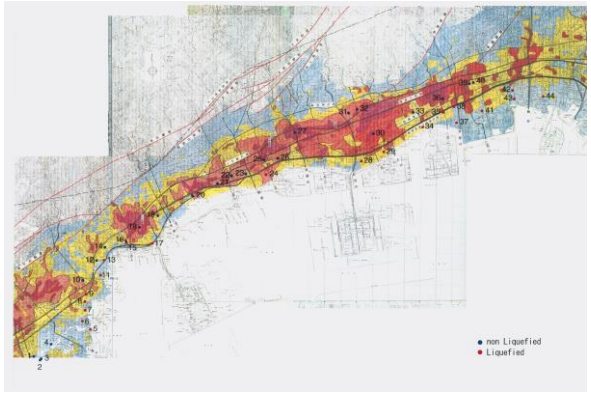
No.	8		5513								
ACC=	500		liquefied					STDEV of corrected N			1.87
W.T=	2.95							Average of corrected N			21.23
	tf/m3	tf/m2	tf/m2								
DEPTH(m)	Density	SV	SVD	Nvalue	C_N	C_S	C_B	C_E	C_R	Corrected N	F.C.	Soil quality
4	1.86	6.8	5.75	18	0.75	1	1	1.22	1.32	21.72	0.00	粗砂
5	1.84	8.64	6.59	15	0.85	1	1	1.22	1.23	19.16	0.00	礫混じり粗砂
6	1.87	10.51	7.48	19	0.85	1	1	1.22	1.16	22.81	0.00	粗砂



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
1.0	3.3	NA	1.0	2.00	0.86	***2.3***		sandy CLAY with gravel
2.0	6.6	NA	1.0	1.80	0.88	***2.2***		sandy CLAY with gravel
3.0	***9.8***	***0.326***	***17.0***	***1.47***	***0.90***	***30.9***		coarse SAND
4.0	***13.1***	***0.380***	***18.0***	***1.34***	***0.92***	***30.3***	***0.0***	coarse SAND
5.0	***16.4***	***0.416***	***15.0***	***1.23***	***0.94***	***23.7***	***0.0***	coarse SAND with gravel
6.0	***19.7***	***0.441***	***19.0***	***1.15***	***0.95***	***28.4***	***0.0***	coarse SAND with gravel
					Mean:	28.3	0.0	
					St. Dev.	3.3	8.6	assigned

Case number:	167
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	7.2 (M_L), 6.9 (M_w)
Location:	Kobe No : 9
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface manifestation of liquefaction
GPS LAT	34.671947 Coordiantes were taken from NGL
GPS LONG	135.175811
Liq. layer consist of:	coarse sand
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is updated basedn Vs-SPTN correlations.
	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	NAV
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	A	-	B	B
$d_{crit.}$ range (m)	-	3.3 - 5.3		3.3 - 5.3	2.8 - 5.5
d_{crt} (m)	-	4.3	4.3	4.3	4.1
GWT (m)	-	2.8 ± 0.3	2.8	2.8 ± 0.1	2.8 ± 0.1
γ_{moist} (kN/m^3)	-	16.5 ± 0.6	-	16.5 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	18.1 ± 0.6	-	18.1 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-	73.5 ± 6.4	79.2	73.5 ± 6.2	69.4 ± 8.7
σ_v' (kPa)	-	58.5 ± 4.2	64.2	58.5 ± 3.2	56.0 ± 4.4
a_{max} (g)	-	0.500 ± 0.075	0.5	0.500 ± 0.100	0.500 ± 0.100
r_d	-	0.89 ± 0.061	0.95	0.89 ± 0.061	0.96 ± 0.059
CSR	-	0.365 ± 0.064	0.383	0.364 ± 0.078	0.385 ± 0.083
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	3.0 ± 1.0	2	2.3 ± 4.0	2.3 ± 4.0
% PI	-	-	-	-	0
N	-	8.7 ± 3.8	8.3	8.6 ± 3.8	8.5 ± 3.6
C_R	-	0.90	0.95	0.90	0.92
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.28	1.27	1.32	1.35
$(N_1)_{60}$	-	12.1 ± 5.3	12.2	12.4 ± 5.5	14.5 ± 6.1
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	173.7	-	160.0	190.5

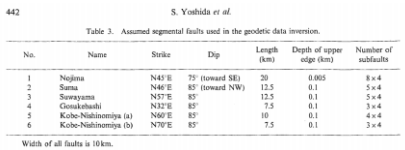
EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 1.0

Dip: 85 Width (km): 16 R_{jb} (km): 1.0



442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

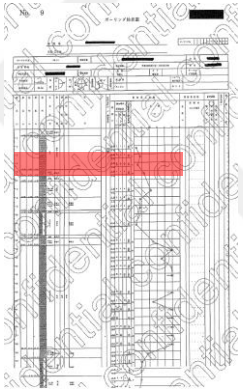
Width of all faults is 10 km.





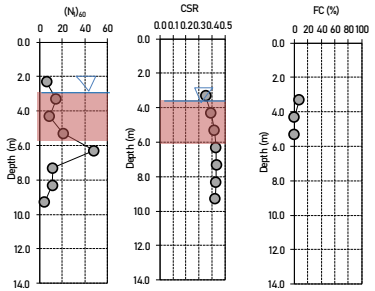
https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive





Personal Communication Prof. Tokimatsu (2000)

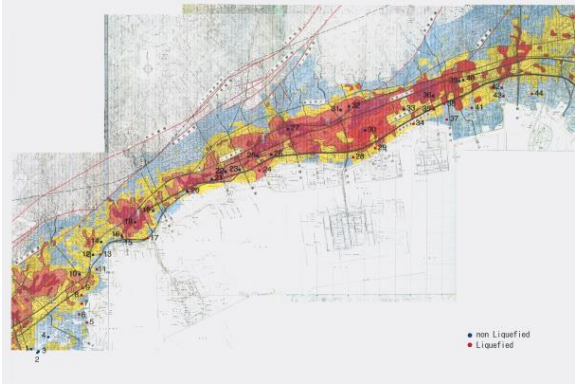
No.	9	kt00999									
AOC=	500	liquefied		△				STDEV of corrected N			4.61
W.T=	2.77							Average of corrected N			10.61
	tf/m3	tf/m2	tf/m2								
DEPTH(m)	Density	SV	SVD	Nvalue	Cn	Cs	Ca	Cr	Cw	Corrected N	F.C.	Soil quality
2.3	1.9	4.60	5.56	5	0.85	1	1	1.22	1.24	5.55	0.00	
3.3	1.9	6.50	6.52	13	0.85	1	1	1.22	1.24	14.42	0.00	
4.3	1.9	8.40	7.48	5	0.85	1	1	1.22	1.24	5.55	0.00	
5.3	1.9	10.30	7.52	13	0.85	1	1	1.22	1.15	14.42	0.00	



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
2.3	7.5	NA	3.0	1.67	0.89	6.1		Coarse SAND
3.3	***10.8***	***0.349***	***8.0***	***1.45***	***0.91***	***14.4***	***7.0***	Coarse SAND
4.3	***14.1***	***0.390***	***5.0***	***1.33***	***0.93***	***8.4***	***0.0***	Coarse SAND
5.3	***17.4***	***0.416***	***13.0***	***1.24***	***0.94***	***20.6***	***0.0***	-
6.3	20.7	0.429	32.0	1.16	0.95	48.2		SAND mixed with SIL
7.3	24.0	0.433	8.0	1.10	0.96	11.5		SAND mixed with SIL
8.3	27.2	0.429	8.0	1.04	0.97	11.0		-
9.3	30.5	0.421	3.0	0.99	0.97	4.0		-
					Mean:	14.5	2.3	
					St. Dev.	6.1	4.0	

Case number:	168
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	7.2 (M_L), 6.9 (M_w)
Location:	Kobe No : 10
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No surface manifestation of liquefaction
GPS LAT	34.675801 Coordiantes were taken from NGL
GPS LONG	135.174759
Liq. layer consist of:	sand
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	NAV
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	No	No	No	No
Data Class	-	B	-	B	B
d_{crLc} range (m)	-	6.0 - 9.0	-	6.0 - 9.0	4.5 - 9.0
d_{crL} (m)	-	7.5	7.5	7.5	6.7
GWT (m)	-	4.5 ± 0.3	4.5	4.5 ± 0.1	4.5 ± 0.1
γ_{moist} (kN/m^3)	-	16.5 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	17.3 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	126.4 ± 9.3	137.3	144.1 ± 10.2	131.1 ± 15.8
σ_v' (kPa)	-	96.5 ± 5.8	107.3	114.3 ± 5.6	108.8 ± 8.5
a_{max} (g)	-	0.600 ± 0.090	0.6	0.600 ± 0.120	0.600 ± 0.120
r_d	-	0.75 ± 0.099	0.9	0.92 ± 0.099	0.99 ± 0.090
CSR	-	0.383 ± 0.078	0.45	0.455 ± 0.104	0.465 ± 0.104
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	9.0 ± 1.0	9	8.8 ± 2.5	8.8 ± 2.5
% PI	-	-	-	-	0
N	-	23.1 ± 3.5	24.1	23.1 ± 3.5	22.0 ± 3.2
C_R	-	0.99	0.95	0.99	0.96
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.00	0.98	0.94	0.97
$(N_1)_{60}$	-	27.7 ± 4.2	27.4	26.2 ± 4.0	27.7 ± 4.1
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	179.8	-	213.4	262.1

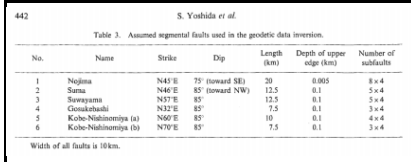
EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 — Yoshida et al (1996)

Fault Type: strike-slip — Z_{tor} (km): 0 — R_{rup} (km): 0.6

Dip: 85 — Width (km): 16 — R_{jb} (km): 0.6



442 S. Yoshida *et al.*

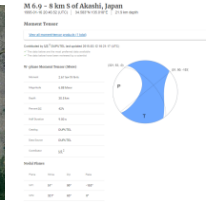
Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gionsukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

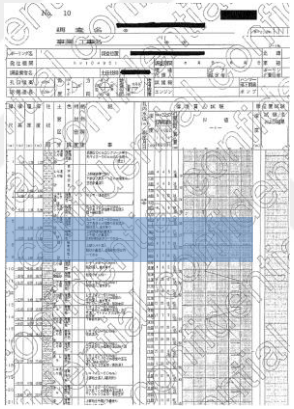
Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



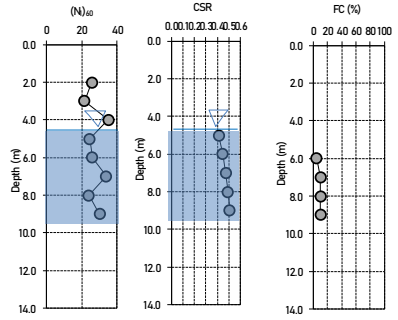






Personal Communication Prof. Tokimatsu (2000)

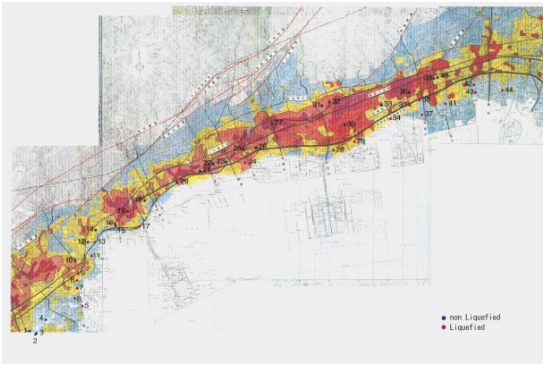
No.	10	hy104951							STDEV of corrected N	4.51
ACC=	600	non-liquefied							Average of corrected N	25.22
W.T=	4.46									
	tf/m3	tf/m2	tf/m2							
DEPTH(m)	Density	SV	SVD	Nvalue	C_N	C_F	C_R	C_S	Corrected N	F.C.	Soil quality		
0	1.6	1.6	1.08	9.54	2.0	0.85	1	1	1.22	1.62	21.22	0.05	1.1	41	85
1	1.6	3.2	2.98	10.45	2.1	0.85	1	1	1.22	0.88	20.51	0.09	41	72	
6	1.87	14.26		1.32	2.0	0.85	1	1	1.22	0.84	21.78	0.10	58	73	
9	1.85	19.01		12.21	2.01	0.85	1	1	1.22	0.87	21.23	0.10	48	62	



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
2.0	6.6	NA	13.0	1.64	0.88	25.7	-	coarse SAND
3.0	9.8	NA	13.0	1.34	0.90	21.5	-	coarse SAND
4.0	13.1	NA	24.0	1.16	0.92	35.1	-	fine SAND with silt
5.0	***16.4***	***0.411***	***18.0***	***1.06***	***0.94***	***24.5***	***-***	***medium SAND***
6.0	***19.7***	***0.445***	***20.0***	***1.00***	***0.95***	***26.0***	***5.0***	***medium SAND***
7.0	***23.0***	***0.471***	***27.0***	***0.95***	***0.96***	***33.7***	***10.0***	***fine SAND***
8.0	***26.2***	***0.492***	***20.0***	***0.91***	***0.97***	***24.0***	***10.0***	***fine SAND***
9.0	***29.5***	***0.508***	***26.0***	***0.87***	***0.97***	***30.2***	***10.0***	***fine SAND***
					Mean:	27.7	8.8	
					St. Dev.	4.1	2.5	

Case number:	169
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 11
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefied
GPS LAT	34.677128 Coordiantes were taken from NGL
GPS LONG	135.18089
Liq. layer consist of:	medium SAND
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is upated based on Vs-SPTN correlations
	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	NAV
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	3.8 - 9.8	-	3.8 - 9.8	3.4 - 10.0
d_{crt} (m)	-	6.8	6.8	6.8	6.7
GWT (m)	-	1.5 ± 0.3	1.5	1.5 ± 0.1	1.5 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-	110.5 ± 16.9	114.3	125.3 ± 19.1	123.9 ± 20.8
σ_v' (kPa)	-	58.4 ± 8.0	62.2	73.2 ± 9.5	72.5 ± 10.3
a_{max} (g)	-	0.500 ± 0.075	0.5	0.500 ± 0.100	0.500 ± 0.100
r_d	-	0.70 ± 0.090	0.91	0.67 ± 0.090	0.75 ± 0.089
CSR	-	0.429 ± 0.090	0.546	0.374 ± 0.091	0.415 ± 0.098
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	5.0 ± 1.0	5	5.0 ± 2.0	5.0 ± 8.6
% PI	-	-	-	-	NAV
N	-	5.5 ± 1.5	5.6	5.6 ± 1.6	5.6 ± 1.7
C_R	-	0.97	0.95	0.97	0.96
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.28	1.31	1.18	1.18
$(N_1)_{60}$	-	8.3 ± 2.3	8.5	7.7 ± 2.2	8.6 ± 2.6
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	158.5	-	137.2	152.4

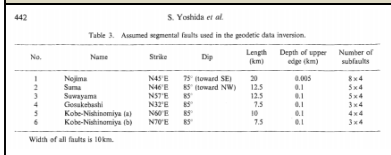
EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 0.9

Dip: 85 Width (km): 16 R_{jb} (km): 0.9



442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Sama	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gosakebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N76°E	85°	7.5	0.1	3 × 4

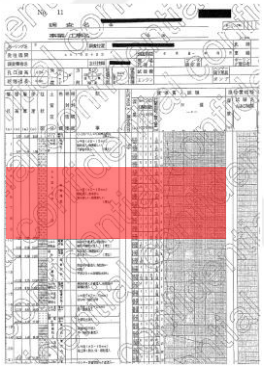
Width of all faults is 16km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



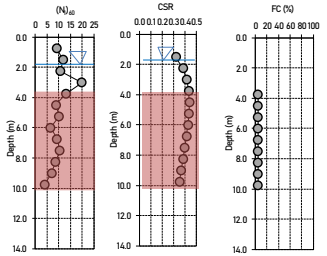






Personal Communication Prof. Tokimatsu (2000)

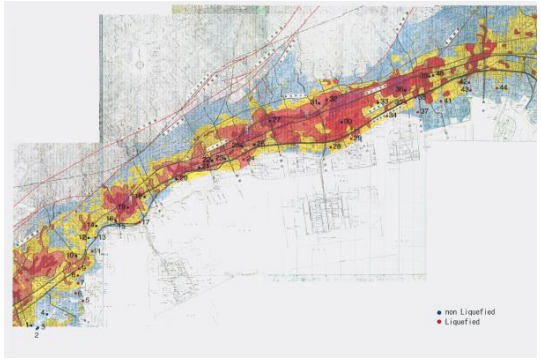
No.	11		qh108423									
ACC=	500		liquefied		○				STDEV of corrected N			2.02
W.T.=	1.45								Average of corrected N			7.59
	tf/m3	tf/m2	tf/m2									
DEPTH(m)	Density	SV	SVD	Nvalue	C_N	C_1	C_2	C_3	C_R	Corrected N	F.C.	Soil quality
3.25	1.75	6.503	4.203	3	0.75	1	1	1.22	1.54	8.68	0.05	シルト混じり中
4.5	1.77	8.064	5.108	3	0.65	1	1	1.22	1.45	7.54	0.05	シルト混じり中
5.25	1.78	9.082	5.833	3	0.65	1	1	1.22	1.36	8.00	0.05	シルト混じり中
6	1.88	10.94	6.913	4	0.65	1	1	1.22	1.33	8.45	0.05	シルト混じり中
6.75	1.79	11.952	7.630	5	0.60	1	1	1.22	1.26	8.14	0.05	シルト混じり中
7.5	1.74	12.956	8.316	5	0.59	1	1	1.22	1.20	8.18	0.05	シルト混じり中
8.25	1.72	14.22	9.428	6	0.55	1	1	1.22	1.15	8.07	0.05	シルト混じり中
9	1.7	15.592	10.648	7	0.53	1	1	1.22	1.12	8.50	0.05	シルト混じり中
9.75	1.65	16.974	11.848	8	0.50	1	1	1.22	1.07	9.06	0.05	シルト混じり中



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
0.8	2.5	NA	4.0	2.00	0.85	9.3		medium SAND
1.5	4.9	0.320	5.0	1.99	0.87	11.8		medium SAND
2.3	7.4	0.382	5.0	1.77	0.89	10.8		medium SAND
3.0	9.8	0.416	10.0	1.61	0.90	19.9		medium SAND
3.8	***12.3***	***0.432***	***7.0***	***1.49***	***0.92***	***13.1***	***5.0***	medium SAND
4.5	***14.8***	***0.438***	***5.0***	***1.39***	***0.93***	***8.8***	***5.0***	medium SAND
5.3	***17.2***	***0.435***	***6.0***	***1.31***	***0.94***	***10.1***	***5.0***	medium SAND
6.0	***19.7***	***0.426***	***4.0***	***1.24***	***0.95***	***6.4***	***5.0***	medium SAND
6.8	***22.1***	***0.414***	***6.0***	***1.18***	***0.96***	***9.2***	***5.0***	medium SAND
7.5	***24.6***	***0.399***	***7.0***	***1.13***	***0.96***	***10.4***	***5.0***	medium SAND
8.3	***27.1***	***0.383***	***6.0***	***1.08***	***0.97***	***8.6***	***5.0***	medium SAND
9.0	***29.5***	***0.367***	***5.0***	***1.04***	***0.97***	***6.9***	***5.0***	medium SAND
9.8	***32.0***	***0.352***	***3.0***	***1.01***	***0.98***	***4.0***	***5.0***	medium SAND
					Mean:	8.6	5.0	
					St. Dev.	2.6	8.6	assg

Case number:	170
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 12
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefied
GPS LAT	34.681294 Coordiantes were taken from NGL
GPS LONG	135.179424
Liq. layer consist of:	Sand
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is updated basedn on Vs-SPTN correlations https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en
Gravel Content (%):	NAV
CPT available:	No
Vs available:	?





Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	No	No	No	No
Data Class	-	A	-	B	B
d_{crtc} range (m)	-	4.3 - 6.3	-	4.3 - 6.3	3.8 - 6.8
d_{crt} (m)	-	5.3	5.3	5.3	5.3
GWT (m)	-	3.2 ± 0.3	3.2	3.2 ± 0.1	3.2 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	15.7 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	85.1 ± 6.0	92.2	91.7 ± 6.8	103.8 ± 10.5
σ_v' (kPa)	-	64.5 ± 4.3	72.2	71.1 ± 3.8	83.2 ± 5.7
a_{max} (g)	-	0.500 ± 0.075	0.5	0.500 ± 0.100	0.500 ± 0.100
r_d	-	0.83 ± 0.073	0.94	0.94 ± 0.073	0.97 ± 0.073
CSR	-	0.355 ± 0.065	0.393	0.396 ± 0.086	0.395 ± 0.086
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	13.0 ± 3.0	14	14.0 ± 14.0	14.0 ± 14.0
% PI	-	-	-	-	NAV
N	-	19.6 ± 1.0	18.6	19.6 ± 1.3	19.4 ± 1.5
C_R	-	0.92	0.95	0.92	0.94
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.22	1.14	1.20	1.11
$(N_1)_{60}$	-	26.7 ± 1.3	24.7	26.2 ± 1.7	27.6 ± 2.2
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	167.6	-	198.1	222.5

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 0.4

Dip: 85 Width (km): 16 R_{jb} (km): 0.4

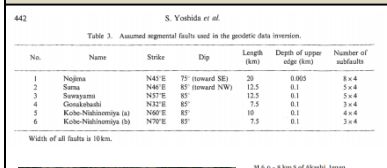
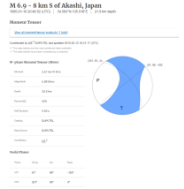

442 S. Yoshida et al.

Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N43°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

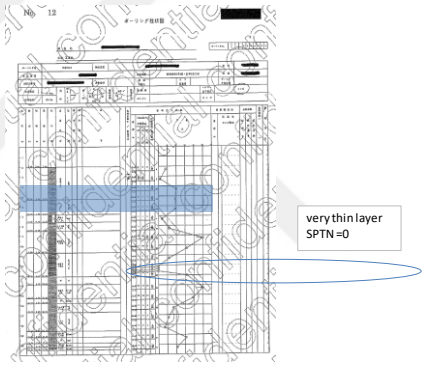
Width of all faults is 10 km.



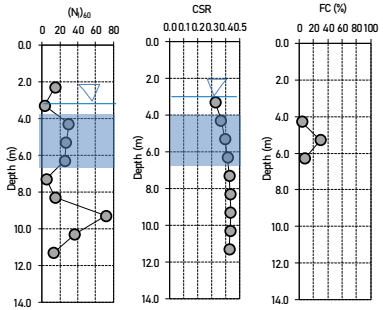


https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive





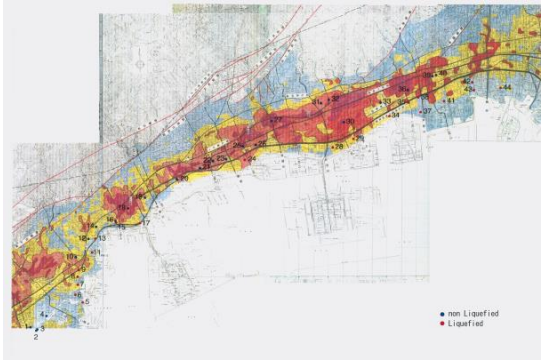
No.	12		kg00464								
ACC=	500		non-liquefied							STDEV of corrected N	1.49
W.T=	3.2									Average of corrected N	24.45
	tf/m3	tf/m2	tf/m2								
DEPTH(m)	Density	SV	SVD	Nvalue	C_N	C_S	C_R	C_E	Corrected N	F.C.	Soil quality
4.3		7.45	6.85	20	0.85	1	1	1.22	20.64	0.04	
5.3		9.40	7.80	19	0.81	1	1	1.21	23.67	0.30	
6.3		11.35	8.25	19	0.81	1	1	1.21	24.25	0.08	



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
2.3	7.5	NA	8.0	1.53	0.89	14.9		-
3.3	10.8	0.327	2.0	1.28	0.91	3.2		-
4.3	***14.1***	***0.367***	***20.0***	***1.18***	***0.93***	***30.0***	***4.0***	-
5.3	***17.4***	***0.395***	***19.0***	***1.11***	***0.94***	***27.0***	***30.0***	sand
6.3	***20.7***	***0.415***	***19.0***	***1.04***	***0.95***	***25.7***	***8.0***	sand
7.3	24.0	0.427	4.0	0.98	0.96	5.2		SILT
8.3	27.2	0.434	12.0	0.94	0.97	14.9		Silty SAND
9.3	30.5	0.435	60.0	0.90	0.97	71.6		-
10.3	33.8	0.432	32.0	0.86	0.98	36.8		-
11.3	37.1	0.426	12.0	0.83	0.98	13.4		Sandy CLAY
					Mean:	27.6	14.0	
					St. Dev.	2.2	14.0	

Case number:	171
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 13
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefied
GPS LAT	34.681524 Coordiantes were taken from NGL
GPS LONG	135.181824
Liq. layer consist of:	Coarse SAND with SILT
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is upated based on Vs-SPTN correlations
	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	NAV
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	A	-	B	B
d_{crtc} range (m)	-	5.0 - 8.0	-	5.0 - 8.0	4.4 - 8.8
d_{crt} (m)	-	6.5	6.5	6.5	6.6
GWT (m)	-	2.3 ± 0.3	2.3	2.3 ± 0.1	2.3 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	19.6 ± 0.5	20.0 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	18.9 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	105.7 ± 8.8	116.3	124.6 ± 9.7	134.2 ± 15.5
σ_v' (kPa)	-	64.4 ± 5.3	74.2	83.4 ± 5.2	92.2 ± 8.4
a_{max} (g)	-	0.500 ± 0.075	0.5	0.500 ± 0.100	0.500 ± 0.100
r_d	-	0.81 ± 0.087	0.92	0.87 ± 0.087	0.96 ± 0.088
CSR	-	0.433 ± 0.083	0.464	0.421 ± 0.095	0.454 ± 0.101
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	18.0 ± 3.0	15	15.0 ± 10.0	15.0 ± 10.0
% PI	-	-	-	-	NAV
N	-	9.3 ± 1.0	9.5	9.3 ± 1.1	9.4 ± 1.2
C_R	-	0.96	0.95	0.96	0.95
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.22	1.16	1.10	1.05
$(N_1)_{60}$	-	13.3 ± 1.5	12.7	12.0 ± 1.4	12.8 ± 1.7
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	179.8	-	179.8	222.5

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 0.5

Dip: 85 Width (km): 16 R_{jb} (km): 0.5

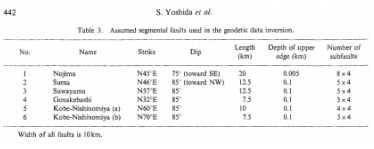

442 S. Yoshida *et al.*

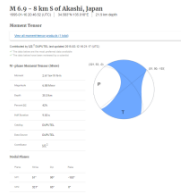
Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N41°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N37°E	85°	12.5	0.1	5 × 4
4	Gosakebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

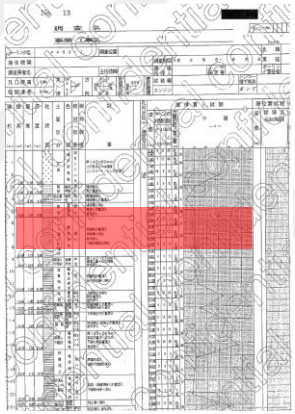
Width of all faults is 10km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive

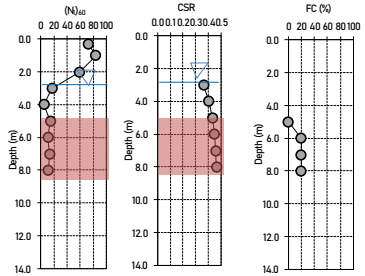








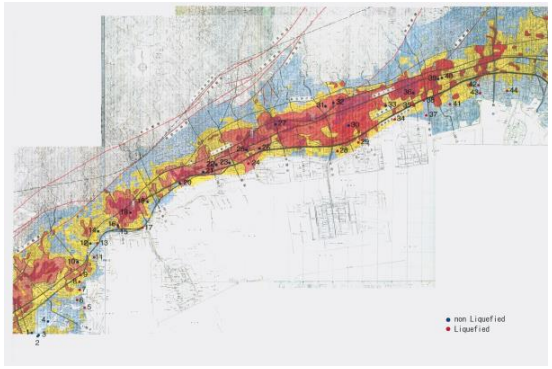
No.	13		4499										
ADC=	500		liquefied								STDEV of corrected N		1.54
W.T=	2.3										Average of corrected N		11.71
	tf/m3	tf/m2	tf/m2										
DEPTH(m)	Density	SV	SVD	Nvalue	C_N	C_S	C_E	C_R	C_N	Corrected N	F.C.	Soil quality	
5	1.8	9.12	6.42	10	0.85	1	1	1.22	1.05	12.4	0.00	砂質土	CU指数
6	1.77	10.89	7.16	8	0.85	1	1	1.22	1.08	10.38	0.20	砂質土	CU指数
7	1.73	12.68	7.93	10	0.85	1	1	1.22	1.12	12.97	0.20	砂質土	CU指数
8	1.78	14.46	8.76	9	0.85	1	1	1.22	1.07	11.14	0.20	砂質土	CU指数



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
0.3	1.0	NA	32.0	2.00	0.83	72.9		Gravel
1.0	3.3	NA	36.0	2.00	0.86	84.2		Gravel
2.0	6.6	NA	31.0	1.59	0.88	59.6		Gravel
3.0	9.8	0.363	10.0	1.38	0.90	17.0		Coarse SAND
4.0	13.1	0.403	3.0	1.26	0.92	4.7		Clayey SILT
5.0	***16.4***	***0.430***	***10.0***	***1.16***	***0.94***	***14.9***	***0.0***	Coarse SAND
6.0	***19.7***	***0.447***	***8.0***	***1.09***	***0.95***	***11.3***	***20.0***	Coarse SAND with SILT
7.0	***23.0***	***0.458***	***10.0***	***1.02***	***0.96***	***13.4***	***20.0***	Coarse SAND with SILT
8.0	***26.2***	***0.463***	***9.0***	***0.97***	***0.97***	***11.5***	***20.0***	Coarse SAND with SILT
					Mean:	12.8	15.0	
					St. Dev.	1.7	10.0	

Case number:	172
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 14
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Non-Liquefied
GPS LAT	34.685055 Coordiantes were taken from NGL
GPS LONG	135.182259
Liq. layer consist of:	sand
Geological Unit:	Late Pleistocene lower terrace
Site Response Anlaysis:	No
Comments:	Vs12m is upated based on Vs-SPTN correlations
	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	NAV
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	No	No	No	No
Data Class	-	A	-	B	B
d_{crtc} range (m)	-	4.3 - 5.3	-	4.3 - 5.3	3.3 - 5.8
d_{crt} (m)	-	4.8	4.8	4.8	4.6
GWT (m)	-	3.1 ± 0.3	3.1	3.1 ± 0.1	3.1 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	18.1 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	76.9 ± 3.6	86.2	89.6 ± 3.7	88.5 ± 8.7
σ_v' (kPa)	-	60.2 ± 3.7	69.2	72.9 ± 2.5	74.2 ± 4.8
a_{max} (g)	-	0.500 ± 0.075	0.5	0.500 ± 0.100	0.500 ± 0.100
r_d	-	0.84 ± 0.068	0.95	0.90 ± 0.068	0.96 ± 0.065
CSR	-	0.350 ± 0.062	0.382	0.360 ± 0.077	0.370 ± 0.079
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	18.0 ± 3.0	19	18.5 ± 16.3	18.5 ± 16.3
% PI	-	-	-	-	NAV
N	-	16.0 ± 1.6	15	16.0 ± 1.8	16.4 ± 1.7
C_R	-	0.91	0.95	0.91	0.93
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.26	1.17	1.18	1.17
$(N_1)_{60}$	-	22.5 ± 2.3	20.3	21.0 ± 2.3	24.3 ± 2.5
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	164.6	-	170.7	196.6

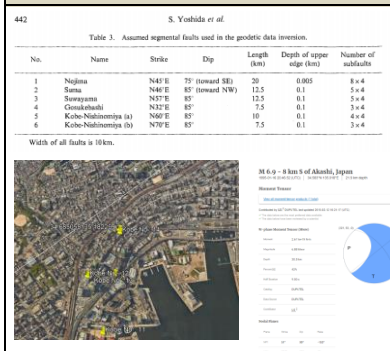
EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 0.3

Dip: 85 Width (km): 16 R_{jb} (km): 0.3



442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

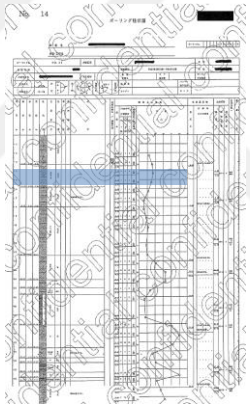
No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

Width of all faults is 10 km.



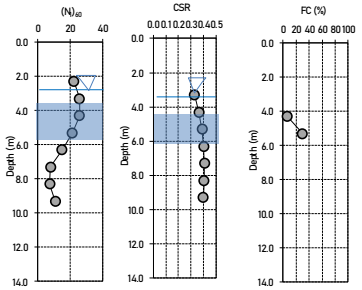
https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive





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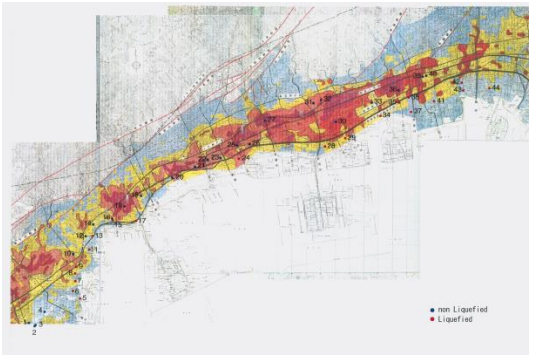
No.	14		kt03012								
ACC=	500		non-liquefied		△				STDEV of corrected N		2.70
W.T=	3.1								Average of corrected N		19.85
	tf/m3	tf/m2	tf/m2								
DEPTH(m)	Density	SV	SVD	Nvalue	C_n	C_s	C_a	C_r	C_h	Corrected N	F.C.	Soil quality
4.3	1.77	7.77	6.57	17	0.85	1	1	1.22	1.23	21.76	0.07	
5.3	1.72	9.72	7.52	15	0.85	1	1	1.22	1.15	17.94	0.30	



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
2.3	7.5	NA	12.0	1.53	0.89	22.3		SAND
3.3	***10.8***	***0.327***	***16.0***	***1.29***	***0.91***	***25.7***		***SAND***
4.3	***14.1***	***0.364***	***17.0***	***1.19***	***0.93***	***25.7***	***7.0***	***SAND (based on approximate translation)***
5.3	***17.4***	***0.387***	***15.0***	***1.11***	***0.94***	***21.4***	***30.0***	***SAND (based on approximate translation)***
6.3	20.7	0.400	11.0	1.04	0.95	14.9		N/A, could not translate description
7.3	24.0	0.405	6.0	0.99	0.96	7.8		N/A, could not translate description
8.3	27.2	0.403	6.0	0.94	0.97	7.5		SAND with SILT
9.3	30.5	0.397	9.0	0.90	0.97	10.8		SAND with SILT
					Mean:	24.3	18.5	
					St. Dev.	2.5	16.3	

Case number:	173
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 15
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefied
GPS LAT	34.686313 Coordiantes were taken from NGL
GPS LONG	135.189653
Liq. layer consist of:	Coarse SAND with GRAVEL
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is upated based on Vs-SPTN correlations
	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	Coarse SAND with GRAVEL (content unkown)
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	A	-	B	B
d_{crtc} range (m)	-	4.7 - 6.9	-	4.7 - 6.9	4.0 - 7.2
d_{crt} (m)	-	5.8	5.7	5.8	5.6
GWT (m)	-	3.7 ± 0.3	3.7	3.7 ± 0.1	3.7 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	92.6 ± 6.8	102.3	99.3 ± 7.7	97.7 ± 11.2
σ_v' (kPa)	-	71.7 ± 4.6	82.2	78.4 ± 4.2	78.5 ± 6.1
a_{max} (g)	-	0.500 ± 0.075	0.5	0.500 ± 0.100	0.500 ± 0.100
r_d	-	0.76 ± 0.079	0.93	0.86 ± 0.079	0.94 ± 0.077
CSR	-	0.320 ± 0.061	0.375	0.356 ± 0.079	0.378 ± 0.083
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	5.0 ± 2.0	5	4.7 ± 4.5	4.7 ± 4.5
% PI	-	-	-	-	NAV
N	-	15.0 ± 3.3	15.1	15.0 ± 3.1	14.9 ± 2.6
C_R	-	0.94	0.95	0.94	0.94
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.16	1.10	1.14	1.14
$(N_1)_{60}$	-	19.9 ± 4.4	19.2	19.6 ± 4.0	21.8 ± 3.8
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	158.5	-	170.7	196.6

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 0.6

Dip: 85 Width (km): 16 R_{jb} (km): 0.6

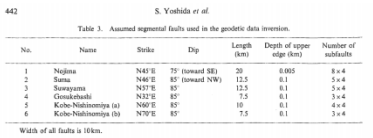
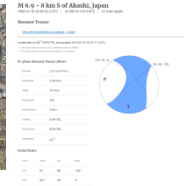

442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N43°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

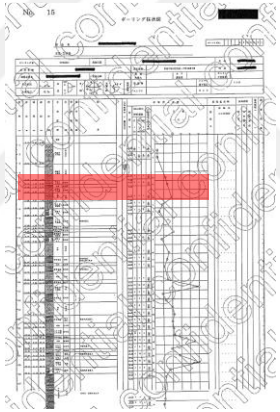
Width of all faults is 10 km.





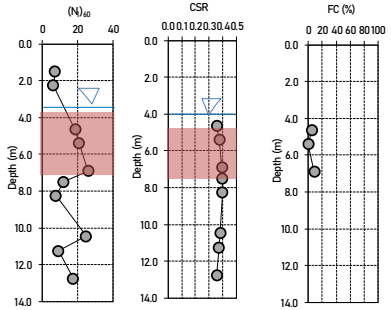
https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive





Personal Communication Prof. Tokimatsu (2000)

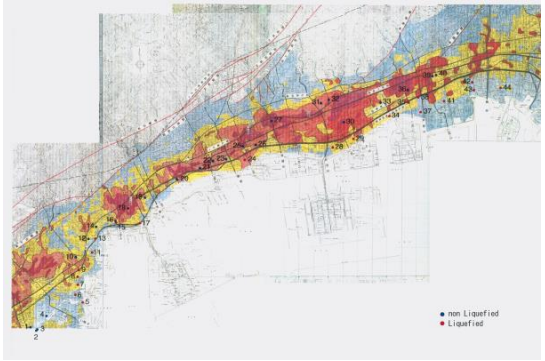
No.	15		kp8051									
ACC=	500		liquefied							STDEV of corrected N		4.20
W.T=	3.65									Average of corrected N		17.65
	tf/m3	tf/m2	tf/m2									
DEPTH(m)	Density	SV	SVD	Nvalue	C_R	C_S	C_B	C_E	C_N	Corrected N	F.C.	Soil quality
4.65		8.40	7.40	12	0.85	1	1	1.22	1.15	14.47	0.05	
5.4		9.81	8.16	14	0.85	1	1	1.22	1.11	16.08	0.00	
6.9		12.90	9.65	19	0.95	1	1	1.22	1.02	22.41	0.09	



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
1.5	4.9	NA	3.0	2.00	0.87	7.1		SAND with GRAVEL
2.3	7.4	NA	3.0	1.69	0.89	6.2		SAND with GRAVEL
4.7	***15.3***	***0.355***	***12.0***	***1.22***	***0.93***	***18.6***	***5.0***	Coarse SAND with GRAVEL
5.4	***17.7***	***0.374***	***14.0***	***1.15***	***0.94***	***20.8***	***0.0***	-
6.9	***22.6***	***0.395***	***19.0***	***1.05***	***0.96***	***26.0***	***9.0***	-
7.5	24.6	0.397	9.0	1.01	0.96	12.0		Silty SAND
8.3	27.1	0.398	6.0	0.97	0.97	7.7		Sandy CLAY
10.5	34.3	0.382	21.0	0.88	0.98	24.8		-
11.3	36.9	0.373	8.0	0.85	0.98	9.2		silt
12.8	41.8	0.356	16.0	0.81	0.99	17.4		Medium SAND
					Mean:	21.8	4.7	
					St. Dev.	3.8	4.5	

Case number:	174
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 16
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Nonliquefied
GPS LAT	34.687017 Coordiantes were taken from NGL
GPS LONG	135.189373
Liq. layer consist of:	Medium SAND
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is upated based on Vs-SPTN correlations
	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	NAV
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	No/Yes	No	No	No
Data Class	-	A	-	B	B
d_{crtc} range (m)	-	4.0 - 5.0	-	4.0 - 5.0	3.7 - 5.5
d_{crt} (m)	-	4.5	4.5	4.5	4.6
GWT (m)	-	2.5 ± 0.3	2.5	2.5 ± 0.1	2.5 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	17.3 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	72.5 ± 3.4	80.2	82.8 ± 3.6	90.1 ± 6.5
σ_v' (kPa)	-	52.3 ± 3.6	60.2	62.7 ± 2.3	69.3 ± 3.7
a_{max} (g)	-	0.600 ± 0.090	0.6	0.600 ± 0.120	0.600 ± 0.120
r_d	-	0.93 ± 0.064	0.95	0.95 ± 0.064	0.98 ± 0.065
CSR	-	0.500 ± 0.088	0.495	0.489 ± 0.104	0.499 ± 0.106
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	5.0 ± 1.0	5	5.0 ± 2.0	5.0 ± 8.6
% PI	-	-	-	-	NAV
N	-	17.5 ± 1.0	17.5	17.6 ± 1.2	17.7 ± 1.5
C_R	-	0.90	0.95	0.90	0.93
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.35	1.23	1.27	1.21
$(N_1)_{60}$	-	26.1 ± 1.5	25	24.6 ± 1.7	27.2 ± 2.3
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	192.0	-	192.0	227.1

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 0.5

Dip: 85 Width (km): 16 R_{jb} (km): 0.5

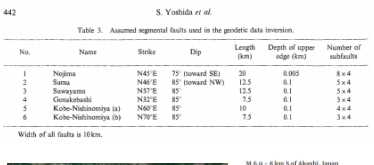

442 S. Yoshida *et al.*

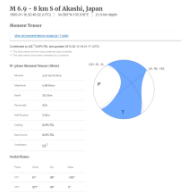
Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N41°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N37°E	85°	12.5	0.1	5 × 4
4	Gosakebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

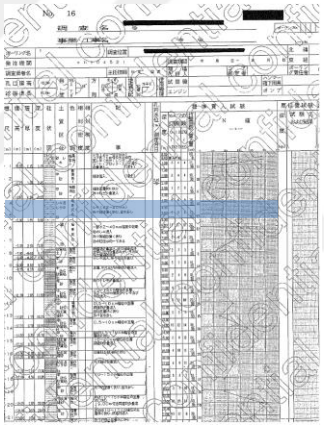
Width of all faults is 10km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



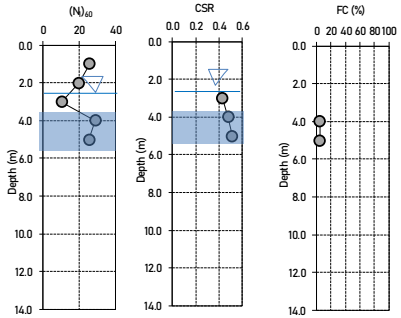

M 6.9 – 8 km S of Akashi, Japan





Personal Communication Prof. Tokimatsu (2000)

No.	16		ch104521									
ACC=	600		non-liquefied	△marginal					STDEV of corrected N			0.01
W.T=	2.45								Average of corrected N			21.82
	tf/m3	tf/m2	tf/m2									
DEPTH(m)	Density	SV	SVD	Nvalue	Ca	Cs	Cb	Cc	Cn	Corrected N	F.C.	Soil quality
A	1.85	7.244	5.694	16	0.75	1	1	1.22	1.38	21.83	0.06	レキ混り砂質土
B	1.64	9.084	6.534	17	0.85	1	1	1.22	1.24	21.81	0.05	レキ混り砂質土

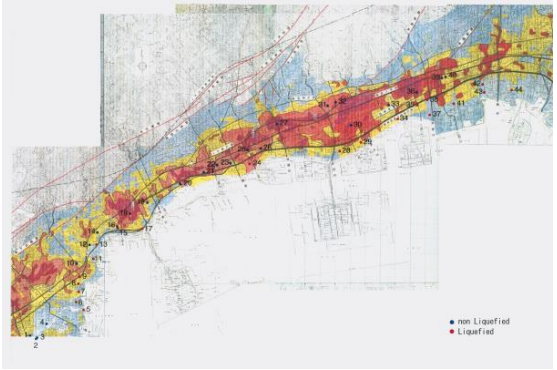


Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
1.0	3.3	NA	11.0	2.00	0.86	25.7		SAND
2.0	6.6	NA	10.0	1.64	0.88	19.8		Medium SAND
3.0	9.8	0.43	6.0	1.39	0.90	10.3		Medium SAND
4.0	***13.1***	***0.48***	***18.0***	***1.27***	***0.92***	***28.8***	***5.0***	Medium SAND
5.0	***16.4***	***0.51***	***17.0***	***1.17***	***0.94***	***25.5***	***5.0***	Medium SAND
					Mean:	27.2	5.0	
					St. Dev.	2.3	8.6	assigned

Case number:	175
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 17
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefied
GPS LAT	34.686117 Coordiantes were taken from NGL
GPS LONG	135.198788
Liq. layer consist of:	Medium SAND with GRAVEL
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	

https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	Medium SAND with GRAVEL (content unknown)
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?		Yes	Yes	Yes	Yes
Data Class		A	-	B	B
d_{crtc} range (m)		3.0 - 6.0		3.0 - 6.0	2.6 - 6.5
d_{crt} (m)		4.5	4.5	4.5	4.6
GWT (m)		0.8 ± 0.3	0.8	0.8 ± 0.1	0.8 ± 0.1
γ_{moist} (kN/m^3)		15.7 ± 0.6	-	17.3 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)		16.5 ± 0.6	-	18.9 ± 0.5	20.6 ± 0.5
σ_v (kPa)		73.8 ± 8.6	80.2	83.9 ± 9.6	92.6 ± 13.5
σ_v' (kPa)		37.0 ± 5.0	43.1	47.0 ± 4.9	55.2 ± 7.3
a_{max} (g)		0.500 ± 0.075	0.5	0.500 ± 0.100	0.500 ± 0.100
r_d		0.93 ± 0.064	0.95	0.95 ± 0.064	0.92 ± 0.065
CSR		0.602 ± 0.112	0.574	0.551 ± 0.117	0.499 ± 0.107
M_w		6.90	6.90	6.90	6.90
D_{50}		-	-	-	-
% Fines		5.0 ± 1.0	5	5.0 ± 2.0	5.0 ± 8.6
% PI		-	-	-	0
N		13.1 ± 4.5	12.6	13.1 ± 4.4	13.1 ± 4.2
C_R		0.90	0.95	0.90	0.93
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.22	1.22	1.22	1.37
C_N		1.61	1.45	1.47	1.36
$(N_1)_{60}$		23.2 ± 7.9	21.1	21.2 ± 7.1	22.6 ± 7.2
V_{s30m} (m/s)		-	-	-	NAV
V_{s12m} (m/s)		192.0	-	192.0	173.7

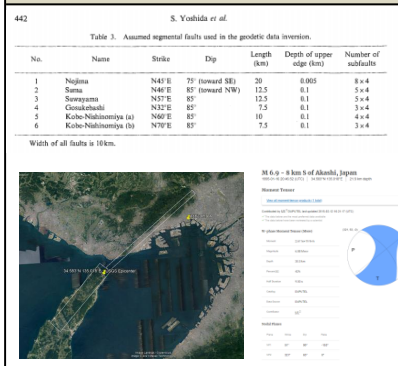
EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 1.0

Dip: 85 Width (km): 16 R_{jb} (km): 1.0



442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

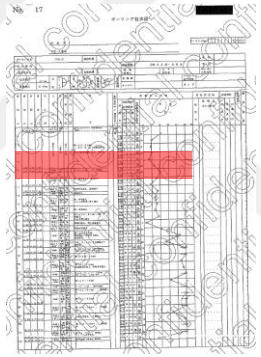
No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 x 4
2	Sarua	N46°E	85° (toward NW)	12.5	0.1	5 x 4
3	Suwayamis	N57°E	85°	12.5	0.1	5 x 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 x 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 x 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 x 4

Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive

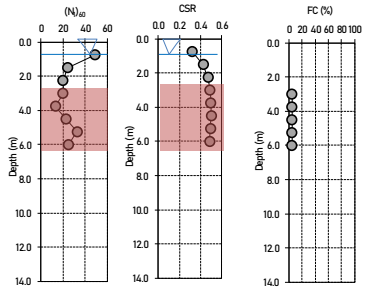






Personal Communication Prof. Tokimatsu (2000)

No.	17		7524							STDEV of corrected N	7.34
ACC=	500		liquefied							Average of corrected N	19.29
W.T=	0.75										
	tf/m3	tf/m2	tf/m2								
DEPTH(m)	密度	SV	SVD	Nvalue	C_R	C_S	C_B	C_E	C_R	Corrected N	F.C.	土質
0.5	1.79	5.43	3.18	10	0.85	1	1	1.22	1.77	14.08	0.05	礫混じり中砂
0.75	1.75	6.743	3.743	7	0.75	1	1	1.22	1.63	10.47	0.05	礫混じり中砂
1.5	1.81	9.01	4.38	13	0.85	1	1	1.22	1.52	20.44	0.05	礫混じり中砂
2.25	1.86	9.495	4.995	20	0.85	1	1	1.22	1.41	29.55	0.05	礫混じり中砂
3	1.83	10.868	5.617	16	0.85	1	1	1.22	1.33	22.14	0.05	礫混じり中砂

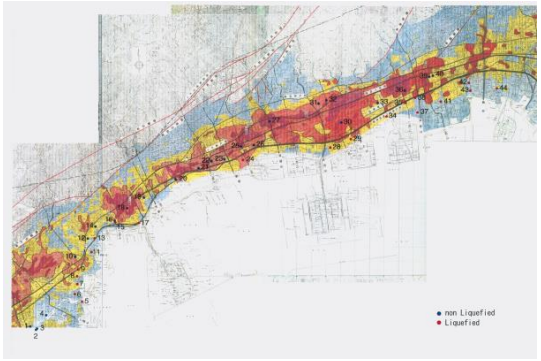


Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
0.8	2.5	0.322	21.0	2.00	0.85	48.7		Medium SAND with GRAVEL
1.5	4.9	0.425	10.0	2.00	0.87	23.8		Medium SAND with GRAVEL
2.3	7.4	0.468	9.0	1.83	0.89	20.0		Medium SAND with GRAVEL
3.0	***9.8***	***0.489***	***10.0***	***1.62***	***0.90***	***20.1***	***5.0***	Medium SAND with GRAVEL
3.8	***12.3***	***0.498***	***7.0***	***1.48***	***0.92***	***13.0***	***5.0***	Medium SAND with GRAVEL
4.5	***14.8***	***0.499***	***13.0***	***1.36***	***0.93***	***22.5***	***5.0***	Medium SAND with GRAVEL
5.3	***17.2***	***0.495***	***20.0***	***1.27***	***0.94***	***32.7***	***5.0***	Medium SAND with GRAVEL
6.0	***19.7***	***0.486***	***16.0***	***1.20***	***0.95***	***24.8***	***5.0***	Medium SAND with GRAVEL
					Mean:	22.6	5.0	
					St. Dev.	7.2	8.6	assigned

Case number:	176
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 18
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Nonliquefied
GPS LAT	34.690939 Coordiantes were taken from NGL
GPS LONG	135.194228
Liq. layer consist of:	Coarse SAND
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	

https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	NAV
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?		No	No	No	No
Data Class		B	-	B	B
d_{crtc} range (m)		9.0 - 12.0		9.0 - 12.0	8.8 - 12.7
d_{crt} (m)		10.5	10.5	10.5	10.8
GWT (m)		7.7 ± 0.3	7.7	7.7 ± 0.1	7.7 ± 0.1
γ_{moist} (kN/m^3)		17.3 ± 0.6	-	19.6 ± 0.5	20.0 ± 0.5
γ_{sat} (kN/m^3)		18.1 ± 0.6	-	21.2 ± 0.5	21.5 ± 0.5
σ_v (kPa)		184.1 ± 10.4	199.5	211.2 ± 11.3	219.9 ± 14.6
σ_v' (kPa)		156.1 ± 7.2	171.4	183.2 ± 6.9	189.4 ± 8.6
a_{max} (g)		0.700 ± 0.105	0.7	0.700 ± 0.140	0.700 ± 0.140
r_d		0.62 ± 0.131	0.85	0.94 ± 0.131	0.90 ± 0.134
CSR		0.333 ± 0.087	0.448	0.493 ± 0.121	0.473 ± 0.119
M_w		6.90	6.90	6.90	6.90
D_{50}		-	-	-	-
% Fines		0.0 ± 0.0	0	0.0 ± 2.0	0.0 ± 8.6
% PI		-	-	-	0
N		40.5 ± 4.3	40.5	40.5 ± 4.2	40.8 ± 4.3
C_R		1.00	1.00	1.00	0.98
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.22	1.22	1.22	1.37
C_N		0.78	0.86	0.74	0.73
$(N_1)_{60}$		38.6 ± 4.1	42.6	36.7 ± 3.8	40.0 ± 4.2
V_{s30m} (m/s)		-	-	-	NAV
V_{s12m} (m/s)		192.0	-	251.5	234.7

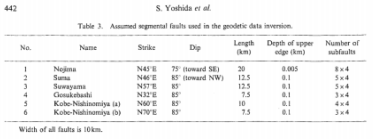
EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 0.4

Dip: 85 Width (km): 16 R_{jb} (km): 0.4



442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

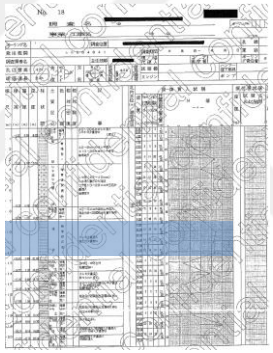
Width of all faults is 10km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



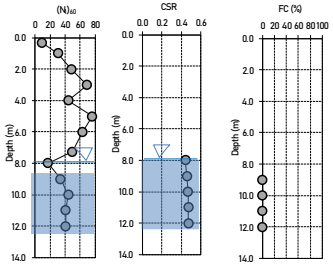






Personal Communication Prof. Tokimatsu (2000)

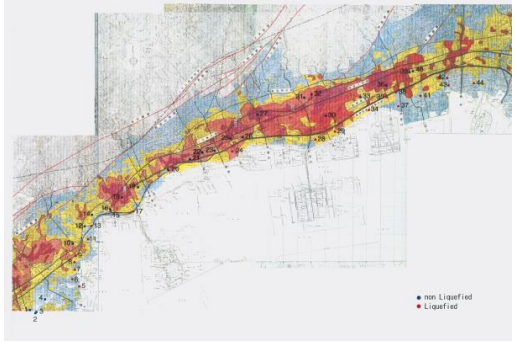
No.	18		ch084841								
ACC=	700		non-liquefied							STDEV of corrected N	4.18
W.T=	7.65									Average of corrected N	38.48
	tf/m3	tf/m2	tf/m2								
DEPTH(m)	Density	ISV	SVD	Nvalue	C_R	C_1	C_B	C_E	C_N	Corrected N	F.C.	Soil quality
8	1.93	17.334	15.844	33	0.95	1	1	1.22	0.79	30.25	0.00	粗砂
9	1.98	19.314	16.844	44	0.95	1	1	1.22	0.77	33.18	0.00	粗砂
10	1.93	21.244	17.854	42	0.95	1	1	1.22	0.75	31.21	0.00	粗砂
11	1.98	23.214	18.854	43	1.00	1	1	1.22	0.74	31.21	0.00	粗砂



Depth (m)	Depth (ft)	CSR	N	C_N	C_B	$(N1)_{60}$	FC	
0.3	1.0	NA	4.0	2.00	0.83	9.1		Coarse SAND with gravel
1.0	3.3	NA	13.0	2.00	0.86	30.4		Coarse SAND
2.0	6.6	NA	25.0	1.59	0.88	48.0		Coarse SAND
3.0	9.8	NA	43.0	1.30	0.90	69.2		Coarse SAND
4.0	13.1	NA	31.0	1.13	0.92	44.0		Coarse SAND with gravel
5.0	16.4	NA	59.0	1.01	0.94	76.1		Coarse SAND with gravel
6.0	19.7	NA	53.0	0.92	0.95	63.2		Coarse SAND with gravel
7.3	23.8	NA	45.0	0.84	0.96	49.4		Coarse SAND with gravel
8.0	26.2	0.443	16.0	0.80	0.97	17.0		Coarse SAND with clay
9.0	***29.5***	***0.459***	***33.0***	***0.78***	***0.97***	***34.0***	***0.0***	Coarse SAND
10.0	***32.8***	***0.469***	***44.0***	***0.75***	***0.98***	***44.1***	***0.0***	Coarse SAND
11.0	***36.1***	***0.474***	***42.0***	***0.73***	***0.98***	***40.9***	***0.0***	Coarse SAND
12.0	***39.4***	***0.473***	***43.0***	***0.71***	***0.99***	***40.8***	***0.0***	Coarse SAND
					Mean:	40.0	0.0	
					St. Dev.	4.2	8.6	

Case number:	177
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 19
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Nonliquefied
GPS LAT	34.694077 Coordiantes were taken from NGL
GPS LONG	135.200514
Liq. layer consist of:	Fine SAND with cobbles
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	cobbles
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?		No	No	No	No
Data Class		B	-	B	B
d_{stc} range (m)		7.0 - 8.0		7.0 - 8.0	6.5 - 8.9
d_{crt} (m)		7.5	7.5	7.5	7.7
GWT (m)		6.1 ± 0.3	6.1	6.1 ± 0.1	6.1 ± 0.1
γ_{moist} (kN/m^3)		16.5 ± 0.6	-	18.9 ± 0.5	20.0 ± 0.5
γ_{sat} (kN/m^3)		18.1 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)		126.2 ± 5.0	137.3	142.8 ± 4.4	154.5 ± 8.6
σ_v' (kPa)		112.5 ± 4.9	124.3	129.1 ± 3.5	139.0 ± 5.2
a_{max} (g)		0.600 ± 0.090	0.6	0.600 ± 0.120	0.600 ± 0.120
r_d		0.86 ± 0.099	0.9	0.95 ± 0.099	0.96 ± 0.101
CSR		0.377 ± 0.072	0.391	0.411 ± 0.093	0.416 ± 0.094
M_w		6.90	6.90	6.90	6.90
D_{50}		0.000 ± 0.000	-	0.000 ± 0.000	-
% Fines		10.0 ± 1.0	10	10.0 ± 2.0	10.0 ± 8.6
% PI		-	-	-	NAV
N		19.5 ± 0.9	20	19.5 ± 0.9	19.6 ± 1.2
C_R		0.99	0.95	0.99	0.96
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.22	1.22	1.22	1.37
C_N		0.92	0.92	0.89	0.85
$(N_1)_{60}$		21.7 ± 1.0	21.3	20.8 ± 1.0	22.1 ± 1.3
V_{s30m} (m/s)		-	-	-	NAV
V_{s12m} (m/s)		207.3	-	228.6	234.7

EVENT PARAMETERS

1995 Hyogoken-Nambu
Magnitude: 6.90 Yoshida et al. (1996)
Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 0.5
Dip: 85 Width (km): 16 R_{jb} (km): 0.5

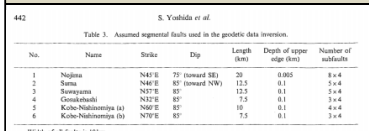
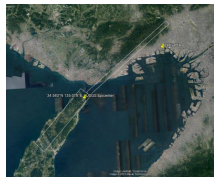

442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N37°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

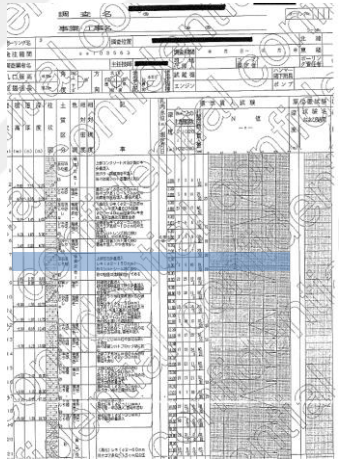
Width of all faults is 10 km.





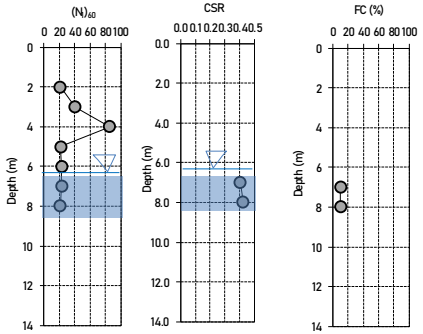
https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive





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No.	19		sa103563								
ACC=	600		non-liquefied	地下水位深い					STDEV of corrected N		1.22
W.T=	6.1								Average of corrected N		20.16
	tf/m3	tf/m2	tf/m2								
DEPTH(m)	Density	SV	SVD	Nvalue	C_R	C_S	C_B	C_E	C_N	Corrected N	F.C.	Soil quality
7	1.87	13.06	12.16	20	0.85	1	1	1.22	0.91	21.02	0.10	玉石混じり細　砂
8	1.88	14.92	13.02	19	0.95	1	1	1.22	0.88	19.30	0.10	玉石混じり細　砂

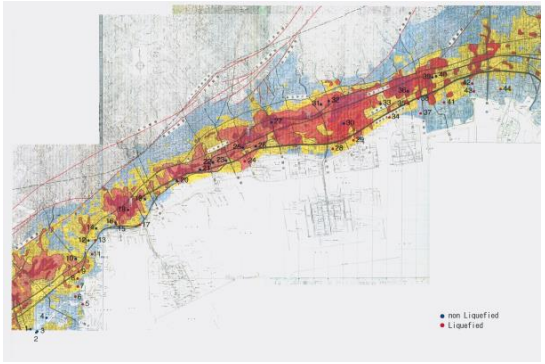


Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
2	6.6	NA	11	1.59	0.88	21.1		Fine SAND with cobbles
3	9.8	NA	25	1.30	0.90	40.2		Medium SAND
4	13.1	NA	60	1.13	0.92	85.2		SAND with cobbles
5	16.4	NA	17	1.01	0.94	21.9		Medium SAND
6	19.7	NA	19	0.92	0.95	22.7		Fine SAND with SILT
7.0	***23.0***	***0.402***	***20***	***0.88***	***0.96***	***23.0***	***10.0***	Fine SAND with cobbles
8.0	***26.2***	***0.421***	***19***	***0.84***	***0.97***	***21.2***	***10.0***	Fine SAND with cobbles
					Mean:	22.1	10.0	
					St. Dev.	1.3	8.6	assigned

Case number:	178
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 20
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Nonliquefied
GPS LAT	34.699984 Coordiantes were taken from NGL
GPS LONG	135.212469
Liq. layer consist of:	Coarse SAND with GRAVEL
Geological Unit:	Late Pleistocene lower terrace
Site Response Anlaysis:	No
Comments:	

https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	Coarse SAND with GRAVEL (content unkown)
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?		No	No	No	No
Data Class		B	-	B	B
d_{crtc} range (m)		4.0 - 8.0		4.0 - 8.0	3.6 - 8.7
d_{crt} (m)		6.0	6.0	6.0	6.2
GWT (m)		2.0 ± 0.3	2	2.0 ± 0.1	2.0 ± 0.1
γ_{moist} (kN/m^3)		16.5 ± 0.6	-	17.3 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)		18.1 ± 0.6	-	21.2 ± 0.5	21.5 ± 0.5
σ_v (kPa)		105.5 ± 12.4	114.3	119.7 ± 14.3	127.3 ± 18.5
σ_v' (kPa)		66.2 ± 6.7	75.2	80.4 ± 7.9	86.5 ± 10.2
a_{max} (g)		0.550 ± 0.090	0.55	0.550 ± 0.110	0.550 ± 0.110
r_d		0.93 ± 0.082	0.93	0.99 ± 0.082	0.99 ± 0.083
CSR		0.529 ± 0.102	0.505	0.530 ± 0.115	0.523 ± 0.115
M_w		6.90	6.90	6.90	6.90
D_{50}		0.000 ± 0.000	-	0.000 ± 0.000	-
% Fines		0.0 ± 0.0	0	0.0 ± 2.0	0.0 ± 8.6
% PI		-	-	-	0
N		46.2 ± 1.4	50.8	50.4 ± 3.5	51.0 ± 4.8
C_R		0.95	0.95	0.95	0.95
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.22	1.22	1.22	1.37
C_N		1.20	1.08	1.12	1.08
$(N_1)_{60}$		64.3 ± 2.0	63.7	65.5 ± 4.5	71.7 ± 6.8
$V_{s,30m}$ (m/s)		-	-	-	NAV
$V_{s,12m}$ (m/s)		213.4	-	274.3	274.3

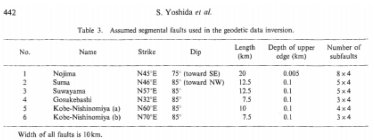
EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 0.7

Dip: 85 Width (km): 16 R_{jb} (km): 0.7



442 S. Yoshida *et al.*

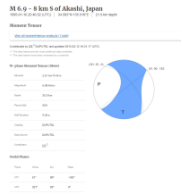
Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N41°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N37°E	85°	12.5	0.1	5 × 4
4	Gosakebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

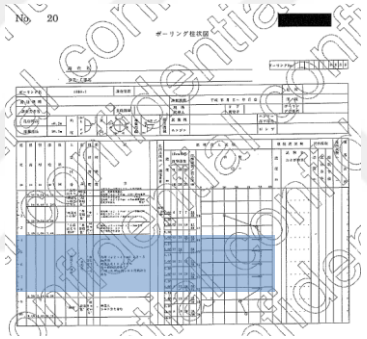
Width of all faults is 10km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



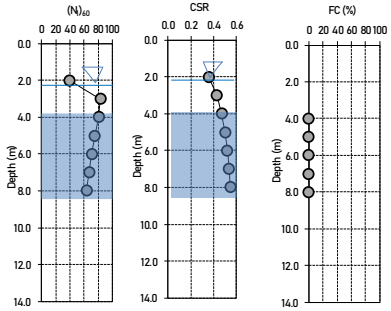






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No.	20		6888							STDEV of corrected N		1.91
ACC=	550		non--liquefied							Average of corrected N		60.94
W.T=	2											
	tf/m3	tf/m2	tf/m2									
DEPTH(m)	密度	SV	SVD	Nvalue	C_R	C_S	C_B	C_E	C_N	Corrected N	F.C.	土質
4	1.98	7.7	5.7	50	0.75	1	1	1.22	1.32	60.60	0	標準しり粗砂
5	1.98	9.68	6.68	50	0.85	1	1	1.22	1.22	63.44	0	標準しり粗砂
6	1.98	11.66	7.66	50	0.85	1	1	1.22	1.14	59.24	0	標準しり粗砂
7	1.98	13.64	8.64	50	0.95	1	1	1.22	1.08	62.34	0	標準しり粗砂
8	1.98	15.62	9.62	50	0.95	1	1	1.22	1.02	59.08	0	標準しり粗砂

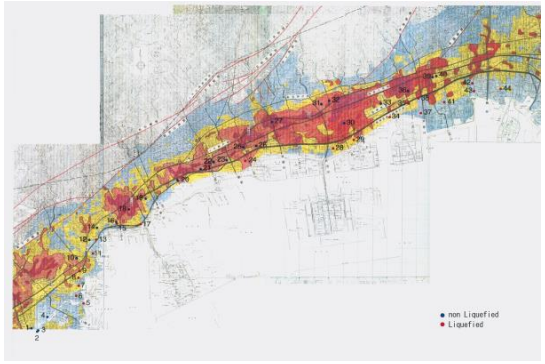


Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
2.0	6.6	0.357	20.0	1.64	0.88	39.5		Medium SAND with GRAVEL
3.0	9.8	0.428	47.0	1.43	0.90	83.2		Coarse SAND (based on approximate translation)
4.0	***13.1***	***0.471***	***50.0***	***1.29***	***0.92***	***81.1***	***0.0***	***Coarse SAND with GRAVEL***
5.0	***16.4***	***0.500***	***50.0***	***1.18***	***0.94***	***75.5***	***0.0***	***Coarse SAND with GRAVEL***
6.0	***19.7***	***0.521***	***50.0***	***1.09***	***0.95***	***70.9***	***0.0***	***Coarse SAND with GRAVEL***
7.0	***23.0***	***0.536***	***50.0***	***1.03***	***0.96***	***67.2***	***0.0***	***Coarse SAND with GRAVEL***
8.0	***26.2***	***0.546***	***50.0***	***0.97***	***0.97***	***63.9***	***0.0***	***Coarse SAND with GRAVEL***
					Mean:	71.7	0.0	
					St. Dev.	6.8	8.6	***assigned***

Case number:	179
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 21
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Nonliquefied
GPS LAT	34.703468 Coordiantes were taken from NGL
GPS LONG	135.221196
Liq. layer consist of:	Coarse SAND
Geological Unit:	Late Pleistocene lower terrace
Site Response Anlaysis:	No
Comments:	

https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	NAV
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?		No	No	No	No
Data Class		B	-	B	B
d_{crtc} range (m)		3.0 - 4.0		3.0 - 4.0	2.7 - 4.5
d_{crt} (m)		3.5	3.5	3.5	3.6
GWT (m)		1.7 ± 0.3	1.7	1.7 ± 0.1	1.7 ± 0.1
γ_{moist} (kN/m^3)		16.5 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)		18.1 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)		60.8 ± 3.4	62.2	62.4 ± 3.5	65.2 ± 6.3
σ_v' (kPa)		42.6 ± 3.3	44.1	44.2 ± 2.1	46.5 ± 3.5
a_{max} (g)		0.600 ± 0.090	0.6	0.600 ± 0.120	0.600 ± 0.120
r_d		0.96 ± 0.052	0.97	0.99 ± 0.052	0.99 ± 0.052
CSR		0.533 ± 0.093	0.531	0.545 ± 0.114	0.541 ± 0.113
M_w		6.90	6.90	6.90	6.90
D_{50}		0.000 ± 0.000	-	0.000 ± 0.000	-
% Fines		0.0 ± 0.0	0	0.0 ± 2.0	0.0 ± 8.6
% PI		-	-	-	0
N		23.0 ± 2.0	24.4	23.0 ± 1.8	23.1 ± 1.2
C_R		0.87	0.85	0.87	0.91
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.22	1.22	1.22	1.37
C_N		1.50	1.32	1.52	1.48
$(N_1)_{60}$		36.4 ± 3.2	33.5	36.8 ± 2.8	42.7 ± 2.3
$V_{s,30m}$ (m/s)		-	-	-	NAV
V_{s12m} (m/s)		198.1	-	231.6	231.6

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 0.8

Dip: 85 Width (km): 16 R_{jb} (km): 0.8

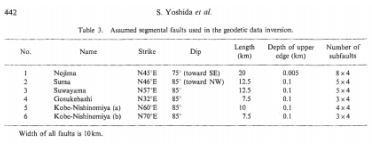

442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N43°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

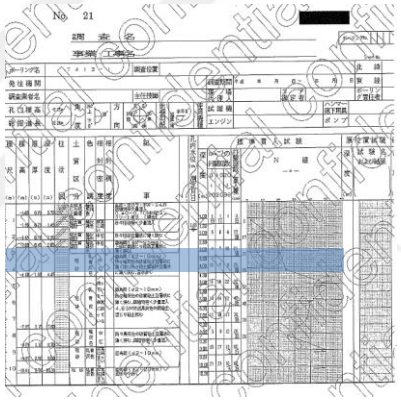
Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



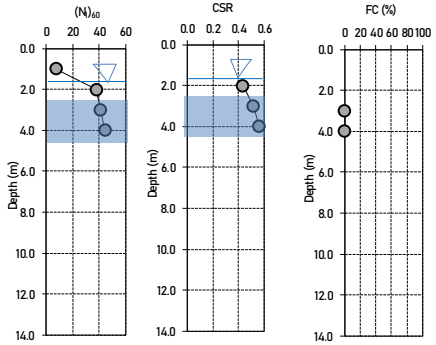






Personal Communication Prof. Tokimatsu (2000)

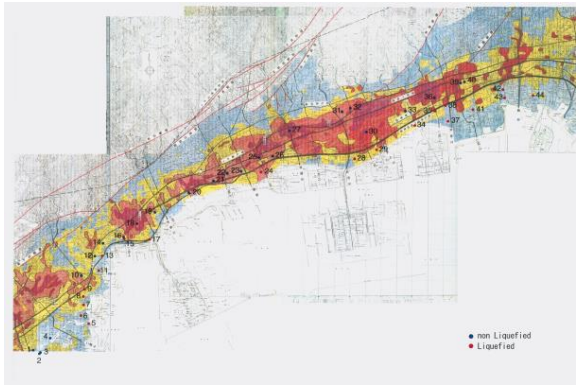
No.	21		7413							STDEV of corrected N		4.49
ACC=	600		non-liquefied							Average of corrected N		29.31
W.T=	1.65											
	tf/m3	tf/m2	tf/m2									
DEPTH(m)	Density	SV	SVD	Nvalue	C_R	C_S	C_B	C_E	C_N	Corrected N	F.C.	Soil quality
3	1.83	5.41	4.06	21	0.85	1	1	1.22	1.57	26.14	0.00	粗粒分
4	1.9	7.31	4.98	25	0.75	1	1	1.22	1.42	32.48	0.00	粗粒分



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
1.0	3.3	NA	3.0	2.00	0.86	7.0		Clayey fine SAND
2.0	6.6	0.433	17.0	1.85	0.88	37.9		Clayey fine SAND
3.0	***9.8***	***0.514***	***21.0***	***1.58***	***0.90***	***41.1***	***0.0***	Coarse SAND
4.0	***13.1***	***0.559***	***25.0***	***1.41***	***0.92***	***44.3***	***0.0***	Coarse SAND
					Mean:	42.7	0.0	
					St. Dev.	2.3	8.6	assigned

Case number:	180
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 22
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Nonliquefied
GPS LAT	34.705729 Coordinates were taken from NGL
GPS LONG	135.225869
Liq. layer consist of:	Sand and Gravel
Geological Unit:	Late Pleistocene lower terrace
Site Response Anlaysis:	No
Comments:	Vs12m is updated based on Vs-SPTN correlations.
	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	Sand and gravel (content unknown)
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	4.0 - 8.0	-	4.0 - 8.0	3.5 - 8.5
d_{crt} (m)	-	6.0	6.0	6.0	6.0
GWT (m)	-	2.4 ± 0.3	2.4	2.4 ± 0.1	2.4 ± 0.1
γ_{moist} (kN/m^3)	-	16.5 ± 0.6	-	18.9 ± 0.5	20.0 ± 0.5
γ_{sat} (kN/m^3)	-	18.1 ± 0.6	-	19.6 ± 0.5	21.5 ± 0.5
σ_v (kPa)	-	104.9 ± 12.4	114.3	116.2 ± 13.3	125.7 ± 18.1
σ_v' (kPa)	-	69.5 ± 6.7	79.2	80.8 ± 6.9	90.3 ± 10.0
a_{max} (g)	-	0.600 ± 0.090	0.6	0.600 ± 0.120	0.600 ± 0.120
r_d	-	0.86 ± 0.082	0.93	0.96 ± 0.082	1.00 ± 0.082
CSR	-	0.509 ± 0.095	0.524	0.539 ± 0.119	0.541 ± 0.119
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	6.0 ± 2.0	6	6.0 ± 5.5	6.0 ± 5.5
% PI	-	-	-	-	NAV
N	-	32.5 ± 9.7	30.8	30.0 ± 9.0	30.3 ± 9.6
C_R	-	0.88	0.95	0.95	0.95
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.18	1.08	1.12	1.06
$(N_1)_{60}$	-	40.8 ± 12.2	38.6	38.9 ± 11.7	41.6 ± 13.2
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	189.0	-	219.5	283.5

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 0.9

Dip: 85 Width (km): 16 R_{jb} (km): 0.9

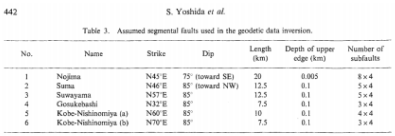

442 S. Yoshida *et al.*

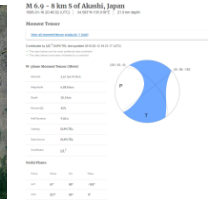
Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gionakebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

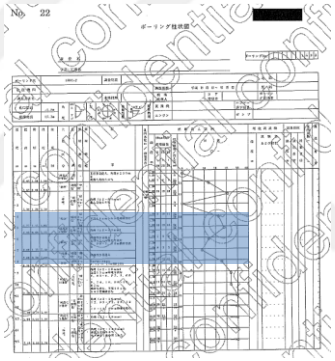
Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



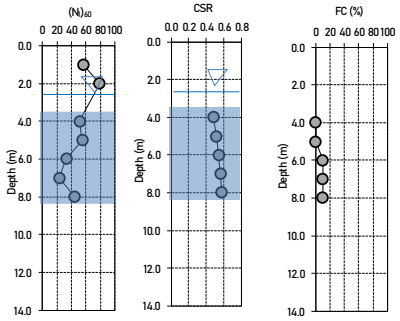






Personal Communication Prof. Tokimatsu (2000)

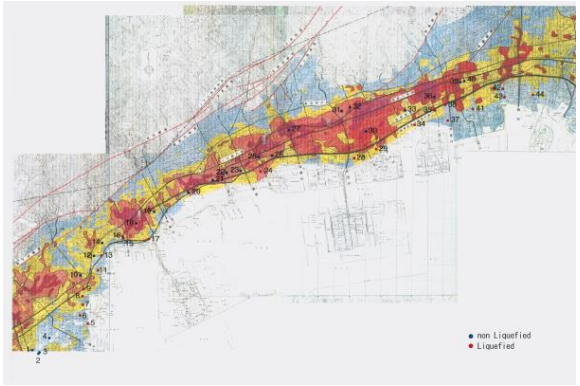
No.	22		1693						STDEV of corrected N	10.17
ACC=	600		non-liquefied						Average of corrected N	35.38
W.T=	2.4									
	tf/m3	tf/m2	tf/m2							
DEPTH(m)	密度	SV	SVD	Nvalue	C_N	C_S	C_D	C_E	C_W	Corrected N	F.C.	土質
4	1.93	7.804	5.204	33	0.75	1	1	1.22	1.27	38.34	0	細砂
5	1.95	9.754	7.154	38	0.85	1	1	1.22	1.18	46.59	0	中詰め細砂
6	1.89	11.644	8.044	24	0.85	1	1	1.22	1.11	27.05	0.1	細砂
7	1.85	13.494	8.894	18	0.95	1	1	1.22	1.06	22.12	0.1	細砂
8	1.93	15.424	9.824	36	0.95	1	1	1.22	1.01	42.10	0.1	細砂



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
1.0	3.3	NA	24.0	2.00	0.86	56.1		-
2.0	6.6	NA	41.0	1.59	0.88	78.8		sand and gravel
4.0	***13.1***	***0.481***	***33.0***	***1.23***	***0.92***	***51.3***	***0.0***	sand
5.0	***16.4***	***0.516***	***38.0***	***1.14***	***0.94***	***55.3***	***0.0***	-
6.0	***19.7***	***0.541***	***24.0***	***1.06***	***0.95***	***33.0***	***10.0***	-
7.0	***23.0***	***0.560***	***18.0***	***1.00***	***0.96***	***23.5***	***10.0***	-
8.0	***26.2***	***0.574***	***36.0***	***0.94***	***0.97***	***44.9***	***10.0***	sand and gravel
					Mean:	41.6	6.0	
					St. Dev.	13.2	5.5	

Case number:	181
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 23
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Nonliquefied
GPS LAT	34.706225 Coordinates were taken from NGL
GPS LONG	135.231018
Liq. layer consist of:	Sand and Gravel
Geological Unit:	Late Pleistocene lower terrace
Site Response Anlaysis:	No
Comments:	Vs12m is updated based on Vs-SPTN correlations. https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	Gravel content unkown
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	No	No	No	No
Data Class	-	A	-	B	B
$d_{crt.}$ range (m)	-	4.0 - 6.0	-	4.0 - 6.0	3.8 - 6.4
d_{crt} (m)	-	5.0	5.0	5.0	5.1
GWT (m)	-	3.0 ± 0.3	3	3.0 ± 0.1	3.0 ± 0.1
γ_{moist} (kN/m^3)	-	16.5 ± 0.6	-	18.9 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	18.1 ± 0.6	-	19.6 ± 0.5	21.5 ± 0.5
σ_v (kPa)	-	85.8 ± 6.5	92.2	96.1 ± 6.8	97.3 ± 9.5
σ_v' (kPa)	-	66.2 ± 4.4	72.2	76.4 ± 3.8	76.6 ± 5.4
a_{max} (g)	-	0.600 ± 0.090	0.6	0.600 ± 0.120	0.600 ± 0.120
r_d	-	0.89 ± 0.070	0.94	0.97 ± 0.070	1.00 ± 0.071
CSR	-	0.449 ± 0.080	0.468	0.477 ± 0.102	0.494 ± 0.106
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	8.0 ± 2.0	10	10.0 ± 2.0	10.0 ± 8.6
% PI	-	-	-	-	NAV
N	-	18.0 ± 0.7	18.1	18.0 ± 0.8	18.2 ± 1.6
C_R	-	0.92	0.95	0.92	0.94
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.20	1.15	1.15	1.15
$(N_1)_{60}$	-	24.3 ± 1.0	24	23.3 ± 1.0	26.9 ± 2.4
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	182.9	-	219.5	280.4

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 1.2

Dip: 85 Width (km): 16 R_{jb} (km): 1.2

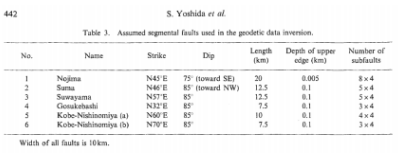

442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

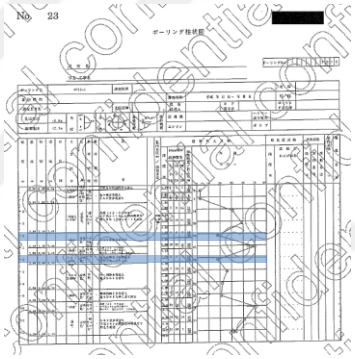
Width of all faults is 10km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



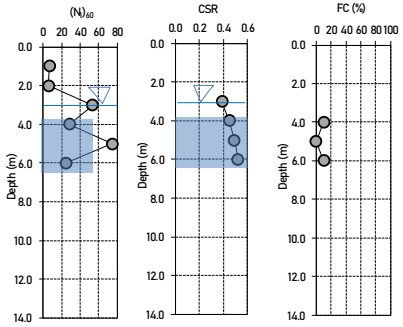






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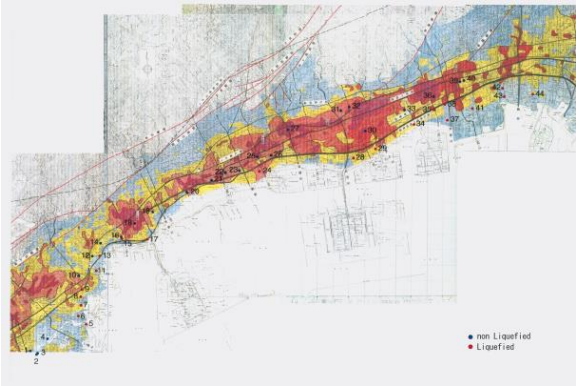
No.	23		4012									
ACC=	600		non-liquefied						STDEV of corrected N			0.01
W.T=	3								Average of corrected N			20.56
	tf/m3	tf/m2	tf/m2									
DEPTH(m)	密度	SV	SVD	Nvalue	C_R	C_S	C_B	C_E	C_N	Corrected N	F.C.	土質
4	1.86	7.41	6.41	18	0.75	1	1	1.22	1.25	20.57	0.1	細砂
5	1.98	9.39	7.39	50	0.85	1	1	1.22	1.16	60.32	0	砂礫
6	1.86	11.25	8.25	18	0.85	1	1	1.22	1.10	20.55	0.1	砂質シルト(互層)細砂



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
1.0	3.3	NA	3.0	2.00	0.86	7.0		sand and gravel
2.0	6.6	NA	3.0	1.71	0.88	6.2		medium sand w gravel
3.0	9.8	0.390	31.0	1.40	0.90	53.6		medium sand w gravel
4.0	***13.1***	***0.449***	***18.0***	***1.26***	***0.92***	***28.6***	***10.0***	sand and gravel
5.0	16.4	0.490	50.0	1.16	0.94	74.3	0.0	-
6.0	***19.7***	***0.520***	***18.0***	***1.08***	***0.95***	***25.2***	***10.0***	-
					Mean:	26.9	10.0	
					St. Dev.	2.4	8.6	assigend

Case number:	182
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 24
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Nonliquefied
GPS LAT	34.706029 Coordiantes were taken from NGL
GPS LONG	135.237908
Liq. layer consist of:	Coarse SAND
Geological Unit:	Late Pleistocene lower terrace
Site Response Anlaysis:	No
Comments:	Vs12m is updated based on Vs-SPTN correlations. https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	NAV
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	3.0 - 4.0	-	3.0 - 4.0	2.4 - 4.5
d_{crt} (m)	-	3.5	3.5	3.5	3.4
GWT (m)	-	2.4 ± 0.3	2.4	2.4 ± 0.1	2.4 ± 0.1
γ_{moist} (kN/m^3)	-	16.5 ± 0.6	-	18.1 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	18.1 ± 0.6	-	18.9 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	59.7 ± 3.5	63.2	64.3 ± 3.4	66.6 ± 7.5
σ_v' (kPa)	-	48.4 ± 3.3	51.1	53.0 ± 2.1	56.0 ± 4.1
a_{max} (g)	-	0.500 ± 0.075	0.5	0.500 ± 0.100	0.500 ± 0.100
r_d	-	0.96 ± 0.052	0.97	0.98 ± 0.052	1.00 ± 0.051
CSR	-	0.383 ± 0.066	0.383	0.388 ± 0.081	0.385 ± 0.081
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	0.0 ± 0.0	0	0.0 ± 2.0	0.0 ± 8.6
% PI	-	-	-	-	0
N	-	17.0 ± 0.9	18	17.0 ± 1.0	16.9 ± 0.5
C_R	-	0.87	0.85	0.87	0.91
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.41	1.32	1.38	1.35
$(N_1)_{60}$	-	25.3 ± 1.4	24.6	24.8 ± 1.4	28.4 ± 0.8
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	195.1	-	213.4	256.0

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 — Yoshida et al (1996)

Fault Type: strike-slip — Z_{tor} (km): 0 — R_{rup} (km): 1.6

Dip: 85 — Width (km): 16 — R_{jb} (km): 1.6

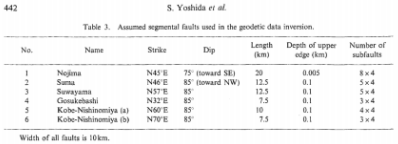

442 S. Yoshida et al.

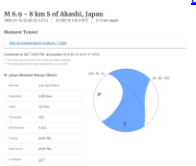
Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N53°E	85°	12.5	0.1	5 × 4
4	Gosakebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



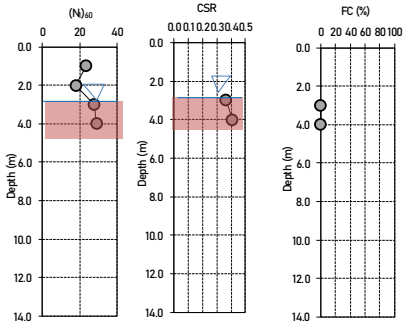






Personal Communication Prof. Tokimatsu (2000)

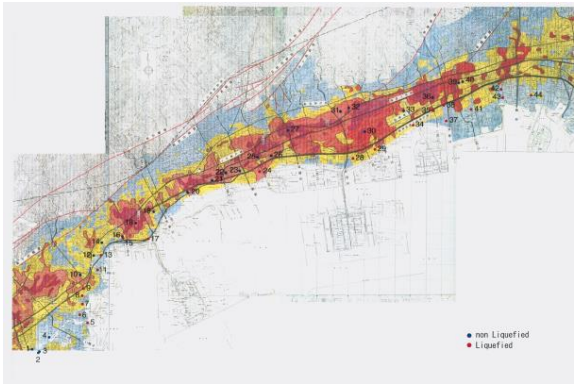
No.	24		5787							STDEV of corrected N		2.53
ACC=	500		liquefied									
W.T=	2.35									Average of corrected N		20.10
	tf/m3	tf/m2	tf/m2									
DEPTH(m)	Density	SV	SVD	Nvalue	C_R	C_S	C_E	C_B	C_M	Corrected N	F.C.	Soil quality
3	1.85	5.454	4.804	16	0.65	1	1	1.22	1.44	18.31	0.00	砂礫
4	1.86	7.314	5.664	18	0.75	1	1	1.22	1.33	21.88	0.00	砂礫



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
1.0	3.3	NA	10.0	2.00	0.86	23.4		medium sand
2.0	6.6	NA	9.0	1.64	0.88	17.8		sand
3.0	***9.8***	***0.364***	***16.0***	***1.41***	***0.90***	***27.8***	***0.0***	***sand***
4.0	***13.1***	***0.408***	***18.0***	***1.28***	***0.92***	***29.0***	***0.0***	***sand***
					Mean:	28.4	0.0	
					St. Dev.	0.8	8.6	assigned

Case number:	183
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 25
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Nonliquefied
GPS LAT	34.710274 Coordinates were taken from NGL
GPS LONG	135.237206
Liq. layer consist of:	Sand and Gravel
Geological Unit:	Late Pleistocene lower terrace
Site Response Anlaysis:	No
Comments:	Vs12m is updated based on Vs-SPTN correlations.
	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	Sand and Gravel (content unknown)
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	No	No	No	No
Data Class	-	B	-	B	B
d_{crt} range (m)	-	3.0 - 4.0	-	3.0 - 4.0	2.3 - 4.0
d_{crt} (m)	-	3.5	3.5	3.5	3.2
GWT (m)	-	2.2 ± 0.3	2.2	2.2 ± 0.1	2.2 ± 0.1
γ_{moist} (kN/m^3)	-	16.5 ± 0.6	-	17.3 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	18.1 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	60.0 ± 3.4	64.2	63.8 ± 3.5	61.3 ± 6.0
σ_v' (kPa)	-	46.7 ± 3.3	50.1	50.6 ± 2.1	51.4 ± 3.3
a_{max} (g)	-	0.700 ± 0.105	0.7	0.700 ± 0.140	0.700 ± 0.140
r_d	-	0.96 ± 0.052	0.97	0.99 ± 0.052	1.00 ± 0.047
CSR	-	0.561 ± 0.097	0.555	0.568 ± 0.118	0.541 ± 0.113
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	4.0 ± 1.0	3	2.5 ± 3.5	2.5 ± 3.5
% PI	-	-	-	-	0
N	-	29.8 ± 0.9	27.5	26.1 ± 0.9	25.4 ± 1.4
C_R	-	0.76	0.85	0.87	0.91
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.43	1.25	1.42	1.41
$(N_1)_{60}$	-	39.4 ± 1.2	35.8	39.0 ± 1.4	44.2 ± 2.5
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	201.2	-	228.6	268.2

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 1.2

Dip: 85 Width (km): 16 R_{jb} (km): 1.2

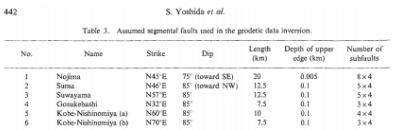

442 S. Yoshida *et al.*

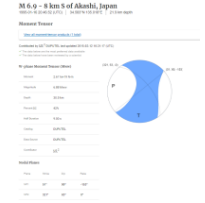
Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

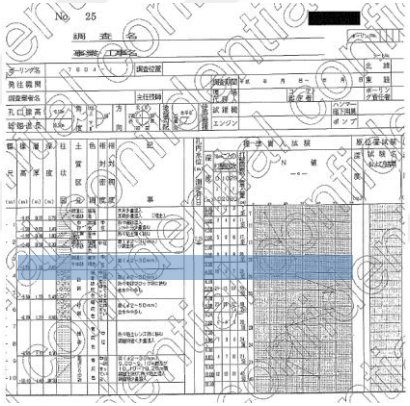
Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



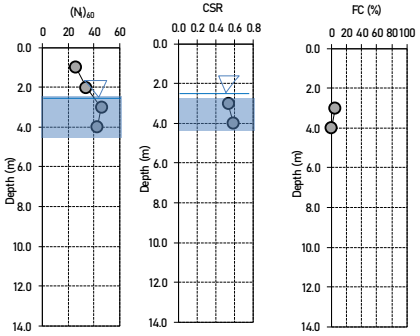






Personal Communication Prof. Tokimatsu (2000)

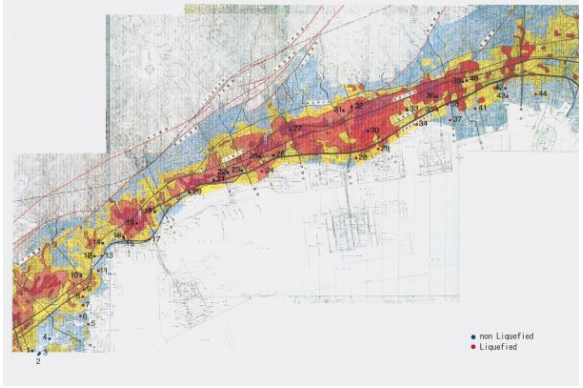
No.	25		7804							STDEV of corrected N		1.21
ACC=	700		non-liquefied							Average of corrected N		30.98
W.T=	2.15											
	tf/m3	tf/m2	tf/m2									
DEPTH(m)	Density	SV	SVD	Nvalue	C_R	C_S	C_B	C_E	C_W	Corrected N	F.C.	Soil quality
3	1.89	5.534	4.684	26	0.65	1	1	1.22	1.46	30.13	0.05	締まった中砂
4	1.9	7.434	5.584	26	0.75	1	1	1.22	1.34	31.84	0.00	砂礫



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
1.0	3.3	NA	11.0	2.00	0.86	25.7		medium sand w gravel
2.0	6.6	NA	17.0	1.64	0.88	33.6		medium sand w gravel
3.0	***9.8***	***0.530***	***26.0***	***1.43***	***0.90***	***45.9***	***5.0***	medium sand w gravel
4.0	***13.1***	***0.590***	***26.0***	***1.29***	***0.92***	***42.4***	***0.0***	sand and gravel
					Mean:	44.2	2.5	
					St. Dev.	2.5	3.5	

Case number:	184
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 26
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Non-liquefied
GPS LAT	34.710689 Coordinates were taken from NGL
GPS LONG	135.242005
Liq. layer consist of:	Coarse SAND with gravel
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is updated based on Vs-SPTN correlations. https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	***Coarse SAND with gravel (content unkown)***
CPT available:	***No***
Vs available:	***?***

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	3.0 - 4.0	-	3.0 - 4.0	2.7 - 4.4
d_{crt} (m)	-	3.5	3.5	3.5	3.5
GWT (m)	-	0.9 ± 0.3	0.9	0.9 ± 0.1	0.9 ± 0.1
γ_{moist} (kN/m^3)	-	16.5 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	17.3 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	59.9 ± 3.4	63.2	65.4 ± 3.5	68.3 ± 5.8
σ_v' (kPa)	-	34.4 ± 3.5	37.1	39.8 ± 2.2	42.5 ± 3.3
a_{max} (g)	-	0.600 ± 0.090	0.6	0.600 ± 0.120	0.600 ± 0.120
r_d	-	0.97 ± 0.052	0.97	0.99 ± 0.052	1.00 ± 0.052
CSR	-	0.660 ± 0.120	0.633	0.634 ± 0.132	0.626 ± 0.130
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	0.0 ± 0.0	0	0.0 ± 2.0	0.0 ± 8.6
% PI	-	-	-	-	0
N	-	24.5 ± 3.9	26	24.5 ± 3.6	24.5 ± 3.1
C_R	-	0.87	0.85	0.87	0.91
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.67	1.37	1.60	1.55
$(N_1)_{60}$	-	43.1 ± 6.8	37	41.2 ± 6.1	47.3 ± 6.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	210.3	-	231.6	286.5

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 — Yoshida et al (1996)

Fault Type: strike-slip — Z_{tor} (km): 0 — R_{rup} (km): 1.4

Dip: 85 — Width (km): 16 — R_{jb} (km): 1.4

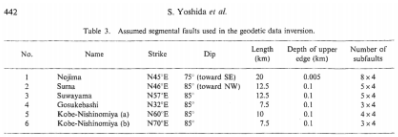

442 S. Yoshida *et al.*

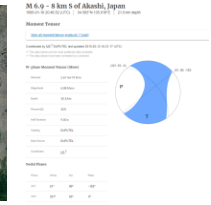
Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 x 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 x 4
3	Suwayama	N53°E	85°	12.5	0.1	5 x 4
4	Gosaikebashi	N32°E	85°	7.5	0.1	3 x 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 x 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 x 4

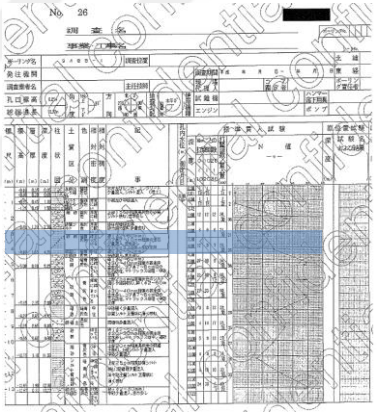
Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



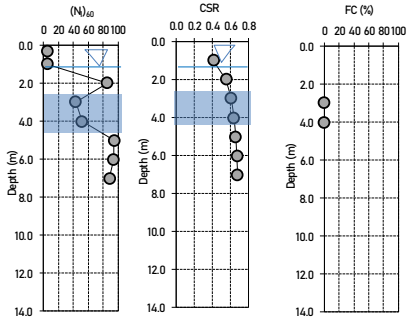

M 6.9 - 8 km S of Akashi, Japan





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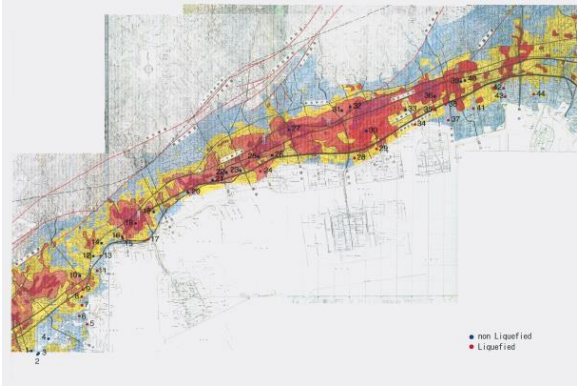
No.	26		9488								
ACC=	600		non-liquefied						STDEV of corrected N		7.41
W.T=	0.9								Average of corrected N		33.95
	tf/m3	tf/m2	tf/m2								
DEPTH(m)	Density	SV	SVD	Nvalue	C_B	C_S	C_B	C_E	C_N	Corrected N	F.C.	Soil quality
3	1.88	5.463	3.363	21	0.65	1	1	1.22	1.72	28.72	0.00	礫混じり粗砂
4	1.91	7.373	4.273	28	0.75	1	1	1.22	1.53	39.19	0.00	礫混じり粗砂



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
0.3	1.0	NA	2	2.00	0.83	4.6		sand w gravel
1.0	3.3	0.415	2	2.00	0.86	4.7		sand
2.0	6.6	0.552	36	1.97	0.88	85.7		sand and gravel
3.0	***9.8***	***0.608***	***21***	***1.66***	***0.90***	***43.1***	***0.0***	sand w gravel
4.0	***13.1***	***0.638***	***28***	***1.46***	***0.92***	***51.5***	***0.0***	sand w gravel
5.0	16.4	0.657	56	1.32	0.94	94.5		sand and gravel
6.0	19.7	0.670	60	1.21	0.95	94.2		sand and gravel
7.0	23.0	0.679	60	1.13	0.96	88.5		sand and gravel
					Mean:	47.3	0.0	
					St. Dev.	6.0	8.6	assigned

Case number:	185
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 27
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Non-liquefied
GPS LAT	34.717978 Coordinates were taken from NGL
GPS LONG	135.248039
Liq. layer consist of:	UNKNOWN
Geological Unit:	Late Pleistocene lower terrace
Site Response Anlaysis:	No
Comments:	Vs12m is updated based on Vs-SPTN correlations. https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	UNKOWN
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	2.0 - 3.0	-	2.0 - 3.0	1.8 - 3.2
d_{crt} (m)	-	2.5	2.5	2.5	2.5
GWT (m)	-	1.1 ± 0.3	1.1	1.1 ± 0.1	1.1 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	19.6 ± 0.5	21.5 ± 0.5
σ_v (kPa)	-	40.5 ± 3.0	43.1	45.1 ± 3.4	46.7 ± 5.1
σ_v' (kPa)	-	26.3 ± 3.2	29.1	30.8 ± 1.9	33.0 ± 2.9
a_{max} (g)	-	0.600 ± 0.090	0.6	0.600 ± 0.120	0.600 ± 0.120
r_d	-	0.98 ± 0.039	0.98	1.00 ± 0.039	1.00 ± 0.038
CSR	-	0.591 ± 0.114	0.568	0.569 ± 0.117	0.552 ± 0.114
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	10.0 ± 2.0	10	10.0 ± 2.0	10.0 ± 8.6
% PI	-	-	-	-	NAV
N	-	27.3 ± 3.0	27.6	27.7 ± 4.1	27.7 ± 5.1
C_R	-	0.82	0.85	0.82	0.89
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.91	1.43	1.82	1.75
$(N_1)_{60}$	-	52.2 ± 5.7	40.8	50.4 ± 7.5	59.3 ± 10.9
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	210.3	-	259.1	289.6

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 1.0

Dip: 85 Width (km): 16 R_{jb} (km): 1.0

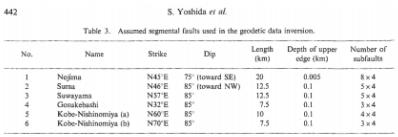

442 S. Yoshida *et al.*

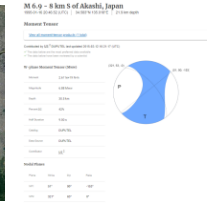
Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

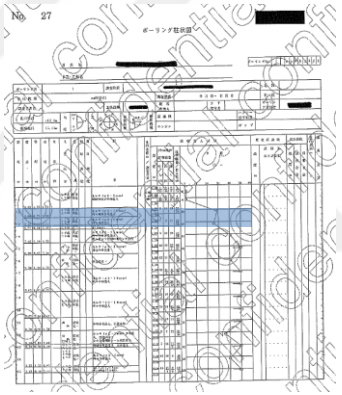
Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



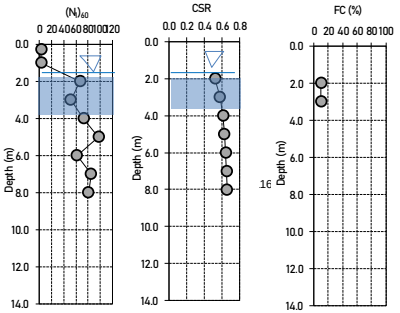

M 6.9 - 8 km S of Akashi, Japan





Personal Communication Prof. Tokimatsu (2000)

No.	27		NA082621									
ACC=	600		non-liquefied							STDEV of corrected N		2.47
W.T=	1.05									Average of corrected N		36.99
	tf/m3	tf/m2	tf/m2									
DEPTH(m)	密度	SV	SVD	Nvalue	C_N	C_S	C_B	C_E	C_R	Corrected N	F.C.	土質
2	1.92	3.473	2.523	29	0.65	1	1	1.22	1.93	39.74	0.1	しまった砂質土
3	1.9	5.373	3.423	26	0.65	1	1	1.22	1.71	35.24	0.1	しまった砂質土

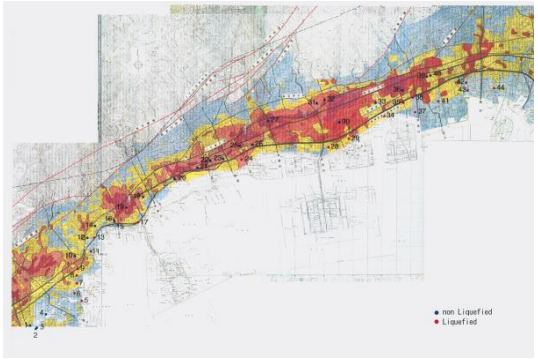


Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC
0.3	1.0	NA	1.0	2.00	0.83	2.3	
1.0	3.3	NA	1.0	2.00	0.86	2.3	
2.0	***6.6***	***0.521***	***29.0***	***1.92***	***0.88***	***67.0***	***10.0***
3.0	***9.8***	***0.579***	***26.0***	***1.60***	***0.90***	***51.6***	***10.0***
4.0	13.1	0.610	41.0	1.41	0.92	72.8	
5.0	16.4	0.629	60.0	1.27	0.94	97.6	
6.0	19.7	0.642	41.0	1.17	0.95	62.0	
7.0	23.0	0.651	60.0	1.08	0.96	85.2	
8.0	26.2	0.658	60.0	1.02	0.97	80.6	
					Mean:	59.3	10.0
					St. Dev.	10.9	8.6

assigned

Case number:	186
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 28
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Non-liquefied
GPS LAT	34.70987 Coordinates were taken from NGL
GPS LONG	135.271079
Liq. layer consist of:	interpreted
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is updated based on Vs-SPTN correlations. https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	NAV
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	4.0 - 5.0	-	3.0 - 5.0	2.5 - 5.5
d_{crt} (m)	-	4.5	3.5	4.0	4.0
GWT (m)	-	1.8 ± 0.3	1.8	1.8 ± 0.1	1.8 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	73.0 ± 3.4	62.2	74.6 ± 6.7	76.7 ± 10.4
σ_v' (kPa)	-	46.0 ± 3.6	44.1	52.5 ± 3.6	54.6 ± 5.6
a_{max} (g)	-	0.400 ± 0.060	0.4	0.400 ± 0.080	0.400 ± 0.080
r_d	-	0.93 ± 0.064	0.97	0.96 ± 0.058	0.98 ± 0.058
CSR	-	0.384 ± 0.068	0.348	0.355 ± 0.075	0.358 ± 0.076
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	10.0 ± 2.0	8	8.0 ± 2.0	8.0 ± 3.5
% PI	-	-	-	-	NAV
N	-	16.6 ± 2.5	14.3	14.3 ± 3.7	14.3 ± 3.5
C_R	-	0.90	0.85	0.89	0.92
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.44	1.42	1.39	1.36
$(N_1)_{60}$	-	26.3 ± 4.0	21.1	21.5 ± 5.6	24.6 ± 6.1
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	192.0	-	192.0	213.4

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 — Yoshida et al (1996)

Fault Type: strike-slip — Z_{tor} (km): 0 — R_{rup} (km): 3.2

Dip: 85 — Width (km): 16 — R_{jb} (km): 3.2

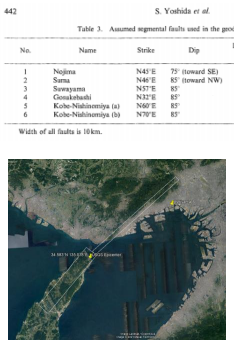
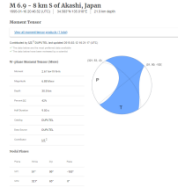

442 S. Yoshida et al.

Table 3. Assumed segmental faults used in the geodetic data inversion.

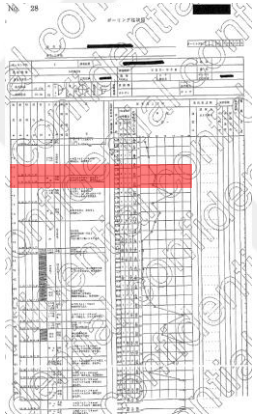
No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N43°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gonakahashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

Width of all faults is 10 km.



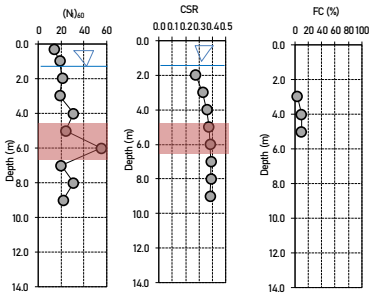
https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive





Personal Communication Prof. Tokimatsu (2000)

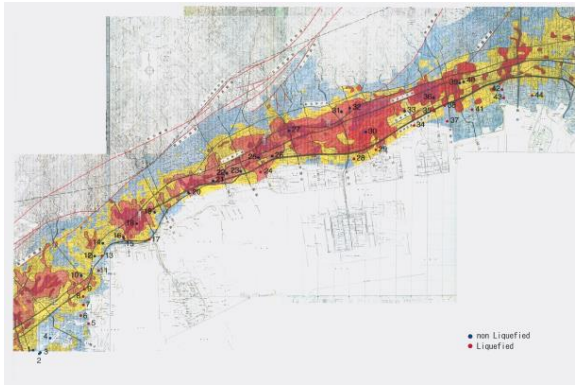
No.	28		H0098522								STDEV of corrected N	2.10
ACC=	400		liquefied								Average of corrected N	21.93
W.T=	1.75											
	tf/m3	tf/m2	tf/m2									
DEPTH(m)	層厚	SV	SVD	Nvalue	C_N	C_1	C_2	C_3	C_4	Corrected N	F.C.	土質
4	1.88	7.158	4.940	21	0.5	1	1.22	1.2	1.2	23.41	0.1	砂
5	1.381	9.058	5.788	19	0.5	1	1.22	1.31	1.2	20.45	0.1	シキ混じり粗



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
0.3	1.0	NA	6.0	2.00	0.83	13.7		sand
1.0	3.3	NA	8.0	2.00	0.86	18.7		sand
2.0	6.6	0.277	10.0	1.75	0.88	21.2		sand
3.0	***9.8***	***0.329***	***10.0***	***1.52***	***0.90***	***18.8***	***4.0***	sand
4.0	***13.1***	***0.358***	***18.0***	***1.36***	***0.92***	***30.9***	***10.0***	-
5.0	***16.4***	***0.376***	***15.0***	***1.25***	***0.94***	***23.9***	***10.0***	-
6.0	19.7	0.385	37.0	1.15	0.95	55.4		-
7.0	23.0	0.390	14.0	1.08	0.96	19.8		-
8.0	26.2	0.390	23.0	1.02	0.97	30.9		-
9.0	29.5	0.386	17.0	0.97	0.97	21.8		sand and gravel
					Mean:	24.6	8.0	
					St. Dev.	6.1	3.5	

Case number:	187
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 29
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefied
GPS LAT	34.71258 Coordinates were taken from NGL
GPS LONG	135.278923
Liq. layer consist of:	Coarse SAND with gravel
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is updated based on Vs-SPTN correlations.
	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	**Coarse SAND with gravel (content unknown)**
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	A	-	B	B
d_{crtc} range (m)	-	3.0 - 4.5	-	3.0 - 4.5	2.1 - 4.8
d_{crt} (m)	-	3.8	3.8	3.8	3.5
GWT (m)	-	2.0 ± 0.3	2	2.0 ± 0.1	2.0 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	17.3 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	17.3 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	61.8 ± 4.7	67.2	69.1 ± 5.1	67.7 ± 9.4
σ_v' (kPa)	-	44.6 ± 3.6	49.1	51.9 ± 2.8	53.5 ± 5.1
a_{max} (g)	-	0.400 ± 0.060	0.4	0.400 ± 0.080	0.400 ± 0.080
r_d	-	0.94 ± 0.055	0.96	0.98 ± 0.055	0.99 ± 0.051
CSR	-	0.338 ± 0.059	0.337	0.339 ± 0.071	0.327 ± 0.069
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	0.0 ± 0.0	0	0.0 ± 2.0	0.0 ± 8.6
% PI	-	-	-	-	0
N	-	12.0 ± 2.2	12.4	12.1 ± 2.2	12.2 ± 2.0
C_R	-	0.88	0.85	0.88	0.91
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.47	1.39	1.40	1.38
$(N_1)_{60}$	-	18.8 ± 3.4	17.9	18.0 ± 3.3	21.0 ± 3.5
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	185.9	-	207.3	240.8

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 3.3

Dip: 85 Width (km): 16 R_{jb} (km): 3.3

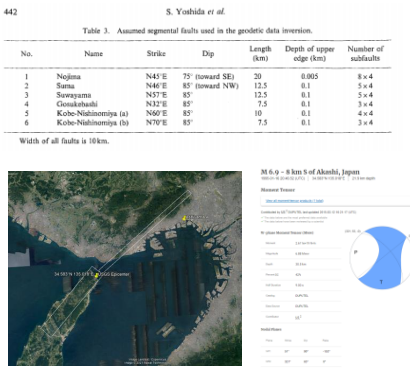
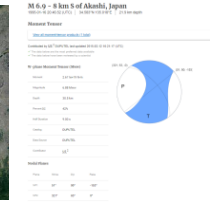

442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

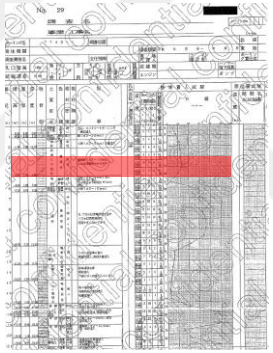
No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gionakehashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive

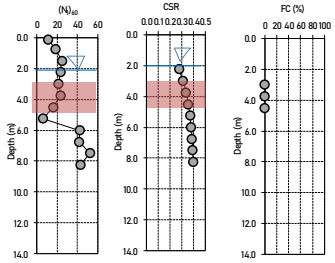






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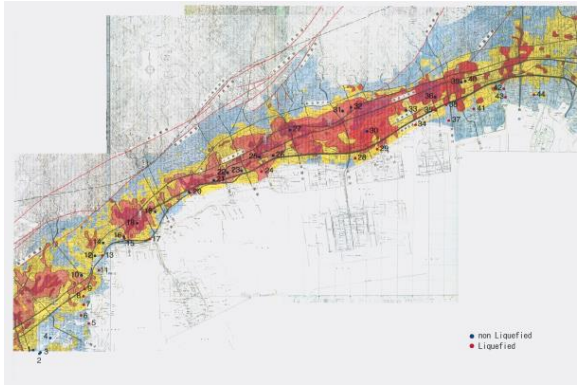
No.	29		7743									
ACC=	400		liquefied							STDEV of corrected N		2.31
W.T=	2									Average of corrected N		15.38
	tf/m3	tf/m2	tf/m2									
DEPTH(m)	Density	SV	SVD	Nvalue	C_R	C_S	C_B	C_E	C_N	Corrected N	F.C.	Soil quality
3	1.82	5.457	4.417	12	0.65	1	1	1.22	1.50	9.02	0.00	Sand (Silty)
3.75	1.84	6.797	5.047	14	0.70	1	1	1.22	1.41	9.93	0.00	Sand (Silty)
4.5	1.8	8.147	5.547	10	0.80	1	1	1.22	1.33	3.80	0.00	Sand (Silty)



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
0.2	0.5	NA	5.0	2.00	0.83	11.3		Coarse SAND with gravel
0.8	2.5	NA	8.0	2.00	0.85	18.5		Coarse SAND with gravel
1.5	4.9	NA	11.0	1.89	0.87	24.7		Medium SAND
2.3	***7.4***	***0.275***	***12.0***	***1.58***	***0.89***	***23.1***		Coarse SAND with gravel
3.0	***9.8***	***0.311***	***12.0***	***1.45***	***0.90***	***21.4***	***0.0***	Coarse SAND with gravel
3.8	***12.3***	***0.337***	***14.0***	***1.34***	***0.92***	***23.5***	***0.0***	Coarse SAND with gravel
4.5	***14.8***	***0.355***	***10.0***	***1.25***	***0.93***	***15.9***	***0.0***	Coarse SAND with gravel
5.3	17.2	0.369	4.0	1.18	0.94	6.1		Fine SAND
6.0	19.7	0.380	29.0	1.12	0.95	42.1		Coarse SAND with gravel
6.8	22.1	0.388	30.0	1.07	0.96	41.8		Fine SAND
7.5	24.6	0.393	39.0	1.02	0.96	52.4		Fine SAND
8.3	27.1	0.397	33.0	0.98	0.97	42.9		Fine SAND
					Mean:	21.0	0.0	
					St. Dev.	3.5	8.6	assigned

Case number:	188
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 30
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Non-Liquefied
GPS LAT	34.717713 Coordinates were taken from NGL
GPS LONG	135.27505
Liq. layer consist of:	Silty Coarse SAND-N/A, could not translate description
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is updated based on Vs-SPTN correlations.
	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	NAV
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	this study
Liquefied?	-	No	No	No	No
Data Class	-	B	-	B	B
$d_{crt.}$ range (m)	-	7.0 - 10.0	-	7.0 - 10.0	6.5 - 10.5
d_{crt} (m)	-	8.5	8.5	8.5	8.5
GWT (m)	-	1.5 ± 0.3	1.5	1.5 ± 0.1	1.5 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	139.4 ± 9.4	146.4	161.4 ± 10.4	168.0 ± 14.2
σ_v' (kPa)	-	70.6 ± 6.3	78.2	92.6 ± 6.0	99.2 ± 8.0
a_{max} (g)	-	0.600 ± 0.090	0.6	0.600 ± 0.120	0.600 ± 0.120
r_d	-	0.73 ± 0.110	0.88	0.90 ± 0.110	0.94 ± 0.110
CSR	-	0.566 ± 0.123	0.649	0.611 ± 0.144	0.622 ± 0.144
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	10.0 ± 1.0	10	10.0 ± 2.0	10.0 ± 8.6
% PI	-	-	-	-	NAV
N	-	30.6 ± 4.7	30.5	30.6 ± 4.6	30.8 ± 4.5
C_R	-	1.00	1.00	1.00	0.97
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.17	1.08	1.05	1.01
$(N_1)_{60}$	-	43.4 ± 6.6	40.1	39.0 ± 5.8	41.2 ± 6.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	189.0	-	213.4	231.6

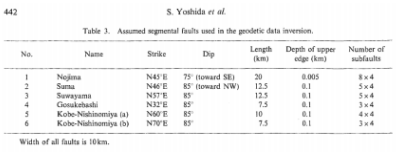
EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 2.6

Dip: 85 Width (km): 16 R_{jb} (km): 2.6



442 S. Yoshida *et al.*

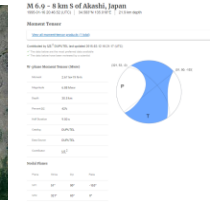
Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N43°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N37°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

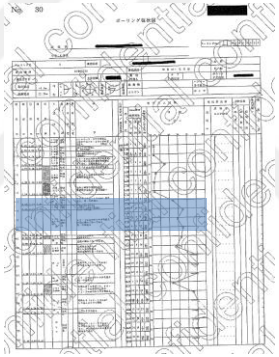
Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



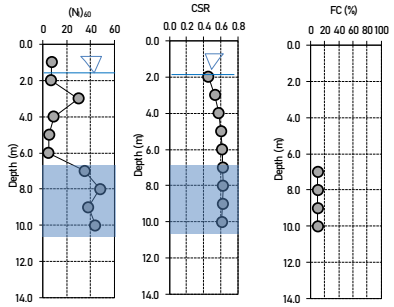






Personal Communication Prof. Tokimatsu (2000)

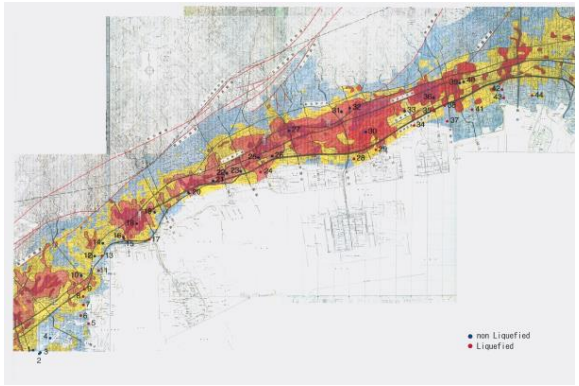
No.	30		HI087532									
ACC=	600		non-liquefied							STDEV of corrected N		5.61
W.T=	1.5									Average of corrected N		40.02
	tf/m3	tf/m2	tf/m2									
DEPTH(m)	密度	SV	SVD	Nvalue	C_N	C_S	C_E	C_R	C_{1N}	Corrected N	F.C.	土質
7	1.89	12.04	6.54	24	0.95	1	1	1.22	1.24	34.40	0.1	シルト混じり細 砂
8	1.99	13.97	7.47	35	0.95	1	1	1.22	1.16	46.93	0.1	シルト混じり細 砂
9	1.91	15.88	8.36	27	0.95	1	1	1.22	1.09	36.72	0.1	シルト混じり細 砂
10	1.93	17.81	9.31	34	0.95	1	1	1.22	1.04	42.04	0.1	シルト混じり細 砂



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
1.0	3.3	NA	3.0	2.00	0.86	7.0		-
2.0	6.6	0.454	3.0	1.87	0.88	6.8		sand
3.0	9.8	0.531	15.0	1.60	0.90	29.6		-
4.0	13.1	0.573	5.0	1.42	0.92	8.9		Silty Sand
5.0	16.4	0.598	3.0	1.29	0.94	4.9		clay
6.0	19.7	0.613	3.0	1.19	0.95	4.6		clay
7.0	***23.0***	***0.620***	***24.0***	***1.11***	***0.96***	***34.8***	***10.0***	Silty Coarse Sand
8.0	***26.2***	***0.622***	***35.0***	***1.04***	***0.97***	***48.1***	***10.0***	-
9.0	***29.5***	***0.619***	***29.0***	***0.99***	***0.97***	***38.0***	***10.0***	-
10.0	***32.8***	***0.612***	***35.0***	***0.94***	***0.98***	***43.9***	***10.0***	-
					Mean:	41.2	10.0	
					St. Dev.	6.0	8.6	assigned

Case number:	189
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 31
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Non-liquefied
GPS LAT	34.723491 Coordinates were taken from NGL
GPS LONG	135.266561
Liq. layer consist of:	sand
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is updated based on Vs-SPTN correlations.
	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	NAV
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	No	No	No	No
Data Class	-	A	-	B	B
d_{crtc} range (m)	-	3.0 - 5.0	-	3.0 - 5.0	2.5 - 5.5
d_{crt} (m)	-	4.0	4.0	4.0	4.0
GWT (m)	-	1.2 ± 0.3	1.2	1.2 ± 0.1	1.2 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	17.3 ± 0.6	-	19.6 ± 0.5	21.5 ± 0.5
σ_v (kPa)	-	67.4 ± 6.1	73.2	74.0 ± 6.7	79.3 ± 10.9
σ_v' (kPa)	-	39.9 ± 4.0	46.1	46.5 ± 3.6	51.8 ± 6.1
a_{max} (g)	-	0.600 ± 0.090	0.6	0.600 ± 0.120	0.600 ± 0.120
r_d	-	0.94 ± 0.058	0.96	0.99 ± 0.058	1.00 ± 0.058
CSR	-	0.622 ± 0.111	0.599	0.614 ± 0.129	0.596 ± 0.125
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	0.0 ± 0.0	0	0.0 ± 2.0	0.0 ± 8.6
% PI	-	-	-	-	0
N	-	35.7 ± 3.8	34.8	35.8 ± 3.7	35.9 ± 3.7
C_R	-	0.89	0.95	0.89	0.92
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.55	1.23	1.48	1.40
$(N_1)_{60}$	-	59.8 ± 6.3	49.7	57.0 ± 5.9	63.3 ± 6.5
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	195.1	-	231.6	280.4

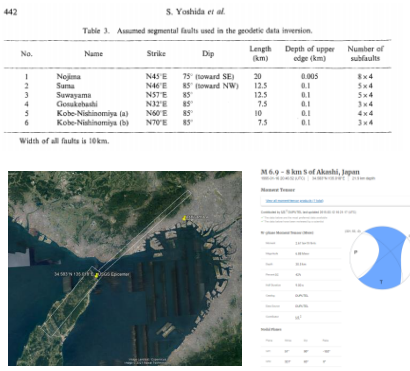
EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 1.6

Dip: 85 Width (km): 16 R_{jb} (km): 1.6

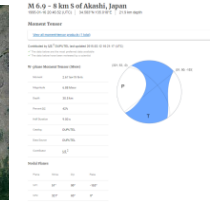


442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

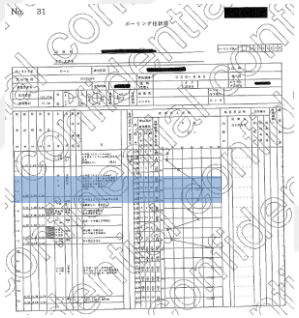
No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gionakehashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

Width of all faults is 10 km.



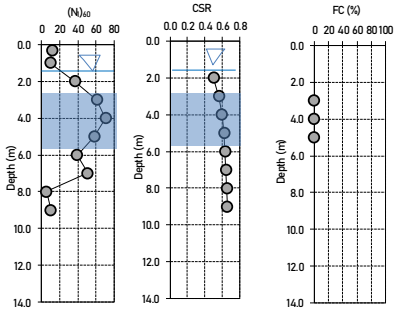
https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive





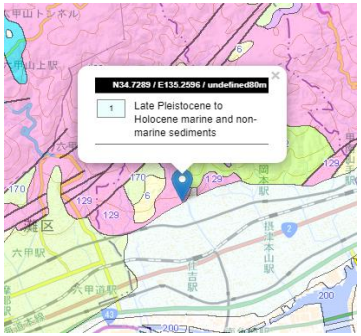
Personal Communication Prof. Tokimatsu (2000)

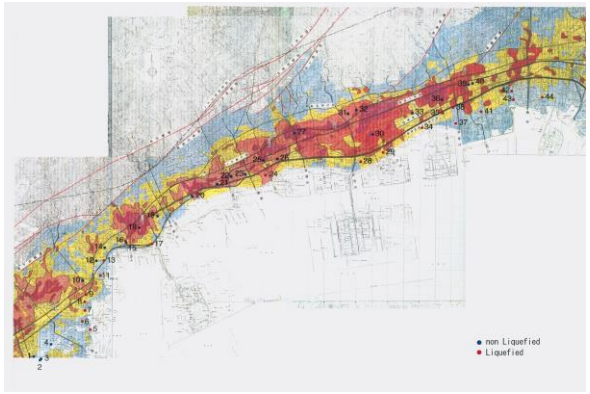
No.	31		HI101342									
ACC=	600		non-liquefied							STDEV of corrected N		6.84
W.T=	1.2									Average of corrected N		48.01
	tf/m3	tf/m2	tf/m2									
DEPTH(m)	密度	SV	SVD	Nvalue	C_R	C_S	C_B	C_E	C_M	Corrected N	F.C.	土質
3	1.93	5.499	3.699	31	0.65	1	1	1.22	1.64	40.42	0	砂レキ
4	1.95	7.449	4.849	40	0.75	1	1	1.22	1.47	53.68	0	砂レキ
5	1.94	9.389	5.589	36	0.85	1	1	1.22	1.34	49.94	0	粗砂



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
0.3	1.0	NA	5.0	2.00	0.83	11.4		-
1.0	3.3	NA	4.0	2.00	0.86	9.4		-
2.0	6.6	0.498	16.0	1.89	0.88	36.6		sand
3.0	***9.8***	***0.562***	***31.0***	***1.59***	***0.90***	***61.0***	***0.0***	sand
4.0	***13.1***	***0.596***	***40.0***	***1.40***	***0.92***	***70.6***	***0.0***	sand
5.0	***16.4***	***0.618***	***36.0***	***1.26***	***0.94***	***58.3***	***0.0***	sand
6.0	19.7	0.632	26.0	1.16	0.95	39.1		-
7.0	23.0	0.642	36.0	1.08	0.96	50.9		-
8.0	26.2	0.648	4.0	1.01	0.97	5.4		-
9.0	29.5	0.653	8.0	0.96	0.97	10.2		-
					Mean:	63.3	0.0	
					St. Dev.	6.5	8.6	assigned

Case number:	190
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 32
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Non-liquefied
GPS LAT	34.72469 Coordinates were taken from NGL
GPS LONG	135.269507
Liq. layer consist of:	Sand
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is updated based on Vs-SPTN correlations.
	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	NAV
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	No	No	No	No
Data Class	-	B	-	B	B
d_{cric} range (m)	-	2.0 - 5.0	-	2.0 - 5.0	1.4 - 5.7
d_{cr1} (m)	-	3.5	3.5	3.5	3.6
GWT (m)	-	1.4 ± 0.3	1.4	1.4 ± 0.1	1.4 ± 0.1
γ_{moist} (kN/m^3)	-	14.9 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	15.7 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	54.0 ± 8.0	61.2	63.4 ± 9.9	66.4 ± 14.8
σ_v' (kPa)	-	33.4 ± 4.3	41.1	42.7 ± 5.1	45.3 ± 7.8
a_{max} (g)	-	0.500 ± 0.090	0.5	0.500 ± 0.100	0.500 ± 0.100
r_d	-	0.94 ± 0.052	0.97	0.98 ± 0.052	1.00 ± 0.052
CSR	-	0.494 ± 0.107	0.472	0.474 ± 0.100	0.475 ± 0.102
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	6.0 ± 2.0	6	6.3 ± 4.8	6.3 ± 4.8
% PI	-	-	-	-	NAV
N	-	18.0 ± 2.0	20.1	18.8 ± 2.2	18.8 ± 2.8
C_R	-	0.87	0.85	0.87	0.91
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.70	1.40	1.54	1.50
$(N_1)_{60}$	-	32.2 ± 3.5	29.1	30.5 ± 3.6	35.2 ± 5.2
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	182.9	-	213.4	262.1

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 1.7

Dip: 85 Width (km): 16 R_{jb} (km): 1.7

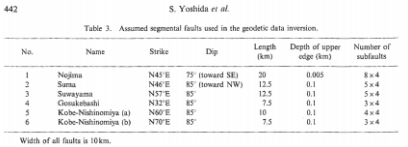

442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

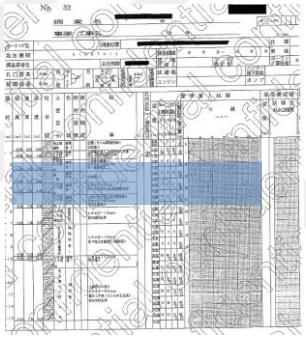
Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



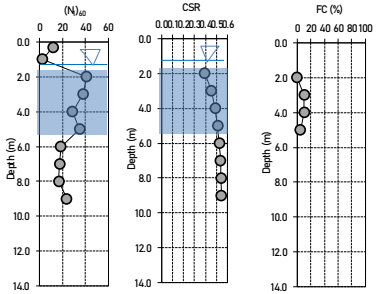






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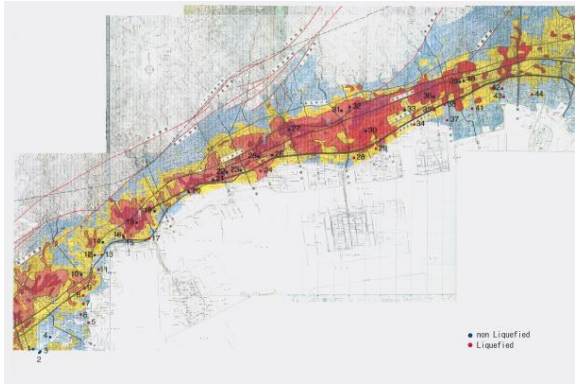
No.	32	hi097411							STDEV of corrected N	4.31
ACC=	500	non-liquefied							Average of corrected N	24.57
W.T=	1.4									
	tf/m3	tf/m2	tf/m2							
DEPTH(m)	Density	SV	SVD	Nvalue	Ca	Cs	Cb	Cr	Cn	Corrected N	F.C.	Soil quality	
2	1.87	3.47	2.82	15	0.85	1	1	1.22	1.07	22.90	0.00	シルト混じり粘	40
3	1.87	5.34	3.74	18	0.85	1	1	1.22	1.04	24.66	0.10	粘	40
4	1.85	7.19	4.59	17	0.85	1	1	1.22	1.01	21.61	0.10	シルト混じり粘	40
5	1.85	9.05	5.45	21	0.85	1	1	1.22	1.00	29.50	0.05	シルト混じり中	40



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
0.3	1.0	NA	5.0	2.00	0.83	11.4		Clayey fine SAND
1.0	3.3	NA	1.0	2.00	0.86	2.3		Sandy CLAY
2.0	***6.6***	***0.392***	***18.0***	***1.89***	***0.88***	***41.0***	***0.0***	***Coarse SAND***
3.0	***9.8***	***0.454***	***19.0***	***1.61***	***0.90***	***37.7***	***10.0***	***Fine SAND***
4.0	***13.1***	***0.489***	***16.0***	***1.42***	***0.92***	***28.7***	***10.0***	***Fine SAND***
5.0	***16.4***	***0.511***	***21.0***	***1.29***	***0.94***	***34.7***	***5.0***	***Medium SAND***
6.0	19.7	0.526	12.0	1.19	0.95	18.5		Sandy CLAY
7.0	23.0	0.535	12.0	1.11	0.96	17.4		Sandy CLAY
8.0	26.2	0.542	12.0	1.04	0.97	16.5		Clayey medium SAND
9.0	29.5	0.545	18.0	0.99	0.97	23.6		Clayey medium SAND
					Mean:	35.5	6.3	
					St. Dev.	5.2	4.8	

Case number:	191
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 33
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Non-liquefied
GPS LAT	34.723791 Coordinates were taken from NGL
GPS LONG	135.288815
Liq. layer consist of:	Silty fine SAND
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments (fill??)
Site Response Anlaysis:	No
Comments:	Vs12m is updated based on Vs-SPTN correlations.
	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	NAV
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	7.0 - 9.0	-	7.0 - 9.0	6.5 - 9.5
d_{crt} (m)	-	8.0	8.0	8.0	8.0
GWT (m)	-	2.0 ± 0.3	2	2.0 ± 0.1	2.0 ± 0.1
γ_{moist} (kN/m^3)	-	15.7 ± 0.6	-	15.7 ± 0.5	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	16.5 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	130.7 ± 6.8	142.4	149.6 ± 7.2	155.3 ± 10.7
σ_v' (kPa)	-	71.7 ± 5.3	83.2	90.6 ± 4.5	96.3 ± 6.2
a_{max} (g)	-	0.500 ± 0.075	0.5	0.500 ± 0.100	0.500 ± 0.100
r_d	-	0.74 ± 0.104	0.89	0.90 ± 0.104	0.92 ± 0.104
CSR	-	0.439 ± 0.093	0.496	0.483 ± 0.112	0.484 ± 0.111
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	- ± -	-	- ± -	NAV
% Fines	-	50.0 ± 5.0	50	50.0 ± 2.0	50.0 ± 8.6
% PI	-	-	-	-	NAV
N	-	21.5 ± 1.5	21.3	21.6 ± 1.6	21.7 ± 1.5
C_R	-	1.00	1.00	1.00	0.97
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.16	1.07	1.06	1.03
$(N_1)_{60}$	-	30.3 ± 2.1	27.9	27.8 ± 2.0	29.4 ± 2.1
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	182.9	-	207.3	216.4

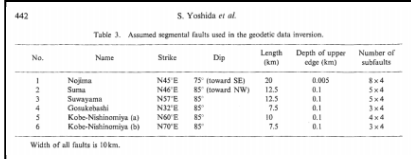
EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 2.9

Dip: 85 Width (km): 16 R_{jb} (km): 2.9



442 S. Yoshida *et al.*

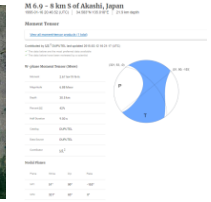
Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gionakahashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

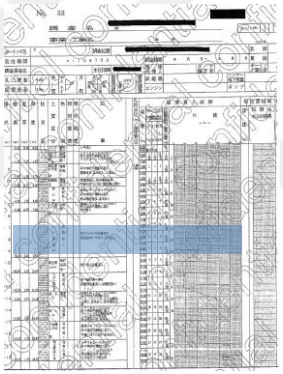
Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



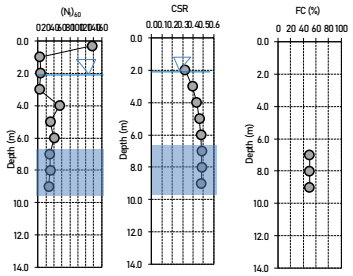






Personal Communication Prof. Tokimatsu (2000)

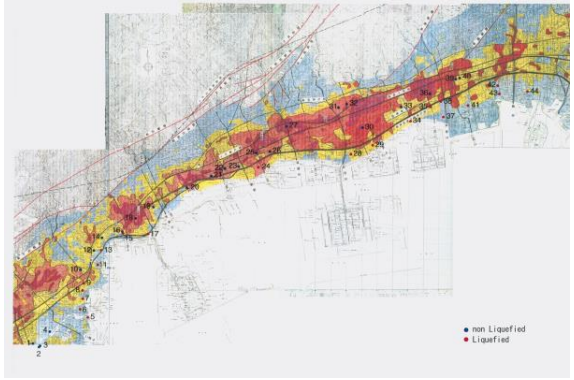
No.	33		hi109752									
ACC=	500		non-liquefied							STDEV of corrected N		1.96
W.T=	2									Average of corrected N		27.38
	tf/m3	tf/m2	tf/m2									
DEPTH(m)	Density	SV	SVD	Nvalue	Ce	Cs	Cb	Cr	Cm	Corrected N	F.C.	Soil quality
7	1.87	12.578	7.578	21	0.95	1	1	1.22	1.15	27.96	0.50	シルト質細砂
8	1.88	14.458	8.458	23	0.95	1	1	1.22	1.09	28.98	0.50	シルト質細砂
9	1.87	16.328	9.328	21	0.95	1	1	1.22	1.04	26.20	0.50	シルト質細砂



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
0.3	1.0	NA	60.0	2.00	0.83	136.6		Fill
1.0	3.3	NA	2.0	2.00	0.86	4.7		Fine SAND
2.0	6.6	0.323	3.0	1.80	0.88	6.5		Coarse SAND with CLAY
3.0	9.8	0.396	2.0	1.55	0.90	3.8		Sandy CLAY
4.0	13.1	0.437	31.0	1.38	0.92	54.0		SAND
5.0	16.4	0.462	19.0	1.26	0.94	30.7		Coarse SAND
6.0	19.7	0.476	27.0	1.17	0.95	40.8		Silty fine SAND
7.0	***23.0***	***0.483***	***21.0***	***1.09***	***0.96***	***30.0***	***50.0***	Silty fine SAND
8.0	***26.2***	***0.484***	***23.0***	***1.03***	***0.97***	***31.2***	***50.0***	Silty fine SAND
9.0	***29.5***	***0.480***	***21.0***	***0.97***	***0.97***	***27.2***	***50.0***	Silty fine SAND
					Mean:	29.4	50.0	
					St. Dev.	2.1	8.6	assigned

Case number:	192
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 34
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefied
GPS LAT	34.719593 Coordinates were taken from NGL
GPS LONG	135.292295
Liq. layer consist of:	Sand and Gravel
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is updated on Vs-SPTN correlations.
	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	**Sand and Gravel (content unkown)**
CPT available:	**No**
Vs available:	**?**

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?		Yes	Yes	Yes	Yes
Data Class		B	-	B	B
d_{crtc} range (m)		4.0 - 10.0		4.0 - 10.0	4.1 - 10.5
d_{crt} (m)		7.0	7.0	7.0	7.3
GWT (m)		1.8 ± 0.3	1.8	1.8 ± 0.1	1.8 ± 0.1
γ_{moist} (kN/m^3)		15.7 ± 0.6	-	16.5 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)		16.5 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)		114.3 ± 16.9	124.3	132.1 ± 19.9	144.6 ± 22.2
σ_v' (kPa)		63.2 ± 8.0	73.2	81.0 ± 10.2	90.6 ± 11.9
a_{max} (g)		0.400 ± 0.060	0.4	0.400 ± 0.080	0.400 ± 0.080
r_d		0.73 ± 0.093	0.91	0.88 ± 0.093	0.94 ± 0.096
CSR		0.345 ± 0.071	0.403	0.374 ± 0.085	0.388 ± 0.088
M_w		6.90	6.90	6.90	6.90
D_{50}		- ± -	-	- ± -	NAV
% Fines		9.0 ± 1.0	9	9.3 ± 1.9	9.3 ± 1.9
% PI		-	-	-	NAV
N		17.6 ± 2.5	18.3	17.7 ± 2.9	18.3 ± 3.5
C_R		0.98	0.95	0.98	0.96
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.22	1.22	1.22	1.37
C_N		1.23	1.14	1.12	1.06
$(N_1)_{60}$		25.8 ± 3.7	24.2	23.5 ± 3.8	25.4 ± 4.8
V_{s30m} (m/s)		-	-	-	NAV
V_{s12m} (m/s)		167.6	-	189.0	213.4

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 3.5

Dip: 85 Width (km): 16 R_{jb} (km): 3.5

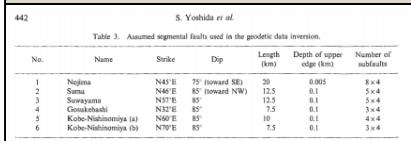
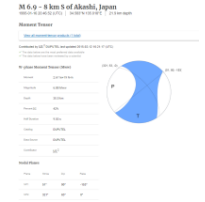

442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Sama	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gosakehashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

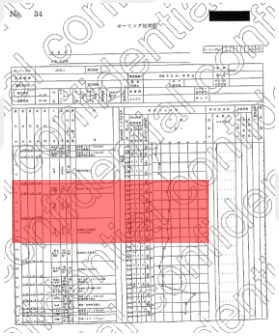
Width of all faults is 10 km.




M 6.9 - 8 km S of Akashi, Japan

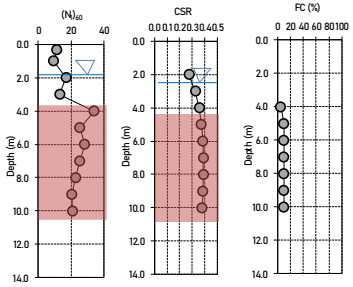
https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive





Personal Communication Prof. Tokimatsu (2000)

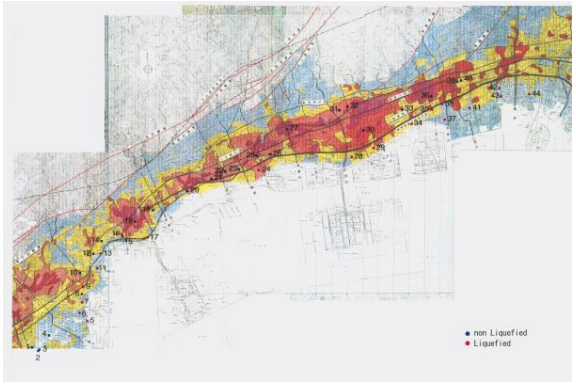
No.	34		2755									
AOC=	400		liquefied							STDEV of corrected N		2.52
W.T=	1.8									Average of corrected N		22.50
	tf/m3	tf/m2	tf/m2									
DEPTH(m)	密度	SV	SVD	Nvalue	C_N	C_S	C_B	C_E	C_R	Corrected N	F.C.	土質
4	1.56	7.072	4.872	20	0.75	1	1	1.22	1.43	26.22	0.05	中砂
5	1.84	8.912	5.712	18	0.85	1	1	1.22	1.32	21.95	0.1	細～粗砂
6	1.66	10.772	6.572	19	0.85	1	1	1.22	1.23	24.30	0.1	細砂
7	1.85	12.622	7.422	18	0.95	1	1	1.22	1.16	24.22	0.1	細砂
8	1.85	14.472	8.272	17	0.95	1	1	1.22	1.10	23.66	0.1	細砂
9	1.84	16.312	9.112	16	0.95	1	1	1.22	1.05	19.49	0.1	細砂
10	1.84	18.152	9.952	17	0.95	1	1	1.22	1.00	19.75	0.1	細砂



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
0.3	1.0	NA	5.0	2.00	0.83	11.4		Medium SAND with GRAVEL
1.0	3.3	NA	4.0	2.00	0.86	9.4		sand
2.0	6.6	0.273	8.0	1.75	0.88	16.8		Medium SAND
3.0	9.8	0.325	7.0	1.52	0.90	13.1		Medium SAND
4.0	***13.1***	***0.355***	***20.0***	***1.36***	***0.92***	***34.3***	***5.0***	Medium SAND
5.0	***16.4***	***0.373***	***16.0***	***1.24***	***0.94***	***25.5***	***10.0***	sand
6.0	***19.7***	***0.383***	***19.0***	***1.15***	***0.95***	***28.4***	***10.0***	-
7.0	***23.0***	***0.388***	***18.0***	***1.08***	***0.96***	***25.4***	***10.0***	-
8.0	***26.2***	***0.388***	***17.0***	***1.02***	***0.97***	***22.8***	***10.0***	SAND and GRAVEL
9.0	***29.5***	***0.384***	***16.0***	***0.97***	***0.97***	***20.5***	***10.0***	SAND and GRAVEL
10.0	***32.8***	***0.377***	***17.0***	***0.92***	***0.98***	***20.9***	***10.0***	SAND and GRAVEL
					Mean:	25.4	9.3	
					St. Dev.	4.8	1.9	

Case number:	193
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 35
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefied
GPS LAT	34.723653 Coordinates were taken from NGL
GPS LONG	135.29931
Liq. layer consist of:	Sand with gravel
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is updated based on Vs-SPTN correlations. https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	Sand with gravel (content unknown)
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?		Yes	Yes	Yes	Yes
Data Class		A	-	B	B
d_{crtc} range (m)		3.0 - 6.0		3.0 - 6.0	2.3 - 6.5
d_{crt} (m)		4.5	4.5	4.5	4.4
GWT (m)		2.1 ± 0.3	2.1	2.1 ± 0.1	2.1 ± 0.1
γ_{moist} (kN/m^3)		15.7 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)		16.5 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)		72.8 ± 8.5	79.2	83.7 ± 10.0	84.0 ± 14.5
σ_v' (kPa)		48.7 ± 4.8	55.1	59.7 ± 5.2	60.9 ± 7.7
a_{max} (g)		0.500 ± 0.075	0.5	0.500 ± 0.100	0.500 ± 0.100
r_d		0.86 ± 0.064	0.95	0.95 ± 0.064	0.98 ± 0.063
CSR		0.417 ± 0.077	0.445	0.432 ± 0.093	0.438 ± 0.095
M_w		6.90	6.90	6.90	6.90
D_{50}		- ± -	-	- ± -	NAV
% Fines		8.0 ± 2.0	6	6.3 ± 4.8	6.3 ± 4.8
% PI		-	-	-	0
N		12.3 ± 1.7	12.3	12.3 ± 1.9	12.3 ± 2.2
C_R		0.90	0.95	0.90	0.93
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.22	1.22	1.22	1.37
C_N		1.40	1.32	1.30	1.29
$(N_1)_{60}$		19.0 ± 2.6	18.9	17.7 ± 2.7	20.2 ± 3.6
V_{s30m} (m/s)		-	-	-	NAV
V_{s12m} (m/s)		164.6	-	189.0	216.4

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 3.5

Dip: 85 Width (km): 16 R_{jb} (km): 3.5

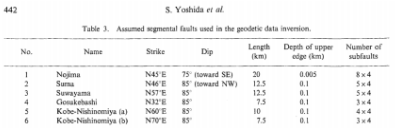

442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gleneketsuhi	N33°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

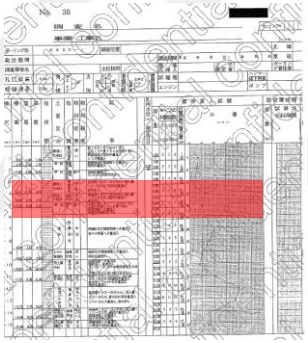
Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



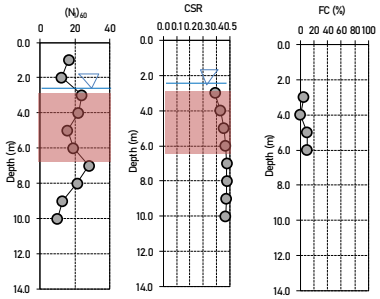






Personal Communication Prof. Tokimatsu (2000)

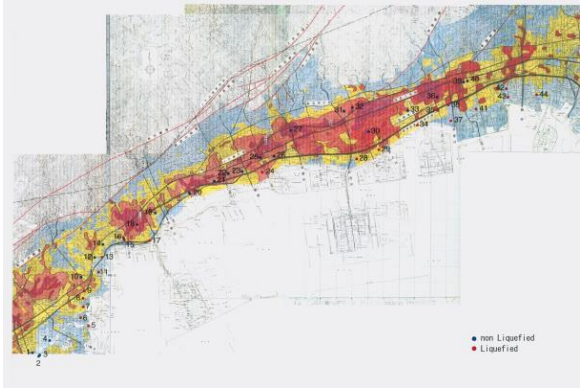
No.	35		6955							STDEV of corrected N	1.43	
ACC=	500		liquefied							Average of corrected N	15.48	
W.T=	2.05											
	tf/m3	tf/m2	tf/m2									
DEPTH(m)	Density	SV	SVD	Nvalue	C_N	C_S	C_B	C_E	C_R	Corrected N	F.C.	Soil quality
3	1.81	5.3	4.35	13	0.95	1	1	1.22	1.52	15.63	0.05	礫混じり中砂
4	1.83	7.13	5.18	13	0.95	1	1	1.22	1.39	16.53	0.00	礫混じり細砂
5	1.79	8.92	5.97	10	0.85	1	1	1.22	1.29	13.42	0.10	細砂
6	1.82	10.74	6.79	13	0.85	1	1	1.22	1.21	16.36	0.10	細砂



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
1.0	3.3	NA	7.0	2.00	0.86	16.4		Medium SAND with gravel
2.0	6.6	NA	6.0	1.71	0.88	12.4		Medium SAND
3.0	***9.8***	***0.387***	***13.0***	***1.49***	***0.90***	***23.9***	***5.0***	***Medium SAND with gravel***
4.0	***13.1***	***0.427***	***13.0***	***1.34***	***0.92***	***22.0***	***0.0***	***Medium SAND with gravel***
5.0	***16.4***	***0.452***	***10.0***	***1.23***	***0.94***	***15.7***	***10.0***	***Fine SAND***
6.0	***19.7***	***0.467***	***13.0***	***1.14***	***0.95***	***19.2***	***10.0***	***Fine SAND***
7.0	23.0	0.474	20.0	1.07	0.96	28.0		Fine SAND
8.0	26.2	0.476	16.0	1.01	0.97	21.3		Fine SAND
9.0	29.5	0.473	10.0	0.96	0.97	12.7		Silty Fine SAND
10.0	32.8	0.465	8.0	0.91	0.98	9.8		Clayey medium SAND
					Mean:	20.2	6.3	
					St. Dev.	3.6	4.8	

Case number:	194
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	7.2 (M_L)
Location:	Kobe No : 36
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Non-liquefied
GPS LAT	34.727551 Coordinates were taken from NGL
GPS LONG	135.299086
Liq. layer consist of:	Medium SAND
Geological Unit:	Late Cretaceous felsic plutonic rocks
Site Response Anlaysis:	No
Comments:	Vs12m is updated based on Vs- SPTN correlations.
	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	NAV
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?		No	No	No	No
Data Class		B	-	B	B
d_{crit} range (m)		3.0 - 4.0		3.0 - 4.0	2.5 - 4.5
d_{crt} (m)		3.5	3.5	3.5	3.5
GWT (m)		0.9 ± 0.3	0.9	0.9 ± 0.1	0.9 ± 0.1
γ_{moist} (kN/m^3)		15.7 ± 0.6	-	15.7 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)		16.5 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)		57.1 ± 3.3	61.2	65.2 ± 3.5	69.1 ± 7.0
σ_v' (kPa)		32.0 ± 3.4	36.1	40.0 ± 2.2	43.9 ± 3.9
a_{max} (g)		0.600 ± 0.090	0.6	0.600 ± 0.120	0.600 ± 0.120
r_d		0.93 ± 0.052	0.97	0.97 ± 0.052	0.98 ± 0.052
CSR		0.646 ± 0.120	0.639	0.617 ± 0.129	0.603 ± 0.126
M_w		6.90	6.90	6.90	6.90
D_{50}		- ± -	-	- ± -	NAV
% Fines		3.0 ± 1.0	3	2.5 ± 3.5	2.5 ± 3.5
% PI		-	-	-	0
N		20.0 ± 0.8	21.2	20.1 ± 1.1	20.1 ± 1.5
C_R		0.87	0.85	0.87	0.91
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.22	1.22	1.22	1.37
C_N		1.73	1.44	1.59	1.52
$(N)_{60}$		36.6 ± 1.5	31.6	33.7 ± 1.8	38.1 ± 2.8
V_{s30m} (m/s)		-	-	-	NAV
V_{s12m} (m/s)		176.8	-	198.1	213.4

EVENT PARAMETERS

1995 Hyogoken-Nambu
Magnitude: 6.90 Yoshida et al (1996)
Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 3.2
Dip: 85 Width (km): 16 R_{jb} (km): 3.2

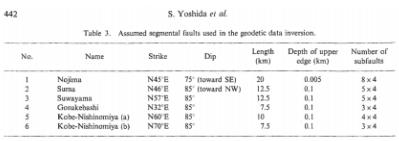
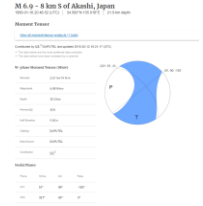

442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

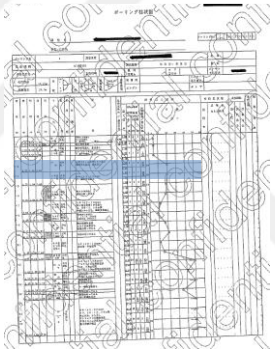
Width of all faults is 10 km.





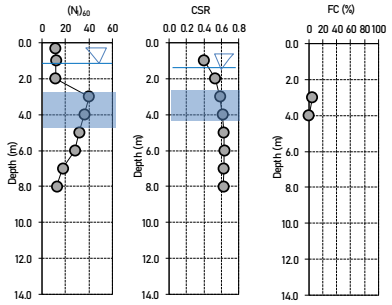
https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive





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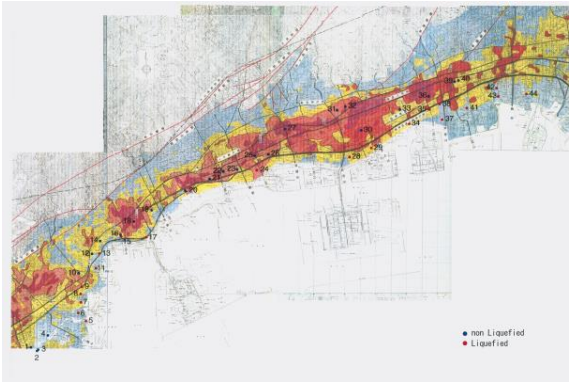
No.	36		HI107431							STDEV of corrected N	0.46
AC/C=	600		non-liquefied							Average of corrected N	28.20
W.T=	0.94										
	tf/m3	tf/m2	tf/m2								
DEPTH(m)	密度	SV	SVD	Nvalue	Cn	Cs	Ce	Cs	Cw	Corrected N	F.C.	土質
3	1.86	5.298	3.236	20	0.65		1	1.22	1.75	27.88	0.05	中 砂
4	1.88	7.178	4.116	20	0.75		1	1.22	1.56	28.52	0	ヒキ混じり砂 80



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
0.3	1.0	NA	5.0	2.00	0.83	11.4		Coarse SAND
1.0	3.3	0.402	5.0	2.00	0.86	11.7		-
2.0	6.6	0.532	5.0	1.91	0.88	11.5		-
3.0	***9.8***	***0.587***	***20.0***	***1.62***	***0.90***	***40.1***	***5.0***	Medium SAND
4.0	***13.1***	***0.614***	***20.0***	***1.43***	***0.92***	***36.2***	***0.0***	-
5.0	16.4	0.628	19.0	1.30	0.94	31.6		-
6.0	19.7	0.633	18.0	1.20	0.95	27.9		Silty Coarse Sand
7.0	23.0	0.631	12.0	1.11	0.96	17.5		-
8.0	26.2	0.623	9.0	1.05	0.97	12.4		Silty CLAY
					Mean:	38.1	2.5	
					St. Dev.	2.8	3.5	

Case number:	195
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 37
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefied
GPS LAT	34.720815 Coordinates were taken from NGL
GPS LONG	135.304053
Liq. layer consist of:	Coarse SAND with gravel
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is updated based on Vs-SPTN correlations. https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	**Coarse SAND with gravel (content unkown)**
CPT available:	**No**
Vs available:	**?**

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?		Yes	Yes	Yes	Yes
Data Class		A	-	B	B
d_{crtc} range (m)		4.0 - 6.0		4.0 - 6.0	4.0 - 6.5
d_{crt} (m)		5.0	5.0	5.0	5.3
GWT (m)		4.0 ± 0.3	4	4.0 ± 0.1	4.0 ± 0.1
γ_{moist} (kN/m^3)		16.5 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)		17.3 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)		83.5 ± 6.3	89.2	95.3 ± 6.8	101.4 ± 8.8
σ_v' (kPa)		73.6 ± 4.5	79.2	85.4 ± 3.9	89.1 ± 5.0
a_{max} (g)		0.350 ± 0.050	0.35	0.350 ± 0.070	0.350 ± 0.070
r_d		0.88 ± 0.070	0.94	0.91 ± 0.070	0.94 ± 0.073
CSR		0.226 ± 0.039	0.241	0.232 ± 0.050	0.244 ± 0.053
M_w		6.90	6.90	6.90	6.90
D_{50}		- ± -	-	- ± -	NAV
% Fines		0.0 ± 0.0	0	0.0 ± 2.0	0.0 ± 8.6
% PI		-	-	-	0
N		17.0 ± 2.4	15	18.4 ± 2.5	19.4 ± 3.6
C_R		0.92	0.95	0.92	0.94
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.22	1.22	1.22	1.37
C_N		1.14	1.12	1.09	1.07
$(N_1)_{60}$		21.7 ± 3.1	19.3	22.5 ± 3.1	26.6 ± 5.0
V_{s30m} (m/s)		-	-	-	NAV
V_{s12m} (m/s)		176.8	-	176.8	195.1

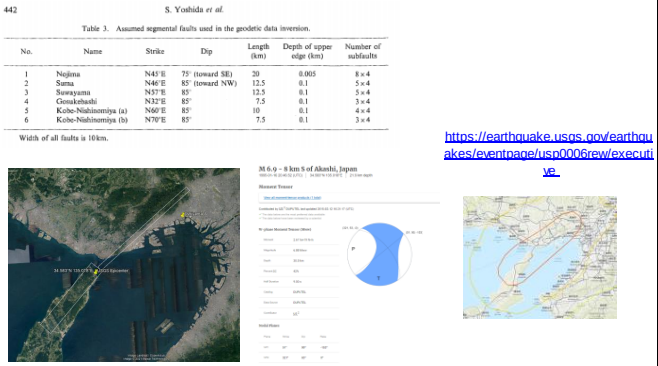
EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 4.0

Dip: 85 Width (km): 16 R_{jb} (km): 4.0



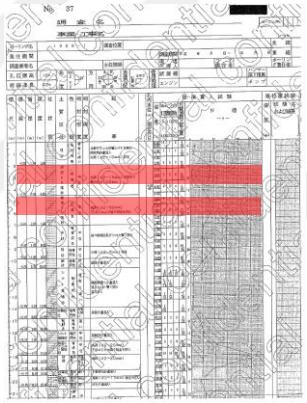
442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

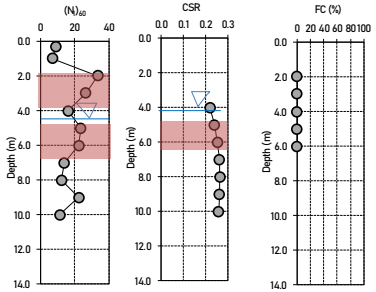
Width of all faults is 10km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



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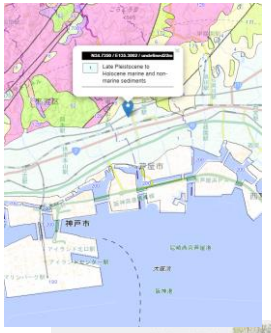
No.	37		1928							STDEV of corrected N	1.02
AOG=	350		liquefied							Average of corrected N	18.67
W.T=	4										
	tf/m3	tf/m2	tf/m2								
DEPTH(m)	Density	SV	SVD	Nvalue	C_R	C_S	C_B	C_E	C_{HI}	Corrected N	F.C.	Soil quality
2	1.86	3.552	3.552	17	0.85	1	1	1.22	1.68	19.14	0.00	礫混り粗砂
3	1.86	5.402	5.402	18	0.85	1	1	1.22	1.50	17.26	0.00	礫混り粗砂
4	1.81	7.212	7.212	11	0.75	1	1	1.22	1.18	11.85	0.00	礫混り粗砂
5	1.86	9.072	8.972	17	0.85	1	1	1.22	1.11	19.62	0.00	礫混り粗砂
6	1.86	10.922	8.922	17	0.85	1	1	1.22	1.06	18.66	0.00	礫混り粗砂

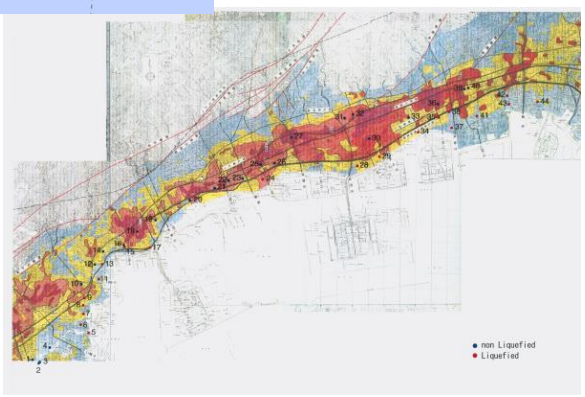


Prof. Tokimatsu suggested to exclude N=11

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
0.3	1.0	NA	4.0	2.00	0.83	*9.1*		Coarse SAND
1.0	3.3	NA	3.0	2.00	0.86	*7.0*		Coarse SAND
2.0	***6.6***	***NA***	***17.0***	***1.64***	***0.88***	***33.6***	***0.0***	Coarse SAND with gravel
3.0	***9.8***	***NA***	***16.0***	***1.34***	***0.90***	***26.5***	***0.0***	Coarse SAND with gravel
4.0	13.1	0.220	11.0	1.16	0.92	*16.1*	*0.0*	Coarse SAND with gravel
5.0	***16.4***	***0.240***	***17.0***	***1.08***	***0.94***	***23.6***	***0.0***	Coarse SAND with gravel
6.0	***19.7***	***0.254***	***17.0***	***1.02***	***0.95***	***22.5***	***0.0***	Coarse SAND with gravel
7.0	23.0	0.261	11.0	0.97	0.96	*14.0*		Medium SAND
8.0	26.2	0.264	10.0	0.92	0.97	*12.2*		Medium SAND
9.0	29.5	0.263	19.0	0.89	0.97	*22.4*		Coarse SAND
10.0	32.8	0.259	10.0	0.85	0.98	*11.4*		Fine SAND
					Mean:	26.6	0.0	
					St. Dev.	5.0	8.6	assigned

Case number:	196
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 38
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefied
GPS LAT	34.725129 Coordinates were taken from NGL
GPS LONG	135.302987
Liq. layer consist of:	Medium SAND with gravel
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is updated based on Vs-SPTN correlations.
	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	**Medium SAND with gravel (content unknown)**
CPT available:	**No**
Vs available:	**?**

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?		Yes	Yes	Yes	Yes
Data Class		B	-	B	B
d_{cTc} range (m)		6.0 - 10.0		6.0 - 10.0	6.5 - 10.5
d_{crt} (m)		8.0	8.0	8.0	8.5
GWT (m)		3.0 ± 0.3	3	3.0 ± 0.1	3.0 ± 0.1
γ_{moist} (kN/m^3)		15.7 ± 0.6	-	18.1 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)		16.5 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)		129.9 ± 11.6	143.4	152.8 ± 13.4	170.2 ± 14.1
σ_v' (kPa)		80.8 ± 6.4	94.2	103.6 ± 7.2	116.1 ± 7.8
a_{max} (g)		0.500 ± 0.075	0.5	0.500 ± 0.100	0.500 ± 0.100
r_d		0.73 ± 0.104	0.89	0.85 ± 0.104	0.91 ± 0.110
CSR		0.380 ± 0.081	0.441	0.409 ± 0.096	0.434 ± 0.102
M_w		6.90	6.90	6.90	6.90
D_{50}		- ± -	-	- ± -	NAV
% Fines		5.0 ± 1.0	5	5.0 ± 2.0	5.0 ± 8.6
% PI		-	-	-	0
N		15.2 ± 2.1	15.1	15.2 ± 2.1	15.7 ± 2.1
C_R		1.00	1.00	1.00	0.97
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.22	1.22	1.22	1.37
C_N		1.09	1.03	0.99	0.94
$(N_1)_{60}$		20.1 ± 2.8	19.1	18.3 ± 2.5	19.5 ± 2.6
V_{s30m} (m/s)		-	-	-	NAV
V_{s12m} (m/s)		179.8	-	192.0	216.4

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 3.6

Dip: 85 Width (km): 16 R_{jb} (km): 3.6

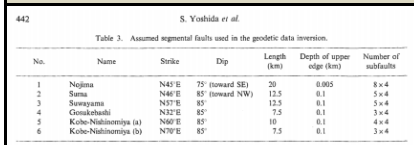

442 S. Yoshida *et al.*

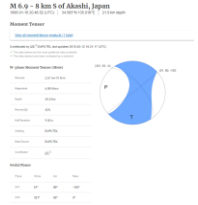
Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

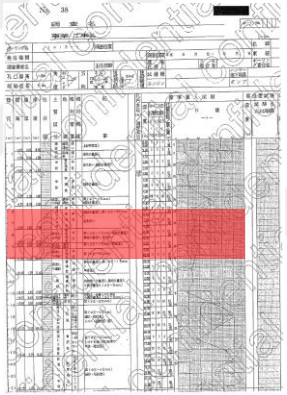
Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



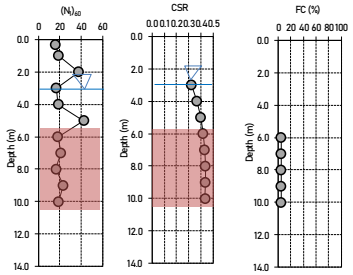

M 6.9 - 8 km S of Akashi, Japan





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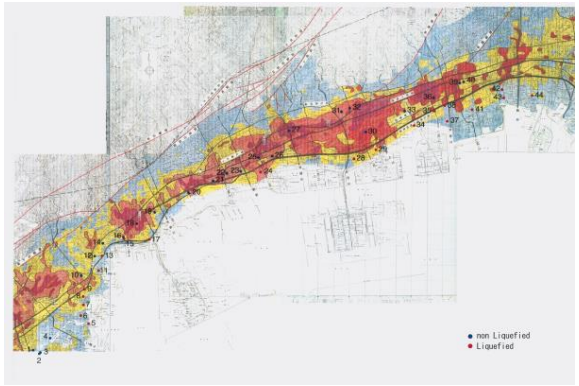
No.	38		1413							STDEV of corrected N	2.79
ACC=	500		liquefied							Average of corrected N	17.88
W.T=	3										
	tf/m3	tf/m2	tf/m2								
DEPTH(m)	Density	SV	SVD	Nvalue	C_N	C_1	C_2	C_E	C_R	Corrected N	F.C.	Soil quality
6	1.81	10.933	7.938	13	0.85	1	1	1.22	1.12	16.14	0.05	礫質砂(中密)
7	1.83	12.763	8.763	16	0.95	1	1	1.22	1.07	19.81	0.05	礫質砂(中密)
8	1.81	14.573	9.573	13	0.95	1	1	1.22	1.02	15.40	0.05	礫質砂(中密)
9	1.85	16.423	10.423	19	0.95	1	1	1.22	0.98	21.57	0.05	礫質砂(中密)
10	1.83	18.253	11.253	16	0.95	1	1	1.22	0.94	17.49	0.05	礫質砂(中密)



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
0.3	1.0	NA	7.0	2.00	0.83	15.9		Fine SAND
1.0	3.3	NA	8.0	2.00	0.86	18.7		Medium SAND
2.0	6.6	NA	19.0	1.64	0.88	37.6		Medium SAND
3.0	9.8	0.321	10.0	1.34	0.90	16.5		Medium SAND
4.0	13.1	0.365	12.0	1.23	0.92	18.6		Medium SAND
5.0	16.4	0.395	29.0	1.14	0.94	42.3		Medium SAND with gravel
6.0	***19.7***	***0.415***	***13.0***	***1.07***	***0.95***	***18.0***	***5.0***	Medium SAND with gravel
7.0	***23.0***	***0.427***	***16.0***	***1.01***	***0.96***	***21.1***	***5.0***	Medium SAND with gravel
8.0	***26.2***	***0.433***	***13.0***	***0.96***	***0.97***	***16.4***	***5.0***	Medium SAND with gravel
9.0	***29.5***	***0.434***	***19.0***	***0.91***	***0.97***	***23.1***	***5.0***	Medium SAND with gravel
10.0	***32.8***	***0.430***	***16.0***	***0.88***	***0.98***	***18.7***	***5.0***	Medium SAND with gravel
					Mean:	19.5	5.0	
					St. Dev.	2.6	8.6	assigned

Case number:	197
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 39
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Non-liquefied
GPS LAT	34.731956 Coordinates were taken from NGL
GPS LONG	135.308291
Liq. layer consist of:	SAND with cobbles
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is updated based on Vs-SPTN correlations. https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	SAND with cobbles
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?		No	No	No	No
Data Class		B	-	B	B
d_{crtc} range (m)		4.0 - 5.0		4.0 - 5.0	3.5 - 5.4
d_{crt} (m)		4.5	4.5	4.5	4.5
GWT (m)		2.6 ± 0.3	2.6	2.6 ± 0.1	2.6 ± 0.1
γ_{moist} (kN/m^3)		16.5 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)		18.1 ± 0.6	-	21.2 ± 0.5	21.5 ± 0.5
σ_v (kPa)		77.4 ± 3.7	84.2	89.5 ± 3.9	89.0 ± 7.0
σ_v' (kPa)		58.7 ± 3.5	66.2	70.9 ± 2.5	70.9 ± 4.1
a_{max} (g)		0.600 ± 0.090	0.6	0.600 ± 0.120	0.600 ± 0.120
r_d		0.96 ± 0.064	0.95	1.00 ± 0.064	1.00 ± 0.063
CSR		0.492 ± 0.085	0.476	0.492 ± 0.104	0.489 ± 0.103
M_w		6.90	6.90	6.90	6.90
D_{50}		- ± -	-	- ± -	NAV
% Fines		0.0 ± 0.0	0	0.0 ± 2.0	0.0 ± 8.6
% PI		-	-	-	0
N		47.0 ± 3.1	47	47.0 ± 2.8	46.9 ± 2.0
C_R		0.90	0.95	0.90	0.93
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.22	1.22	1.22	1.37
C_N		1.28	1.12	1.20	1.20
$(N_1)_{60}$		66.1 ± 4.4	61	61.9 ± 3.7	71.2 ± 3.1
V_{s30m} (m/s)		-	-	-	NAV
V_{s12m} (m/s)		213.4	-	289.6	278.9

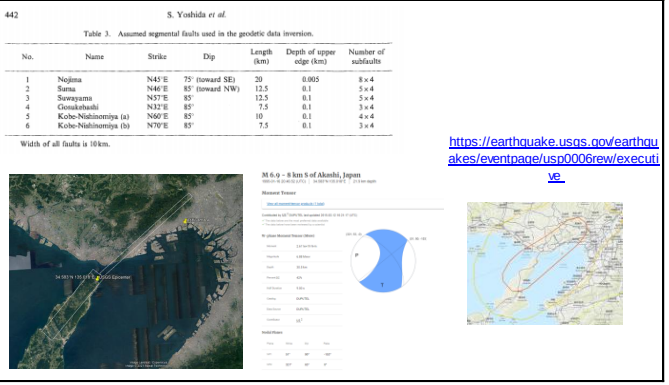
EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 3.3

Dip: 85 Width (km): 16 R_{jb} (km): 3.3



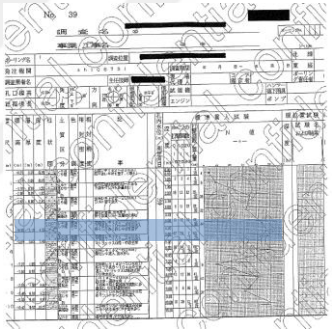
442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gionakehashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

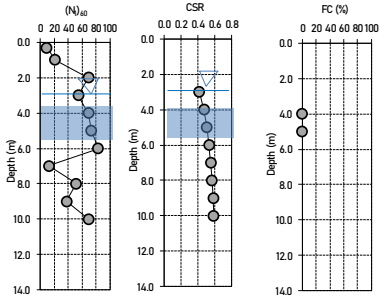
Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



Personal Communication Prof. Tokimatsu (2000)

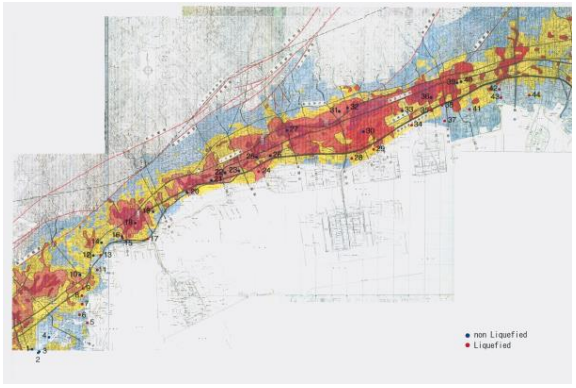
No.	39	sh10873!							STDEV of corrected N	7.11
ACC=	600	non-liquefied							Average of corrected N	56.12
W.T=	2.6									
	tf/m3	tf/m2	tf/m2							
DEPTH(m)	Density	SV	SVD	Nvalue	C_R	C_S	C_E	C_N	Corrected N	F.C.	Soil quality
4	1.87	7.479	5.209	44	0.75	1	1	1.22	1.27	51.00	0.00	非液状(D50=0.86mm, 上下
5	1.88	9.359	7.149	60	0.85	1	1	1.22	1.18	61.45	0.00	非液状(D50=0.86mm, 上下



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
0.3	1.0	NA	4.0	2.00	0.83	9.1		Coarse SAND
1.0	3.3	NA	9.0	2.00	0.86	21.0		Fine SAND
2.0	6.6	NA	35.0	1.64	0.88	69.2		Fine SAND
3.0	9.8	0.418	32.0	1.37	0.90	54.3		SAND with cobbles
4.0	***13.1***	***0.471***	***44.0***	***1.24***	***0.92***	***69.0***	***0.0***	SAND with cobbles
5.0	***16.4***	***0.507***	***50.0***	***1.15***	***0.94***	***73.4***	***0.0***	Coarse SAND
6.0	19.7	0.534	60.0	1.07	0.95	83.1		SAND with cobbles
7.0	23.0	0.554	9.0	1.00	0.96	11.8		SAND with cobbles
8.0	26.2	0.569	41.0	0.95	0.97	51.4		Fine SAND with SILT
9.0	29.5	0.580	31.0	0.90	0.97	37.2		Silty Fine SAND
10.0	32.8	0.588	60.0	0.86	0.98	69.3		-
					Mean:	71.2	0.0	
					St. Dev.	3.1	8.6	assigned

Case number:	198
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 40
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Non-liquefied
GPS LAT	34.732302 Coordinates were taken from NGL
GPS LONG	135.309778
Liq. layer consist of:	SAND (based on approximate translation)
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is updated based on Vs-SPTN correlations. https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	NAV
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?		No	No	No	No
Data Class		B	-	B	B
d_{crtc} range (m)		3.0 - 4.0		3.0 - 4.0	2.5 - 4.5
d_{crt} (m)		3.5	3.5	3.5	3.5
GWT (m)		2.8 ± 0.3	2.8	2.8 ± 0.1	2.8 ± 0.1
γ_{moist} (kN/m^3)		17.3 ± 0.6	-	18.9 ± 0.5	20.0 ± 0.5
γ_{sat} (kN/m^3)		18.1 ± 0.6	-	19.6 ± 0.5	21.5 ± 0.5
σ_v (kPa)		61.2 ± 3.5	66.2	66.7 ± 3.6	71.1 ± 7.3
σ_v' (kPa)		54.3 ± 3.6	59.1	59.8 ± 2.3	64.2 ± 4.2
a_{max} (g)		0.600 ± 0.090	0.6	0.600 ± 0.120	0.600 ± 0.120
r_d		0.97 ± 0.052	0.97	1.00 ± 0.052	1.00 ± 0.052
CSR		0.425 ± 0.072	0.421	0.433 ± 0.090	0.431 ± 0.091
M_w		6.90	6.90	6.90	6.90
D_{50}		0.000 ± 0.000	-	0.000 ± 0.000	NAV
% Fines		0.0 ± 0.0	0	0.0 ± 2.0	0.0 ± 8.6
% PI		-	-	-	0
N		31.1 ± 7.7	32.5	31.1 ± 7.9	31.3 ± 8.7
C_R		0.87	0.85	0.87	0.91
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.22	1.22	1.22	1.37
C_N		1.33	1.18	1.30	1.26
$(N_1)_{60}$		43.6 ± 10.8	39.7	42.8 ± 10.8	49.1 ± 13.6
V_{s30m} (m/s)		-	-	-	NAV
V_{s12m} (m/s)		207.3	-	249.9	289.6

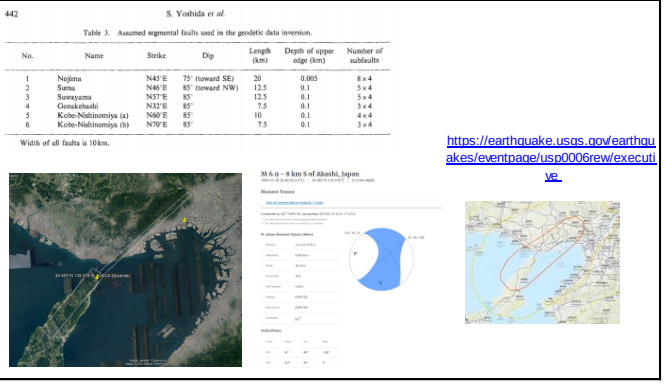
EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 3.3

Dip: 85 Width (km): 16 R_{jb} (km): 3.3



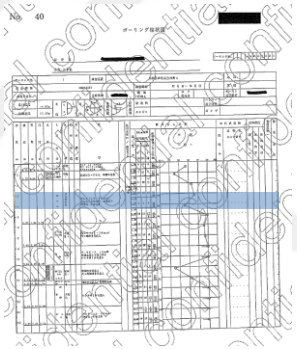
442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N50°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

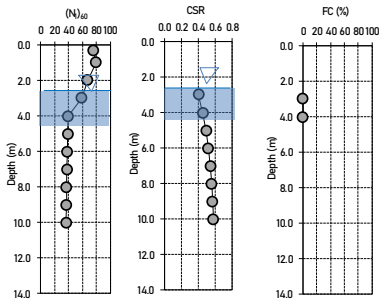
Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



Personal Communication Prof. Tokimatsu (2000)

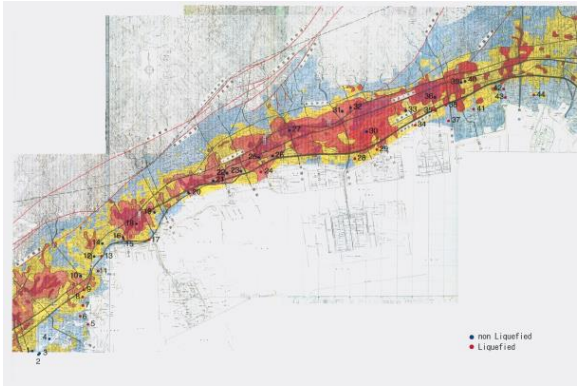
No.	40		SH082481									
AOG=	600		non-liquefied							STDEV of corrected N		6.15
W.T=	2.8									Average of corrected N		33.96
	tf/m3	tf/m2	tf/m2									
DEPTH(m)	密度	SV	SVD	Nvalue	Ca	Cs	Cg	Cr	Cw	Corrected N	F.C.	土質
3	1.94	5.755	5.554	36	0.68	1	1	1.22	1.34	39.21	0	砂、ﾚｷ土
4	1.9	7.654	6.454	26	0.75	1	1	1.22	1.24	29.61	0	砂、ﾚｷ土



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
0.3	1.0	NA	33.0	2.00	0.83	75.1		-
1.0	3.3	NA	34.0	2.00	0.86	79.5		-
2.0	6.6	NA	35.0	1.59	0.88	67.3		sand
3.0	***9.8***	***0.403***	***36.0***	***1.32***	***0.90***	***58.7***	***0.0***	sand
4.0	***13.1***	***0.455***	***26.0***	***1.20***	***0.92***	***39.4***	***0.0***	sand
5.0	16.4	0.492	27.0	1.11	0.94	38.5		sand
6.0	19.7	0.520	28.0	1.04	0.95	37.8		-
7.0	23.0	0.541	29.0	0.98	0.96	37.3		-
8.0	26.2	0.557	30.0	0.93	0.97	36.9		Coarse SAND
9.0	29.5	0.570	31.0	0.89	0.97	36.6		Coarse SAND
10.0	32.8	0.580	32.0	0.85	0.98	36.3		Sandy SILT
					Mean:	49.1	0.0	
					St. Dev.	13.6	8.6	assigned

Case number:	199
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 41
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefied
GPS LAT	34.724114 Coordinates were taken from NGL
GPS LONG	135.312556
Liq. layer consist of:	Coarse SAND
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is updated based on Vs-SPTN correlations.
	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	NAV
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?		Yes	Yes	Yes	Yes
Data Class		A	-	B	B
d_{crtc} range (m)		2.3 - 6.0		2.3 - 6.0	1.9 - 6.5
d_{crt} (m)		4.1	4.1	4.1	4.2
GWT (m)		2.0 ± 0.3	2	2.0 ± 0.1	2.0 ± 0.1
γ_{moist} (kN/m^3)		16.5 ± 0.6	-	15.7 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)		17.3 ± 0.6	-	18.9 ± 0.5	20.6 ± 0.5
σ_v (kPa)		69.9 ± 11.0	71.2	71.7 ± 11.9	80.0 ± 15.9
σ_v' (kPa)		49.0 ± 5.7	50.1	50.8 ± 5.9	58.4 ± 8.4
a_{max} (g)		0.400 ± 0.060	0.4	0.400 ± 0.080	0.400 ± 0.080
r_d		0.93 ± 0.059	0.96	0.96 ± 0.059	0.98 ± 0.060
CSR		0.346 ± 0.064	0.352	0.351 ± 0.076	0.351 ± 0.076
M_w		6.90	6.90	6.90	6.90
D_{50}		- ± -	-	- ± -	NAV
% Fines		0.0 ± 0.0	0	0.0 ± 2.0	0.0 ± 8.6
% PI		-	-	-	0
N		9.7 ± 1.9	9.2	9.7 ± 2.0	9.9 ± 2.2
C_R		0.89	0.95	0.89	0.93
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.22	1.22	1.22	1.37
C_N		1.40	1.41	1.41	1.32
$(N_1)_{60}$		14.7 ± 2.9	15	14.9 ± 3.0	16.5 ± 3.7
V_{s30m} (m/s)		-	-	-	NAV
V_{s12m} (m/s)		189.0	-	189.0	222.5

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 4.2

Dip: 85 Width (km): 16 R_{jb} (km): 4.2

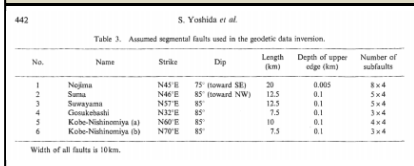

442 S. Yoshida *et al.*

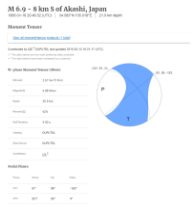
Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N51°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

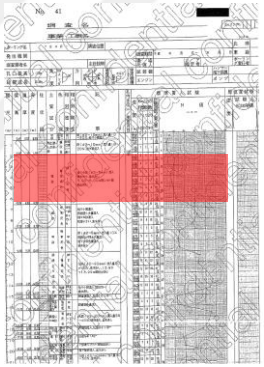
Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



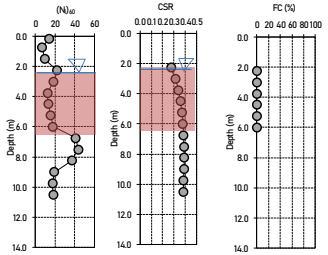






Personal Communication Prof. Tokimatsu (2000)

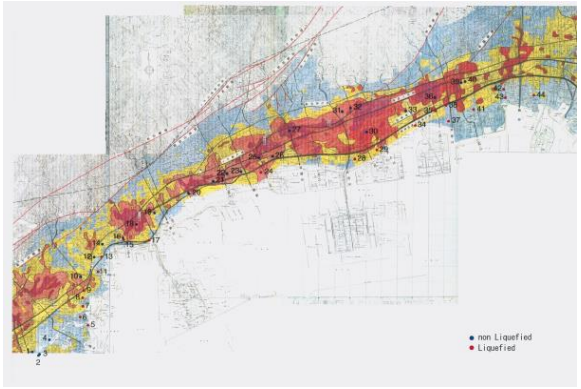
No.	41		7240							STDEV of corrected N	2.22
ADD=	400		liquefied							Average of corrected N	12.65
W.T=	2										
	tf/m3	tf/m2	tf/m2								
DEPTH(m)	Density	SV	SVD	Nvalue	C_R	C_S	C_E	C_B	C_N	Corrected N	F.C.	Soil quality
2.25	1.81	3.89	3.64	11	0.85	1	1	1.22	1.06	14.48	0.00	非液
3	1.8	5.24	4.24	10	0.85	1	1	1.22	1.04	12.16	0.00	非液
3.75	1.75	6.56	4.81	7	0.75	1	1	1.22	0.94	9.24	0.00	非液
4.5	1.77	7.87	5.37	9	0.85	1	1	1.22	1.06	11.30	0.00	非液
5.25	1.79	9.27	5.92	10	0.85	1	1	1.22	1.09	13.40	0.00	非液
6	1.81	10.65	6.45	12	0.85	1	1	1.22	1.13	15.37	0.00	非液



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
0.2	0.5	NA	6.0	2.00	0.83	13.6		Medium SAND
0.8	2.5	NA	3.0	2.00	0.85	7.0		Medium SAND with CLAY
1.5	4.9	NA	4.0	1.98	0.87	9.4		Medium SAND with CLAY
2.3	***7.4***	***0.275***	***11.0***	***1.65***	***0.89***	***22.0***	***0.0***	Coarse SAND
3.0	***9.8***	***0.313***	***10.0***	***1.49***	***0.90***	***18.5***	***0.0***	Coarse SAND
3.8	***12.3***	***0.339***	***7.0***	***1.38***	***0.92***	***12.1***	***0.0***	Coarse SAND
4.5	***14.8***	***0.357***	***8.0***	***1.28***	***0.93***	***13.0***	***0.0***	Coarse SAND
5.3	***17.2***	***0.370***	***10.0***	***1.21***	***0.94***	***15.5***	***0.0***	Coarse SAND
6.0	***19.7***	***0.379***	***12.0***	***1.14***	***0.95***	***17.8***	***0.0***	Coarse SAND
6.8	22.1	0.385	29.0	1.09	0.96	41.2		Fine SAND
7.5	24.6	0.388	32.0	1.04	0.96	43.7		Fine SAND
8.3	27.1	0.389	28.0	1.00	0.97	36.9		Fine SAND
9.0	29.5	0.388	15.0	0.96	0.97	19.1		Medium SAND
9.8	32.0	0.385	14.0	0.93	0.98	17.3		Medium SAND
10.5	34.4	0.381	15.0	0.90	0.98	18.0		Medium SAND
					Mean:	16.5	0.0	
					St. Dev.	3.7	8.6	assigned

Case number:	200
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 42
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefied
GPS LAT	34.730088 Coordinates were taken from NGL
GPS LONG	135.323248
Liq. layer consist of:	Fine SAND
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is updated based on Vs-SPTN correlations.
	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	NAV
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?		Yes	Yes	Yes	Yes
Data Class		A	-	B	B
d_{crt} range (m)		4.0 - 6.0	-	4.0 - 6.0	3.8 - 6.6
d_{crt} (m)		5.0	5.0	5.0	5.2
GWT (m)		1.2 ± 0.3	1.2	1.2 ± 0.1	1.2 ± 0.1
γ_{moist} (kN/m^3)		14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)		15.7 ± 0.6	-	18.9 ± 0.5	18.9 ± 0.5
σ_v (kPa)		77.8 ± 5.8	84.2	92.7 ± 6.6	96.5 ± 9.0
σ_v' (kPa)		40.0 ± 4.2	46.1	54.8 ± 3.6	56.7 ± 4.7
a_{max} (g)		0.400 ± 0.060	0.4	0.400 ± 0.080	0.400 ± 0.080
r_d		0.81 ± 0.070	0.94	0.78 ± 0.070	0.86 ± 0.072
CSR		0.412 ± 0.078	0.445	0.343 ± 0.076	0.380 ± 0.083
M_w		6.90	6.90	6.90	6.90
D_{50}		0.000 ± 0.000	-	0.000 ± 0.000	NAV
% Fines		10.0 ± 1.0	10	10.0 ± 2.0	10.0 ± 8.6
% PI		-	-	-	NAV
N		7.0 ± 0.3	7	7.0 ± 0.3	7.2 ± 0.5
C_R		0.92	0.95	0.92	0.94
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.22	1.22	1.22	1.37
C_N		1.55	1.48	1.36	1.34
$(N_1)_{60}$		12.2 ± 0.5	12.1	10.7 ± 0.5	12.3 ± 0.9
V_{s30m} (m/s)		-	-	-	NAV
V_{s12m} (m/s)		158.5	-	137.2	160.0

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 4.3

Dip: 85 Width (km): 16 R_{jb} (km): 4.3

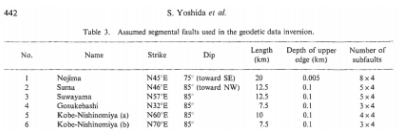

442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Sama	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N37°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

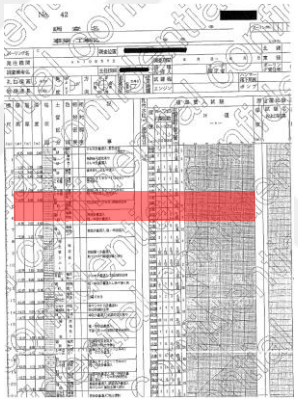
Width of all faults is 10km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



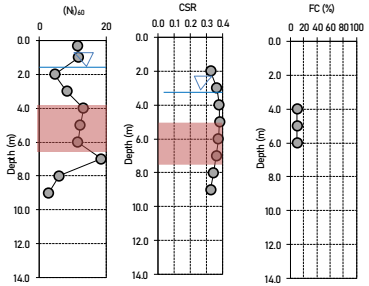






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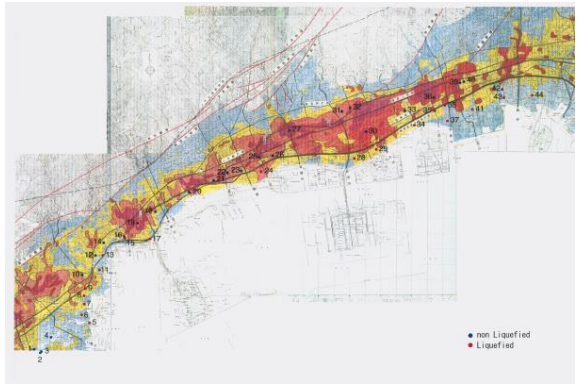
No.	42		sh108572									
ACC=	400		liquefied							STDEV of corrected N		0.36
W.T=	1.15									Average of corrected N		10.18
	tf/m3	tf/m2	tf/m2									
DEPTH(m)	Density	SV	SVD	Nvalue	C_B	C_S	C_E	C_R	C_N	Corrected N	F.C.	Soil quality
4	1.75	6.923	3.973	7	0.75	1	1	1.22	1.59	10.16	0.10	砂
5	1.75	8.673	4.723	7	0.85	1	1	1.22	1.46	10.56	0.10	砂
6	1.75	10.423	5.473	7	0.85	1	1	1.22	1.35	9.81	0.10	砂



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
0.3	1.0	NA	5.0	2.00	0.83	11.4		Fine SAND
1.0	3.3	NA	5.0	2.00	0.86	11.7		Fine SAND
2.0	6.6	0.326	2.0	1.92	0.88	4.6		Fine SAND
3.0	9.8	0.364	4.0	1.66	0.90	8.2		Fine SAND
4.0	***13.1***	***0.379***	***7.0***	***1.49***	***0.92***	***13.1***	***10.0***	Fine SAND
5.0	***16.4***	***0.380***	***7.0***	***1.36***	***0.94***	***12.2***	***10.0***	Fine SAND
6.0	***19.7***	***0.373***	***7.0***	***1.26***	***0.95***	***11.4***	***10.0***	Fine SAND
7.0	23.0	0.360	12.0	1.18	0.96	18.5	11.0	Fine SAND
8.0	26.2	0.343	4.0	1.11	0.97	5.9	12.0	Clayey SILT
9.0	29.5	0.326	2.0	1.06	0.97	2.8	13.0	Clayey SILT
					Mean:	12.3	10.0	
					St. Dev.	0.9	8.6	assigned

Case number:	201
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 43
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefied
GPS LAT	34.727597 Coordinates were taken from NGL
GPS LONG	135.324118
Liq. layer consist of:	Fine SAND with SILT
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is updated based on Vs-SPTN correlations. https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	NAV
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?		Yes	Yes	Yes	Yes
Data Class		B	-	B	B
$d_{crt.}$ range (m)		4.2 - 5.2		4.2 - 5.2	3.9 - 5.7
$d_{crt.}$ (m)		4.7	4.7	4.7	4.8
GWT (m)		2.2 ± 0.3	2.2	2.2 ± 0.1	2.2 ± 0.1
γ_{moist} (kN/m^3)		15.7 ± 0.6	-	15.7 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)		16.5 ± 0.6	-	18.9 ± 0.5	20.6 ± 0.5
σ_v (kPa)		75.2 ± 3.5	80.2	82.0 ± 3.5	91.4 ± 6.2
σ_v' (kPa)		50.6 ± 3.6	55.1	57.0 ± 2.3	65.6 ± 3.6
a_{max} (g)		0.350 ± 0.050	0.35	0.350 ± 0.070	0.350 ± 0.070
r_d		0.91 ± 0.066	0.95	0.96 ± 0.066	0.98 ± 0.067
CSR		0.307 ± 0.053	0.311	0.314 ± 0.067	0.309 ± 0.066
M_w		6.90	6.90	6.90	6.90
D_{50}		- ± -	-	- ± -	NAV
% Fines		20.0 ± 2.0	20	20.0 ± 2.0	20.0 ± 8.6
% PI		-	-	-	NAV
N		10.0 ± 0.2	10	10.0 ± 0.3	10.1 ± 0.5
C_R		0.91	0.95	0.91	0.93
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.22	1.22	1.22	1.37
C_N		1.38	1.31	1.34	1.24
$(N_1)_{60}$		15.2 ± 0.3	15.2	14.8 ± 0.5	16.0 ± 0.8
V_{s30m} (m/s)		-	-	-	NAV
V_{s12m} (m/s)		182.9	-	198.1	216.4

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 4.7

Dip: 85 Width (km): 16 R_{jb} (km): 4.7

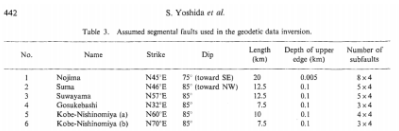
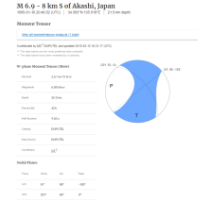

442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Gosukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

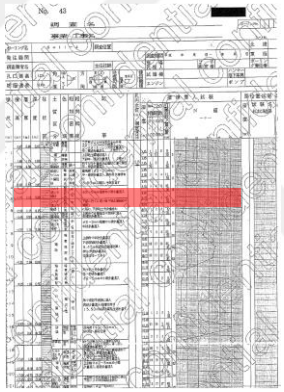
Width of all faults is 10 km.





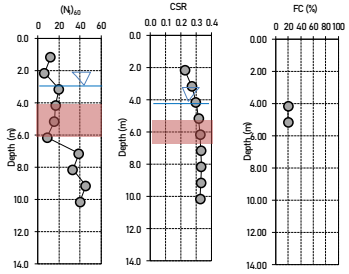
https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive





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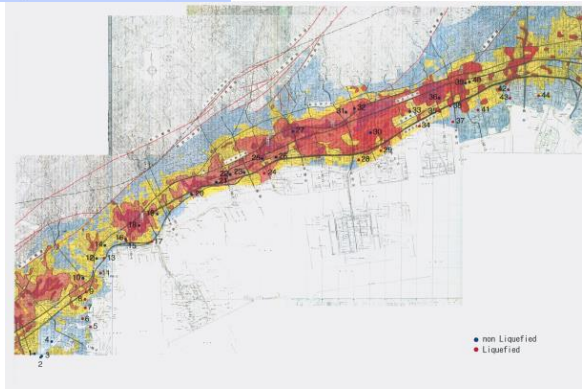
No.	43		8411									
ACC=	350		liquefied							STDEV of corrected N		0.68
W.T=	2.15									Average of corrected N		13.82
	tf/m3	tf/m2	tf/m2									
DEPTH(m)	Density	SV	SVD	Nvalue	C_N	C_1	C_2	C_3	C_4	Corrected N	F.C.	Soil quality
4	1.75	7.01	7.26	5.26	1.10	0.85	1.1	1	1.22	1.38	4.30	0.20	シルト質細砂混り砂
5	1.75	8.76	9.049	6.049	1.10	0.85	1.1	1	1.22	1.29	3.33	0.20	シルト質細砂混り砂



Depth (m)	Depth (ft)	CSR	N	C_N	C_D	$(N1)_{60}$	FC	
1.15	3.8	NA	5.0	2.00	0.86	11.8		Fine SAND
2.15	7.1	0.226	3.0	1.65	0.89	6.0		Silty fine SAND
3.15	10.3	0.271	11.0	1.45	0.91	19.8		Silty Coarse SAND with gravel
4.15	***13.6***	***0.298***	***10.0***	***1.31***	***0.92***	***16.6***	***20.0***	Fine SAND with SILT
5.15	***16.9***	***0.315***	***10.0***	***1.21***	***0.94***	***15.5***	***20.0***	Fine SAND with SILT
6.15	20.2	0.325	6.0	1.12	0.95	8.8		Silty fine SAND
7.15	23.5	0.331	28.0	1.06	0.96	38.7		Fine SAND with SILT
8.15	26.7	0.332	25.0	1.00	0.97	33.0		Fine SAND
9.15	30.0	0.331	36.0	0.95	0.97	45.4		Fine SAND
10.15	33.3	0.326	33.0	0.91	0.98	40.0		Fine SAND
					Mean:	16.0	20.0	
					St. Dev.	0.8	8.6	assigned

Case number:	202
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Kobe No : 44
References:	Kobe City Office, Constr.Eng.Res. Inst. (1999), Tokimatsu, K. Personal Com. (2000), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Liquefied
GPS LAT	34.728266 Coordinates were taken from NGL
GPS LONG	135.333941
Liq. layer consist of:	Medium SAND with SILT
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments
Site Response Anlaysis:	No
Comments:	Vs12m is updated based on Vs-SPTN correlations.
	https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en





Gravel Content (%):	NAV
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?		Yes	Yes	Yes	Yes
Data Class		B	-	B	B
d_{crit} range (m)		3.0 - 5.0		3.0 - 5.0	2.6 - 5.2
d_{crt} (m)		4.0	4.0	4.0	3.9
GWT (m)		1.6 ± 0.3	1.6	1.6 ± 0.1	1.6 ± 0.1
γ_{moist} (kN/m^3)		14.9 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)		15.7 ± 0.6	-	17.3 ± 0.5	18.9 ± 0.5
σ_v (kPa)		61.8 ± 5.6	67.2	69.3 ± 5.9	71.3 ± 8.3
σ_v' (kPa)		37.7 ± 3.8	43.1	45.2 ± 3.0	48.2 ± 4.2
a_{max} (g)		0.400 ± 0.060	0.4	0.400 ± 0.080	0.400 ± 0.080
r_d		0.87 ± 0.058	0.96	0.90 ± 0.058	0.93 ± 0.057
CSR		0.370 ± 0.068	0.388	0.359 ± 0.076	0.356 ± 0.076
M_w		6.90	6.90	6.90	6.90
D_{50}		- ± -	-	- ± -	NAV
% Fines		5.0 ± 1.0	5	5.0 ± 2.0	5.0 ± 8.6
% PI		-	-	-	NAV
N		4.7 ± 1.2	4.4	4.7 ± 1.2	4.7 ± 1.1
C_R		0.89	0.95	0.89	0.92
C_S		1.00	1.00	1.00	1.00
C_B		1.00	1.00	1.00	1.00
C_E		1.22	1.22	1.22	1.37
C_N		1.60	1.61	1.50	1.45
$(N_1)_{60}$		8.0 ± 2.0	8.3	7.6 ± 1.9	8.5 ± 2.1
V_{s30m} (m/s)		-	-	-	NAV
V_{s12m} (m/s)		158.5	-	158.5	167.6

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 5.2

Dip: 85 Width (km): 16 R_{jb} (km): 5.2

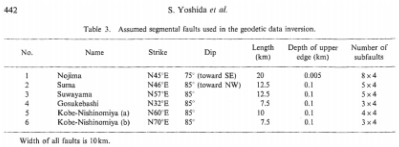

442 S. Yoshida *et al.*

Table 3. Assumed segmental faults used in the geodetic data inversion.

No.	Name	Strike	Dip	Length (km)	Depth of upper edge (km)	Number of subfaults
1	Nojima	N45°E	75° (toward SE)	20	0.005	8 × 4
2	Suma	N46°E	85° (toward NW)	12.5	0.1	5 × 4
3	Suwayama	N57°E	85°	12.5	0.1	5 × 4
4	Genukebashi	N32°E	85°	7.5	0.1	3 × 4
5	Kobe-Nishinomiya (a)	N60°E	85°	10	0.1	4 × 4
6	Kobe-Nishinomiya (b)	N70°E	85°	7.5	0.1	3 × 4

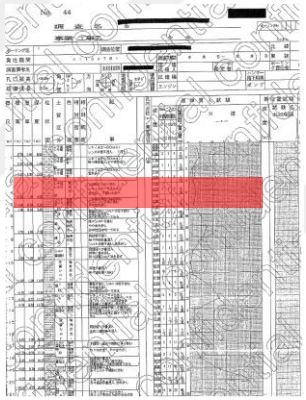
Width of all faults is 10 km.

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive

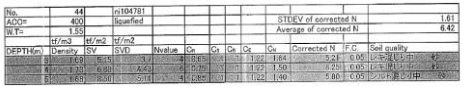


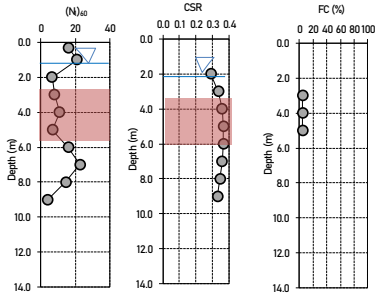






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Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
0.3	1.0	NA	7.0	2.00	0.83	15.9		Fine SAND
1.0	3.3	NA	9.0	2.00	0.86	21.0		Medium SAND
2.0	6.6	0.289	3.0	1.81	0.88	6.6		Coarse SAND
3.0	***9.8***	***0.335***	***4.0***	***1.59***	***0.90***	***7.9***	***5.0***	Medium SAND
4.0	***13.1***	***0.357***	***6.0***	***1.44***	***0.92***	***10.9***	***5.0***	Medium SAND
5.0	***16.4***	***0.366***	***4.0***	***1.32***	***0.94***	***6.8***	***5.0***	Medium SAND with SILT
6.0	19.7	0.365	10.0	1.23	0.95	15.9		Fine SAND
7.0	23.0	0.357	15.0	1.15	0.96	22.7		Fine SAND
8.0	26.2	0.345	10.0	1.09	0.97	14.4		Fine SAND
9.0	29.5	0.330	3.0	1.04	0.97	4.1		Silty fine SAND
					Mean:	8.5	5.0	
					St. Dev.	2.1	8.6	assigned

Case number:	203
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	7.2 (M_L), 6.9 (M_w)
Location:	Port Island Borehole Array Site
References:	Shibata et al.(1996), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Densification after earthquake, pore pressure increase, change in frequency
GPS LAT	34.673385 content of the strong motion recordings at depths 0 and 16 m. Liquefied.
GPS LONG	135.205767
Liq. layer consist of:	Sandy gravel
Geological Unit:	Af (Fill)
Site Response Anlaysis:	No
Comments:	Cetin (2000) "On January 17, 1995, an earthquake of magnitude 7.2 (Richter scale) struck the southern part of Hyogo Prefecture. Sand boils and liquefied, ejected soil were observed art numerous sites, mainly in the coastal areas of Hyogo and Osaka Prefectures. In particular, massive liquefaction was observed on man-made islands and in inland areas with high ground water tables. The entire area of the first stage reclaimed land for Port Island and the northern area of Rokko Island were filled mainly with Masado. The first stage reclamation of Port Island was carried out at its northern part of the island from 1966-1980. Rokko Ilsand was constructed from 1972 to 1990. The second stage reclamation of Port Island started in 1986 and would be finished by 1996. Masado is a weathered and decomposed low plasticity, low cohesion, high permeability, erodible granite. It is a sandy soil with much gravel, silt and clay. The mean grain diameter is mostly 0.2-6 mm. The contents of gravel and fines are about 0-65 % and 5-35 % respectively. PGA was recorded as 0.34g at the site. Based on the recordings, it became apparent that the site has liquefied before 6th second. Also the liquefied layer was estimated at depths 0-16 m. The average Japanese SPT energy ratio of 73% is used."

Port Island Borehole Array Site (SMS) is composed of loose deposits. However other sites composed of denser deposits. Site classes are different hence PGA is adjusted accordingly. Cetin (2000) used 0.34 g for the Port Island Borehole array, Port Island I and Rokko Island Site G sites (#203, 207, 209), and used 0.40 g for the Port Island Improved sites and Rokko Island Building D (#204,205,206,208). Scale factors are calculated in this study for sites (#203, 207, 209 and #204,205,206,208). PGA at the SMS is revised as this study attained the digital recording of the two component e.g. 0.296 g for Port Island Borehole Array Station. PGA values are slightly updated based on these information.

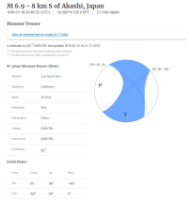
		Scale factors	amax
Port Island Borehole Array Station	Yes	1.00	0.350
Port Island Improved Site (Ikegaya)	No	1.04	0.363
Port Island Improved Site (Tanahashi)	No	1.01	0.354
Port Island Improved Site (Watanabe)	No	1.08	0.380
Port Island Site I	Yes	1.09	0.382
Rokko Island Building D	Yes	0.98	0.343
Rokko Island Site G	Yes	0.98	0.344

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



PI is assigned as 0 since FC<10%.





Gravel Content (%):	31.00
CPT available:	No
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	A	-	B	A
d_{crtc} range (m)	-	2.4 - 13.1	-	2.1 - 13.1	2.1 - 13.1
d_{crt} (m)	-	7.8	7.8	7.6	7.6
GWT (m)	-	2.4 ± 0.3	2.4	2.4 ± 0.1	2.4 ± 0.1
γ_{moist} (kN/m^3)	-	17.3 ± 0.6	-	17.3 ± 0.5	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	19.6 ± 0.6	-	19.6 ± 0.5	18.9 ± 0.5
σ_v (kPa)	-	146.9 ± 35.3	149.4	143.9 ± 36.2	139.8 ± 34.8
σ_v' (kPa)	-	94.3 ± 18.1	96.2	92.8 ± 18.3	88.7 ± 16.9
a_{max} (g)	-	0.340 ± 0.010	0.34	0.340 ± 0.068	0.350 ± 0.018
r_d	-	0.71 ± 0.101	0.9	0.72 ± 0.100	0.87 ± 0.100
CSR	-	0.244 ± 0.039	0.307	0.245 ± 0.061	0.313 ± 0.044
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	0.400 ± 0.200	-	0.400 ± 0.020	0.400 ± 0.657
% Fines	-	20.0 ± 5.0	20	20.0 ± 2.0	9.8 ± 8.3
% PI	-	-	-	-	0
N	-	5.7 ± 1.4	5.7	5.7 ± 1.4	5.8 ± 1.6
C_R	-	0.99	0.95	0.99	0.96
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	1.01	1.03	1.05	1.07
$(N_1)_{60}$	-	6.9 ± 1.7	6.8	7.1 ± 1.8	8.2 ± 2.2
$V_{s,30m}$ (m/s)	-	-	-	-	198.0
$V_{s,12m}$ (m/s)	-	170.7	-	152.4	191.3

EVENT PARAMETERS

1995 Hyogoken-Nambu

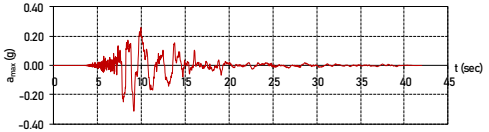
Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 2.6

Dip: 85 Width (km): 16 R_{jb} (km): 2.6

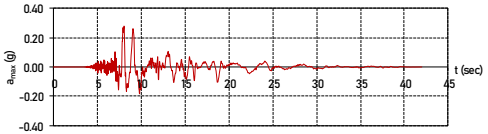
Full Record https://www.strongmotioncenter.org/vdc/scripts/event.plx?evt=1098#4047

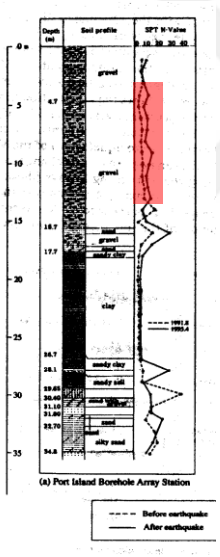
N_{H1}	5.2
N_{H2}	5.6
N_{gm}	5.4
PGA_{H1}	0.315
PGA_{H2}	0.278
PGA	0.296
M_w	6.9
$M_{w,cycle}$	3.9



Untill Liquefaction

$N_{H1,L}$	8.1
$N_{H2,L}$	7.6
$N_{gm,L}$	7.8
PGA_{H1}	0.083
PGA_{H2}	0.077
PGA_L	0.080
$M_{w,eq}$	5.70
t_L	??





(a) Port Island Borehole Array Station

Ishihara et al (1996)

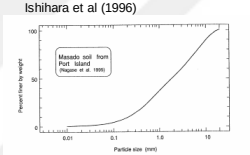
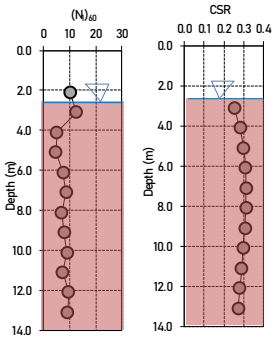
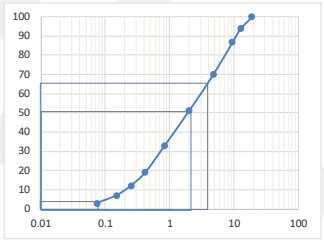


Fig. 3. Grain size distribution curve for the Masado soil tested



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
2.1	6.9	NA	5.0	1.67	0.88	10.1	man-made fill
3.1	10.2	0.253	7.0	1.46	0.91	12.6	man-made fill
4.1	13.5	0.282	3.0	1.34	0.92	5.1	man-made fill
5.1	16.7	0.300	3.0	1.24	0.94	4.8	man-made fill
6.1	20.0	0.310	5.0	1.16	0.95	7.5	man-made fill
7.1	23.3	0.313	6.0	1.10	0.96	8.6	man-made fill
8.1	26.6	0.312	5.0	1.04	0.97	6.9	man-made fill
9.1	29.9	0.306	6.0	1.00	0.97	7.9	man-made fill
10.1	33.1	0.299	7.0	0.95	0.98	8.9	man-made fill
11.1	36.4	0.290	6.0	0.92	0.98	7.4	man-made fill
12.1	39.7	0.281	8.0	0.89	0.99	9.5	man-made fill
13.1	43.0	0.272	8.0	0.86	0.99	9.2	man-made fill
					Mean:	8.2	
					St. Dev.	2.2	



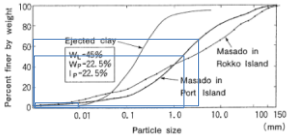


Fig. 16. Particle size distribution curves of Masado including coarse gravel up to 150 mm and ejected cohesive soil

Shibata et al (1996)

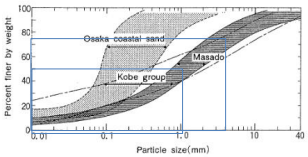


Fig. 15. Particle size distribution curve of Masado

	FC	GC	D50
Ishihara et al (1996) Figure 3	3	35	2
Shibata et al (1996) Figure 16	3	35	2
Shibata et al (1996) Figure 15	3	25	1
Yasuda et al (1996) Figure 2	20	30	1
Tokimatsu et al. (1996) Figure 11	10	30	0.8
Cetin (2000)	**20**		**0.4**
mean	10	31	1.2
stdev	8.3	4.2	0.7

Ishihara et al (1996)

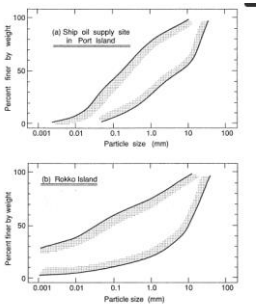


Fig. 1. Grain size distribution of the materials used for land reclamation: (a) Ship oil supply site in Port Island; (b) Rokko Island



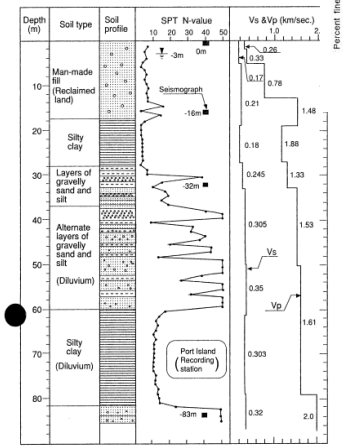


Fig. 5. Soil profile at the site of vertical array of seismograph (Toki, 1995)

GWT (m)

2.4 Shibara indicates groundwater was 2.4 m deep before earthquake

3.5 Shibara indicates groundwater was 3.5 m deep after earthquake

4 Groundwater level described by Elgamal et al.

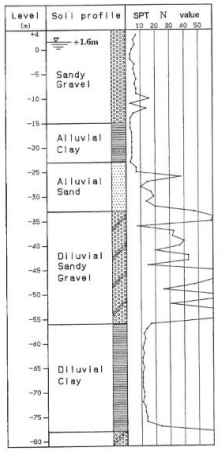


Fig. 20. Soil profile at Port Island Borehole Array Station

Case number:	204
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	7.2 (M_L), 6.9 (Mw)
Location:	Port Island Improved Site (Ikegaya, 80)
References:	Yasuda et al.(1996), Ikegaya (1980) in Japanese, Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No subsidence and no damage to structures were observed in the zones
GPS LAT	34.66056 densified by rod (vibro) compaction.
GPS LONG	135.21096
Liq. layer consist of:	gravel-sand-fines (fill)
Geological Unit:	Fill
Site Response Anlaysis:	No
Comments:	Cetin (2000) "On January 17, 1995, an earthquake of magnitude 7.2 (Richter scale) struck the southern part of Hyogo Prefecture. Sand boils and liquefied, ejected soil were observed at numerous sites, mainly in the coastal areas of Hyogo and Osaka Prefectures. In particular, massive liquefaction was observed on man-made islands and in inland areas with high ground water tables. The entire area of the first stage reclaimed land for Port Island and the northern area of Rokko Island were filled mainly with Masado. The first stage reclamation of Port Island was carried out at its northern part of the island from 1966-1980. Rokko Ilsand was constructed from 1972 to 1990. The second stage reclamation of Port Island started in 1986 and would be finished by 1996. The improved site is located on Port Island. Masado is a weathered and decomposed low plasticity, low cohesion, high permeability, erodible granite. It is a sandy soil with much gravel, silt and clay. The mean grain diameter is mostly 0.2-6 mm. The contents of gravel and fines are about 0-65 % and 5-35 % respectively. PGA was recorded as 0.34g at Port Island. The recorded motion was obtained at a liquefied site. Liquefaction of the site is believed not affected the PGA significantly because the fling was recorded at very early stages of the shaking. The water table is at depth 4-6 m at the island. The average Japanese SPT energy ratio of 73% is used." Port Island Borehole Array Site (SMS) is composed of loose deposits. However other sites composed of denser deposits. Site classes are different hence PGA is adjusted accordingly. Cetin (2000) used 0.34 g for the Port Island Borehole array, Port Island I and Rokko Island Site G sites (#203, 207, 209), and used 0.40 g for the Port Island Improved sites and Rokko Island Building D (#204,205,206,208). Scale factors are calculated in this study for sites (#203, 207, 209 and #204,205,206,208). PGA at the SMS is revised as this study attained the digital recording of the two component e.g. 0.296 g for Port Island Borehole Array Station. PGA values are slightly updated based on these information.

		Scale factors	amax
Port Island Borehole Array Station	Yes	1.00	0.350
Port Island Improved Site (Ikegaya)	No	1.04	0.363
Port Island Improved Site (Tanahashi)	No	1.01	0.354
Port Island Improved Site (Watanabe)	No	1.08	0.380
Port Island Site I	Yes	1.09	0.382
Rokko Island Building D	Yes	0.98	0.343
Rokko Island Site G	Yes	0.98	0.344

PI is assigned as 0 since FC<10%.

Vs12m is updated based on Vs-SPTN correlations.

https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en

Gravel Content (%):	31.00
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	No	No	No	No
Data Class	-	A	-	B	B
$d_{crt.}$ range (m)	-	5.0 - 12.0	-	5.0 - 12.0	5.0 - 12.0
d_{crt} (m)	-	8.5	8.5	8.5	8.5
GWT (m)	-	5.0 ± 0.3	5	5.0 ± 0.1	5.0 ± 0.1
γ_{moist} (kN/m^3)	-	17.3 ± 0.6	-	17.3 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	19.6 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	155.5 ± 23.3	159.4	155.5 ± 23.1	166.7 ± 24.2
σ_v' (kPa)	-	121.1 ± 12.3	125.3	121.1 ± 11.9	132.3 ± 13.0
a_{max} (g)	-	0.400 ± 0.040	0.4	0.400 ± 0.080	0.363 ± 0.073
r_d	-	0.80 ± 0.110	0.88	0.87 ± 0.110	0.95 ± 0.110
CSR	-	0.268 ± 0.048	0.293	0.291 ± 0.071	0.283 ± 0.067
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	0.400 ± 0.200	-	0.400 ± 0.050	0.400 ± 0.657
% Fines	-	20.0 ± 5.0	20	20.0 ± 2.0	9.8 ± 8.3
% PI	-	-	-	-	0
N	-	20.2 ± 3.8	20.2	20.3 ± 3.8	21.0 ± 4.5
C_R	-	1.00	1.00	1.00	0.97
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	0.89	0.92	0.92	0.88
$(N_1)_{60}$	-	21.9 ± 4.1	22.7	22.6 ± 4.2	24.4 ± 5.2
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	201.2	-	201.2	234.7

EVENT PARAMETERS

1995 Hyogoken-Nambu

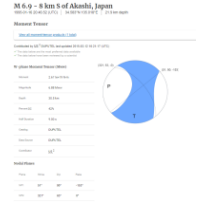
Magnitude: 6.90 — Yoshida et al (1996)

Fault Type: strike-slip — Z_{tor} (km): 0 — R_{rup} (km): 4.0

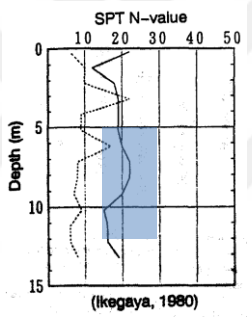
Dip: 85 — Width (km): 16 — R_{jb} (km): 4.0

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive









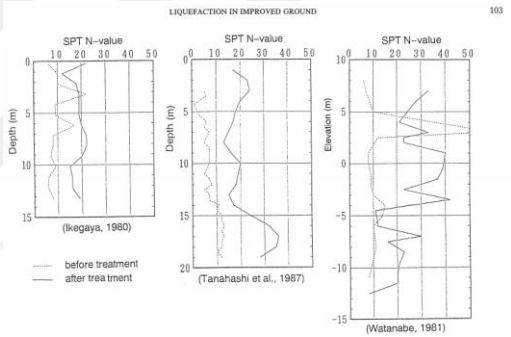
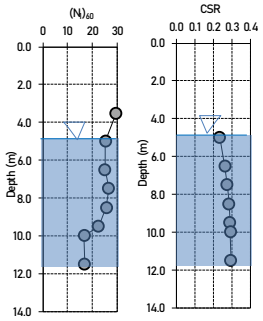


Fig. 9. Increase in *N*-value due to treatment using rod (vibro) compaction method



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
2.5	*8.2*	*NA*	*18.0*	*1.47*	*0.89*	*32.2*
3.5	*11.5*	*NA*	*19.0*	*1.24*	*0.91*	*29.4*
5.0	*16.4*	*0.233*	*19.0*	*1.04*	*0.94*	*25.2*
6.5	*21.3*	*0.261*	*20.0*	*0.96*	*0.95*	*25.0*
7.5	*24.6*	*0.274*	*22.0*	*0.91*	*0.96*	*26.5*
8.5	*27.9*	*0.283*	*22.0*	*0.88*	*0.97*	*25.5*
9.5	*31.2*	*0.290*	*20.0*	*0.84*	*0.97*	*22.5*
10.0	*32.8*	*0.292*	*15.0*	*0.83*	*0.98*	*16.6*
11.5	*37.7*	*0.294*	*16.0*	*0.79*	*0.98*	*16.9*
					Mean:	24.4
					St. Dev.	5.2

Yasuda et al (1996) "The mean grain diameter is mostly 0.2mm to 6mm. The contents of gravel and fines are about O to 65% and 5% to 35%, respectively.

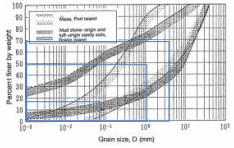


Fig. 2. Grain size distribution curves for fill soils at Port and Rokko Islands

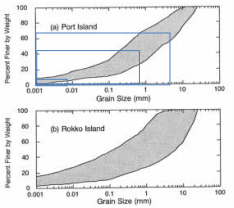


Fig. 11. Grain size distribution curves for fill materials at (a) Site A in Port Island and (b) Site C in Rokko Island (after Takenaka Corporation, 1995)

Tokimatsu et al. (1996)
"shows the range of the grain size distribution curves for the fill materials obtained with an SPT sampler. It should be noted that the actual fill materials often contain gravel particles up to 150 mm, which could not be recovered with the SPT

	FC	GC	D50
Ishihara et al (1996) Figure 3	3	35	2
Shibata et al (1996) Figure 16	3	35	2
Shibata et al (1996) Figure 15	3	25	1
Yasuda et al (1996) Figure 2	20	30	1
Tokimatsu et al. (1996) Figure 11	10	30	0.8
Cetin (2000)	**20**		**0.4**
mean	10	31	1.2
stdev	8.3	4.2	0.7

Ishihara et al (1996)

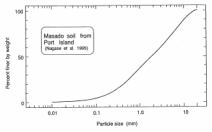


Fig. 3. Grain size distribution curve for the Masado soil tested

Shibata et al (1996)

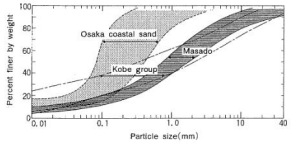
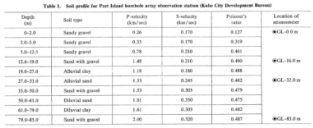


Fig. 15. Particle size distribution curve of Masado



Case number:	205
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	7.2 (M_L), 6.9 (Mw)
Location:	Port Island Improved Site (Tanahashi 87)
References:	Yasuda et al.(1996), Tanahashi (1978) in Japanese, Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No subsidence and no damage to structures were observed in the zones
GPS LAT	34.66945 densified by rod (vibro) compaction.
GPS LONG	135.23212
Liq. layer consist of:	gravel-sand-fines (fill)
Geological Unit:	Fill
Site Response Anlaysis:	No
Comments:	Cetin (2000) "On January 17, 1995, an earthquake of magnitude 7.2 (Richter scale) struck the southern part of Hyogo Prefecture. Sand boils and liquefied, ejected soil were observed at numerous sites, mainly in the coastal areas of Hyogo and Osaka Prefectures. In particular, massive liquefaction was observed on man-made islands and in inland areas with high ground water tables. The entire area of the first stage reclaimed land for Port Island and the northern area of Rokko Island were filled mainly with Masado. The first stage reclamation of Port Island was carried out at its northern part of the island from 1966-1980. Rokko Ilsand was constructed from 1972 to 1990. The second stage reclamation of Port Island started in 1986 and would be finished by 1996. The improved site is located on Port Island. Masado is a weathered and decomposed low plasticity, low cohesion, high permeability, erodible granite. It is a sandy soil with much gravel, silt and clay. The mean grain diameter is mostly 0.2-6 mm. The contents of gravel and fines are about 0-65 % and 5-35 % respectively. PGA was recorded as 0.34g at Port Island. The recorded motion was obtained at a liquefied site. Liquefaction of the site is believed not affected the PGA significantly because the fling was recorded at very early stages of the shaking. The water table is at depth 4-6 m at the island. The average Japanese SPT energy ratio of 73% is used."

Port Island Borehole Array Site (SMS) is composed of loose deposits. However other sites composed of denser deposits. Site classes are different hence PGA is adjusted accordingly. Cetin (2000) used 0.34 g for the Port Island Borehole array, Port Island I and Rokko Island Site G sites (#203, 207, 209), and used 0.40 g for the Port Island Improved sites and Rokko Island Building D (#204,205,206,208). Scale factors are calculated in this study for sites (#203, 207, 209 and #204,205,206,208). PGA at the SMS is revised as this study attained the digital recording of the two component e.g. 0.296 g for Port Island Borehole Array Station. PGA values are slightly updated based on these information.

		Scale factors	amax
Port Island Borehole Array Station	Yes	1.00	0.350
Port Island Improved Site (Ikegaya)	No	1.04	0.363
Port Island Improved Site (Tanahashi)	No	1.01	0.354
Port Island Improved Site (Watanabe)	No	1.08	0.380
Port Island Site I	Yes	1.09	0.382
Rokko Island Building D	Yes	0.98	0.343
Rokko Island Site G	Yes	0.98	0.344

PI is assigned as 0 since FC<10%.

Vs12m is updated based on Vs-SPTN correlations.

https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en



Gravel Content (%):	31.00
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	No	No	No	No
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	5.0 - 15.0	-	5.0 - 15.0	5.0 - 15.0
d_{crt} (m)	-	10.0	10.0	10.0	10.0
GWT (m)	-	5.0 ± 0.3	5	5.0 ± 0.1	5.0 ± 0.1
γ_{moist} (kN/m^3)	-	17.3 ± 0.6	-	17.3 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	19.6 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	185.0 ± 33.1	189.5	185.0 ± 33.0	197.6 ± 34.5
σ_v' (kPa)	-	135.9 ± 17.2	140.4	135.9 ± 16.8	148.5 ± 18.3
a_{max} (g)	-	0.400 ± 0.040	0.4	0.400 ± 0.080	0.354 ± 0.071
r_d	-	0.73 ± 0.126	0.86	0.82 ± 0.126	0.93 ± 0.126
CSR	-	0.257 ± 0.054	0.301	0.291 ± 0.075	0.284 ± 0.070
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	0.400 ± 0.200	-	0.400 ± 0.050	0.400 ± 0.657
% Fines	-	20.0 ± 5.0	20	20.0 ± 2.0	9.8 ± 8.3
% PI	-	-	-	-	0
N	-	18.2 ± 3.2	18.2	18.2 ± 3.2	18.5 ± 3.6
C_R	-	1.00	1.00	1.00	0.98
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	0.84	0.88	0.86	0.83
$(N_1)_{60}$	-	18.6 ± 3.3	19.5	19.1 ± 3.4	20.4 ± 4.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	201.2	-	201.2	234.7

EVENT PARAMETERS

1995 Hyogoken-Nambu

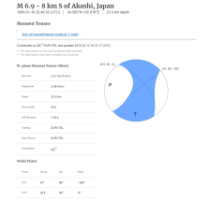
Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 4.4

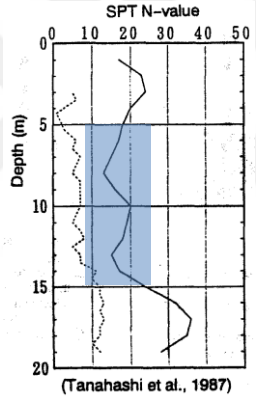
Dip: 85 Width (km): 16 R_{jb} (km): 4.4

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive









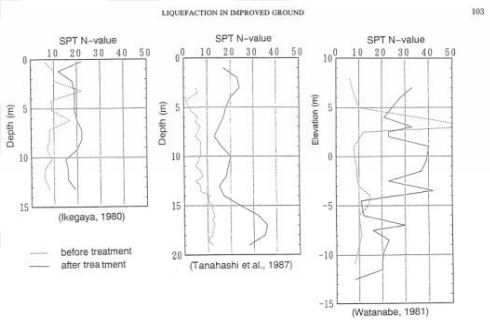


Fig. 9. Increase in *N*-value due to treatment using rod (vibro) compaction method

	FC	GC	D50
Ishihara et al (1996) Figure 3	3	35	2
Shibata et al (1996) Figure 16	3	35	2
Shibata et al (1996) Figure 15	3	25	1
Yasuda et al (1996) Figure 2	20	30	1
Tokimatsu et al. (1996) Figure 11	10	30	0.8
Cetin (2000)	**20**		**0.4**
mean	10	31	1.2
stdev	8.3	4.2	0.7

Ishihara et al (1996)

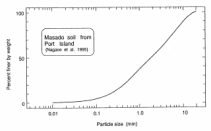
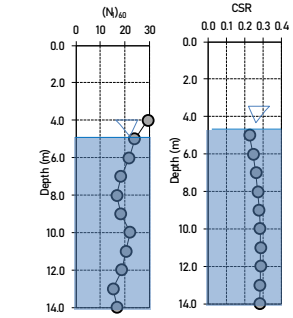


Fig. 3. Grain size distribution curve for the Masado soil tested



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
4.0	*13.1*	*NA*	*20.0*	*1.16*	*0.92*	*29.2*
5.0	*16.4*	*0.227*	*18.0*	*1.04*	*0.94*	*23.9*
6.0	*19.7*	*0.247*	*17.0*	*0.98*	*0.95*	*21.6*
7.0	*23.0*	*0.261*	*15.0*	*0.94*	*0.96*	*18.4*
8.0	*26.2*	*0.272*	*14.0*	*0.89*	*0.97*	*16.5*
9.0	*29.5*	*0.280*	*16.0*	*0.86*	*0.97*	*18.3*
10.0	*32.8*	*0.284*	*20.0*	*0.83*	*0.98*	*22.1*
11.0	*36.1*	*0.286*	*19.0*	*0.80*	*0.98*	*20.4*
12.0	*39.4*	*0.286*	*18.0*	*0.77*	*0.99*	*18.7*
13.0	*42.7*	*0.284*	*15.0*	*0.75*	*0.99*	*15.2*
14.0	*45.9*	*0.281*	*17.0*	*0.73*	*0.99*	*16.7*
15.0	*49.2*	*0.277*	*25.0*	*0.71*	*0.99*	*24.0*
					Mean:	20.4
					St. Dev.	4.0

Yasuda et al (1996) "The mean grain diameter is mostly 0.2mm to 6mm. The contents of gravel and fines are about O to 65% and 5% to 35%, respectively.

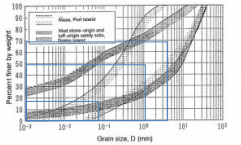


Fig. 2. Grain size distribution curves for fill soils at Port and Rokko Islands

Shibata et al (1996)

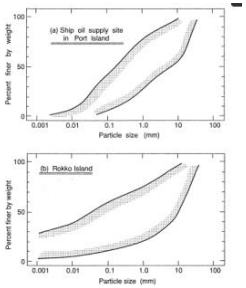


Fig. 1. Grain size distribution of the materials used for land reclamation: (a) Ship oil supply site in Port Island; (b) Rokko Island

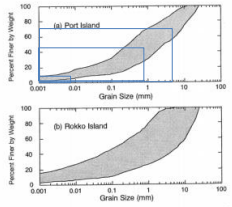
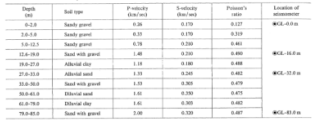


Fig. 11. Grain size distribution curves for fill materials at (a) Site A in Port Island and (b) Site C in Rokko Island (after Takenaka Corporation, 1995)

Tokimatsu et al. (1996)
"shows the range of the grain size distribution curves for the fill materials obtained with an SPT sampler. It should be noted that the actual fill materials often contain gravel particles up to 150 mm, which could not be recovered with the SPT



Case number:	206
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	7.2 (M_L), 6.9 (M_w)
Location:	Port Island Improved Site (Watanabe 81)
References:	Yasuda et al.(1996), Tanahashi (1978) in Japanese, Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	No subsidence and no damage to structures were observed in the zones
GPS LAT	34.66462 densified by rod (vibro) compaction.
GPS LONG	135.21818
Liq. layer consist of:	gravel-sand-fines (fill)
Geological Unit:	Fill
Site Response Anlaysis:	No
Comments:	Cetin (2000) "On January 17, 1995, an earthquake of magnitude 7.2 (Richter scale) struck the southern part of Hyogo Prefecture. Sand boils and liquefied, ejected soil were observed at numerous sites, mainly in the coastal areas of Hyogo and Osaka Prefectures. In particular, massive liquefaction was observed on man-made islands and in inland areas with high ground water tables. The entire area of the first stage reclaimed land for Port Island and the northern area of Rokko Island were filled mainly with Masado. The first stage reclamation of Port Island was carried out at its northern part of the island from 1966-1980. Rokko Ilsand was constructed from 1972 to 1990. The second stage reclamation of Port Island started in 1986 and would be finished by 1996. The improved site is located on Port Island. Masado is a weathered and decomposed low plasticity, low cohesion, high permeability, erodible granite. It is a sandy soil with much gravel, silt and clay. The mean grain diameter is mostly 0.2-6 mm. The contents of gravel and fines are about 0-65 % and 5-35 % respectively. PGA was recorded as 0.34g at Port Island. The recorded motion was obtained at a liquefied site. Liquefaction of the site is believed not affected the PGA significantly because the fling was recorded at very early stages of the shaking. The water table is at depth 4-6 m at the island. The average Japanese SPT energy ratio of 73% is used." Port Island Borehole Array Site (SMS) is composed of loose deposits. However other sites composed of denser deposits. Site classes are different hence PGA is adjusted accordingly. Cetin (2000) used 0.34 g for the Port Island Borehole array, Port Island I and Rokko Island Site G sites (#203, 207, 209), and used 0.40 g for the Port Island Improved sites and Rokko Island Building D (#204,205,206,208). Scale factors are calculated in this study for sites (#203, 207, 209 and #204,205,206,208). PGA at the SMS is revised as this study attained the digital recording of the two component e.g. 0.296 g for Port Island Borehole Array Station. PGA values are slightly updated based on these information.

		Scale factors	amax
Port Island Borehole Array Station	Yes	1.00	0.350
Port Island Improved Site (Ikegaya)	No	1.04	0.363
Port Island Improved Site (Tanahashi)	No	1.01	0.354
Port Island Improved Site (Watanabe)	No	1.08	0.380
Port Island Site I	Yes	1.09	0.382
Rokko Island Building D	Yes	0.98	0.343
Rokko Island Site G	Yes	0.98	0.344

PI is assigned as 0 since FC<10%.

Vs12m is updated based on Vs-SPTN correlations.

https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en



Gravel Content (%):	31.00
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	No	No	No	No
Data Class	-	A	-	B	B
d_{crtc} range (m)	-	5.0 - 14.0	-	5.0 - 14.0	5.0 - 14.0
d_{crt} (m)	-	9.5	9.5	9.5	9.5
GWT (m)	-	5.0 ± 0.3	5	5.0 ± 0.1	5.0 ± 0.1
γ_{moist} (kN/m^3)	-	17.3 ± 0.6	-	17.3 ± 0.5	20.0 ± 0.5
γ_{sat} (kN/m^3)	-	19.6 ± 0.6	-	20.4 ± 0.5	21.5 ± 0.5
σ_v (kPa)	-	175.2 ± 29.8	179.4	178.7 ± 30.9	197.1 ± 32.5
σ_v' (kPa)	-	131.0 ± 15.5	135.3	134.5 ± 16.3	152.9 ± 17.9
a_{max} (g)	-	0.400 ± 0.040	0.4	0.400 ± 0.080	0.380 ± 0.076
r_d	-	0.84 ± 0.121	0.87	0.96 ± 0.121	0.98 ± 0.121
CSR	-	0.293 ± 0.054	0.299	0.332 ± 0.080	0.313 ± 0.075
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	0.400 ± 0.200	-	0.400 ± 0.050	0.400 ± 0.657
% Fines	-	20.0 ± 5.0	20	20.0 ± 2.0	9.8 ± 8.3
% PI	-	-	-	-	0
N	-	30.9 ± 6.7	30.9	31.0 ± 6.7	31.4 ± 6.8
C_R	-	1.00	1.00	1.00	0.97
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	0.86	0.92	0.87	0.82
$(N_1)_{60}$	-	32.2 ± 7.0	34.6	32.8 ± 7.1	34.1 ± 7.4
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	222.5	-	249.9	271.3

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 Yoshida et al (1996)

Fault Type: strike-slip Z_{tor} (km): 0 R_{rup} (km): 4.0

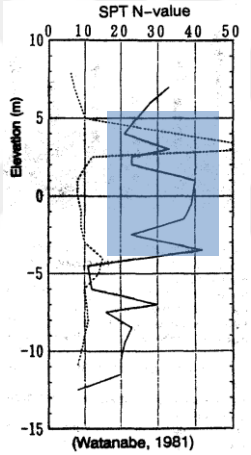
Dip: 85 Width (km): 16 R_{jb} (km): 4.0

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive









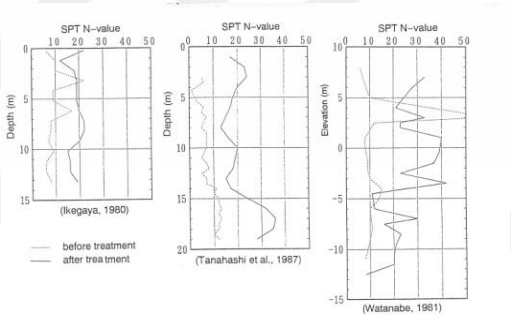


Fig. 9. Increase in *N*-value due to treatment using rod (vibro) compaction method

	FC	GC	D50
Ishihara et al (1996) Figure 3	3	35	2
Shibata et al (1996) Figure 16	3	35	2
Shibata et al (1996) Figure 15	3	25	1
Yasuda et al (1996) Figure 2	20	30	1
Tokimatsu et al. (1996) Figure 11	10	30	0.8
Cetin (2000)	**20**		**0.4**
mean	10	31	1.2
stdev	8.3	4.2	0.7

Ishihara et al (1996)

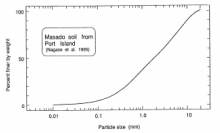


Fig. 3. Grain size distribution curve for the Masado soil tested

Yasuda et al (1996) "The mean grain diameter is mostly 0.2mm to 6mm. The contents of gravel and fines are about O to 65% and 5% to 35%, respectively.

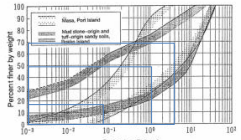


Fig. 2. Grain size distribution curves for fill soils at Port and Rokko Islands

Shibata et al (1996)

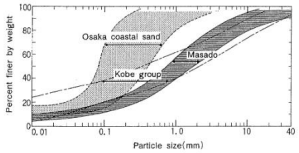
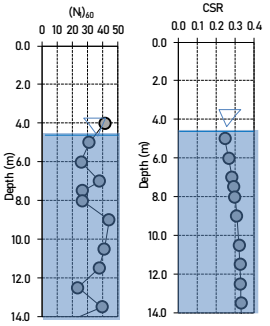


Fig. 15. Particle size distribution curve of Masado



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
4.0	*13.1*	*NA*	*29.0*	*1.13*	*0.92*	*41.2*	
5.0	*16.4*	*0.246*	*24.0*	*1.01*	*0.94*	*31.0*	
6.0	*19.7*	*0.267*	*21.0*	*0.95*	*0.95*	*26.0*	
7.0	*23.0*	*0.284*	*32.0*	*0.91*	*0.96*	*38.0*	
7.5	*24.6*	*0.291*	*23.0*	*0.89*	*0.96*	*26.8*	
8.0	*26.2*	*0.298*	*23.0*	*0.87*	*0.97*	*26.3*	
9.0	*29.5*	*0.309*	*40.0*	*0.83*	*0.97*	*44.2*	
10.5	*34.4*	*0.321*	*39.0*	*0.79*	*0.98*	*41.0*	
11.5	*37.7*	*0.326*	*37.0*	*0.76*	*0.98*	*37.7*	
12.5	*41.0*	*0.330*	*24.0*	*0.73*	*0.99*	*23.8*	
13.5	*44.3*	*0.332*	*41.0*	*0.71*	*0.99*	*39.5*	
14.5	47.6	0.332	11.0	0.69	0.99	10.3	clay layer
					Mean:	34.1	
					St. Dev.	7.4	

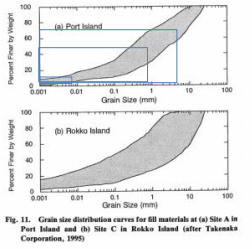


Fig. 11. Grain size distribution curves for fill materials at (a) Site A in Port Island and (b) Site C in Rokko Island (after Takenaka Corporation, 1995)

Tokimatsu et al. (1996)
"shows the range of the grain size distribution curves for the fill materials obtained with an SPT sampler. It should be noted that the actual fill materials often contain gravel particles up to 150 mm, which could not be recovered with the SPT



Case number:	207
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Port Island Site I
References:	Tokimatsu et al. (1996), Yasuda et al (1996), Cetin (2000), Cetin et al (2004
Nature of Failure:	Up to 50 cm of settlements; sand boils
GPS LAT	34.6764556
GPS LONG	135.2062028
Liq. layer consist of:	gravel-sand-fines (fill)
Geological Unit:	Fill
Site Response Anlaysis:	No



Comments: Cetin (2000) "On January 17, 1995, an earthquake of magnitude 7.2 (Richter scale) struck the southern part of Hyogo Prefecture. Sand boils and liquefied, ejected soil were observed at numerous sites, mainly in the coastal areas of Hyogo and Osaka Prefectures. In particular, massive liquefaction was observed on man-made islands and in inland areas with high ground water tables. The entire area of the first stage reclaimed land for Port Island and the northern area of Rokko Island were filled mainly with Masado. The first stage reclamation of Port Island was carried out at its northern part of the island from 1966-1980. Rokko Island was constructed from 1972 to 1990. The second stage reclamation of Port Island started in 1986 and would be finished by 1996. The improved site is located on Port Island. Masado is a weathered and decomposed low plasticity, low cohesion, high permeability, erodible granite. It is a sandy soil with much gravel, silt and clay. The mean grain diameter is mostly 0.2-6 mm. The contents of gravel and fines are about 0-65 % and 5-35 % respectively. PGA was recorded as 0.34g at Port Island. The recorded motion was obtained at a liquefied site. Liquefaction of the site is believed not to affect the PGA because the fling was recorded at very early stages of the shaking. The water table is at depth 4-6 m at the island. The average Japanese SPT energy ratio of 73% is used."

Port Island Borehole Array Site (SMS) is composed of loose deposits. However other sites composed of denser deposits. Site classes are different hence PGA is adjusted accordingly. Cetin (2000) used 0.34 g for the Port Island Borehole array, Port Island I and Rokko Island Site G sites (#203, 207, 209), and used 0.40 g for the Port Island Improved sites and Rokko Island Building D (#204,205,206,208). Scale factors are calculated in this study for sites (#203, 207, 209 and #204,205,206,208). PGA at the SMS is revised as this study attained the digital recording of the two component e.g. 0.296 g for Port Island Borehole Array Station. PGA values are slightly updated based on these information.

		Scale factors	amax
Port Island Borehole Array Station	Yes	1.00	0.350
Port Island Improved Site (Ikegaya)	No	1.04	0.363
Port Island Improved Site (Tanahashi)	No	1.01	0.354
Port Island Improved Site (Watanabe)	No	1.08	0.380
Port Island Site I	Yes	1.09	0.382
Rokko Island Building D	Yes	0.98	0.343
Rokko Island Site G	Yes	0.98	0.344

Gravel Content (%):	1.20
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	6.0 - 14.0	-	6.0 - 14.0	6.0 - 14.0
d_{crt} (m)	-	10.0	10.0	10.0	10.0
GWT (m)	-	3.0 ± 0.3	3	3.0 ± 0.1	3.0 ± 0.1
γ_{moist} (kN/m^3)	-	17.3 ± 0.6	-	17.3 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	18.9 ± 0.6	-	18.9 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	184.3 ± 25.7	192.5	184.3 ± 25.5	201.1 ± 27.7
σ_v' (kPa)	-	115.5 ± 13.3	123.3	115.5 ± 12.6	132.3 ± 14.9
a_{max} (g)	-	0.340 ± 0.040	0.34	0.340 ± 0.068	0.382 ± 0.076
r_d	-	0.67 ± 0.126	0.86	0.78 ± 0.126	0.87 ± 0.126
CSR	-	0.236 ± 0.053	0.295	0.274 ± 0.071	0.328 ± 0.082
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	0.400 ± 0.200	-	0.400 ± 0.050	0.400 ± 0.000
% Fines	-	20.0 ± 5.0	20	20.0 ± 2.0	9.8 ± 8.3
% PI	-	-	-	-	0
N	-	9.7 ± 1.6	9.7	9.7 ± 1.6	9.8 ± 1.6
C_R	-	1.00	1.00	1.00	0.98
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	0.91	0.91	0.94	0.88
$(N_1)_{60}$	-	10.8 ± 1.8	10.8	11.1 ± 1.8	11.5 ± 1.9
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	189.0	-	189.0	213.4

EVENT PARAMETERS

1995 Hyogoken-Nambu

Magnitude: 6.90 — Yoshida et al (1996)

Fault Type: strike-slip — Z_{tor} (km): 0 — R_{rup} (km): 2.3

Dip: 85 — Width (km): 16 — R_{jb} (km): 2.3





https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



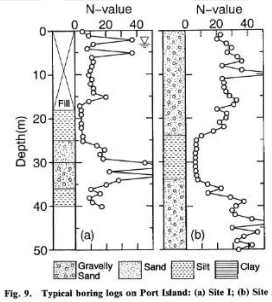
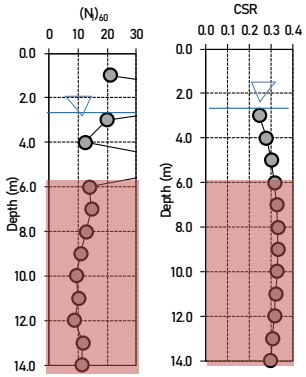


Fig. 9. Typical boring logs on Port Island: (a) Site 1; (b) Site A



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
1.0	3.3	NA	9.0	2.00	0.86	21.0	Fill
2.0	6.6	NA	37.0	1.64	0.88	73.2	Fill
3.0	9.8	0.245	12.0	1.34	0.90	19.9	Fill
4.0	13.1	0.279	8.0	1.23	0.92	12.4	Fill
5.0	16.4	0.302	37.0	1.14	0.94	53.9	Fill
6.0	***19.7***	***0.317***	***10.0***	***1.07***	***0.95***	***13.8***	Fill
7.0	***23.0***	***0.326***	***11.0***	***1.01***	***0.96***	***14.5***	Fill
8.0	***26.2***	***0.330***	***10.0***	***0.96***	***0.97***	***12.6***	Fill
9.0	***29.5***	***0.331***	***9.0***	***0.91***	***0.97***	***10.9***	Fill
10.0	***32.8***	***0.328***	***8.0***	***0.88***	***0.98***	***9.4***	Fill
11.0	***36.1***	***0.322***	***9.0***	***0.84***	***0.98***	***10.2***	Fill
12.0	***39.4***	***0.315***	***8.0***	***0.81***	***0.99***	***8.7***	Fill
13.0	***42.7***	***0.307***	***11.0***	***0.79***	***0.99***	***11.7***	Fill
14.0	***45.9***	***0.300***	***11.0***	***0.76***	***0.99***	***11.3***	Fill
					Mean:	11.5	
					St. Dev.	1.9	

	FC	GC	D50
Ishihara et al (1996) Figure 3	3	35	2
Shibata et al (1996) Figure 16	3	35	2
Shibata et al (1996) Figure 15	3	25	1
Yasuda et al (1996) Figure 2	20	30	1
Tokimatsu et al. (1996) Figure 11	10	30	0.8
Cetin (2000)	**20**		**0.4**
mean	10	31	1.2
stdev	8.3	4.2	0.7

Yasuda et al (1996) "The mean grain diameter is mostly 0.2mm to 6mm. The contents of gravel and fines are about O to 65% and 5% to 35%, respectively.

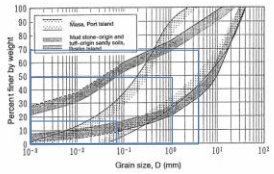


Fig. 2. Grain size distribution curves for fill soils at Port and Rokko Islands

Depth (m)		
0	18	Fill
18	25.11	Silt
25.11	30.02	Sand
30.02	36.05	Gravelly Sand
36.05	40	Silt

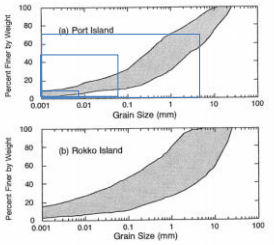


Fig. 11. Grain size distribution curves for fill materials at (a) Site A in Port Island and (b) Site C in Rokko Island (after Takenaka Corporation, 1995)

Tokimatsu et al. (1996) "shows the range of the grain size distribution curves for the fill materials obtained with an SPT sampler. It should be noted that the actual fill materials often contain gravel particles up to 150 mm, which could not be recovered with the SPT sampler. "

Ishihara et al (1996)

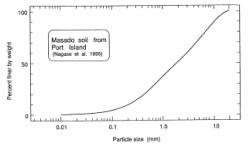


Fig. 3. Grain size distribution curve for the Masado soil tested

Shibata et al (1996)

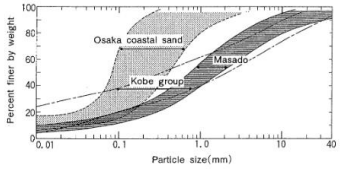


Fig. 15. Particle size distribution curve of Masado

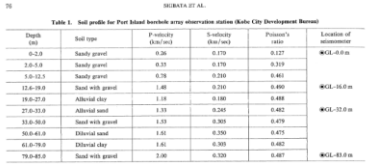


Table 1. Soil profile for Port Island borehole array observation station (Kobe City Development Bureau)

Case number:	208
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Rokko Island Building D
References:	Tokimatsu et al. (1996), Ishihara et al (1996), Shibata et al (1996), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Ground settlement, tilted structures
GPS LAT	34.6866944
GPS LONG	135.2604194
Liq. layer consist of:	gravel-sand-fines (fill)
Geological Unit:	Fill
Site Response Anlaysis:	No
Comments:	Cetin (2000) "On January 17, 1995, an earthquake of magnitude 7.2 (Richter scale) struck the southern part of Hyogo Prefecture. Sand boils and liquefied, ejected soil were observed at numerous sites, mainly in the coastal areas of Hyogo and Osaka Prefectures. In particular, massive liquefaction was observed on man-made islands and in inland areas with high ground water tables. The entire area of the first stage reclaimed land for Port Island and the northern area of Rokko Island were filled mainly with Masado. The first stage reclamation of Port Island was carried out at its northern part of the island from 1966-1980. Rokko Island was constructed from 1972 to 1990. The second stage reclamation of Port Island started in 1986 and would be finished by 1996. The southern part of Rokko Island consist of mainly of crsuhed tuff and sand- stone of the Kobe and Osaka Groups from Rokko Mountains. The soils of southern Rokko Island includes more fines and clay, i.e about 20 % and 10 % compared with about 15 % and 5 % of decomposed granite (Masado). Site G is located in the northern part of Rokko Island. Masado is a weathered and decomposed low plasticity, low cohesion, high permeability, erodible granite. It is a sandy soil with much gravel, silt and clay. The mean grain diameter is mostly 0.2-6 mm. The contents of gravel and fines are about 0-65 % and 5-35 % respectively. PGA was recorded as 0.34g at Port Island. The recorded motion was obtained at a liquefied site. Liquefaction of the site is believed not affected the PGA significantly because the fling was recorded at very early stages of the shaking. Rokko Island is predicted to have experienced the same level of shaking The water table is at depth 4-6 m at the island. The average Japanese SPT energy ratio of 73% is used. Port Island Borehole Array Site (SMS) is composed of loose deposits. However other sites composed of denser deposits. Site classes are different hence PGA is adjusted accordingly. Cetin (2000) used 0.34 g for the Port Island Borehole array, Port Island I and Rokko Island Site G sites (#203, 207, 209), and used 0.40 g for the Port Island Improved sites and Rokko Island Building D (#204,205,206,208). Scale factors are calculated in this study for sites (#203, 207, 209 and #204,205,206,208). PGA at the SMS is revised as this study attained the digital recording of the two component e.g. 0.296 g for Port Island Borehole Array Station. PGA values are slightly updated based on these information.

		Scale factors	amax
Port Island Borehole Array Station	Yes	1.00	0.350
Port Island Improved Site (Ikegaya)	No	1.04	0.363
Port Island Improved Site (Tanahashi)	No	1.01	0.354
Port Island Improved Site (Watanabe)	No	1.08	0.380
Port Island Site I	Yes	1.09	0.382
Rokko Island Building D	Yes	0.98	0.343
Rokko Island Site G	Yes	0.98	0.344

https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en

Gravel Content (%):	31.00
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	A	-	B	B
d_{crtc} range (m)	-	4.0 - 11.0	-	4.0 - 11.0	4.0 - 11.0
d_{crt} (m)	-	7.5	7.5	7.5	7.5
GWT (m)	-	4.0 ± 0.3	4	4.0 ± 0.1	4.0 ± 0.1
γ_{moist} (kN/m^3)	-	17.3 ± 0.6	-	17.3 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	19.6 ± 0.6	-	19.6 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	138.2 ± 23.2	141.4	138.2 ± 23.1	147.8 ± 24.2
σ_v' (kPa)	-	103.8 ± 12.2	107.3	103.8 ± 11.8	113.4 ± 12.9
a_{max} (g)	-	0.400 ± 0.050	0.4	0.400 ± 0.080	0.343 ± 0.069
r_d	-	0.89 ± 0.099	0.9	0.93 ± 0.099	0.93 ± 0.099
CSR	-	0.307 ± 0.055	0.31	0.322 ± 0.075	0.271 ± 0.063
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	0.800 ± 0.300	-	0.800 ± 0.050	1.540 ± 1.381
% Fines	-	25.0 ± 5.0	25	25.0 ± 2.0	12.6 ± 8.1
% PI	-	-	-	-	NAV
N	-	14.8 ± 6.0	14.8	14.8 ± 6.0	15.3 ± 6.1
C_R	-	0.99	0.95	0.99	0.96
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	0.96	0.98	0.99	0.95
$(N_1)_{60}$	-	17.1 ± 6.9	16.8	17.6 ± 7.1	19.0 ± 7.6
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	213.4	-	213.4	213.4

EVENT PARAMETERS

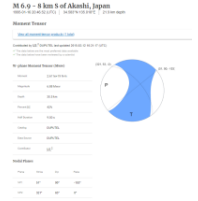
1995 Hyogoken-Nambu

Magnitude: 6.90 — Yoshida et al (1996)

Fault Type: strike-slip — Z_{tor} (km): 0 — R_{rup} (km): 4.5

Dip: 85 — Width (km): 16 — R_{jb} (km): 4.5





https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive



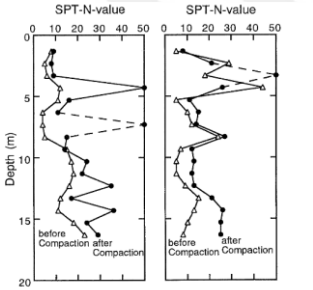
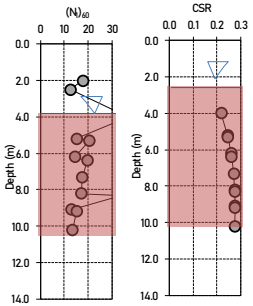


Fig. 24. SPT *N*-values before and after installation of sand compaction piles



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	Borehole
2.0	*6.6*	*NA*	*9.0*	*1.64*	*0.88*	*17.8*	1
2.5	*8.2*	*NA*	*7.0*	*1.47*	*0.89*	*12.5*	2
4.0	*13.1*	*0.219*	*25.0*	*1.16*	*0.92*	*36.5*	2
5.2	*17.1*	*0.245*	*11.0*	*1.07*	*0.94*	*15.1*	2
5.3	*17.4*	*0.247*	*15.0*	*1.06*	*0.94*	*20.5*	1
6.2	*20.3*	*0.260*	*11.0*	*1.01*	*0.95*	*14.4*	1
6.4	*21.0*	*0.262*	*15.0*	*1.00*	*0.95*	*19.5*	2
7.3	*24.0*	*0.270*	*14.0*	*0.96*	*0.96*	*17.6*	2
8.2	*26.9*	*0.275*	*14.0*	*0.92*	*0.97*	*17.0*	1
8.3	*27.2*	*0.275*	*28.0*	*0.91*	*0.97*	*33.8*	2
9.1	*29.9*	*0.276*	*11.0*	*0.88*	*0.97*	*12.9*	2
9.2	*30.2*	*0.276*	*13.0*	*0.88*	*0.97*	*15.2*	1
10.2	*33.5*	*0.275*	*12.0*	*0.84*	*0.98*	*13.5*	2
					Mean:	19.0	
					St. Dev.	7.6	

Yasuda et al (1996)

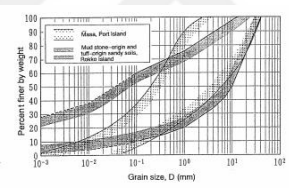


Fig. 2. Grain size distribution curves for fill soils at Port and Rokko Islands

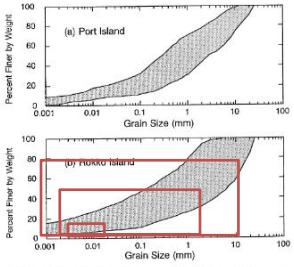


Fig. 11. Grain size distribution curves for fill materials at (a) Site A in Port Island and (b) Site C in Rokko Island (after Takenaka Corporation, 1995)

Depth (m)	N	Depth (m)	N
1.15	9	1.17	8
2.16	8	2.15	21
3.17	9	3.18	50
4.17	50	4.15	26
5.17	16	5.17	11
6.15	11	6.15	15
7.15	50	7.14	14
8.18	15	8.16	27
9.19	14	9.18	12
10.18	24	10.18	13
11.17	22	11.17	12
12.16	35	12.18	13
13.2	17	13.17	21
14.17	36	14.16	26
15.18	24	15.17	25
16.18	29	16.18	25

Ishihara et al (1996)

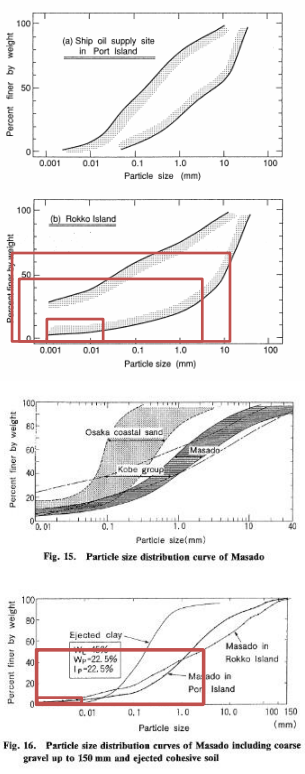


Fig. 15. Particle size distribution curve of Masado

Fig. 16. Particle size distribution curves of Masado including coarse gravel up to 150 mm and ejected cohesive soil

	FC	GC	D50
Ishihara et al (1996)	20	30	1
Shibata et al (1996)	5	50	4
Shibata et al (1996)	3	25	1
Yasuda et al (1996)	20	30	1
Tokimatsu et al. (1996	15	20	0.7
Cetin (2000)			
mean	13	31	1.5
stdev	8.1	11.4	1.4

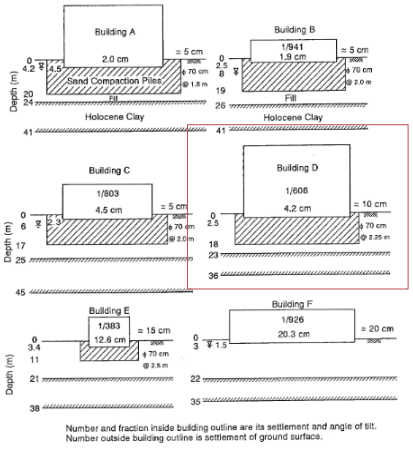


Fig. 23. Effects of sand compaction piles on building performance in Rokko Island

Case number:	209
Earthquake:	1995 Hyogoken-Nambu
Magnitude:	6.9
Location:	Rokko Island Site G
References:	Tokimatsu et al. (1996), Ishihara et al (1996), Shibata et al (1996), Cetin (2000), Cetin et al (2004, 2018)
Nature of Failure:	Up to 50 cm of settlements; sand boils
GPS LAT	34.6928111
GPS LONG	135.2556889
Liq. layer consist of:	gravel-sand-fines (fill)
Geological Unit:	Fill
Site Response Anlaysis:	No
Comments:	Cetin (2000) "On January 17, 1995, an earthquake of magnitude 7.2 (Richter scale) struck the southern part of Hyogo Prefecture. Sand boils and liquefied, ejected soil were observed at numerous sites, mainly in the coastal areas of Hyogo and Osaka Prefectures. In particular, massive liquefaction was observed on man-made islands and in inland areas with high ground water tables. The entire area of the first stage reclaimed land for Port Island and the northern area of Rokko Island were filled mainly with Masado. The first stage reclamation of Port Island was carried out at its northern part of the island from 1966-1980. Rokko Island was constructed from 1972 to 1990. The second stage reclamation of Port Island started in 1986 and would be finished by 1996. The southern part of Rokko Island consist of mainly of crsuhed tuff and sand- stone of the Kobe and Osaka Groups from Rokko Mountains. The soils of southern Rokko Island includes more fines and clay, i.e about 20 % and 10 % compared with about 15 % and 5 % of decomposed granite (Masado). Site G is located in the northern part of Rokko Island. Masado is a weathered and decomposed low plasticity, low cohesion, high permeability, erodible granite. It is a sandy soil with much gravel, silt and clay. The mean grain diameter is mostly 0.2-6 mm. The contents of gravel and fines are about 0-65 % and 5-35 % respectively. PGA was recorded as 0.34g at Port Island. The recorded motion was obtained at a liquefied site. Liquefaction of the site is believed not affected the PGA significantly because the fling was recorded at very early stages of the shaking. Rokko Island is predicted to have experienced the same level of shaking The water table is at depth 4-6 m at the island. The average Japanese SPT energy ratio of 73% is used. Port Island Borehole Array Site (SMS) is composed of loose deposits. However other sites composed of denser deposits. Site classes are different hence PGA is adjusted accordingly. Cetin (2000) used 0.34 g for the Port Island Borehole array, Port Island I and Rokko Island Site G sites (#203, 207, 209), and used 0.40 g for the Port Island Improved sites and Rokko Island Building D (#204,205,206,208). Scale factors are calculated in this study for sites (#203, 207, 209 and #204,205,206,208). PGA at the SMS is revised as this study attained the digital recording of the two component e.g. 0.296 g for Port Island Borehole Array Station. PGA values are slightly updated based on these information.

		Scale factors	amax
Port Island Borehole Array Station	Yes	1.00	0.350
Port Island Improved Site (Ikegaya)	No	1.04	0.363
Port Island Improved Site (Tanahashi)	No	1.01	0.354
Port Island Improved Site (Watanabe)	No	1.08	0.380
Port Island Site I	Yes	1.09	0.382
Rokko Island Building D	Yes	0.98	0.343
Rokko Island Site G	Yes	0.98	0.344

https://gbank.gsj.jp/seamless/seamless2015/2d/index.html?lang=en

Gravel Content (%):	31.00
CPT available:	No
Vs available:	?

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	Yes	Yes	Yes	Yes
Data Class	-	B	-	B	B
d_{crtc} range (m)	-	4.0 - 19.0	-	4.0 - 19.0	4.0 - 19.0
d_{crt} (m)	-	11.5	11.5	11.5	11.5
GWT (m)	-	4.0 ± 0.3	4	4.0 ± 0.1	4.0 ± 0.1
γ_{moist} (kN/m^3)	-	17.3 ± 0.6	-	17.3 ± 0.5	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	18.9 ± 0.6	-	18.9 ± 0.5	20.6 ± 0.5
σ_v (kPa)	-	211.0 ± 47.5	219.5	211.0 ± 47.4	230.3 ± 51.7
σ_v' (kPa)	-	137.3 ± 23.4	146.4	137.3 ± 23.0	156.6 ± 27.3
a_{max} (g)	-	0.340 ± 0.040	0.34	0.340 ± 0.068	0.344 ± 0.069
r_d	-	0.59 ± 0.142	0.83	0.72 ± 0.142	0.72 ± 0.142
CSR	-	0.199 ± 0.055	0.275	0.245 ± 0.070	0.237 ± 0.068
M_w	-	6.90	6.90	6.90	6.90
D_{50}	-	0.400 ± 0.200	-	0.400 ± 0.050	1.540 ± 1.381
% Fines	-	20.0 ± 5.0	20	20.0 ± 2.0	12.6 ± 8.1
% PI	-	-	-	-	NAV
N	-	12.0 ± 3.4	12	12.0 ± 3.4	12.1 ± 3.3
C_R	-	1.00	1.00	1.00	0.98
C_S	-	1.00	1.00	1.00	1.00
C_B	-	1.00	1.00	1.00	1.00
C_E	-	1.22	1.22	1.22	1.37
C_N	-	0.84	0.84	0.86	0.81
$(N_1)_{60}$	-	12.2 ± 3.5	12.3	12.5 ± 3.6	13.1 ± 3.6
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	189.0	-	189.0	189.0

EVENT PARAMETERS

1995 Hyogoken-Nambu

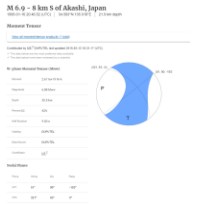
Magnitude: 6.90 — Yoshida et al (1996)

Fault Type: strike-slip — Z_{tor} (km): 0 — R_{rup} (km): 3.7

Dip: 85 — Width (km): 16 — R_{jb} (km): 3.7

https://earthquake.usgs.gov/earthquakes/eventpage/usp0006rew/executive







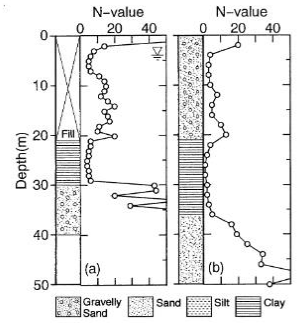
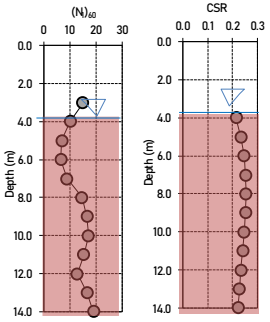


Fig. 10. Typical boring logs on Rokko Island: (a) Site G; (b) Site B



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
3.0	*9.8*	*NA*	*9.0*	*1.34*	*0.90*	*14.9*	*Fill*
4.0	*13.1*	*0.214*	*7.0*	*1.16*	*0.92*	*10.2*	*Fill*
5.0	*16.4*	*0.234*	*5.0*	*1.08*	*0.94*	*6.9*	*Fill*
6.0	*19.7*	*0.246*	*5.0*	*1.02*	*0.95*	*6.6*	*Fill*
7.0	*23.0*	*0.252*	*7.0*	*0.97*	*0.96*	*8.9*	*Fill*
8.0	*26.2*	*0.253*	*12.0*	*0.92*	*0.97*	*14.6*	*Fill*
9.0	*29.5*	*0.251*	*14.0*	*0.89*	*0.97*	*16.5*	*Fill*
10.0	*32.8*	*0.247*	*15.0*	*0.85*	*0.98*	*17.0*	*Fill*
11.0	*36.1*	*0.240*	*14.0*	*0.82*	*0.98*	*15.4*	*Fill*
12.0	*39.4*	*0.234*	*12.0*	*0.79*	*0.99*	*12.8*	*Fill*
13.0	*42.7*	*0.228*	*16.0*	*0.77*	*0.99*	*16.6*	*Fill*
14.0	*45.9*	*0.223*	*19.0*	*0.74*	*0.99*	*19.1*	*Fill*
15.0	*49.2*	*0.219*	*14.0*	*0.72*	*0.99*	*13.7*	*Fill*
16.0	*52.5*	*0.216*	*15.0*	*0.70*	*0.99*	*14.3*	*Fill*
17.0	*55.8*	*0.214*	*16.0*	*0.69*	*0.99*	*14.9*	*Fill*
18.0	*59.1*	*0.213*	*12.0*	*0.67*	*1.00*	*10.9*	*Fill*
19.0	*62.3*	*0.212*	*11.0*	*0.65*	*1.00*	*9.8*	*Fill*
					Mean:	13.1	
					St. Dev.	3.6	

Yasuda et al (1996)

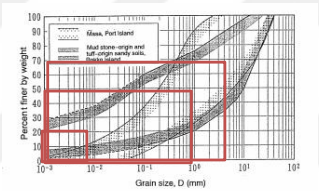


Fig. 2. Grain size distribution curves for fill soils at Port and Rokko Islands

Tokimatsu et al (1996)

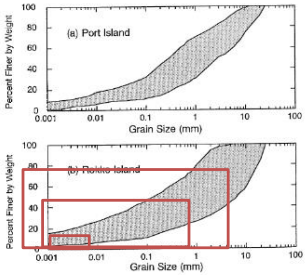


Fig. 11. Grain size distribution curves for fill materials at (a) Site A in Port Island and (b) Site C in Rokko Island (after Takenaka Corporation, 1995)

Depth (m)	
0	21 Fill
21	30 Clay
30	40 Gravelly Sand

Ishihara et al (1996)

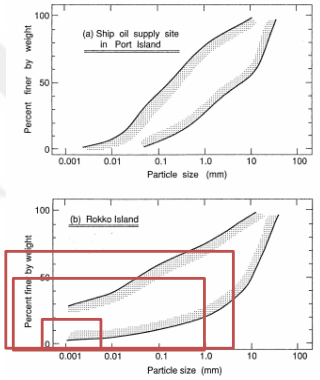


Fig. 1. Grain size distribution of the materials used for land reclamation: (a) Ship oil supply site in Port Island; (b) Rokko Island

Shibata et al (1996)

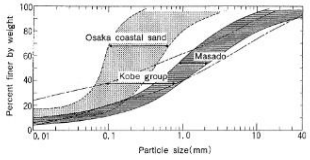


Fig. 15. Particle size distribution curve of Masado

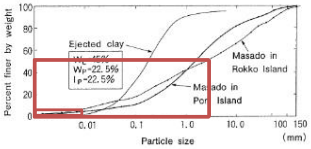


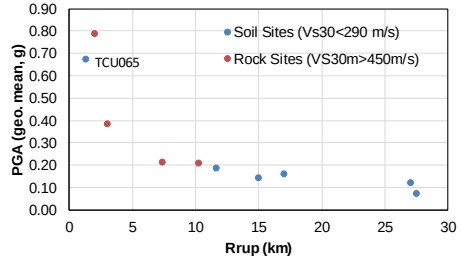
Fig. 16. Particle size distribution curves of Masado including coarse gravel up to 150 mm and ejected cohesive soil

	FC	GC	D50
Ishihara et al (1996) Figure 1	20	30	1
Shibata et al (1996) Figure 16	5	50	4
Shibata et al (1996) Figure 15	3	25	1
Yasuda et al (1996) Figure 2	20	30	1
Tokimatsu et al. (1996) Figure 11	15	20	0.7
Cetin (2000)			
mean	13	31	1.5
stdev	8.1	11.4	1.4

Case number:	308
Earthquake:	1999 Chi-Chi Earthquake
Magnitude:	7.6
Location:	Wufeng Site A WAS-1(Chi-Li Rd. and Lan-Shen Day Cares, Wufeng)
References:	PEER, Stweart et al 2004, Zheng and Chen 2001, Chu et al 2004, 2006
Nature of Failure:	No ground failure https://apps.peer.berkeley.edu/lifelines/research_projects
GPS LAT	24.05606
GPS LONG	120.69849
Liq. layer consist of:	Sand (SM) https://cecas.clemson.edu/chichi
Geological Unit:	alluvial plain are underlainby Pliocene sandstones, shales and mudstones Stewart et al (2004)
Site Response Anlaysis:	No
Comments:	The site is located near a one storey building where liquefaction was not observed hence decided to be included in the database. Vs measurements are not available at the SPT location. Moss et al. (2003) "Strong motion station in the direct vicinity on similar soil stratigraphy, PGA=0.6." . Boulanger and Idriss (2014) took PGA=0.65g for site A1 and 0.67 g for Site B (WBS-1) (SPT catalogue) and took 0.60 g Site B for CPT catalogue. Nearest station TCU065 is located 800 m from site A and 965 m from site B. SMS Vs3m is 290 m/s. Geometric mean of the two component recorded at the station is 0.67 g at TCU065. Site A has Vs12m of 190 m/s based on Vs-SPTN correlations. Vs30m of the site is unkown but probably close to a value of 200 m/s (average Vs30m values of the sites around Wufeng). Site specific amplification (Abrahamson and Silva 2014) is calculated as 0.85 hence amax is calibrated as 0.569 g. Event specific model is constructed by using the nearby station data located on the footwall site as shown on the right bottom. Stewart et al. (2004) "Mean energy ratios (ER) of about 75% are observed for depths 3 m, with a small reduction in ER at shallow depths (mean of 69% in upper 3 m)."



st	y	x	Epicenter	Vertical	N-S	E-W	Rrup	Vs30 (m/S	pga (G)
TCU065	24°03.54'	120°41.46'	25.57	257.8	563.22	774.42	1.3	290	0.673222
TCU076	23°54.47'	120°40.54'	15.25	275.38	420.02	340.1	3	573	0.385274
TCU110	23°57.70'	120°34.19'	27.5	116.28	187.52	178.24	11.6	199.5	0.186362
TCU112	24°03.36'	120°25.41'	45.5	65.26	68	78.3	27.5	191	0.074382
TCU117	24°07.98'	120°27.62'	47.22	89.96	113.46	121.3	27	207	0.119587
TCU120	23°58.80'	120°36.78'	24.62	166.52	193.5	222.98	7.4	458	0.211741
TCU123	24°01.06'	120°32.56'	32.89	85.54	131.96	149	15	289	0.142937
TCU129	23°52.70'	120°41.06	13.54	334.96	610.76	983	2	506.5	0.789847
TCU138	23°55.34'	120°35.07'	55.34	110.36	207.4	202.24	10.2	604	0.20877
CHY104	23°40.19'	120°27.94'	41.33	129.68	177.12	142.9	17	218.8	0.162174



Gravel Contents (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	No	-	No
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	6.2 - 11.0
d_{crt} (m)	-	-	7.4	-	8.6
GWT (m)	-	-	1.1	-	1.1 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	19.6 ± 0.5
σ_v (kPa)	-	-	147	-	168.4 ± 16.1
σ_v' (kPa)	-	-	85	-	95.1 ± 8.7
a_{max} (g)	-	-	0.65	-	0.569 ± 0.114
r_d	-	-	0.94	-	0.84 ± 0.111
CSR	-	-	0.686	-	0.551 ± 0.133
M_w	-	-	7.6	-	7.62
D_{50}	-	-	-	-	0.123 ± 0.019
% Fines	-	-	24	-	23.5 ± 6.2
% PI	-	-	-	-	3.2
N	-	-	12.6	-	16.2 ± 2.9
C_R	-	-	0.97	-	0.97
C_S	-	-	1	-	1.00
C_B	-	-	1	-	1.01
C_E	-	-	1.25	-	1.25
C_N	-	-	1.08	-	1.03
$(N_1)_{60}$	-	-	16.5	-	20.4 ± 3.7
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	191.7

EVENT PARAMETERS

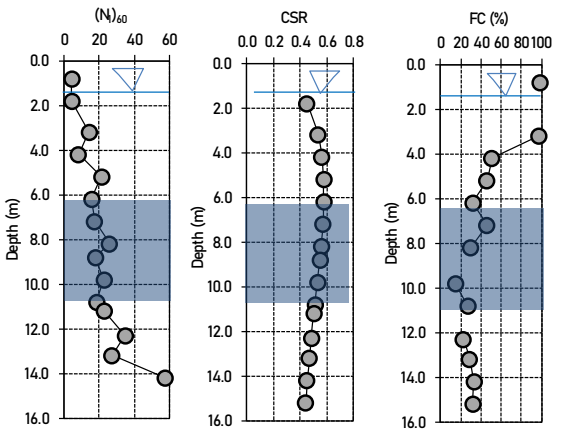
1999 Chi-Chi Earthquake — Zheng and Chen 2001

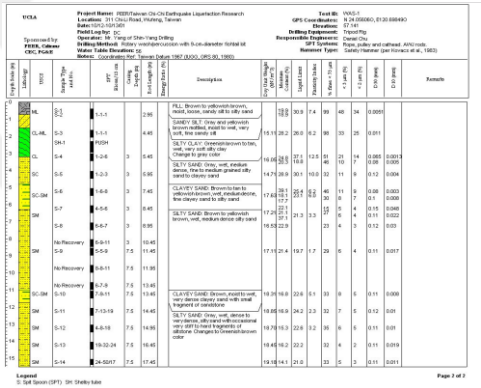
Magnitude: 7.62 — footwall

Fault Type: inland thrust ea — Z_{tor} (km): 0 — R_{rup} (km): 0.6

Dip: 30 — Width (km): 40 — R_{jb} (km): 0.6

ACCELERATION TIME HISTORY





	Rod Length (m)	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
Sandy Silt	2.95	0.8	2.6	NA	2	2.00	0.85	4.3
CL-ML	4.45	1.8	5.9	0.450	2	1.90	0.89	4.3
CL	5.45	3.2	10.5	0.534	8	1.56	0.91	14.3
SC	5.95	4.2	13.8	0.561	5	1.40	0.92	8.1
SC-SM	7.45	5.2	17.1	0.573	14	1.28	0.94	21.3
SC-SM/SM	8.45	6.2	20.3	0.575	11	1.19	0.95	15.7
SM	***8.95***	***7.2***	***23.6***	***0.569***	***13***	***1.12***	***0.96***	***17.5***
SM	***10.45***	***8.2***	***26.9***	***0.557***	***20***	***1.06***	***0.97***	***25.7***
SM	***11.45***	***8.8***	***28.9***	***0.548***	***14***	***1.02***	***0.97***	***17.6***
SM	***11.95***	***9.8***	***32.2***	***0.529***	***19***	***0.97***	***0.98***	***22.8***
SM	***13.45***	***10.8***	***35.4***	***0.510***	***16***	***0.93***	***0.98***	***18.5***
SC-SM	13.45	11.2	36.7	0.502	20	0.92	0.98	22.7
SM	14.45	12.3	40.4	0.481	32	0.88	0.99	34.9
SM	14.95	13.2	43.3	0.466	26	0.85	0.99	27.5
SM	16.45	14.2	46.6	0.451	56	0.82	0.99	57.4
SM	17.45	15.2	49.9	0.440	67	0.80	0.99	66.7
							Mean:	20.4
							St. Dev.	3.7

stick-up is approx. 2.1 m

Boundary

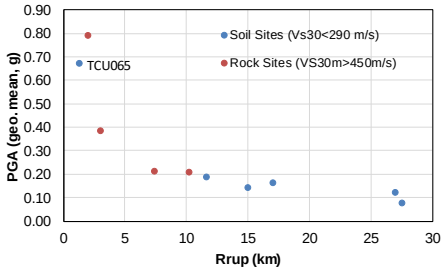
Depth (m)	Moisture Content (%)	LL	PI	FC (<75 µm)	Clay (<2 µm)	Silt	D_{50}	D_{10}	
0.6	19.9	30.9	7.4	99.0	34.0	65.0	0.005	-	WAS 1
	18.9	-	-		-	-	-	-	WAS 1
1.8	28.2	26.0	6.2	98.0	25.0	73.0	0.011	-	WAS 1
3.2	24.8	37.1	12.5	51.0	14.0	37.0	0.065	0.001	WAS 1
	20.3	18.8		46.0	7.0	39.0	0.080	0.005	WAS 1
4.2	28.9	30.1	10.0	32.0	9.0	23.0	0.120	0.004	WAS 1
5.4	39.1	25.4	6.2	46.0	9.0	37.0	0.080	0.003	WAS 1
	18.1	23.1	6.0	30.0	7.0	23.0	0.100	0.008	WAS 1
	17.7	-	-		-	-	-	-	WAS 1
6.4	***22.1***	***-***	***-***	***15.0***	***4.0***	***11.0***	***0.150***	***0.048***	WAS 1
	21.1	***21.3***	***3.3***	***27.0***	***4.0***	***23.0***	***0.110***	***0.022***	WAS 1
	37.1	***-***	***-***		***-***	***-***	***-***		WAS 1
7.2	***22.9***	***-***	***-***	***23.0***	***3.0***	***20.0***	***0.120***	***0.030***	WAS 1
8.8	***21.4***	***19.7***	***1.7***	***29.0***	***4.0***	***25.0***	***0.110***	***0.017***	WAS 1
11.2	16.8	22.6	5.1	33.0	5.0	-	0.110	0.008	WAS 1
12.2	16.9	24.2	2.3	32.0	5.0	-	0.120	0.100	WAS 1
13.2	15.3	22.6	3.2	35.0	5.0	-	0.110	0.010	WAS 1
14.2	16.2	22.2	-	32.0	2.0	-	0.110	0.019	WAS 1
15.2	14.1	21.0	-	33.0	3.0	-	0.110	0.110	WAS 1
	Mean:	20.5	2.5	23.5	3.8	19.8	0.123	0.029	
	St. Dev.	1.1	1.1	6.2	0.5	6.2	0.019	0.014	

Case number:	309
Earthquake:	1999 Chi-chi Earthquake
Magnitude:	7.6
Location:	Wufeng Site B -WBS1 (Chi-Li Rd. and Lan-Shen Day Cares, Wufeng)
References:	PEER, Stweart et al 2004, Zheng and Chen 2001, Chu et al 2004, 2006
Nature of Failure:	Lateral Spreads and sand boil https://apps.peer.berkeley.edu/lifelines/research_projects
GPS LAT	24.05359
GPS LONG	120.698939
Liq. layer consist of:	Sand (SM) https://cecas.clemson.edu/chichi
Geological Unit:	alluvial plain are underlainby Pliocene sandstones, shales and mudstones Stewart et al (2004)
Site Response Anlaysis:	No
Comments:	"Strong motion station in the direct vicinity on similar soil stratigraphy, PGA=0.6." Moss et al. (2003). Boulanger and Idriss (2014) took PGA=0.65 for site A1 and 0.67 for Site B (WBS-1) (SPT catalogue) and took 0.60g Site B for CPT catalogue. Nearest station TCU065 is located 800 m from site A and 965 m from site B the station has Vs3m of 290 m/s. Geometric mean of the two component recorded at the station is 0.67g at TCU065. Site B has Vs12m of 183 m/s based on Vs measurement. Vs30m of the site is 190 m/s. Site specific amplification (Abrahamson and Silva 2014) is calculated as 0.82 hence amax is calibrated as 0.551 g. Event specific model is constructed by using the nearby station data located on the footwall site as shown on the right bottom. SPT hammer energy measurements are available.





st	y	x	Epicenter (	Vertical	N-S	E-W	Rrup	Vs30 (m/S	pga (G)
TCU065	24°03.54'	120°41.46'	25.57	257.8	563.22	774.42	1.3	290	0.673222
TCU076	23°54.47'	120°40.54'	15.25	275.38	420.02	340.1	3	573	0.385274
TCU110	23°57.70'	120°34.19'	27.5	116.28	187.52	178.24	11.6	199.5	0.186362
TCU112	24°03.36'	120°25.41'	45.5	65.26	68	78.3	27.5	191	0.074382
TCU117	24°07.98'	120°27.62'	47.22	89.96	113.46	121.3	27	207	0.119587
TCU120	23°58.80'	120°36.78'	24.62	166.52	193.5	222.98	7.4	458	0.211741
TCU123	24°01.06'	120°32.56'	32.89	85.54	131.96	149	15	289	0.142937
TCU129	23°52.70'	120°41.06	13.54	334.96	610.76	983	2	506.5	0.789847
TCU138	23°55.34'	120°35.07'	55.34	110.36	207.4	202.24	10.2	604	0.20877
CHY104	23°40.19'	120°27.94'	41.33	129.68	177.12	142.9	17	218.8	0.162174



Gravel Contents (%):	NAV
CPT available:	Yes
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	Yes	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	1.6 - 8.5
d_{crt} (m)	-	-	3.3	-	5.0
GWT (m)	-	-	1.5	-	1.6 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	65	-	101.2 ± 23.9
σ_v' (kPa)	-	-	47	-	67.2 ± 12.6
a_{max} (g)	-	-	0.67	-	0.551 ± 0.110
r_d	-	-	0.98	-	0.93 ± 0.070
CSR	-	-	0.587	-	0.501 ± 0.110
M_w	-	-	-	-	7.62
D_{50}	-	-	-	-	0.208 ± 0.242
% Fines	-	-	-	-	29.8 ± 10.7
% PI	-	-	-	-	0
N	-	-	7.9	-	12.0 ± 4.6
C_R	-	-	0.86	-	1.00
C_S	-	-	1	-	1.00
C_B	-	-	1	-	1.01
C_E	-	-	1.25	-	1.11
C_N	-	-	1.42	-	1.23
$(N_1)_{60}$	-	-	12.1	-	16.5 ± 6.3
V_{s30m} (m/s)	-	-	-	-	190.0
V_{s12m} (m/s)	-	-	-	-	183.0

EVENT PARAMETERS

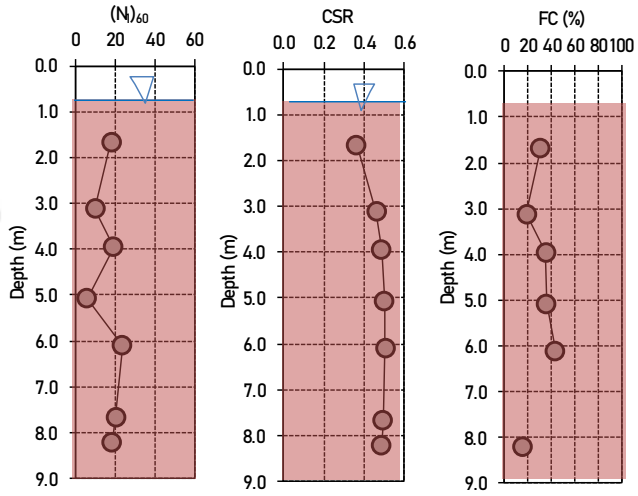
1999 Chi-chi Earthquake — Zheng and Chen 2001

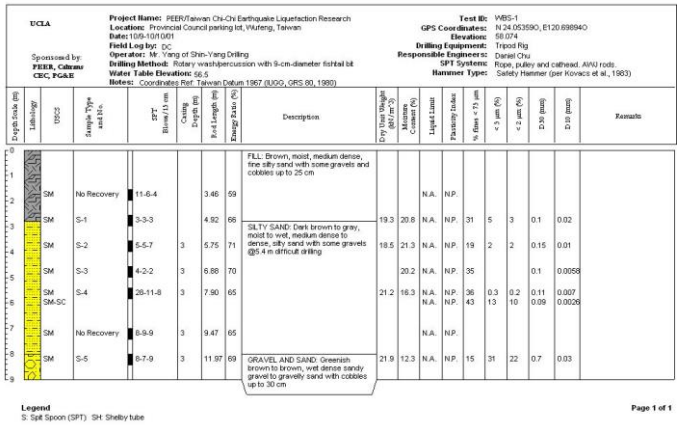
Magnitude: 7.62

Fault Type: inland thrust ea — Z_{tor} (km): 0 — R_{rup} (km): 0.35

Dip: 30 — Width (km): 40 — R_{jb} (km): 0.35

ACCELERATION TIME HISTORY



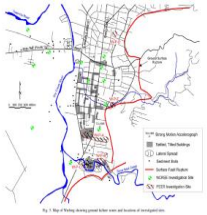


no short rod correction as energy measurements were available. <75 µm <2 µm

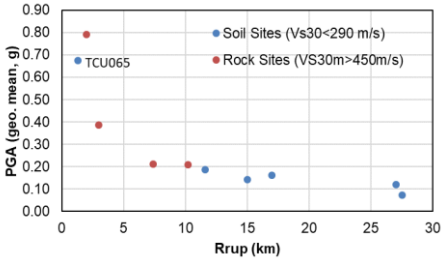
Rod Length (m)	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		ER	C_E	PI	FC	Silt	Clay	D_{50}	D_{10}
3.5	*1.7*	*5.4*	*0.363*	*10*	*1.82*	*1.00*	*18*	*SM*	*59.0*	*0.98*	*NP*	*31.0*	*28.0*	*3.0*	*0.100*	*0.020*
4.9	*3.1*	*10.2*	*0.460*	*6*	*1.48*	*1.00*	*10*	*SM*	*66.0*	*1.10*	*NP*	*19.0*	*17.0*	*2.0*	*0.150*	*0.010*
5.8	*4.0*	*13.0*	*0.485*	*12*	*1.35*	*1.00*	*19*	*SM*	*71.0*	*1.18*	*NP*	*35.0*	*35.0*	*0.0*	*0.100*	*0.006*
6.9	*5.1*	*16.7*	*0.501*	*4*	*1.23*	*1.00*	*6*	*SM*	*70.0*	*1.17*	*NP*	*36.0*	*35.8*	*0.2*	*0.110*	*0.007*
7.9	*6.1*	*20.0*	*0.504*	*19*	*1.14*	*1.00*	*24*	*SM/SM-SC*	*65.0*	*1.08*	*NP*	*43.0*	*33.0*	*10.0*	*0.090*	*0.003*
9.5	*7.7*	*25.2*	*0.492*	*18*	*1.03*	*1.00*	*20*	*SM*	*65.0*	*1.08*	*NP*				*-*	*-*
12.0	*8.2*	*26.9*	*0.485*	*16*	*1.00*	*1.00*	*19*	*SM*	*69.0*	*1.15*	*NP*	*15.0*		*22??*	*0.700*	*0.030*
						Mean:	16.5	*gravel?*	66.4	1.11	NP	29.8	29.8	3.0	0.208	0.013
						St. Dev.	6.3		4.1	0.07	NP	10.7	7.8	4.1	0.242	0.010

CPT indicates plastic material below 5 m (RF=3%). However atterberg limits are available which indicates non plastic material. Hence the selection was made based on SPT sounding since field performance was available at SPT also.

Case number:	310
Earthquake:	1999 Chi-Chi Earthquake
Magnitude:	7.6
Location:	Wufeng Site C, WCS-1 (Yue-The Rd. Rice Paddy, Wufeng)
References:	PEER, Stweart et al 2004, Zheng and Chen 2001, Chu et al 2004, 2006
Nature of Failure:	Lateral Spreads https://apps.peer.berkeley.edu/lifelines/research_projects
GPS LAT	24.05282
GPS LONG	120.69624
Liq. layer consist of:	Silty Sand https://cecas.clemson.edu/chichi
Geological Unit:	alluvial plain are underlainby Pliocene sandstones, shales and mudstones
Site Response Anlaysis:	No
Comments:	"Strong motion station in the direct vicinity on similar soil stratigraphy, PGA=0.6." Moss et al. (2003). Boulanger and Idriss (2014) took PGA=0.67 (SPT catalogue) and took 0.60 for CPT catalogue. Nearest station TCU065 is located 800 m from site C and the station has Vs30 of 290 m/s where the PGA is measured as 0.67 g. Site A has Vs12 of 190 m/s based on Vs-SPTN correlations. Vs30m of the site is unkown but probably close to a value of 200 m/s (average Vs30m values of the sites around Wufeng). Site specific amplification (Abrahamson and Silva 2014) is calculated as 0.85 hence amax is calibrated as 0.570 g. Event specific model is constructed by using the nearby station data located on the footwall site as shown on the right bottom. SPT hammer energy measurements are available.



st	y	x	Epicenter	Vertical	N-S	E-W	Rrup	Vs30 (m/S)	pga (G)
TCU065	24°03.54'	120°41.46'	25.57	257.8	563.22	774.42	1.3	290	0.673222
TCU076	23°54.47'	120°40.54'	15.25	275.38	420.02	340.1	3	573	0.385274
TCU110	23°57.70'	120°34.19'	27.5	116.28	187.52	178.24	11.6	199.5	0.186362
TCU112	24°03.36'	120°25.41'	45.5	65.26	68	78.3	27.5	191	0.074382
TCU117	24°07.98'	120°27.62'	47.22	89.96	113.46	121.3	27	207	0.119587
TCU120	23°58.80'	120°36.78'	24.62	166.52	193.5	222.98	7.4	458	0.211741
TCU123	24°01.06'	120°32.56'	32.89	85.54	131.96	149	15	289	0.142937
TCU129	23°52.70'	120°41.06'	13.54	334.96	610.76	983	2	506.5	0.789847
TCU138	23°55.34'	120°35.07'	55.34	110.36	207.4	202.24	10.2	604	0.20877
CHY104	23°40.19'	120°27.94'	41.33	129.68	177.12	142.9	17	218.8	0.162174



Gravel Contents (%):	NAV
CPT available:	Yes
Vs available:	No

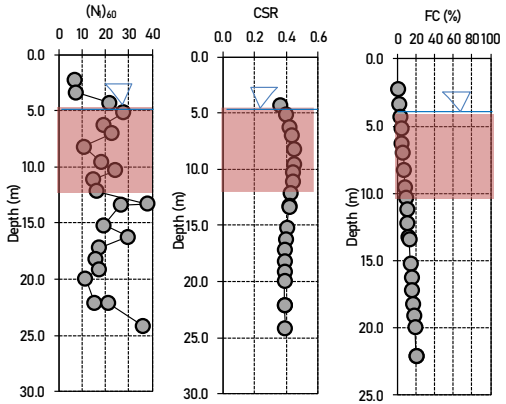
Summary of Input Data

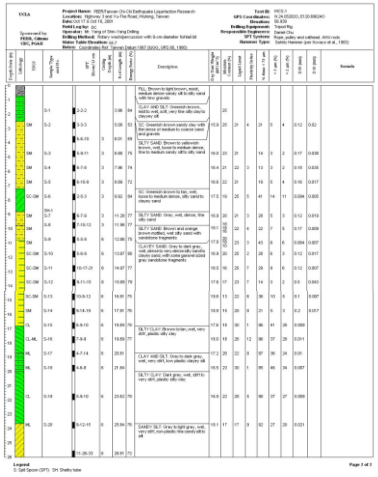
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	4.2 - 11.0
d_{crt} (m)	-	-	-	-	7.6
GWT (m)	-	-	-	-	4.2 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.4 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	143.8 ± 23.4
σ_v' (kPa)	-	-	-	-	110.6 ± 12.5
a_{max} (g)	-	-	-	-	0.570 ± 0.114
r_d	-	-	-	-	0.92 ± 0.100
CSR	-	-	-	-	0.442 ± 0.103
M_w	-	-	-	-	7.62
D_{50}	-	-	-	-	0.158 ± 0.026
% Fines	-	-	-	-	19.2 ± 6.1
% PI	-	-	-	-	3.3 ± 6.1
N	-	-	-	-	18.6 ± 0.6
C_R	-	-	-	-	1.00
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.01
C_E	-	-	-	-	1.24
C_N	-	-	-	-	0.96
$(N_1)_{60}$	-	-	-	-	22.3 ± 3.5
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	207.1

EVENT PARAMETERS

1999 Chi-Chi Earthquake	Zheng and Chen 2001	
Magnitude: 7.62		footwall
Fault Type: inland thrust ea	Z_{tor} (km): 0	R_{rup} (km): 0.45
Dip: 30	Width (km): 40	R_{jb} (km): 0.45

ACCELERATION TIME HISTORY





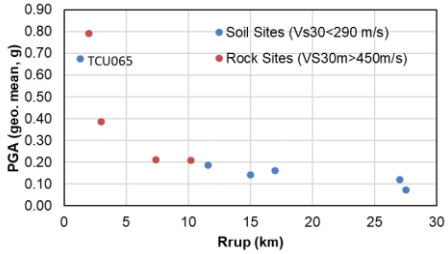
*no short rod correction since hammer energy was measured.

Rod Length (m)	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	ER	C_E		PI	<75 µm FC	Silt	<2 µm Clay	D_{50}	D_{10}	wc	LL	wc/LL	
3.96	2.3	7.4	NA	4	1.60	1.00	6.9	64	1.07	Clay and Silt										
5.08	3.4	11.1	NA	6	1.31	1.00	7.0	53	0.88	Silty Sand	4.0	21.0	17.0	4.0	0.12					
6.01	***4.3***	***14.1***	***0.364***	***16***	***1.16***	***1.00***	***21.6***	***69***	***1.15***	***Silty Sand***	***-***	***-***	***-***	***-***	***-***					
6.88	***5.2***	***17.0***	***0.396***	***20***	***1.10***	***1.00***	***27.6***	***75***	***1.25***	***Silty Sand***	***-***	***14.0***	***12.0***	***2.0***	***0.170***					
7.96	***6.3***	***20.5***	***0.423***	***15***	***1.03***	***1.00***	***19.2***	***74***	***1.23***	***Silty Sand***	***3.0***	***13.0***	***11.0***	***2.0***	***0.180***		***21.0***	***22.0***	0.95	susceptible
8.69	***7.0***	***22.9***	***0.435***	***19***	***0.99***	***1.00***	***22.7***	***72***	***1.20***	***Silty Sand***	***-***	***19.0***	***15.0***	***4.0***	***0.160***					
9.92	**8.2**	**27.0**	**0.446**	**8**	**0.93**	**1.00**	**10.5**	**84**	**1.40**	**SC-SM**	**5.0**	**41.0**	**30.0**	**11.0**	**0.094**		**19.0**	**25.0**	0.76	not susceptible
11.28	***9.6***	***31.4***	***0.447***	***16***	***0.88***	***1.00***	***18.2***	***77***	***1.28***	***Silty Sand***	***3.0***	***28.0***	***25.0***	***3.0***	***0.120***		***20.0***	***21.0***	0.95	susceptible
11.98	***10.3***	***33.7***	***0.445***	***22***	***0.85***	***1.00***	***24.3***	***77***	***1.28***	***Silty Sand***	***4.0***	***22.0***	***17.0***	***5.0***	***-***		***18.0***	***22.0***	0.82	susceptible
12.85	11.2	36.6	0.439	14	0.83	1.00	14.6	75	1.25	Clayey sand	3.0	43.0	37.0	6.0	0.084					
13.87	12.2	39.9	0.430	15	0.80	1.00	16.1	80	1.33	Clayey sand	2.0	28.0	25.0	3.0	0.120					
14.97	13.3	43.5	0.420	38	0.77	1.00	37.8	77	1.28	Clayey sand	7.0	29.0	23.0	6.0	0.120					
15.09	13.4	43.9	0.419	26	0.77	1.00	26.4	79	1.32	Clayey sand	7.0	14.0	12.0	2.0	0.500					
16.91	15.2	49.9	0.404	21	0.73	1.00	19.2	75	1.25	Clayey sand	6.0	36.0	31.0	5.0	0.100					
17.91	16.2	53.2	0.399	33	0.71	1.00	29.7	76	1.27	Clayey sand	8.0	21.0	18.0	3.0	0.200					
18.89	17.2	56.4	0.394	19	0.69	1.00	17.1	78	1.30		1.0	96.0	68.0	28.0	0.009					
19.89	18.2	59.7	0.392	18	0.67	1.00	15.6	77	1.28		12.0	96.0	68.0	28.0	0.001					
20.81	19.1	62.7	0.390	21	0.66	1.00	17.3	-	***1.24***	assigned	8.0	97.0	73.0	24.0	0.010					
21.64	19.9	65.4	0.389	14	0.65	1.00	11.3	-	***1.24***	assigned	1.0	95.0	61.0	34.0	0.007					
23.82	22.1	72.6	0.390	19	0.62	1.00	15.3	78	1.30		5.0	98.0	71.0	27.0	0.009					
23.82	22.1	72.6	0.390	27	0.62	1.00	21.2	76	1.27		9.0	92.0	65.0	27.0	0.021					
25.84	24.1	79.2	0.392	50	0.59	1.00	35.8	72	1.20											
						Mean:	22.3	74.4	1.24		3.3	19.2	16.0	3.2	0.158					
						St. Dev.	3.5	9.1	0.15		0.6	6.1	5.6	1.3	0.026					

Case number:	311
Earthquake:	1999 Chi-Chi Earthquake
Magnitude:	7.6
Location:	Wufeng Site C, WCS-2 (Yue-The Rd. Rice Paddy, Wufeng)
References:	PEER, Stweart et al 2004, Zheng and Chen 2001, Chu et al 2004, 2006
Nature of Failure:	Lateral Spreads https://apps.peer.berkeley.edu/lifelines/research_projects
GPS LAT	24.0533333
GPS LONG	120.69624
Liq. layer consist of:	Sand (SM-SC) https://cecas.clemson.edu/chichi
Geological Unit:	alluvial plain are underlainby Pliocene sandstones, shales and mudstones Stewart et al (2004)
Site Response Anlaysis:	No
Comments:	"Strong motion station in the direct vicinity on similar soil stratigraphy, PGA=0.6." Moss et al. (2003). Boulanger and Idriss (2014) took PGA=0.67 (SPT catalogue) and took 0.60 for CPT catalogue. Nearest station TCU065 is located 800 m from site C and the station has Vs30 of 290 m/s where the PGA is measured as 0.67 g. Site C (WCS-2) has Vs12 of 208 m/s based on Vs-SPTN correlations. Vs30m of the site is unkown but probably close to a value of 200 m/s (average Vs30m values of the sites around Wufeng). Site specific amplification (Abrahamson and Silva 2014) is calculated as 0.85 hence amax is calibrated as 0.570 g. Event specific model is constructed by using the nearby station data located on the footwall site as shown on the right bottom.



st	y	x	Epicenter	Vertical	N-S	E-W	Rrup	Vs30 (m/S	pga (G)
TCU065	24°03.54'	120°41.46'	25.57	257.8	563.22	774.42	1.3	290	0.673222
TCU076	23°54.47'	120°40.54'	15.25	275.38	420.02	340.1	3	573	0.385274
TCU110	23°57.70'	120°34.19'	27.5	116.28	187.52	178.24	11.6	199.5	0.186362
TCU112	24°03.36'	120°25.41'	45.5	65.26	68	78.3	27.5	191	0.074382
TCU117	24°07.98'	120°27.62'	47.22	89.96	113.46	121.3	27	207	0.119587
TCU120	23°58.80'	120°36.78'	24.62	166.52	193.5	222.98	7.4	458	0.211741
TCU123	24°01.06'	120°32.58'	32.89	85.54	131.96	149	15	289	0.142937
TCU129	23°52.70'	120°41.06'	13.54	334.96	610.76	983	2	506.5	0.789947
TCU138	23°55.34'	120°35.07'	55.34	110.36	207.4	202.24	10.2	604	0.20877
CHY104	23°40.19'	120°27.94'	41.33	129.68	177.12	142.9	17	218.8	0.162174



Gravel Contents (%):	NAV
CPT available:	Yes
Vs available:	No

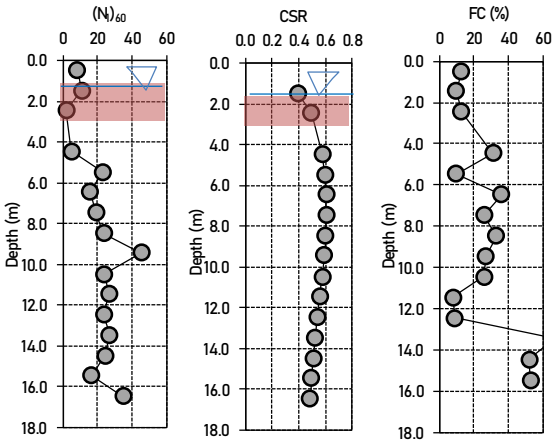
Summary of Input Data

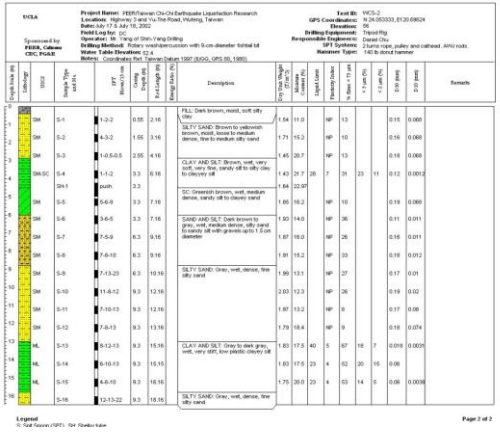
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	Yes	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	1.3 - 2.8
d_{crt} (m)	-	-	2.8	-	2.1
GWT (m)	-	-	1.3	-	1.3 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	55	-	36.7 ± 4.8
σ_v' (kPa)	-	-	41	-	29.3 ± 2.5
a_{max} (g)	-	-	0.67	-	0.570 ± 0.114
r_d	-	-	0.99	-	0.99 ± 0.033
CSR	-	-	0.584	-	0.460 ± 0.097
M_w	-	-	7.6	-	7.62
D_{50}	-	-	-	-	0.163 ± 0.015
% Fines	-	-	7.3	-	12.0 ± 1.7
% PI	-	-	-	-	0
N	-	-	2.2	-	3.4 ± 2.2
C_R	-	-	1	-	0.87
C_S	-	-	1	-	1.00
C_B	-	-	1	-	1.01
C_E	-	-	1.25	-	1.25
C_N	-	-	1.69	-	1.86
$(N_1)_{60}$	-	-	4.6	-	7.0 ± 4.6
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	207.7

EVENT PARAMETERS

1999 Chi-Chi Earthquake	Zheng and Chen 2001	
Magnitude: 7.62		footwall
Fault Type: inland thrust ea	Z_{tor} (km): 0	R_{rup} (km): 0.49
Dip: 30	Width (km): 40	R_{jb} (km): 0.49

ACCELERATION TIME HISTORY





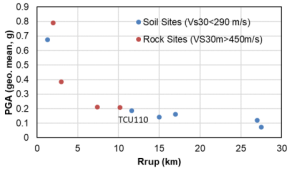
CN>2 at 0.46m but SPT values belong to the same layer SPT-N=4 and 5, hence it was also used to characterize the layer.

Rod Length (m)	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		PI	<75 µm FC	Silt	<2 µm Clay	D_{50}	D_{10}	
2.16	0.46	1.5	NA	4	2.00	0.82	8.3	SM	NP	13	13	0	0.15	0.07	
3.16	***1.46***	***4.8***	***0.393***	***5***	***2.00***	***0.86***	***10.8***	***SM***	***NP***	***10***	***10***	***0***	***0.16***	***0.07***	
4.16	***2.46***	***8.1***	***0.493***	***1***	***1.75***	***0.88***	***2.0***	***SM***	***NP***	***13***	***13***	***0***	***0.18***	***0.07***	
6.16	4.46	14.6	0.579	3	1.41	0.92	4.9	SM-SC	7.00	31	20	11	0.12	0.00	wc/LL=21.7/28=0.775 PI=7 Not Susceptible
7.16	***5.46***	***17.9***	***0.597***	***15***	***1.30***	***0.94***	***23.0***	***SM***	***NP***	***10***	***10***	***0***	***0.19***	***0.07***	
8.16	***6.46***	***21.2***	***0.605***	***11***	***1.21***	***0.95***	***15.9***	***SM***	***NP***	***36***	***36***	***0***	***0.11***	***0.01***	***upper layer SPT is***
9.16	***7.46***	***24.5***	***0.606***	***14***	***1.14***	***0.96***	***19.2***	***SM***	***NP***	***26***	***26***	***0***	***0.16***	***0.01***	***lower***
10.16	8.46	27.8	0.600	18	1.08	0.97	23.6	SM	NP	33	33	0	0.18	0.01	
11.13	9.43	30.9	0.590	36	1.03	0.97	45.3	SM	NP	27	27	0	0.17	0.01	
12.16	10.46	34.3	0.575	20	0.98	0.98	24.1	SM	NP	26	26	0	0.19	0.02	
13.16	11.46	37.6	0.558	23	0.94	0.98	26.8	SM	NP	8	8	0	0.17	0.08	
14.16	12.46	40.9	0.541	21	0.91	0.99	23.6	SM	NP	9	9	0	0.18	0.07	
15.16	13.46	44.2	0.524	25	0.87	0.99	27.2	ML	5.00	67	60	7	0.02	0.00	
16.16	14.46	47.4	0.509	23	0.85	0.99	24.3	ML	4.00	52	37	15	0.06		
17.16	15.46	50.7	0.496	16	0.82	0.99	16.4	ML	4.00	53	48	5	0.06	0.04	
18.16	16.46	54.0	0.486	35	0.80	0.99	34.9	SM				0			
						Mean:	7.0			12.0	12.0	0.0	0.163	0.068	
stick-up 1.7 m						**St. Dev.**	4.6			1.7	1.7	2.3	0.015	0.050	

Case number:	312
Earthquake:	1999 Chi-Chi Earthquake
Magnitude:	7.6
Location:	Yuanlin-NCREEMAA Sites
References:	PEER, Stweart et al 2004, Zheng and Chen 2001, Chu et al 2006, MAA (2000a)
Nature of Failure:	No liquefaction https://apps.peer.berkeley.edu/lifelines/research_projects
GPS LAT	23.964756 E 204455.466 The coordinates were determined from the map provided by PEER hence they are approximate.
GPS LONG	120.561948 N 2651182.502
Liq. layer consist of:	Sand (SP-SW-SM) https://cecas.clemson.edu/chichi
Geological Unit:	Holocene deltaic deposits west of Shan-Jao Road, and older Pleistocene sandstone Stewart et al (2004)
Site Response Anlaysis:	No
Comments:	" .... The town of Yuanlin (population ≈ 116,000, area = 40 km2) is located approximately 15 km from the Chelungpu fault rupture, yet was subject to severe liquefaction. Figure 4 is a map of Yuanlin showing locations of sediment boils, regions of building subsidence, and investigated sites. As shown in Figure 4, the township is located on flat Holocene deltaic deposits west of Shan-Jao Road, and older Pleistocene sandstone, siltstone and conglomerate east of Shan-Jao Road that slopes gently up to the east. Groundwater levels are relatively shallow, generally occurring at depths between 0.5-7 m. Ground motions records from station TCU110 in Yuanlin indicate a geometric mean peak acceleration of 0.18 g. This station is located in an area where ground failure was not observed. Ground failure in Yuanlin from the Chi-Chi earthquake typically took the form of building subsidence and sediment boils. The case histories of ground failure and non ground failure are principally from well-developed areas. Free-field sites consist of open lots within otherwise developed areas. Unlike Nantou and Wufeng, case histories of building subsidence in Yuanlin often include sediment boils as well. As shown in Figure 4, site exploration was performed both in areas with and without evidence of ground failure...." Stewart et al 2004.



The nearest station is TCU110 which recorded 0.186 g (geometric mean of the two component) has a rupture distance of 11.6 km and Vs30m of 200 m/s. No shear wave velocity measurements were available at the site. Vs-SPTN correlation were used and Vs30m is estimated as 192 m/s. Site specific amplification (Abrahamson and Silva 2014) is calculated as 0.96 hence amax is calibrated as 0.179 g. Event specific model is constructed by using the nearby station data located on the footwall site as shown on the right bottom.



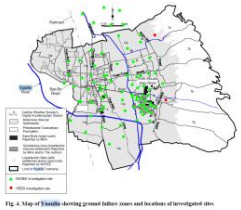


Fig. 4. Map of Yuanlin showing ground failure zones and locations of investigated sites

Gravel Contents (%):	NAV
CPT available:	No
Vs available:	No

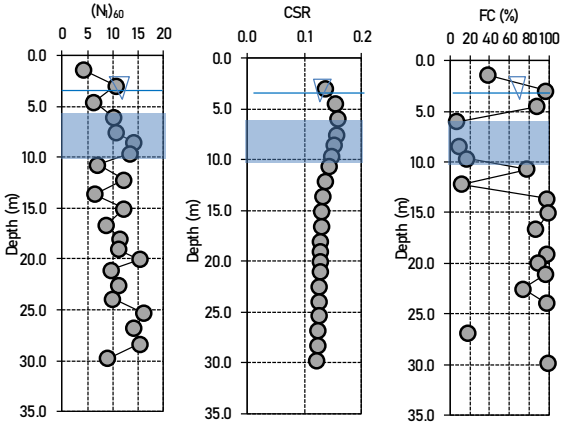
Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	No	-	No
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	5.0 - 9.7
d_{crt} (m)	-	-	7.1	-	7.4
GWT (m)	-	-	2	-	2.0 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	131	-	132.6 ± 15.0
σ_v' (kPa)	-	-	81	-	80.0 ± 7.6
a_{max} (g)	-	-	0.18	-	0.179 ± 0.036
r_d	-	-	0.98	-	0.81 ± 0.097
CSR	-	-	0.179	-	0.157 ± 0.037
M_w	-	-	7.6	-	7.62
D_{50}	-	-	-	-	0.407 ± 0.169
% Fines	-	-	9	-	12.1 ± 2.0
% PI	-	-	-	-	0
N	-	-	8.7	-	9.0 ± 1.5
C_R	-	-	1.0	-	0.96
C_S	-	-	1.0	-	1.00
C_B	-	-	1.0	-	1.00
C_E	-	-	1.16	-	1.25
C_N	-	-	1.13	-	1.13
$(N_1)_{60}$	-	-	11.3	-	12.1 ± 2.0
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	164.9

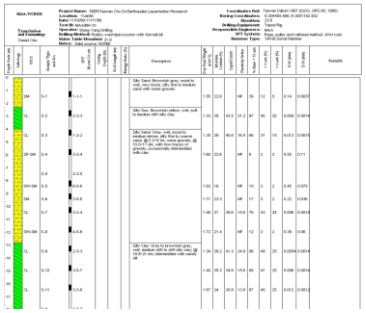
EVENT PARAMETERS

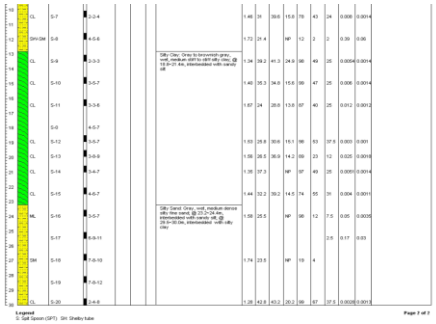
1999 Chi-Chi Earthquake	Zheng and Chen 2001	
Magnitude: 7.62		footwall
Fault Type: inland thrust ea	Z_{tor} (km): 0	R_{rup} (km): 12.5
Dip: 30	Width (km): 40	R_{jb} (km): 12.5

ACCELERATION TIME HISTORY



https://apps.peer.berkeley.edu/lifelines/research_projects/3A02/yuanlin.html
https://apps.peer.berkeley.edu/lifelines/research_projects/3A02/SPT/Yuanlin%20MAA/MAAYS-10.html





	Depth (m)	Depth (ft)	r_d	CSR	N	C_N	C_R	$(N1)_{60}$
SM	1.4	4.7	0.983	NA	2	2.00	0.85	4.3
CL	3.0	9.8	0.955	0.138	6	1.59	0.89	10.6
CL	4.5	14.9	0.915	0.155	4	1.36	0.92	6.3
SP-SM	***6.0***	***19.7***	***0.865***	***0.159***	***7***	***1.22***	***0.94***	***10.1***
SP-SM	***7.6***	***24.9***	***0.806***	***0.156***	***8***	***1.11***	***0.96***	***10.7***
SW-SM	***8.5***	***27.9***	***0.769***	***0.153***	***11***	***1.06***	***0.97***	***14.1***
SM	***9.6***	***31.6***	***0.728***	***0.148***	***11***	***1.00***	***0.97***	***13.4***
CL	10.7	35.1	0.693	0.143	6	0.96	0.98	7.0
SW-SM	12.2	39.9	0.653	0.137	11	0.91	0.98	12.3
CL	13.6	44.7	0.625	0.133	6	0.86	0.99	6.4
CL	15.1	49.4	0.606	0.131	12	0.82	0.99	12.2
CL	16.6	54.5	0.593	0.129	9	0.79	0.99	8.8
CL	18.0	59.1	0.585	0.129	12	0.76	1.00	11.3
CL	19.0	62.4	0.581	0.128	12	0.74	1.00	11.0
CL	20.0	65.6	0.578	0.128	17	0.72	1.00	15.3
CL	21.1	69.1	0.573	0.128	11	0.70	1.00	9.7
CL	22.5	73.9	0.566	0.127	13	0.68	1.00	11.1
ML	23.9	78.6	0.560	0.126	12	0.66	1.00	9.9
ML	25.3	83.2	0.554	0.125	20	0.65	1.00	16.1
SM	26.8	88.0	0.547	0.124	18	0.63	1.00	14.1
SM	28.3	93.0	0.540	0.123	20	0.61	1.00	15.3
CL	29.8	97.7	0.533	0.122	12	0.60	1.00	9.0
							Mean:	12.1
							St. Dev.	2.0

**stick-up is assumed to be 1.5 m*

	<75 µm		<2 µm		
	FC	**Silt**	**Clay**	**D_{50}**	**PI**
	39	34	5	0.14	NP
	97	77	20	0.008	21.2
	88	73	15	0.013	16.4
	8	***6***	***2***	***0.55***	***NP***
		-	-	-	-
	10	***8***	***2***	***0.45***	***NP***
	17	***15***	***2***	***0.22***	***NP***
	78	54	24	0.008	15.8
	12	10	2	0.39	NP
	98	73	25	0.0054	24.9
	99	74	25	0.006	15.6
	87	62	25	0.012	13.8
	98	60.5	37.5	0.003	15.1
	89	77	12	0.025	14.2
	97	72	25	0.0051	NP
	74	43	31	0.004	14.5
	98	90.5	7.5	0.05	NP
			2.5	0.17	
	19	19	0		NP
	99	61.5	37.5	0.0028	
	11.7	9.7	2.0	0.407	NP
	4.7	4.7	2.3	0.169	

assigned

Case number: 313

Earthquake: 1999 Chi-Chi Earthquake



Magnitude: 7.6

Location: Yuanlin BH27

References: PEER, Stewart et al 2004, Zheng and Chen 2001, Chu et al 2006

Nature of Failure: No liquefaction https://apps.peer.berkeley.edu/lifelines/research_projects

GPS LAT 23.946964 The coordinates were determined from the map

GPS LONG 120.586761 provided by PEER hence they are approximate.

Liq. layer consist of: Sand (SW-SP-SM) https://cecas.clemson.edu/chichi

Geological Unit: Holocene deltaic deposits west of Shan-Jao Road, and older Pleistocene sandstone Stewart et al (2004)

Site Response Anlaysis: No

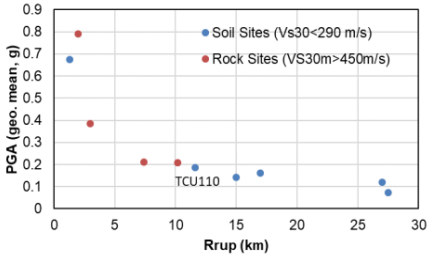
Comments: " .... The town of Yuanlin (population ≈ 116,000, area = 40 km2) is located approximately 15 km from the Chelungpu fault rupture, yet was subject to severe liquefaction. Figure 4 is a map of Yuanlin showing locations of sediment boils, regions of building subsidence, and investigated sites. As shown in Figure 4, the township is located on flat Holocene deltaic deposits west of Shan-Jao Road, and older Pleistocene sandstone, siltstone and conglomerate east of Shan-Jao Road that slopes gently up to the east. Groundwater levels are relatively shallow, generally occurring at depths between 0.5-7 m. Ground motions records from station TCU110 in Yuanlin indicate a geometric mean peak acceleration of 0.18 g. This station is located in an area where ground failure was not observed. Ground failure in Yuanlin from the Chi-Chi earthquake typically took the form of building subsidence and sediment boils. The case histories of ground failure and non ground failure are principally from well-developed areas. Free-field sites consist of open lots within otherwise developed areas. Unlike Nantou and Wufeng, case histories of building subsidence in Yuanlin often include sediment boils as well. As shown in Figure 4, site exploration was performed both in areas with and without evidence of ground failure...." Stewart et al 2004.

The nearest station is TCU110 which recorded 0.186 g (geometric mean of the two component) has a rupture distance of 11.6 km and Vs30m of 200 m/s. No shear wave velocity measurements were available at the site. Vs-SPTN correlation were used and Vs30m is estimated as 186 m/s. Site specific amplification (Abrahamson and Silva 2014) is calculated as 1.01 hence amax is calibrated as 0.187 g. Event specific model is constructed by using the nearby station data located on the footwall site as shown

st	y	x	Epicenter (V	ertical	N-S	E-W	Rrup	Vs30 (m/S	pga (G)
TCU065	24°03.54'	120°41.46'	25.57	257.8	563.22	774.42	1.3	290	0.673222
TCU076	23°54.47'	120°40.54'	15.25	275.38	420.02	340.1	3	573	0.385274
TCU110	23°57.70'	120°34.19'	27.5	116.28	187.52	178.24	11.6	199.5	0.186362
TCU112	24°03.36'	120°25.41'	45.5	65.26	68	78.3	27.5	191	0.074382
TCU117	24°07.98'	120°27.62'	47.22	89.96	113.46	121.3	27	207	0.119587
TCU120	23°58.80'	120°36.78'	24.62	166.52	193.5	222.98	7.4	458	0.211741
TCU123	24°01.06'	120°32.56'	32.89	85.54	131.96	149	15	289	0.142937
TCU129	23°52.70'	120°41.06'	13.54	334.96	610.76	983	2	506.5	0.788947
TCU138	23°55.34'	120°35.07'	55.34	110.36	207.4	202.24	10.2	604	0.20877
CHY104	23°40.19'	120°27.94'	41.33	129.68	177.12	142.9	17	218.8	0.162174



Fig. 4. Map of Yuanlin showing ground failure zones and locations of investigated sites



Gravel Contents (%): NAV

CPT available: No

Vs available: No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	No	-	No
Data Class	-	-	-	-	B
d_{crt} range (m)	-	-	-	-	8.0 - 13.0
d_{crt} (m)	-	-	7.3	-	10.5
GWT (m)	-	-	0.4	-	0.4 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.6 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	19.5 ± 0.9
σ_v (kPa)	-	-	80	-	204.5 ± 18.9
σ_v' (kPa)	-	-	41	-	105.3 ± 12.6
a_{max} (g)	-	-	0.18	-	0.187 ± 0.037
r_d	-	-	0.97	-	0.70 ± 0.131
CSR	-	-	0.22	-	0.165 ± 0.046
M_w	-	-	7.6	-	7.62
D_{50}	-	-	-	-	0.247 ± 0.134
% Fines	-	-	54	-	8.6 ± 6.6
% PI	-	-	-	-	0
N	-	-	2.9	-	12.3 ± 1.1
C_R	-	-	1.00	-	0.98
C_S	-	-	1.00	-	1.00
C_B	-	-	1.00	-	1.01
C_E	-	-	1.03	-	1.25
C_N	-	-	1.62	-	0.98
$(N_1)_{60}$	-	-	4.8	-	14.8 ± 1.3
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	164.9

EVENT PARAMETERS

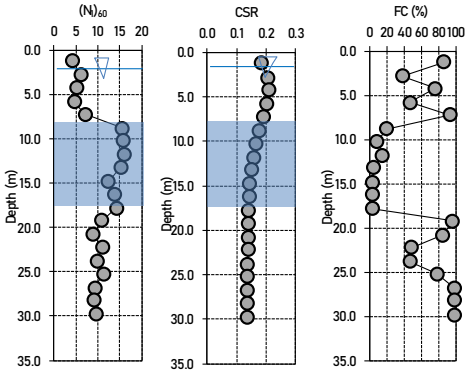
1999 Chi-Chi Earthquake Zheng and Chen 2001

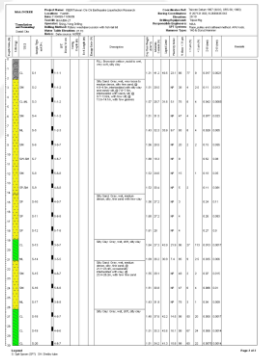
Magnitude: 7.62 footwall

Fault Type: inland thrust ea Z_{tor} (km): 0 R_{rup} (km): 10.6

Dip: 30 Width (km): 40 R_{jb} (km): 10.6

ACCELERATION TIME HISTORY





	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC (<75 µm)	Silt	Clay (<2 µm)	PI	D_{50}	γ (kN/m³) (sat? Dry??)	GS	WL (0/0)	IP (0/0)	
CL	1.2	3.9	0.183	2	2.00	0.84	4.2	86.0	77.0	9.0	23.1	0.017	18.1	2.730	49.5	23.1	Mixture of CL-ML-SM.
SM	*2.8*	*9.2*	*0.207*	*3*	*1.83*	*0.89*	*6.1*	*38.0*	*35.5*	*2.5*	*NP*	*0.110*	*19.1*	*2.750*		*NP*	Susceptible ? PI 5-23
CL-ML	*4.2*	*13.8*	*0.208*	*3*	*1.52*	*0.92*	*5.3*	*76.0*	*72.0*	*4.0*	*5.1*	*0.042*	*19.8*	*2.720*	*31.6*	*5.1*	Not susceptible?
SM	*5.8*	*19.0*	*0.201*	*3*	*1.31*	*0.94*	*4.6*	*47.0*	*43.0*	*4.0*	*NP*	*0.077*	*19.4*	*2.750*		*NP*	wc/LL=28.7/31.6=0.90 PI=5.1 Susceptible
ML	*7.2*	*23.6*	*0.191*	*5*	*1.18*	*0.95*	*7.1*	*93.0*	*89.0*	*4.0*	*9.7*	*0.029*	*18.5*	*2.750*	*33.9*	*9.7*	wc/LL=32.3/33.9=0.95 PI=9.7 Susceptible
SM	***8.8***	***28.9***	***0.178***	***12***	***1.07***	***0.97***	***15.6***	***20.0***	***18.0***	***2.0***	***NP***	***0.150***	***19.7***	***2.750***		***NP***	
SW-SM	***10.2***	***33.5***	***0.167***	***13***	***1.00***	***0.98***	***15.9***	***9.0***	***9.0***	***0.0***	***NP***	***0.520***	***21.8***	***2.740***		***NP***	
SM	***11.8***	***38.7***	***0.157***	***14***	***0.93***	***0.98***	***16.1***	***15.0***	***14.0***	***1.0***	***NP***	***0.180***	***18.5***	***2.750***		***NP***	
SP-SM	***13.2***	***43.3***	***0.150***	***14***	***0.88***	***0.99***	***15.3***	***5.0***	***5.0***	***0.0***	***NP***	***0.110***	***19.4***	***2.750***		***NP***	
SP	***14.8***	***48.6***	***0.145***	***12***	***0.83***	***0.99***	***12.4***	***3.0***	***3.0***	***0.0***	***NP***	***0.240***	***19.5***	***2.740***		***NP***	
SP	***16.2***	***53.1***	***0.142***	***14***	***0.79***	***0.99***	***13.9***	***4.0***	***4.0***	***0.0***	***NP***	***0.260***	***19.9***	***2.750***		***NP***	
SP	***17.8***	***58.4***	***0.140***	***15***	***0.76***	***0.99***	***14.3***	***4.0***	***4.0***	***0.0***	***NP***	***0.270***	***20.2***	***2.750***		***NP***	
CL	19.2	63.0	0.139	12	0.73	1.00	11.0	96.0	84.7	11.3	21.9	0.013	20.5	2.730	43.9	21.9	
ML	20.8	68.2	0.138	10	0.70	1.00	8.8	85.0	82.5	2.5	7.4	0.035	20.9	2.730	30.9	7.4	
SM	22.2	72.8	0.138	13	0.68	1.00	11.1	49.0	47.0	2.0	NP	0.070	19.6	2.750		NP	
SM	23.8	78.1	0.138	12	0.66	1.00	9.9	47.0	43.0	4.0	NP	0.056	19.4	2.750		NP	
ML	25.2	82.7	0.138	14	0.64	1.00	11.3	78.0	77.0	1.0	NP	0.040	18.4	2.750		NP	
CL	26.8	87.9	0.138	12	0.62	1.00	9.4	98.0	78.0	20.0	14.5	0.005	18.8	2.730	42.2	14.5	
CL	28.2	92.5	0.138	12	0.61	1.00	9.1	99.0	75.0	24.0	16.1	0.006	20.0	2.730	43.6	16.1	
CL	29.8	97.8	0.138	13	0.59	1.00	9.6	99.0	77.0	22.0	15.8	0.008	19.8	2.730	41.3	15.8	
						Mean:	14.8	8.6	8.1	0.4		0.2471					
						St. Dev.	1.3	6.6	5.8	0.8		0.1341					

**stick-up is assumed to be 1.5 m*

Case number:	315
Earthquake:	1999 Chi-Chi Earthquake
Magnitude:	7.6
Location:	Yuanlin BH30
References:	PEER, Stewart et al 2004, Zheng and Chen 2001, Chu et al 2006, MAA (2000a)
Nature of Failure:	Yes https://apps.peer.berkeley.edu/lifelines/research_projects
GPS LAT	23.951972 208070.716 The coordinates were determined from the map
GPS LONG	120.595448 2649923.892 provided by PEER hence they are approximate.
Liq. layer consist of:	Sand and Silt (SM-ML) https://cecas.clemson.edu/chichi
Geological Unit:	Holocene deltaic deposits west of Shan-Jao Road, and older Pleistocene sandstone Stewart et al (2004)
Site Response Anlaysis:	No
Comments:	" .... The town of Yuanlin (population ≈ 116,000, area = 40 km2) is located approximately 15 km from the Chelungpu fault rupture, yet was subject to severe liquefaction. Figure 4 is a map of Yuanlin showing locations of sediment boils, regions of building subsidence, and investigated sites. As shown in Figure 4, the township is located on flat Holocene deltaic deposits west of Shan-Jao Road, and older Pleistocene sandstone, siltstone and conglomerate east of Shan-Jao Road that slopes gently up to the east. Groundwater levels are relatively shallow, generally occurring at depths between 0.5-7 m. Ground motions records from station TCU110 in Yuanlin indicate a geometric mean peak acceleration of 0.18 g. This station is located in an area where ground failure was not observed. Ground failure in Yuanlin from the Chi-Chi earthquake typically took the form of building subsidence and sediment boils. The case histories of ground failure and non ground failure are principally from well-developed areas. Free-field sites consist of open lots within otherwise developed areas. Unlike Nantou and Wufeng, case histories of building subsidence in Yuanlin often include sediment boils as well. As shown in Figure 4, site exploration was performed both in areas with and without evidence of ground failure..." Stewart et al 2004. The nearest station is TCU110 which recorded 0.186 g (geometric mean of the two component) has a rupture distance of 11.6 km and Vs30m of 200 m/s. No shear wave velocity measurements were available at the site. Vs-SPTN correlation were used and Vs30m is estimated as 213 m/s. Site specific amplification (Abrahamson and Silva 2014) is calculated as 1.08 hence amax is calibrated as 0.202 g. Event specific model is constructed by using the nearby station data located on the footwall site as shown on the right bottom.
Gravel Contents (%):	NAV
CPT available:	No
Vs available:	No



1-2 storey building

st	y	x	Epicenter (Vertical	N-S	E-W	Rrup	Vs30 (m/S	pga (G)
TCU065	24°03.54'	120°41.46'	25.57	257.8	563.22	774.42	1.3	290	0.673222
TCU076	23°54.47'	120°40.54'	15.25	275.38	420.02	340.1	3	573	0.385274
TCU110	23°57.70'	120°34.19'	27.5	116.28	187.52	178.24	11.6	199.5	0.186362
TCU112	24°03.36'	120°25.41'	45.5	65.26	68	78.3	27.5	191	0.074382
TCU117	24°07.98'	120°27.62'	47.22	89.96	113.46	121.3	27	207	0.119587
TCU120	23°58.80'	120°36.78'	24.62	166.52	193.5	222.98	7.4	458	0.211741
TCU123	24°01.06'	120°32.56'	32.89	85.54	131.96	149	15	289	0.142937
TCU129	23°52.70'	120°41.06'	13.54	334.96	610.76	983	2	506.5	0.789847
TCU138	23°55.34'	120°35.07'	55.34	110.36	207.4	202.24	10.2	604	0.20877
CHY104	23°40.19'	120°27.94'	41.33	129.68	177.12	142.9	17	218.8	0.162174

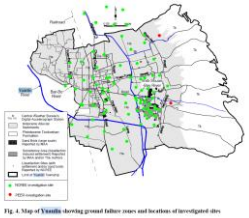
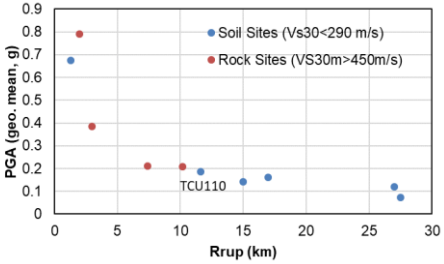


Fig. 4. Map of Yuanlin showing ground failure zones and locations of investigated sites



Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	Yes	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	1.1 - 7.5
d_{cr1} (m)	-	-	3.9	-	4.3
GWT (m)	-	-	1.1	-	1.1 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.4 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	19.9 ± 1.0
σ_v (kPa)	-	-	73	-	83.1 ± 21.5
σ_v' (kPa)	-	-	46	-	51.6 ± 11.3
a_{max} (g)	-	-	0.18	-	0.202 ± 0.040
r_d	-	-	0.98	-	0.95 ± 0.061
CSR	-	-	0.181	-	0.200 ± 0.044
M_w	-	-	7.6	-	7.62
D_{50}	-	-	-	-	0.178 ± 0.125
% Fines	-	-	46	-	33.4 ± 24.3
% PI	-	-	-	-	0
N	-	-	4.9	-	5.7 ± 0.6
C_R	-	-	1	-	0.92
C_S	-	-	1	-	1.00
C_B	-	-	1	-	1.01
C_E	-	-	1.01	-	1.25
C_N	-	-	1.49	-	1.40
$(N_1)_{60}$	-	-	7.3	-	9.2 ± 0.9
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	179.3

EVENT PARAMETERS

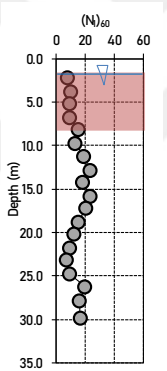
1999 Chi-Chi Earthquake — Zheng and Chen 2001

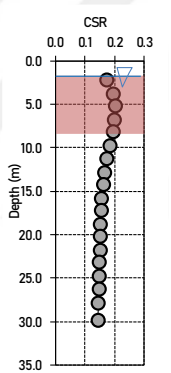
Magnitude: 7.62 — footwall

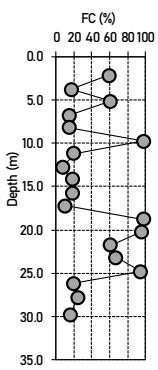
Fault Type: inland thrust ea — Z_{tor} (km): 0 — R_{rup} (km): 9.7

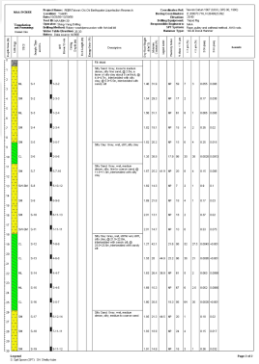
Dip: 30 — Width (km): 40 — R_{jb} (km): 9.7

ACCELERATION TIME HISTORY









									<75 µm		<2 µm							
	Depth (m)	**Depth (ft)**	**rd**	**CSR**	**N**	**C_N**	**C_R**	**$(N1)_{60}$**	**FC**	**Silt**	**Clay**	**PI**	**D_{50}**	**D_{10}**	**(kN/m3)**	**GS**	**WL (0/0)**	**IP (0/0)**	
ML	***2.20***	***7.2***	***0.981***	***0.175***	***4***	***1.83***	***0.87***	***8.0***	***59.0***	***56.0***	***3.0***	***NP***	***0.055***	***0.008***	***18.8***	***2.710***		***NP***	
SM	***3.80***	***12.5***	***0.957***	***0.197***	***6***	***1.48***	***0.91***	***10.1***	***17.0***	***17.0***	***0.0***	***NP***	***0.170***	***0.004***	***19.5***	***2.760***		***NP***	more critical layer
ML	***5.20***	***17.1***	***0.927***	***0.202***	***6***	***1.29***	***0.93***	***9.1***	***61.0***	***60.0***	***1.0***	***NP***	***0.065***	***0.008***	***20.0***	***2.730***		***NP***	
SM	***6.80***	***22.3***	***0.882***	***0.200***	***7***	***1.15***	***0.95***	***9.6***	***15.0***	***13.0***	***2.0***	***NP***	***0.350***	***0.020***	***21.3***	***2.750***		***NP***	
SM	8.20	26.9	0.836	0.194	12	1.06	0.96	15.4	15.0	11.0	4.0	NP	0.250	0.018	21.5	2.760		NP	outlier
CL	9.80	32.2	0.780	0.184	11	0.97	0.97	13.1	98.0	60.0	38.0	NP	0.003	0.001	18.3	2.730	41.900	17.900	
SM	11.20	36.7	0.735	0.175	17	0.91	0.98	19.2	20.0	16.0	4.0	NP	0.150	0.008	20.5	2.750		NP	
SW-SM	12.80	42.0	0.693	0.167	22	0.86	0.99	23.4	7.0	6.0	1.0	NP	0.900	0.100	20.4	2.750		NP	
SM	14.20	46.6	0.665	0.161	18	0.82	0.99	18.3	18.0	17.0	1.0	NP	0.180	0.030	20.2	2.750		NP	
SM	15.80	51.8	0.643	0.157	24	0.78	0.99	23.3	18.0	18.0	0.0	NP	0.380	0.020	22.2	2.750		NP	
SW-SM	17.20	56.4	0.631	0.155	22	0.75	0.99	20.6	10.0	10.0	0.0	NP	0.520	0.075	22.5	2.750		NP	
CL	18.80	61.7	0.622	0.153	17	0.72	1.00	15.2	98.0	70.5	27.5	21.6	0.005	small	17.7	2.730	44.900	21.600	
CL	20.20	66.3	0.616	0.152	14	0.69	1.00	12.1	96.0	75.0	21.0	23.2	0.010	small	19.5	2.720	36.900	23.200	
ML	**21.80**	**71.5**	**0.609**	**0.151**	**11**	**0.67**	**1.00**	**9.2**	**61.0**	**59.0**	**2.0**	**NP**	**0.062**	**0.010**	**20.2**	**2.730**		**NP**	DEEP LAYER LOWER CSR
ML	**23.20**	**76.1**	**0.603**	**0.150**	**9**	**0.65**	**1.00**	**7.3**	**67.0**	**64.5**	**2.5**	**NP**	**0.052**	**0.009**	**18.2**	**2.730**		**NP**	DEEP LAYER LOWER CSR
CL	24.80	81.4	0.595	0.148	12	0.63	1.00	9.4	95.0	65.0	30.0	18.3	0.004	small	21.3	2.720	44.500	18.300	
SM	26.20	86.0	0.589	0.147	26	0.61	1.00	19.9	20.0	20.0	0.0	NP	0.180	0.020	22.1	2.760		NP	
SM	27.80	91.2	0.581	0.145	22	0.59	1.00	16.4	24.0	24.0	0.0	NP	0.150	0.017	21.4	2.750		NP	
SM	29.80	97.8	0.572	0.144	23	0.57	1.00	16.6	16.0	15.0	1.0	NP	0.370	0.032	21.6	2.750		NP	
							Mean:	9.2	33.4	31.4	2.0		0.2	0.012					
							St. Dev.:	0.9	24.3	24.4	1.6		0.1	0.007					

**stick-up is assumed to be 1.5 m*

Case number:	316
Earthquake:	1999 Chi-Chi Earthquake
Magnitude:	7.6
Location:	Yuanlin BH31
References:	PEER, Stewart et al 2004, Zheng and Chen 2001, Chu et al 2006
Nature of Failure:	No ground failure
GPS LAT	23.944623
GPS LONG	120.570904
Liq. layer consist of:	Sand and Silt (SM-ML)
Geological Unit:	Holocene deltaic deposits west of Shan-Jao Road, and older Pleistocene sandstone
Site Response Anlaysis:	No
Comments:	" .... The town of Yuanlin (population ≈ 116,000, area = 40 km2) is located approximately 15 km from the Chelungpu fault rupture, yet was subject to severe liquefaction. Figure 4 is a map of Yuanlin showing locations of sediment boils, regions of building subsidence, and investigated sites. As shown in Figure 4, the township is located on flat Holocene deltaic deposits west of Shan-Jao Road, and older Pleistocene sandstone, siltstone and conglomerate east of Shan-Jao Road that slopes gently up to the east. Groundwater levels are relatively shallow, generally occurring at depths between 0.5-7 m. Ground motions records from station TCU110 in Yuanlin indicate a geometric mean peak acceleration of 0.18 g. This station is located in an area where ground failure was not observed. Ground failure in Yuanlin from the Chi-Chi earthquake typically took the form of building subsidence and sediment boils. The case histories of ground failure and non ground failure are principally from well-developed areas. Free-field sites consist of open lots within otherwise developed areas. Unlike Nantou and Wufeng, case histories of building subsidence in Yuanlin often include sediment boils as well. As shown in Figure 4, site exploration was performed both in areas with and without evidence of ground failure...." Stewart et al 2004.
Gravel Contents (%):	NAV
CPT available:	No
Vs available:	No



https://apps.peer.berkeley.edu/lifelines/research_projects

The coordinates were determined from the map provided by PEER hence they are approximate.

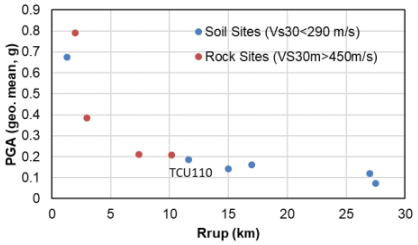
https://cecas.clemson.edu/chichi





Fig. 4. Map of Yuanlin showing ground failure zones and locations of investigated sites

st	y	x	Epicenter (Vertical	N-S	E-W	Rrup	Vs30 (m/S	pga (G)
TCU065	24°03.54'	120°41.46'	25.57	257.8	563.22	774.42	1.3	290	0.673222
TCU076	23°54.47'	120°40.54'	15.25	275.38	420.02	340.1	3	573	0.385274
TCU110	23°57.70'	120°34.19'	27.5	116.28	187.52	178.24	11.6	199.5	0.186362
TCU112	24°03.39'	120°25.41'	45.5	65.26	68	78.3	27.5	191	0.074382
TCU117	24°07.98'	120°27.62'	47.22	89.96	113.46	121.3	27	207	0.119587
TCU120	23°58.80'	120°36.78'	24.62	166.52	193.5	222.98	7.4	458	0.211741
TCU123	24°01.06'	120°32.56'	32.89	85.54	131.96	149	15	289	0.142937
TCU129	23°52.70'	120°41.06	13.54	334.96	610.76	983	2	506.5	0.789847
TCU138	23°55.34'	120°35.07'	55.34	110.36	207.4	202.24	10.2	604	0.20877
CHY104	23°40.19'	120°27.94'	41.33	129.68	177.12	142.9	17	218.8	0.162174



The nearest station is TCU110 which recorded 0.186 g (geometric mean of the two component) has a rupture distance of 11.6 km and Vs30m of 200 m/s. No shear wave velocity measurements were available at the site. Vs-SPTN correlation were used and Vs30m is estimated as 186 m/s. Site specific amplification (Abrahamson and Silva 2014) is calculated as 0.96 hence amax is calibrated as 0.179 g. Event specific model is constructed by using the nearby station data located on the footwall site as shown on the right bottom.

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	No	-	No
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	4.0 - 9.0
d_{crt} (m)	-	-	6.6	-	6.5
GWT (m)	-	-	4.2	-	4.2 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.2 ± 1.0
γ_{sat} (kN/m^3)	-	-	-	-	18.6 ± 0.8
σ_v (kPa)	-	-	120	-	119.4 ± 16.2
σ_v' (kPa)	-	-	96	-	96.8 ± 8.8
a_{max} (g)	-	-	0.18	-	0.179 ± 0.036
r_d	-	-	0.95	-	0.78 ± 0.087
CSR	-	-	0.138	-	0.112 ± 0.026
M_w	-	-	7.6	-	7.62
D_{50}	-	-	-	-	0.101 ± 0.093
% Fines	-	-	47	-	47.3 ± 28.1
% PI	-	-	-	-	0
N	-	-	3.7	-	4.3 ± 1.2
C_R	-	-	1.00	-	0.95
C_S	-	-	1.00	-	1.00
C_B	-	-	1.00	-	1.01
C_E	-	-	1.13	-	1.25
C_N	-	-	1.03	-	1.02
$(N_1)_{60}$	-	-	4.3	-	5.2 ± 1.5
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	147.4

EVENT PARAMETERS

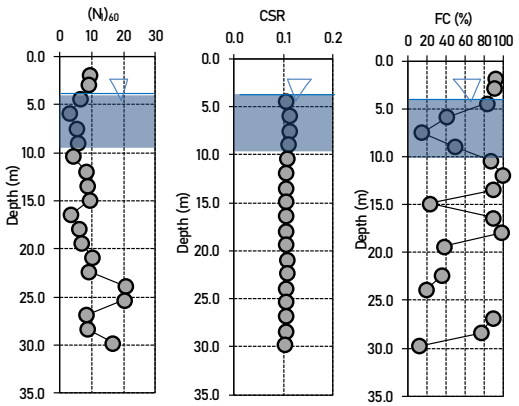
1999 Chi-Chi Earthquake

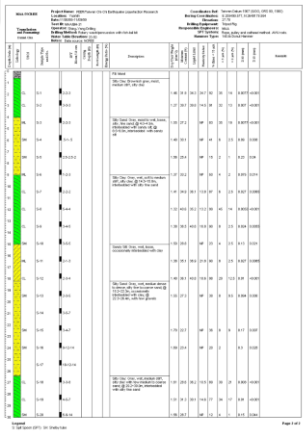
Magnitude: 7.62

Fault Type: inland thrust ea — Z_{tor} (km): 0 — R_{rup} (km): 12.2

Dip: 30 — Width (km): 40 — R_{jb} (km): 12.2

ACCELERATION TIME HISTORY





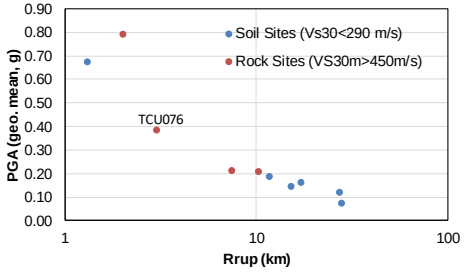
										<75 µm		<2 µm							
	Depth (m)	**Depth (ft)**	**rd**	**CSR**	**N**	**C_N**	**C_R**	**$(N1)_{60}$**	**FC**	**Silt**	**Clay**	**PI**	**D_{50}**	**D_{10}**	**Depth (m)**	**(kN/m3)**	**GS**	**WL (0/0)**	**IP (0/0)**
CL	1.87	6.1	0.960	NA	5	1.72	0.86	9.4	92.0	78.0	14.0	24.7	0.0077	SMALL	1.80	18.91	0.72	34.30	24.70
CL	2.87	9.4	0.930	NA	6	1.39	0.89	9.4	91.0	78.0	13.0	14.5	0.0070	SMALL	2.80	17.44	0.72	39.80	14.50
ML	***4.41***	***14.5***	***0.874***	***0.104***	***5***	***1.14***	***0.92***	***6.6***	***83.0***	***64.0***	***19.0***	***NP***	***0.0077***	***SMALL***	***4.20***	***19.31***	***0.75***		***NP***
SM	***5.87***	***19.2***	***0.811***	***0.111***	***2.5***	***1.06***	***0.94***	***3.1***	***41.0***	***38.5***	***2.5***	***NP***	***0.0900***	***0.01***	***5.80***	***17.84***	***0.75***		***NP***
SM	***7.49***	***24.6***	***0.738***	***0.112***	***4.5***	***0.98***	***0.96***	***5.3***	***15.0***	***14.0***	***1.0***	***NP***	***0.2300***	***0.04***	***7.20***	***19.21***	***0.79***		***NP***
ML	***8.95***	***29.4***	***0.679***	***0.110***	***5***	***0.93***	***0.97***	***5.6***	***50.0***	***48.0***	***2.0***	***NP***	***0.0750***	***0.01***	***8.80***	***17.93***	***0.75***		***NP***
CL	10.40	34.1	0.630	0.107	4	0.88	0.98	4.3	87.0	84.5	2.5	13.8	0.0270	0.01	10.20	18.62	0.72	36.10	13.80
CL	11.90	39.0	0.594	0.105	8	0.84	0.98	8.3	99.0	85.0	14.0	13.2	0.0053	SMALL	11.80	18.13	0.73	35.20	13.20
CL	13.44	44.1	0.568	0.104	9	0.80	0.99	9.0	90.0	87.5	2.5	16.8	0.0240	0.01	13.20	18.42	0.72	40.60	16.80
SM	14.90	48.9	0.552	0.104	10	0.77	0.99	9.6	23.0	20.5	2.5	NP	0.1300	0.02	14.80	18.91	0.76		NP
ML	16.39	53.8	0.542	0.104	4	0.74	0.99	3.7	90.0	87.5	2.5	21.8	0.0270	0.01	16.20	18.33	0.73	36.90	21.80
CL	17.93	58.8	0.535	0.105	7	0.72	1.00	6.3	98.0	85.5	12.5	18.6	0.0100	SMALL	17.80	18.62	0.73	40.80	18.60
SM	19.39	63.6	0.531	0.106	8	0.70	1.00	7.0	38.0	28.5	9.5	NP	0.0940	0.01	19.20	19.31	0.75		NP
	20.93	68.7	0.525	0.106	12	0.67	1.00	10.2		-	-	-	-	-	22.20	20.38	0.75		NP
SM	22.34	73.3	0.519	0.106	11	0.66	1.00	9.1	36.0	27.0	9.0	NP	0.1700	0.01	23.80	20.38	0.75		NP
SM	23.88	78.4	0.512	0.106	26	0.64	1.00	20.8	20.0	20.0	0.0	NP	0.3000	0.03	26.80	20.29	0.72	36.20	10.50
	25.30	83.0	0.505	0.105	26	0.62	1.00	20.3		-	-	-	-	-	28.20	19.40	0.71	39.10	14.60
CL	26.84	88.1	0.498	0.105	11	0.61	1.00	8.4	89.0	68.0	21.0	10.5	0.0080	SMALL	29.80	19.70	0.75		NP
CL	28.38	93.1	0.491	0.104	12	0.59	1.00	8.9	77.0	60.0	17.0	14.6	0.0100	SMALL					
SM	29.75	97.6	0.485	0.103	23	0.58	1.00	16.8	12.0	11.0	1.0	12.0	0.1500	0.04					
							Mean:	5.2	47.3	41.1	6.1	**NP**	0.101	0.0207					
							St. Dev.	1.5	28.1	20.9	8.6	**NP**	0.093	0.0170					

**stick-up is assumed to be 1.5 m*

Case number:	415
Earthquake:	1999 Chi-chi Earthquake
Magnitude:	7.6
Location:	NANTOU BH-3 Nantou- NCREE/MAA Sites
References:	PEER, Stewart et al 2004, Zheng and Chen 2001, Chu et al 2003, 2004, 2006, MAA (2000b)
Nature of Failure:	Sand boils https://apps.peer.berkeley.edu/lifelines/research_projects/3A02/index.h
GPS LAT	23.917808 23°55'4.11"N https://apps.peer.berkeley.edu/lifelines/research_projects/3A02/SPT/M
GPS LONG	120.691203 120°41'28.33"E https://cecas.clemson.edu/chichi/TW-LIQ/Nantou-SPT.htm
Liq. layer consist of:	Silty Sand (SM) https://cecas.clemson.edu/chichi
Geological Unit:	alluvial plane Stewart et al (2004)
Site Response Anlaysis:	No
Comments:	Chu et al (2006) "Although located on alluvium, no evidence of ground failure from soil softening or liquefaction was observed in the areas near the strong motion stations in Wufeng and Nantou." Chu et al. (2004) "The geometric mean peak ground acceleration recorded in Nantou (station TCU076) is 0.38 g. The station is located on Holocene alluvial soils at a distance of 3 km from the ruptured fault. The area immediately surrounding this station showed no evidence of ground failure." Chu et al. (2003) also suggest 0.39 g for the area. Boulanger and Idriss 2014 took PGA=0.38 for Nantou Site C, NCC-1,2,&3, Nantou Site C-7 and C-8 (CPT catalogue). Moss (2003) took 0.38 g for Nantou Site C-8 NCREE. Nearest station TCU079 is located 3 km away from the fault and the station has Vs30 of 573 m/s. Recorded PGA is 0.38 g at that station. Site has Vs12m of approx. 210 m/s based on Vs-SPTN correlations, Vs30m of the site is unkown but probably close to a value of 220 m/s (average of the Vs30 m around Nantou). Site specific amplification (Abrahamson and Silva 2014) is calculated as 0.91 hence amax is calibrated as 0.349 g. Event specific model is constructed by using the nearby station data located on the footwall site as shown on the right bottom. Juang et al., Clemson University reported PGA as 0.428 g (max component).



st	y	x	Epicenter (r	Vertical	N-S	E-W	Rrup	Vs30 (m/S	ppa (G)
TCU065	24°03.54'	120°41.46'	25.57	257.8	563.22	774.42	1.3	290	0.673222
TCU076	23°54.47'	120°40.54'	15.25	275.38	420.02	340.1	3	573	0.385274
TCU110	23°57.70'	120°34.19'	27.5	116.28	187.52	178.24	11.6	199.5	0.186362
TCU112	24°03.36'	120°25.41'	45.5	65.26	68	78.3	27.5	191	0.074382
TCU117	24°07.98'	120°27.62'	47.22	89.96	113.46	121.3	27	207	0.119587
TCU120	23°58.80'	120°36.78'	24.62	166.52	193.5	222.98	7.4	458	0.211741
TCU123	24°01.06'	120°32.56'	32.89	85.54	131.96	149	15	289	0.142937
TCU129	23°52.70'	120°41.06'	13.54	334.96	610.76	983	2	506.5	0.789847
TCU138	23°55.34'	120°35.07'	55.34	110.36	207.4	202.24	10.2	604	0.20877
CHY104	23°40.19'	120°27.94'	41.33	129.68	177.12	142.9	17	218.8	0.162174



Gravel Contents (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	4.0 - 7.0
d_{crt} (m)	-	-	-	-	5.5
GWT (m)	-	-	-	-	4.0 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.4 ± 0.6
γ_{sat} (kN/m^3)	-	-	-	-	19.8 ± 0.8
σ_v (kPa)	-	-	-	-	103.4 ± 10.3
σ_v' (kPa)	-	-	-	-	88.6 ± 5.8
a_{max} (g)	-	-	-	-	0.349 ± 0.070
r_d	-	-	-	-	0.96 ± 0.076
CSR	-	-	-	-	0.255 ± 0.056
M_w	-	-	-	-	7.62
D_{50}	-	-	-	-	0.155 ± 0.007
% Fines	-	-	-	-	19.0 ± 1.4
% PI	-	-	-	-	0
N	-	-	-	-	8.1 ± 1.7
C_R	-	-	-	-	0.94
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.01
C_E	-	-	-	-	1.25
C_N	-	-	-	-	1.07
$(N_1)_{60}$	-	-	-	-	10.2 ± 2.1
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	207.7

EVENT PARAMETERS

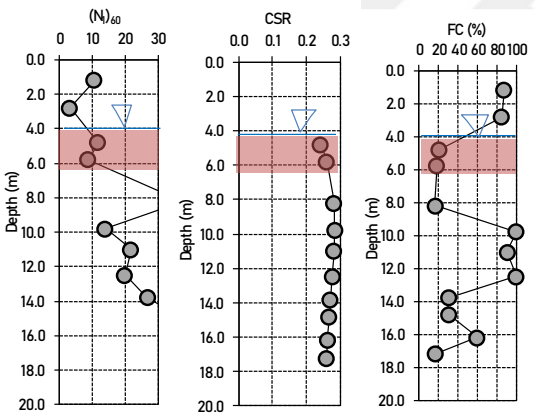
1999 Chi-chi Earthquake

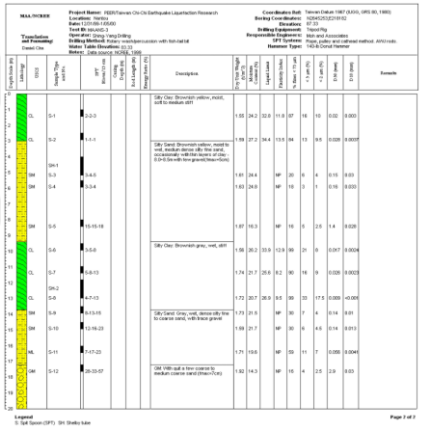
Magnitude: 7.62

Fault Type: inland thrust ea Z_{tor} (km): 0 R_{rup} (km): 1.1

Dip: 30 Width (km): 40 R_{jb} (km): 1.1

ACCELERATION TIME HISTORY





	Depth (m)	Depth (ft)	rd	CSR	N	C_N	C_R	$(N1)_{60}$	FC (<75 µm)	clay (<2 µm)	silt	PI	D_{50}	D_{10}	ρ_{dry} (t/m^3)	γ (kN/m^3) (γ_{sat}? Assumed to be saturated)	GS	WL (0/0)	IP (0/0)
CL	1.20	3.9	0.996	NA	5	2.00	0.84	10.6	87.0	10.0	77.0	11.8	0.0200	0.0030	1.55	18.91	2.71	32.80	11.80
CL	2.80	9.2	0.989	NA	2	1.40	0.89	3.1	84.0	9.5	74.5	13.5	0.0280	0.0037	1.59	19.80	2.71	34.40	13.50
SM	***4.80***	***15.7***	***0.972***	***0.242***	***9***	***1.12***	***0.93***	***11.7***	***20.0***	***4.0***	***16.0***	***NP***	***0.1500***	***0.0300***	***1.61***	***19.60***	***2.74***		***NP***
SM	***5.80***	***19.0***	***0.959***	***0.260***	***7***	***1.05***	***0.94***	***8.7***	***18.0***	***1.0***	***17.0***	***NP***	***0.1600***	***0.0330***	***1.63***	***19.89***	***2.74***		***NP***
SM	8.20	26.9	0.915	0.282	33	0.94	0.96	37.5	16.0	2.5	13.5	NP	1.4000	0.0280	1.87	21.36	2.74		NP
CL	9.80	32.2	0.874	0.284	13	0.88	0.97	14.0	99.0	8.0	91.0	12.9	0.0170	0.0024	1.56	19.31	2.72	33.90	12.90
CL	11.00	36.1	0.840	0.282	21	0.84	0.98	21.8	90.0	9.0	81.0	8.2	0.0260	0.0023	1.74	20.78	2.71	25.60	8.20
CL	12.50	41.0	0.797	0.276	20	0.80	0.98	19.8	99.0	17.5	81.5	9.5	0.0090	<0.001	1.72	20.38	2.72	26.90	9.50
SM	13.80	45.3	0.764	0.270	28	0.77	0.99	26.8	30.0	4.0	26.0	NP	0.1400	0.0100	1.73	20.58	2.74		NP
SM	14.80	48.6	0.742	0.267	39	0.75	0.99	36.4	30.0	4.5	25.5	NP	0.1400	0.1300	1.59	18.91	2.74		NP
ML	16.20	53.1	0.718	0.263	40	0.72	0.99	36.0	59.0	7.0	52.0	NP	0.0560	0.0041	1.71	20.09	2.74		NP
GM	17.20	56.4	0.705	0.261	90	0.70	0.99	79.2	16.0	2.5	13.5	NP	2.9000	0.0300	1.92	21.46	2.74		NP
							Mean:	10.2	19.0	2.5	16.5	**NP**	0.155	0.032					
							St. Dev.	2.1	1.4	2.1	0.7	**NP**	0.007	0.002					

**stick-up is assumed to be 1.5 m*

Case number:	416
Earthquake:	1999 Chi-chi Earthquake
Magnitude:	7.6
Location:	Nantaou, NBS-1
References:	PEER, Stewart et al 2004, Zheng and Chen 2001, Chu et al 2003, 2004, 2006
Nature of Failure:	No
GPS LAT	23.912836
GPS LONG	120.684575
Liq. layer consist of:	Silty Sand (SM)
Geological Unit:	alluvial plane
Site Response Anlaysis:	No

https://apps.peer.berkeley.edu/lifelines/research_projects/3A02/SPT/N

https://apps.peer.berkeley.edu/lifelines/research_projects/3A02/nantou

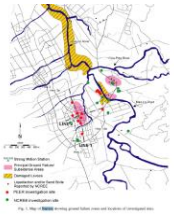
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120°41'4.47"E

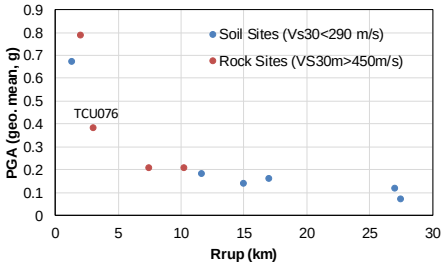
https://cecas.clemson.edu/chichi

Stewart et al (2004)

Comments: Chu et al (2006) "Although located on alluvium, no evidence of ground failure from soil softening or liquefaction was observed in the areas near the strong motion stations in Wufeng and Nantou.". Chu et al 2004 "The geometric mean peak ground acceleration recorded in Nantou (station TCU076) is 0.38 g. The station is located on Holocene alluvial soils at a distance of 3 km from the ruptured fault. The area immediately surrounding this station showed no evidence of ground failure. "Chu et al 2003 also suggest 0.39 g for the area. Boulanger and Idriss 2014 took PGA=0.38 for Nantou Site C, NCC-1,2,&3, Nantou Site C-7 and C-8 (CPT catalogue). Moss 2003 took 0.38 g for Nantou Site C-8 NCREE. Nearest station TCU079 is located 3 km away from the fault and the station has Vs30 of 573 m/s. Recorded PGA is 0.38 g at that station. Site has Vs12m of approx. 172 m/s based on Vs-SPTN correlations, Vs30m of the site is unkown but probably close to a value of 220 m/s (average of the Vs30m of the sites around Nantou). Site specific amplification (Abrahamson and Silva 2014) is calculated as 0.88 hence amax is calibrated as 0.340 g. Event specific model is constructed by using the nearby station data located on the footwall site as shown on the right bottom. Juang et al., Clemson University reported PGA as 0.428 g (max component).



st	y	x	Epicenter (	Vertical	N-S	E-W	Rrup	Vs30 (m/S	pga (G)
TCU065	24°03.54'	120°41.46'	25.57	257.8	563.22	774.42	1.3	290	0.673222
TCU076	23°54.47'	120°40.54'	15.25	275.38	420.02	340.1	3	573	0.385274
TCU110	23°57.70'	120°34.19'	27.5	116.28	187.52	178.24	11.6	199.5	0.186362
TCU112	24°03.36'	120°25.41'	45.5	65.26	68	78.3	27.5	191	0.074382
TCU117	24°07.98'	120°27.62'	47.22	89.96	113.46	121.3	27	207	0.119587
TCU120	23°58.80'	120°36.78'	24.62	166.52	193.5	222.98	7.4	458	0.211741
TCU123	24°01.06'	120°32.56'	32.89	85.54	131.96	149	15	289	0.142937
TCU129	23°52.70'	120°41.06	13.54	334.96	610.76	983	2	506.5	0.789847
TCU138	23°55.34'	120°35.07'	55.34	110.36	207.4	202.24	10.2	604	0.20877
CHY104	23°40.19'	120°27.94'	41.33	129.68	177.12	142.9	17	218.8	0.162174



Gravel Contents (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	1.0 - 3.5
d_{crt} (m)	-	-	-	-	2.3
GWT (m)	-	-	-	-	1.0 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	19.6 ± 0.5
σ_v (kPa)	-	-	-	-	40.4 ± 8.2
σ_v' (kPa)	-	-	-	-	28.1 ± 4.2
a_{max} (g)	-	-	-	-	0.340 ± 0.068
r_d	-	-	-	-	0.97 ± 0.035
CSR	-	-	-	-	0.307 ± 0.066
M_w	-	-	-	-	7.62
D_{50}	-	-	-	-	0.120 ± 0.050
% Fines	-	-	-	-	32.0 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	4.5 ± 1.3
C_R	-	-	-	-	1.00
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.01
C_E	-	-	-	-	1.11
C_N	-	-	-	-	1.90
$(N_1)_{60}$	-	-	-	-	9.6 ± 2.7
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	165.6

EVENT PARAMETERS

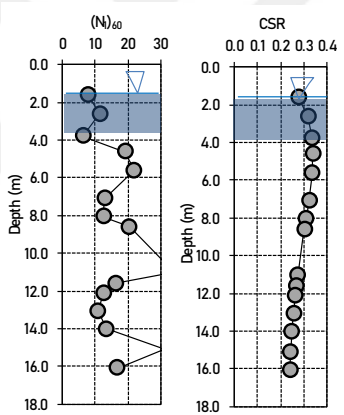
1999 Chi-chi Earthquake

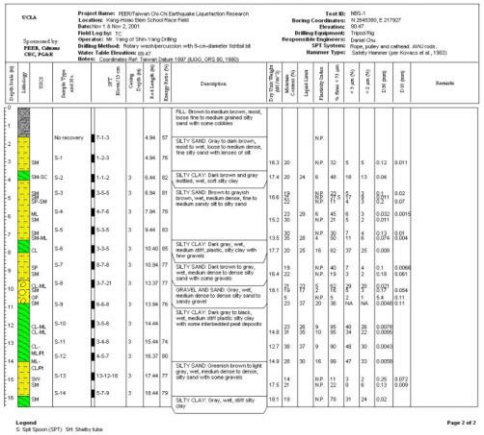
Magnitude: 7.62

Fault Type: inland thrust ea — Z_{tor} (km): 0 — R_{rup} (km): 2.1

Dip: 30 — Width (km): 40 — R_{jb} (km): 2.1

ACCELERATION TIME HISTORY

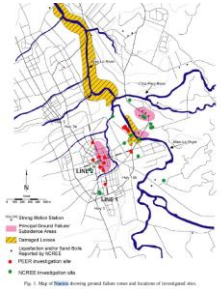


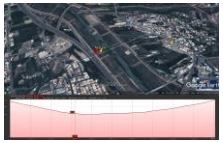


	Rod Length	Depth (m)	Depth (ft)	rd	CSR	N	C_N	C_R	$(N1)_{60}$	ER	C_E	FC (<75 μm)	clay (<2 μm)	silt	PI	D_{50}	D_{10}	γ_{dry} (kN/m^3)
No Recovery	***4.94***	***1.60***	***5.2***	***0.979***	***0.275***	***4***	***2.00***	***1.00***	***7.7***	***57.0***	***0.95***	***-***	***-***	***-***	***NP***	***-***		
SM	***4.94***	***2.60***	***8.5***	***0.961***	***0.318***	***5***	***1.80***	***1.00***	***11.5***	***76.0***	***1.27***	***32.0***	***5.0***	***27.0***	***NP***	***0.1200***	***0.01***	***16.3***
SM-SC	6.44	3.80	12.5	0.932	0.337	3	1.53	1.00	6.3	82.0	1.37	48.0	13		6.0	0.0400	-	17.4
SM	6.94	4.60	15.1	0.909	0.339	10	1.41	1.00	19.1	81.0	1.35	20.5	3//9//3		NP	0.1037	0.05	16.6
ML	7.94	5.60	18.4	0.874	0.336	13	1.29	1.00	21.9	78.0	1.30	45//21	3//2		NP-6	0.032/0.011	0.00	15.2
SM	9.44	7.10	23.3	0.816	0.323	8	1.16	1.00	12.9	83.0	1.38	30//50	4//6		NP-4	0.13/0.074	0.01/0.004	13.5
CL	10.40	8.06	26.4	0.776	0.311	8	1.09	1.00	12.5	85.0	1.42	82.0	25		16.0	0.0080	-	17.7
SP-SM	10.94	8.60	28.2	0.754	0.304	15	1.06	1.00	20.5	77.0	1.28	40//19	4//2		NP	0.1/0.18	0.0066/0.061	16.4
CL-ML-SM	13.37	11.03	36.2	0.665	0.273	28	0.94	1.00	34.1	77.0	1.28	62//16	20//3		5//2			18.1
SM	13.94	11.60	38.1	0.648	0.267	14	0.92	1.00	16.4	76.0	1.27	5//36	1		NP/20			
CL-ML	14.44	12.10	39.7	0.635	0.263	11	0.90	1.00	12.5	-	***1.25***	95//95	26//22		9//10			
CL-ML	15.44	13.10	43.0	0.612	0.254	10	0.87	1.00	10.8	74.0	1.23	90.0	30		6.0			
CL-ML-PT	16.37	14.03	46.0	0.596	0.249	12	0.84	1.00	13.5	80.0	1.33	99.0	33		16.0			
SW-SM	17.44	15.10	49.5	0.581	0.244	30	0.81	1.00	31.4	77.0	1.28	11//12	2//6		NP			
SM	18.44	16.10	52.8	0.571	0.240	16	0.79	1.00	16.7	79.0	1.32	78.0	24		NP			
								Mean:	9.6	66.5	1.11	32.0	5.0	27.0	**NP**	0.120	0.011	
								St. Dev.	2.7	13.4	0.22	8.6	2.3	8.3	**NP**	0.050	0.050	
													assigned uncertainty					

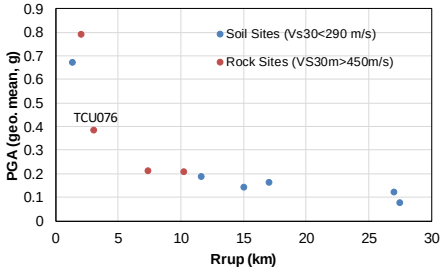
**No short rod correction since energy measurements were available*

Case number: 417
Earthquake: 1999 Chi-chi Earthquake
Magnitude: 7.6
Location: Nantou Site C, NCC-1, 2, & 3 and NCS-1 & 2
References: PEER, Stewart et al 2004, Zheng and Chen 2001, Chu et al 2006
Nature of Failure: Lateral spreading and sand boils https://apps.peer.berkeley.edu/lifelines/research_projects
GPS LAT 23.917808
GPS LONG 120.691202
Liq. layer consist of: Silty sand https://cecas.clemson.edu/chichi
Geological Unit: Levee site? / alluvial plane Stewart et al (2004)
Site Response Anlaysis: No
Comments: Chu et al (2006) "Although located on alluvium, no evidence of ground failure from soil softening or liquefaction was observed in the areas near the strong motion stations in Wufeng and Nantou.". Chu et al. (2004) "The geometric mean peak ground acceleration recorded in Nantou (station TCU076) is 0.39 g. The station is located on Holocene alluvial soils at a distance of 3 km from the ruptured fault. The area immediately surrounding this station showed no evidence of ground failure. "Chu et al. (2003) also suggest 0.39 g for the area. Boulanger and Idriss (2014) took PGA=0.39 for Nantou Site C, NCC-1,2,&3, Nantou Site C-7 and C-8 (CPT catalogue). Moss (2003) took 0.5 g for Nantou Site C. Nearest station TCU076 is located 1900 m from the site and the station has Vs of 573 m/s. Recorded PGA is 0.38 g at that station. Site has Vs12m (approx. 202 m/s) calculated based on nearby Vs (127TWN), Vs30 nearby sites about 250 m/s. Site specific amplification (Abrahamson and Silva 2014) is calculated as 0.97 hence amax is calibrated as 0.375 g.





st	y	x	Epicenter (km)	Vertical	N-S	E-W	Rrup	Vs30 (m/s)	pga (G)
TCU065	24°03.54'	120°41.46'	25.57	257.8	563.22	774.42	1.3	290	0.673222
TCU076	23°54.47'	120°40.54'	15.25	275.38	420.02	340.1	3	573	0.385274
TCU110	23°57.70'	120°34.19'	27.5	116.28	187.52	178.24	11.6	199.5	0.186362
TCU112	24°03.36'	120°25.41'	45.5	65.26	68	78.3	27.5	191	0.074382
TCU117	24°07.98'	120°27.62'	47.22	89.96	113.46	121.3	27	207	0.119587
TCU120	23°58.80'	120°36.78'	24.62	166.52	193.5	222.98	7.4	458	0.211741
TCU123	24°01.06'	120°32.56'	32.89	85.54	131.96	149	15	289	0.142937
TCU129	23°52.70'	120°41.06'	13.54	334.96	610.76	983	2	506.5	0.789847
TCU138	23°55.34'	120°35.07'	55.34	110.36	207.4	202.24	10.2	604	0.20877
CHY104	23°40.19'	120°27.94'	41.33	129.68	177.12	142.9	17	218.8	0.162174



Gravel Contents (%): NAV
CPT available: Yes
Vs available: No

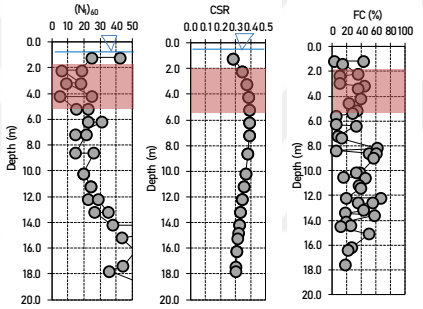
Summary of Input Data

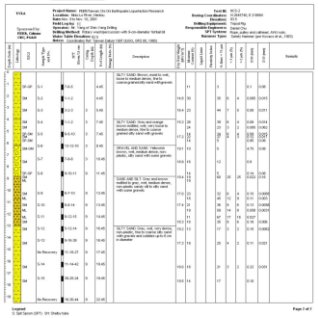
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.0 - 5.2
d_{crt} (m)	-	-	-	-	3.6
GWT (m)	-	-	-	-	0.9 ± 0.2
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	72.8 ± 11.1
σ_v' (kPa)	-	-	-	-	45.8 ± 6.2
a_{max} (g)	-	-	-	-	0.375 ± 0.075
r_d	-	-	-	-	0.98 ± 0.053
CSR	-	-	-	-	0.380 ± 0.081
M_w	-	-	-	-	7.62
D_{50}	-	-	-	-	0.114 ± 0.041
% Fines	-	-	-	-	28.8 ± 13.0
% PI	-	-	-	-	NAV
N	-	-	-	-	6.8 ± 3.4
C_R	-	-	-	-	0.93
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.01
C_E	-	-	-	-	1.25
C_N	-	-	-	-	1.49
$(N_1)_{60}$	-	-	-	-	11.9 ± 6.0
V_{s30m} (m/s)	-	-	-	-	254
V_{s12m} (m/s)	-	-	-	-	201.9

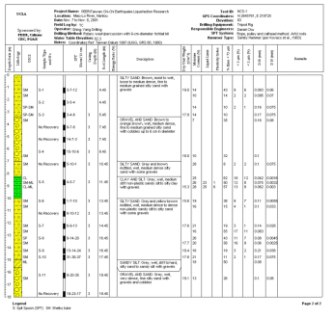
EVENT PARAMETERS

1999 Chi-chi Earthquake
Magnitude: 7.62
Fault Type: inland thrust ea Z_{tor} (km): 0 R_{rup} (km): 1.1
Dip: 30 Width (km): 40 R_{jb} (km): 1.1

ACCELERATION TIME HISTORY







Borehole	Soil Layer	Rod length	Depth (m)	Depth (ft)	rd	CSR	N	C_N	C_R	$(N1)_{60}$	
NCS-1	SM	4.45	1.20	3.9	0.995	0.285	19	2.00	0.89	42.6	CN>2
NCS-2	SP-GP	4.45	1.20	3.9	0.995	0.285	11	2.00	0.89	24.7	CN>2
NCS-1	***SM***	***4.45***	***2.20***	***7.2***	***0.990***	***0.346***	***9***	***1.82***	***0.89***	***18.4***	
NCS-2	***SM***	***4.45***	***2.20***	***7.2***	***0.990***	***0.346***	***3***	***1.82***	***0.89***	***6.1***	
NCS-1	***SP-SM***	***5.45***	***3.20***	***10.5***	***0.983***	***0.373***	***10***	***1.57***	***0.91***	***18.0***	
NCS-2	***SM***	***5.45***	***3.20***	***10.5***	***0.983***	***0.373***	***5***	***1.57***	***0.91***	***9.0***	
NCS-1	SM	7.45	4.20	13.8	0.973	0.387	15	1.39	0.94	24.8	outlier
NCS-2	***SM***	***7.45***	***4.20***	***13.8***	***0.973***	***0.387***	***3***	***1.39***	***0.94***	***5.0***	
NCS-1	***SM***	***7.45***	***5.20***	***17.1***	***0.960***	***0.393***	***10***	***1.27***	***0.94***	***15.0***	
NCS-2	SP-SM	7.45	5.20	17.1	0.960	0.393	15	1.27	0.94	22.6	another layer
NCS-1	SM	8.45	6.20	20.3	0.944	0.394	16	1.17	0.95	22.5	
NCS-2	SM-GM/SP-SM	8.45	6.20	20.3	0.944	0.394	22	1.17	0.95	30.9	outlier
NCS-1	SM	10.45	7.20	23.6	0.923	0.391	11	1.10	0.97	14.7	
NCS-2	SM	10.45	7.20	23.6	0.923	0.391	16	1.10	0.97	21.4	
NCS-1	SM-ML	11.45	8.60	28.2	0.888	0.381	12	1.01	0.97	14.8	high FC
NCS-2	SP-GP	11.45	8.60	28.2	0.888	0.381	21	1.01	0.97	26.0	
NCS-1	SM	13.45	10.20	33.5	0.840	0.366	17	0.93	0.98	19.6	
NCS-2	SM	13.45	10.20	33.5	0.840	0.366	17	0.93	0.98	19.6	
NCS-1	SM	13.45	11.20	36.7	0.809	0.354	22	0.89	0.98	24.3	
NCS-2	SM	13.45	11.20	36.7	0.809	0.354	22	0.89	0.98	24.3	
NCS-1	SM	14.45	12.20	40.0	0.779	0.343	21	0.86	0.99	22.3	
NCS-2	ML	14.45	12.20	40.0	0.779	0.343	27	0.86	0.99	28.7	
NCS-1	SP-SM	16.45	13.20	43.3	0.752	0.332	34	0.82	0.99	35.0	
NCS-2	SM	16.45	13.20	43.3	0.752	0.332	26	0.82	0.99	26.7	
NCS-1	SM	16.45	14.20	46.6	0.728	0.323	38	0.80	0.99	37.7	
NCS-2	SM	16.45	14.20	46.6	0.728	0.323	55	0.80	0.99	54.6	
NCS-1	SM	17.45	14.80	48.6	0.716	0.318	67	0.78	0.99	65.3	
NCS-2	No recovery	17.45	15.20	49.9	0.708	0.315	45	0.77	0.99	43.3	
NCS-1	SM	19.45	16.20	53.1	0.692	0.309	55	0.75	1.00	51.5	
NCS-2	SM	19.45	16.20	53.1	0.692	0.309	56	0.75	1.00	52.4	
NCS-2	SM	19.45	17.40	57.1	0.678	0.303	49	0.72	1.00	44.3	
NCS-1	SM	19.45	17.80	58.4	0.674	0.302	40	0.71	1.00	35.8	
NCS-2	No recovery	22.45	19.20	63.0	0.664	0.298	74	0.69	1.00	64.0	
									Mean:	11.9	
									St. Dev.	6.0	

**stick-up is assumed to be 3.25 m (unusual)*

Depth (m)	FC	clay	silt	PI	D_{50}	D_{10}	
1.20	43	6	37		0.0830	0.06	NCS-1
1.20	3	0	3		0.1000	0.08	NCS-2
1.40	14	2	12		0.0950	0.07	NCS-1
2.20	***35***	***4***	***31***		***0.0850***	***0.02***	***NCS-2***
2.40	***10***	***1***	***9***		***0.1600***	***0.08***	***NCS-1***
3.00	***10***	***0***	***10***		***0.1700***	***0.08***	***NCS-1***
3.20	***44***	***5***	***39***		***0.0800***	***0.01***	***NCS-2***
3.40	***35***	***0***	***35***		***0.1600***	***0.08***	***NCS-1***
4.20	***39***	***4***	***35***		***0.0800***	***0.01***	***NCS-2***
4.60	***23***	***2***	***21***		***0.0850***	***0.06***	***NCS-2***
5.20	***34***	***4***	***30***		***0.0900***	***0.02***	***NCS-2***
5.40	27	3	24		0.1200	0.02	NCS-2
5.60	5	0	5		0.8500	0.08	NCS-2
6.30	5	0	5		4.7500	0.08	NCS-2
6.40	32	0	32		0.1000		NCS-1
7.20	8	2	6		0.1000	0.08	NCS-1
7.40	12	0	12		0.8000		NCS-2
8.20	62	12	50		0.0420	0.00	NCS-1
8.40	5	0	5		0.1400	0.08	NCS-2
8.60	50	8	42	1.00	0.0750	0.00	NCS-1
8.60	60	25	35		0.0220	0.16	NCS-2
9.00	57	8	49	6.00	0.0620	0.00	NCS-1
10.20	38	7	31		0.1100	0.01	NCS-1
10.20	32	4	28		0.1500	0.01	NCS-2
10.50	15	1	14		0.1000	0.03	NCS-1
10.60	45	9	36		0.1100	0.00	NCS-2
11.20	36	6	30		0.1300	0.01	NCS-2
11.40	39	8	31		0.0580	0.00	NCS-2
12.20	19	1	18		0.1400	0.03	NCS-1
12.20	67	16	51		0.0270		NCS-2
12.60	55	11	44		0.0630		NCS-1
12.60	35	6	29		0.1800	0.01	NCS-2
13.20	43	7	36		0.0800	0.00	NCS-1
13.40	17	2	15		0.1500	0.01	NCS-2
13.60	58	9	49		0.0600	0.00	NCS-1
14.10	19	2	17		0.2100	0.04	NCS-1
14.40	25	2	23		0.1100	0.02	NCS-2
14.50	11	1	10		0.1700	0.08	NCS-1
15.10	50	0	50		0.0800		NCS-1
16.20	26	0	26		0.1000	0.08	NCS-1
16.40	21	2	19		0.2200	0.03	NCS-2
17.60	17	0	17		0.1000	-	NCS-2
Mean:	28.8	2.5	26.3		0.114	0.043	
St. Dev.	13.0	2.0	11.6		0.041	0.032	

Earthquake:	1999 Chi-chi Earthquake
Magnitude:	7.6
Location:	Yuanlin BH-3 (C-2)
References:	PEER, Stewart et al 2004, Zheng and Chen 2001, Chu et al 2006
Nature of Failure:	Yes
GPS LAT	23.986817
GPS LONG	120.571572
Liq. layer consist of:	Silty sand (SM)
Geological Unit:	Holocene deltaic deposits west of Shan-Jao Road, and older Pleistocene sandstone
Site Response Anlaysis:	No
Comments:	"…. The town of Yuanlin (population ≈ 116,000, area = 40 km2) is located approximately 15 km from the Chelungpu fault rupture, yet was subject to severe liquefaction. Figure 4 is a map of Yuanlin showing locations of sediment boils, regions of building subsidence, and investigated sites. As shown in Figure 4, the township is located on flat Holocene deltaic deposits west of Shan-Jao Road, and older Pleistocene sandstone, siltstone and conglomerate east of Shan-Jao Road that slopes gently up to the east. Groundwater levels are relatively shallow, generally occurring at depths between 0.5-7 m. Ground motions records from station TCU110 in Yuanlin indicate a geometric mean peak acceleration of 0.18 g. This station is located in an area where ground failure was not observed. Ground failure in Yuanlin from the Chi-Chi earthquake typically took the form of building subsidence and sediment boils. The case histories of ground failure and non ground failure are principally from well-developed areas. Free-field sites consist of open lots within otherwise developed areas. Unlike Nantou and Wufeng, case histories of building subsidence in Yuanlin often include sediment boils as well. As shown in Figure 4, site exploration was performed both in areas with and without evidence of ground failure...." Stewart et al 2004.
Gravel Contents (%):	NAV
CPT available:	No
Vs available:	No



https://apps.peer.berkeley.edu/lifelines/research_projects

https://cecas.clemson.edu/chichi

The coordinates were determined from the map provided by PEER hence they are approximate.

The nearest station is TCU110 which recorded 0.186 g (geometric mean of the two component) has a rupture distance of 11.6 km and Vs30m of 200 m/s. Shear wave velocity measurements were available at the site. Vs30m is estimated as 199 m/s. Site specific amplification (Abrahamson and Silva 2014) is calculated as 0.99 hence amax is calibrated as 0.185 g. Event specific model is constructed by using the nearby station data located on the footwall site as shown on the right bottom.

The site is not listed in https://cecas.clemson.edu/chichi/TW-LIQ/Yuanlin-SPT.htm

CPT data indicates the same layer selection. Moss (2006) selected 2.5-4 m.

st	y	x	Epicenter	Vertical	N-S	E-W	Rrup	Vs30 (m/S)	pga (G)
TCU065	24°03.54'	120°41.46'	25.57	257.8	563.22	774.42	1.3	290	0.673222
TCU076	23°54.47'	120°40.54'	15.25	275.38	420.02	340.1	3	573	0.385274
TCU110	23°57.70'	120°34.19'	27.5	116.28	187.52	178.24	11.6	199.5	0.186362
TCU112	24°03.36'	120°25.41'	45.5	65.26	68	78.3	27.5	191	0.074382
TCU117	24°07.98'	120°27.62'	47.22	89.96	113.46	121.3	27	207	0.119587
TCU120	23°58.80'	120°36.78'	24.62	166.52	193.5	222.98	7.4	458	0.211741
TCU123	24°01.06'	120°32.56'	32.89	85.54	131.96	149	15	289	0.142937
TCU129	23°52.70'	120°41.06'	13.54	334.96	610.76	983	2	506.5	0.789847
TCU138	23°55.34'	120°35.07'	55.34	110.36	207.4	202.24	10.2	604	0.20877
CHY104	23°40.19'	120°27.94'	41.33	129.68	177.12	142.9	17	218.8	0.162174

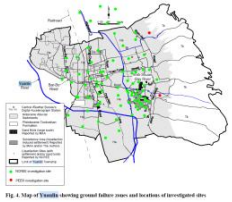


Fig. 4. Map of Yuanlin showing ground failure zones and locations of investigated sites

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.5 - 4.0
d_{crt} (m)	-	-	-	-	3.3
GWT (m)	-	-	-	-	0.6 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	60.5 ± 4.9
σ_v' (kPa)	-	-	-	-	34.4 ± 2.7
a_{max} (g)	-	-	-	-	0.185 ± 0.037
r_d	-	-	-	-	0.94 ± 0.048
CSR	-	-	-	-	0.198 ± 0.041
M_w	-	-	-	-	7.62
D_{50}	-	-	-	-	0.210 ± 0.050
% Fines	-	-	-	-	18.0 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	5.4 ± 1.0
C_R	-	-	-	-	0.90
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.25
C_N	-	-	-	-	1.72
$(N_1)_{60}$	-	-	-	-	10.4 ± 2.0
V_{s30m} (m/s)	-	-	-	-	199
V_{s12m} (m/s)	-	-	-	-	157.0

EVENT PARAMETERS

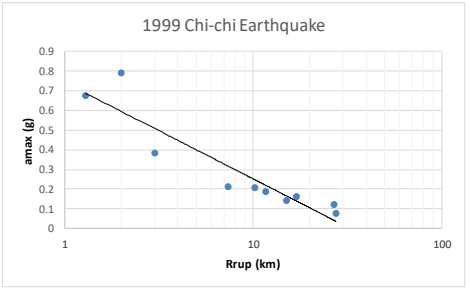
1999 Chi-chi Earthquake — Zheng and Chen 2001

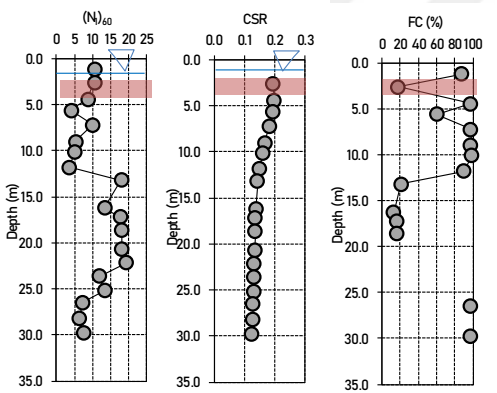
Magnitude: 7.62 — footwall

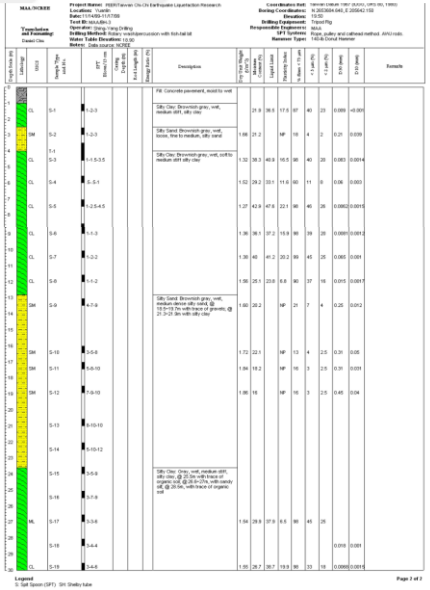
Fault Type: inland thrust ea — Z_{tor} (km): 0 — R_{rup} (km): 11.8

Dip: 30 — Width (km): 40 — R_{jb} (km): 11.8

ACCELERATION TIME HISTORY







										<75 µm		<2 µm			
	Depth (m)	**Depth (ft)**	**rd**	**CSR**	**N**	**C_N**	**C_R**	**$(N1)_{60}$**	**PI**	**FC**	**Silt**	**Clay**	**D_{50}**	**D_{10}**	
CL	1.20	3.9	0.982	0.162	5	2.00	0.84	10.5	17.5	87.0	64.0	23.0	0.009	0.001	
SM	***2.60***	***8.5***	***0.953***	***0.194***	***5***	***1.89***	***0.88***	***10.4***	***NP***	***18.0***	***16.0***	***2.0***	***0.21***	***0.039***	*CPT data indicates the same layer selection.*
CL	4.40	14.4	0.900	0.198	5	1.50	0.92	8.6	16.5	98.0	78.0	20.0	0.083	0.0014	Moss (2006) selected 2.5-4 m.
CL	5.60	18.4	0.856	0.194	2.5	1.35	0.94	4.0	11.6	60.0	52.0	8.0	0.06	0.003	
CL	7.20	23.6	0.790	0.183	7	1.20	0.95	10.0	22.1	98.0	72.0	26.0	0.0062	0.0015	
CL	9.00	29.5	0.717	0.168	4	1.08	0.97	5.2	15.9	98.0	78.0	20.0	0.0081	0.0012	
CL	10.10	33.1	0.678	0.160	4	1.03	0.97	5.0	20.2	99.0	74.0	25.0	0.065	0.001	
CL	11.80	38.7	0.631	0.150	3	0.95	0.98	3.5	6.8	90.0	74.0	16.0	0.015	0.0017	
SM	**13.20**	**43.3**	**0.603**	**0.145**	**16**	**0.90**	**0.99**	**17.8**	**NP**	**21.0**	**17.0**	**4.0**	**0.25**	**0.012**	***high SPT low***
SM	**16.20**	**53.1**	**0.570**	**0.138**	**13**	**0.82**	**0.99**	**13.2**	**NP**	**13.0**	**10.5**	**2.5**	**0.31**	**0.05**	***CSR, upper***
SM	**17.20**	**56.4**	**0.564**	**0.137**	**18**	**0.79**	**0.99**	**17.8**	**NP**	**16.0**	**13.5**	**2.5**	**0.31**	**0.031**	***layer is more***
SM	**18.60**	**61.0**	**0.559**	**0.136**	**19**	**0.76**	**1.00**	**18.1**	**NP**	**16.0**	**13.5**	**2.5**	**0.45**	**0.04**	***critical***
	20.70	67.9	0.551	0.134	20	0.73	1.00	18.1							PI unknown
	22.20	72.8	0.545	0.133	22	0.70	1.00	19.3							PI unknown
	23.60	77.4	0.538	0.131	14	0.68	1.00	11.9							PI unknown
ML	25.20	82.7	0.531	0.130	16	0.66	1.00	13.2							trace organics
	26.50	86.9	0.525	0.129	9	0.64	1.00	7.2	6.5	98.0	73.0	25.0			
	28.20	92.5	0.517	0.127	8	0.62	1.00	6.2					0.018	0.001	
CL	29.80	97.8	0.510	0.125	10	0.61	1.00	7.6	19.9	98.0	80.0	18.0	0.0068	0.0015	
							Mean:	10.4		18.0	16.0	2.0	0.2		
							St. Dev.	2.0		8.6	8.3	2.3	0.050	assigned	

**stick-up is assumed to be 1.5 m*

Case number:	421
Earthquake:	1999 Chi-chi Earthquake
Magnitude:	7.6
Location:	Yuanlin BH-21 (C-32)
References:	PEER, Stewart et al 2004, Zheng and Chen 2001, Chu et al 2006
Nature of Failure:	Yes
GPS LAT	23.958869
GPS LONG	120.600294
Liq. layer consist of:	Silt (ML)
Geological Unit:	Holocene deltaic deposits west of Shan-Jao Road, and older Pleistocene sandstone
Site Response Anlaysis:	No
Comments:	" .... The town of Yuanlin (population ≈ 116,000, area = 40 km2) is located approximately 15 km from the Chelungpu fault rupture, yet was subject to severe liquefaction. Figure 4 is a map of Yuanlin showing locations of sediment boils, regions of building subsidence, and investigated sites. As shown in Figure 4, the township is located on flat Holocene deltaic deposits west of Shan-Jao Road, and older Pleistocene sandstone, siltstone and conglomerate east of Shan-Jao Road that slopes gently up to the east. Groundwater levels are relatively shallow, generally occurring at depths between 0.5-7 m. Ground motions records from station TCU110 in Yuanlin indicate a geometric mean peak acceleration of 0.18 g. This station is located in an area where ground failure was not observed. Ground failure in Yuanlin from the Chi-Chi earthquake typically took the form of building subsidence and sediment boils. The case histories of ground failure and non ground failure are principally from well-developed areas. Free-field sites consist of open lots within otherwise developed areas. Unlike Nantou and Wufeng, case histories of building subsidence in Yuanlin often include sediment boils as well. As shown in Figure 4, site exploration was performed both in areas with and without evidence of ground failure...." Stewart et al. (2004).
Gravel Contents (%):	NAV
CPT available:	Yes
Vs available:	Yes



https://apps.peer.berkeley.edu/lifelines/research_projects/3A02/SPT/Y

The coordinates were determined from the map provided by PEER hence they are approximate.

https://cecas.clemson.edu/chichi

23°57'31.93"N

120°36'1.06"E

The nearest station is TCU110 which recorded 0.186 g (geometric mean of the two component) has a rupture distance of 11.6 km and Vs30m of 200 m/s. Shear wave velocity measurements were available at the site. Vs30m is estimated as 185 m/s. Site specific amplification (Abrahamson and Silva 2014) is calculated as 1.07 hence amax is calibrated as 0.199 g. Event specific model is constructed by using the nearby station data located on the footwall site as shown on the right bottom.

st	y	x	Epicenter r	Vertical	N-S	E-W	Rrup	Vs30 (m/S)	pga (G)
TCU065	24°03.54'	120°41.46'	25.57	257.8	563.22	774.42	1.3	290	0.673222
TCU076	23°54.47'	120°40.54'	15.25	275.38	420.02	340.1	3	573	0.385274
TCU110	23°57.70'	120°34.19'	27.5	116.28	187.52	178.24	11.6	199.5	0.186362
TCU112	24°03.36'	120°25.41'	45.5	65.26	68	78.3	27.5	191	0.074382
TCU117	24°07.98'	120°27.62'	47.22	89.96	113.46	121.3	27	207	0.119587
TCU120	23°58.80'	120°36.78'	24.62	166.52	193.5	222.98	7.4	458	0.211741
TCU123	24°01.06'	120°32.56'	32.89	85.54	131.96	149	15	289	0.142937
TCU129	23°52.70'	120°41.06'	13.54	334.96	610.76	983	2	506.5	0.788947
TCU138	23°55.34'	120°35.07'	55.34	110.36	207.4	202.24	10.2	604	0.20877
CHY104	23°40.19'	120°27.94'	41.33	129.68	177.12	142.9	17	218.8	0.162174

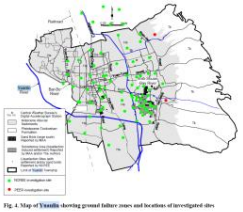
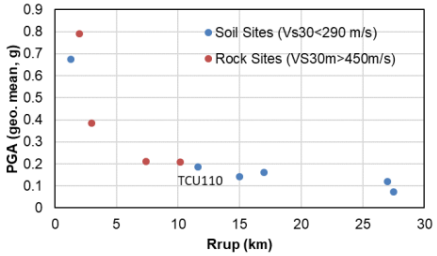


Fig. 4. Map of Yuanlin showing ground failure zones and locations of investigated sites



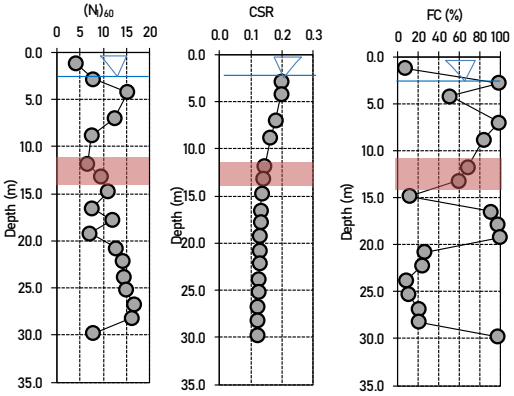
Summary of Input Data

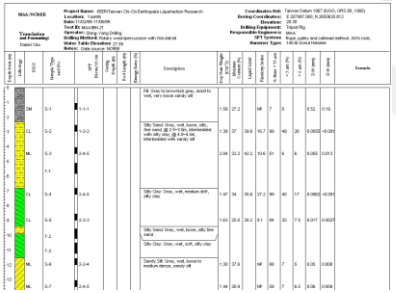
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	11.5 - 13.5
d_{crt} (m)	-	-	-	-	12.5
GWT (m)	-	-	-	-	0.7 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.0 ± 0.5
σ_v (kPa)	-	-	-	-	247.6 ± 8.7
σ_v' (kPa)	-	-	-	-	131.8 ± 6.6
a_{max} (g)	-	-	-	-	0.199 ± 0.040
r_d	-	-	-	-	0.58 ± 0.149
CSR	-	-	-	-	0.141 ± 0.046
M_w	-	-	-	-	7.62
D_{50}	-	-	-	-	0.055 ± 0.007
% Fines	-	-	-	-	63.5 ± 6.4
% PI	-	-	-	-	0
N	-	-	-	-	7.5 ± 1.9
C_R	-	-	-	-	0.98
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.25
C_N	-	-	-	-	0.88
$(N_1)_{60}$	-	-	-	-	8.1 ± 2.0
V_{s30m} (m/s)	-	-	-	-	184.7
V_{s12m} (m/s)	-	-	-	-	147.5

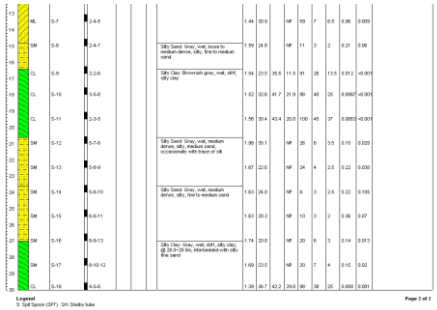
EVENT PARAMETERS

1999 Chi-chi Earthquake	Zheng and Chen 2001	
Magnitude: 7.62		footwall
Fault Type: inland thrust ea	Z_{tor} (km): 0	R_{rup} (km): 8.5
Dip: 30	Width (km): 40	R_{jb} (km): 8.5

ACCELERATION TIME HISTORY







	Depth (m)	Depth (ft)	rd	CSR	N	C_N	C_R	$(N1)_{60}$	PI	FC (<75 μm)	Silt	Clay (<2 μm)	D_{50}	(kN/m3)	GS	WL (0/0)	
SM	1.20	3.9	0.98	0.16	2	2.00	0.84	4.2	N	7.0	7.0	0.0	0.5	19.8	2.8		
CL	2.80	9.2	0.93	0.197	4	1.77	0.89	7.8	16.7	99.0	73.0	26.0	0.0	18.7	2.7	39.8	
ML	4.20	13.8	0.88	0.197	9	1.47	0.92	15.2	10.6	51.0	45.0	6.0	0.1	26.5	2.7	42.2	plastic
CL	7.00	23.0	0.76	0.178	9	1.16	0.95	12.4	27.2	99.0	82.0	17.0	0.0	19.3	2.7	35.6	plastic
CL	8.80	28.9	0.68	0.163	6	1.04	0.97	7.5	8.1	84.0	76.5	7.5	0.0	20.1	2.7	28.2	
ML	***11.80***	***38.7***	***0.59***	***0.144***	***6***	***0.90***	***0.98***	***6.7***	***NP***	***68.0***	***63.0***	***5.0***	***0.1***	***17.5***	***2.8***		higher CSR
ML	***13.20***	***43.3***	***0.57***	***0.138***	***9***	***0.86***	***0.99***	***9.5***	***NP***	***59.0***	***52.5***	***6.5***	***0.1***	***18.5***	***2.8***		higher CSR
SM	***14.80***	***48.6***	***0.55***	***0.135***	***11***	***0.81***	***0.99***	***11.0***	***NP***	***11.0***	***9.0***	***2.0***	***0.2***	***19.5***	***2.7***		another layer whose SPT is higher
CL	16.50	54.1	0.54	0.132	8	0.77	0.99	7.6	11.5	91.0	77.5	13.5	0.0	18.6	2.7	35.5	
CL	17.80	58.4	0.53	0.131	13	0.74	0.99	11.9	21.9	98.0	73.0	25.0	0.0	19.7	2.7	41.7	
CL	19.20	63.0	0.53	0.130	8	0.71	1.00	7.1	20.8	100.0	63.0	37.0	0.0	19.9	2.7	43.4	
SM	20.80	68.2	0.52	0.129	15	0.68	1.00	12.8	NP	26.0	22.5	3.5	0.2	26.2	2.7		
SM	22.20	72.8	0.52	0.128	17	0.66	1.00	14.1	NP	24.0	21.5	2.5	0.2	20.1	2.8		
SM	23.80	78.1	0.51	0.126	18	0.64	1.00	14.4	NP	8.0	5.5	2.5	0.2	20.0	2.7		
SM	25.20	82.7	0.50	0.125	19	0.62	1.00	14.8	NP	10.0	8.0	2.0	0.4	20.5	2.8		
SM	26.80	87.9	0.50	0.123	22	0.60	1.00	16.6	NP	20.0	17.0	3.0	0.1	20.6	2.7		
SM	28.20	92.5	0.49	0.122	22	0.59	1.00	16.2	NP	20.0	16.0	4.0	0.2	20.5	2.7		
CL	29.80	97.8	0.48	0.120	11	0.57	1.00	7.9	29.8	98.0	73.0	25.0	0.0	18.6	2.8	42.2	
							Mean:	8.1		63.5	57.8	5.8	0.055				
							St. Dev.	2.0		6.4	7.4	1.1	0.007				

**stick-up is assumed to be 1.5 m*

Case number:	363
Earthquake:	1999 Hokkaido Earthquake
Magnitude:	6.2
Location:	Hakodate
References:	Iai. et. al. (1989), Greenfield (2017, 2018), NGL Project
GPS LAT	42.8542
GPS LONG	143.8579
Liq. layer consist of:	Silt
Geological Unit:	Quaternary terrace deposits of the Shiranuka Formation
Site Response Anlaysis:	No
Nature of Failure:	no accounts of liquefaction have been documented
Comments:	Greenfield (2018) "A strong motion recorder, HKD086, was installed near the Chokubetsu Train Station as part of Japan's National Research Institute for Earth Science and Disaster Resilience (NIED) K-net strong motion network. The coordinates of HKD086 are 42.8526O N and 143.8636OE. The strong motion recorder was first installed in June 1996. The K-net database lists the shear wave velocity in the upper 30 m, vs,30, of the HKD086 site as 205 m/s. This vs,30 value indicates HKD086 is founded on site class D soil. NIED performed an investigation prior to the installation of HKD086.....The Mw = 6.2 1999 Hokkaido earthquake occurred on May 12, 1999. Under southern Hokkaido, the Pacific Plate is subducting deep under the Okhotsk Plate. This interface frequently produces large, very deep earthquakes. According to the USGS ShakeMap, the initial rupture of the 1999 Hokkaido occurred at a depth of 103 km. The epicenter of the rupture was about 16 km from HKD086. The event was very deep, is related to subcrustal and subduction processes, and is not listed in the NGA West-2 database for shallow crustal earthquakes. The strong motion recorder HKD086 recorded ground motions during the 1999 Hokkaido earthquake and these motions have processed and cataloged in the K-net database. Figure 2 shows the three-component acceleration time histories recorded at HKD086 during the 1999 Hokkaido earthquake. The ground motion is recorded at a frequency of 100 Hz. ."
	Hakodate site is a non-liquefied site. SPT procedures were not clearly documented. However, on page 66 in Iai et. al. for comparison with Seed et. al. 1985, an average Japanese SPT energy ratio of 73% was reported to be used. On the basis of this, with some uncertainty Iai et. al. N values may be adopted as N73 values. Note that Seed et. al. (1985) adopted an energy ratio of 73% for liquefied cases. The rationale behind this choice could be field data which is unknown to us or simply a conservative engineering judgement. Back in 2018 the site was rejected due to missing soil layering information, now it is available thus the site is included. Greenfield (2018) reported amax as 0.386g. The record that have been found seems top match with Greenfield a-t histories but gives amax as 0.409g and 0.440 g geometric mean of whic is 0.424 g. This values is used in the analysis. This value is very high to perform deconvolution analysis (limitiation of EQL analysis) as a result CSR is estimated by simplified procedure. PI info were not available hence assigned based on USCS.
Gravel Content (%):	NAV
CPT available:	No
Vs available:	Yes

epicenter 43.032°N 143.835°E
https://earthquake.usgs.gov/earthquakes/eventpage/usp00097v1/executive

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{rtlc} range (m)	-	-	-	-	2.5 - 14.0
d_{rt} (m)	-	-	-	-	8.3
GWT (m)	-	-	-	-	1.6 ± 0.5
g_{moist} (kN/m^3)	-	-	-	-	18.1 ± 0.5
g_{sat} (kN/m^3)	-	-	-	-	19.6 ± 0.5
s_v (kPa)	-	-	-	-	159.9 ± 37.9
s_v' (kPa)	-	-	-	-	94.5 ± 19.6
a_{max} (g)	-	-	-	-	0.424 ± 0.021
r_d	-	-	-	-	0.52 ± 0.107
CSR	-	-	-	-	0.244 ± 0.054
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV
% Fines	-	-	-	-	50.7 ± 41.6
% PI	-	-	-	-	NAV
N	-	-	-	-	9.1 ± 3.6
C_R	-	-	-	-	0.97
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.04
$(N_1)_{60}$	-	-	-	-	12.5 ± 4.9
$V_{s,30m}$ (m/s)	-	-	-	-	205.0
$V_{s,12m}$ (m/s)	-	-	-	-	127.4

EVENT PARAMETERS

1999 Hokkaido Earthquake

Magnitude: 6.20 — The epicenter of the rupture was about 16 km

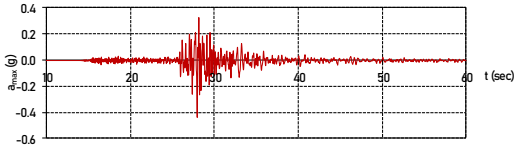
Fault Type: subcrustal and — Z_{tor} (km): - — R_{rup} (km): NAV

Dip: 21-69 — Width (km): - — R_{jb} (km): NAV

ACCELERATION TIME HISTORY

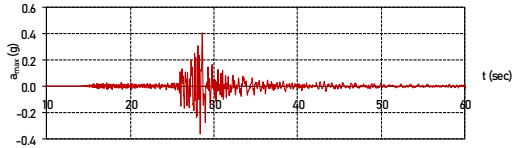
Full Record

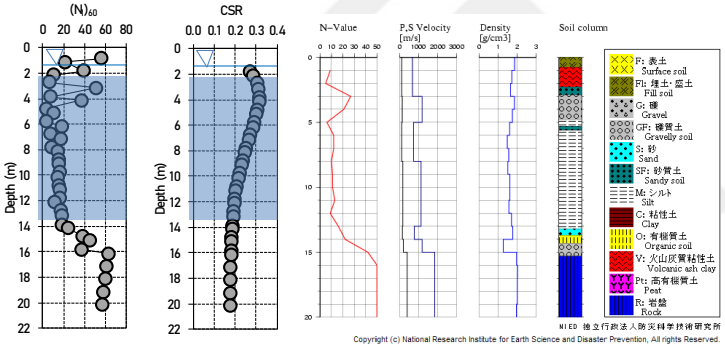
N_{H1}	10.0
N_{H2}	6.8
N_{gm}	8.2
PGA_{H1}	0.409
PGA_{H2}	0.440
PGA	0.424
M_w	6.2
$M_{w,cycle}$	2.6

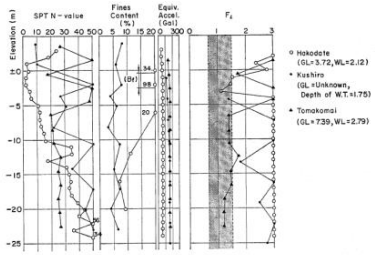


Untill Liquefaction

$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-







(b) Hakodate, Kushiro, and Tomakomai (Nonliquefied)

Fig. 13. Ground conditions and resulted liquefaction potentials at other strong-motion observation stations

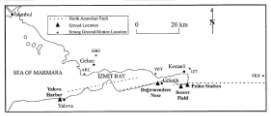
	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC		
lai. et. al. (1989)	0.86	2.81	NA	24	2.00	0.85	56	-		
From K-net boring log	1.15	3.77	NA	9	2.00	0.86	21	-	Volcanic Ash Clay	
lai. et. al. (1989)	1.81	5.94	0.27	18	1.81	0.88	39	-		
From K-net boring log	2.15	7.05	0.29	5	1.72	0.89	10	-	Volcanic Ash Clay	
lai. et. al. (1989)	***2.74***	***8.98***	***0.31***	***3***	***1.59***	***0.90***	***6***	***-***		
From K-net boring log	***3.15***	***10.33***	***0.31***	***27***	***1.51***	***0.91***	***51***	***-***	***Silty gravel***	outlier
lai. et. al. (1989)	***3.85***	***12.63***	***0.31***	***4***	***1.41***	***0.92***	***7***	***34***		
From K-net boring log	***4.15***	***13.62***	***0.31***	***21***	***1.37***	***0.92***	***36***	***-***	***Silty gravel***	outlier
lai. et. al. (1989)	***4.78***	***15.69***	***0.31***	***2***	***1.30***	***0.93***	***3***	***-***		
From K-net boring log	***5.15***	***16.90***	***0.30***	***6***	***1.26***	***0.94***	***10***	***-***	***Silt***	
lai. et. al. (1989)	***5.79***	***19.00***	***0.29***	***2***	***1.20***	***0.95***	***3***	***98***		
From K-net boring log	***6.15***	***20.18***	***0.28***	***12***	***1.17***	***0.95***	***18***	***-***	***Silty Sand***	
lai. et. al. (1989)	***6.75***	***22.16***	***0.27***	***5***	***1.13***	***0.96***	***7***	***-***		
From K-net boring log	***7.15***	***23.46***	***0.26***	***12***	***1.10***	***0.96***	***17***	***-***	***Silt***	
lai. et. al. (1989)	***7.78***	***25.54***	***0.25***	***6***	***1.06***	***0.96***	***8***	***-***		
From K-net boring log	***8.15***	***26.74***	***0.25***	***10***	***1.04***	***0.97***	***14***	***-***	***Silt***	
lai. et. al. (1989)	***8.81***	***28.91***	***0.23***	***11***	***1.01***	***0.97***	***15***	***-***		
From K-net boring log	***9.15***	***30.02***	***0.23***	***11***	***0.99***	***0.97***	***14***	***-***	***Silt***	
lai. et. al. (1989)	***9.74***	***31.97***	***0.22***	***12***	***0.96***	***0.98***	***15***	***20***		
From K-net boring log	***10.15***	***33.30***	***0.22***	***11***	***0.95***	***0.98***	***14***	***-***	***Silt***	
lai. et. al. (1989)	***10.81***	***35.46***	***0.21***	***12***	***0.92***	***0.98***	***15***	***-***		
From K-net boring log	***11.15***	***36.58***	***0.20***	***13***	***0.91***	***0.98***	***16***	***-***	***Silt***	
lai. et. al. (1989)	***11.79***	***38.67***	***0.20***	***13***	***0.89***	***0.98***	***15***	***-***		
From K-net boring log	***12.15***	***39.86***	***0.20***	***9***	***0.87***	***0.99***	***11***	***-***	***Silt***	
lai. et. al. (1989)	***12.80***	***42.00***	***0.19***	***15***	***0.85***	***0.99***	***17***	***-***		
From K-net boring log	***13.15***	***43.14***	***0.19***	***16***	***0.84***	***0.99***	***18***	***-***	***Silt***	
lai. et. al. (1989)	***13.92***	***45.67***	***0.19***	***16***	***0.82***	***0.99***	***18***	***-***		
From K-net boring log	14.15	46.42	0.18	22	0.82	0.99	24	-	Organic soil	
lai. et. al. (1989)	14.78	48.48	0.18	35	0.80	0.99	38	-		
From K-net boring log	15.15	49.70	0.18	42	0.79	0.99	45	-	Silty Gravel	
lai. et. al. (1989)	15.83	51.94	0.18	35	0.77	0.99	37	-		
From K-net boring log	16.15	52.99	0.18	60	0.77	0.99	63	-	Rock	
From K-net boring log	17.15	56.27	0.18	60	0.75	0.99	61	-	Rock	
From K-net boring log	18.15	59.55	0.18	60	0.73	1.00	59	-	Rock	
From K-net boring log	19.15	62.83	0.18	60	0.71	1.00	58	-	Rock	
From K-net boring log	20.15	66.11	0.18	60	0.69	1.00	57	-	Rock	
						Mean:	**12.5**	**50.7**		
						St. Dev.	**4.9**	**41.6**		

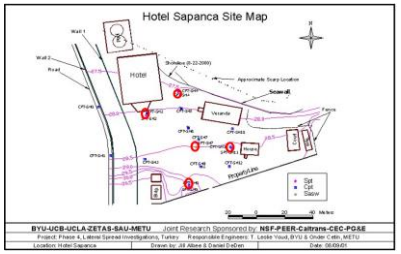
GWT (m)

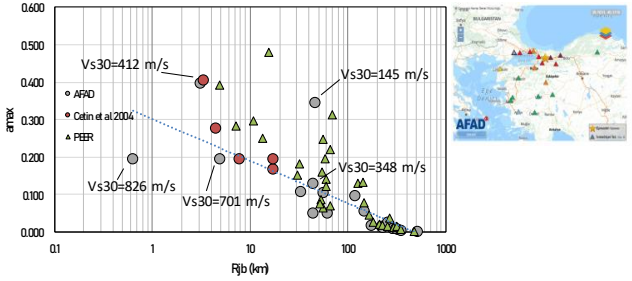
1.6	lai et al Borehole
4	Inferred from increased P-wave velocity in B-1

Depth (m)	Vs (m/s)	Vp (m/s)	time (s)
1	105	670	0.0095
2	105	670	0.0095
3	105	670	0.0095
4	135	1180	0.0074
5	135	1180	0.0074
6	110	730	0.0091
7	110	730	0.0091
8	110	730	0.0091
9	170	1130	0.0059
10	170	1130	0.0059
11	170	1130	0.0059
12	170	1130	0.0059
13	170	1130	
14	150	770	
15	190	1180	
16	400	1850	
17	400	1850	
18	400	1850	
19	400	1850	
20	400	1850	
		$V_{s,12m}$ (m/s)	127.4

Case number:	303
Earthquake:	1999 Kocaeli Earthquake
Magnitude:	7.51
Location:	Hotel Sapanca SH-7 https://apps.peer.berkeley.edu/publications/turkey/adapazari/index.html
References:	Cetin et al (2004), PEER(2000a), Personal Com. with Prof. Dr. Kemal Onder Cetin
Nature of Failure:	Sand Boil SPT-SH11 Vertical settlement
GPS LAT	40.6987 SPT-SH7 Sand Boil
GPS LONG	30.2654 SPT-SH9 Lateral Spread
Liq. layer consist of:	Sand (SW-SM)
Geological Unit:	Alluvium young flood-plain-deposits of Sakarya River
Site Response Anlaysis:	No
Comments:	A rope and cathead system was used to perform the Standard Penetration Test. Event specific gorund motion local model is contructed by using the available SMS data provided by AFAD. The fault rupture is measured as approximately as 1.2 km. The closest station to the site is called "5401" (Vs30=412 m/s, Rrup=6 km, PGA=0.399 g (only EW available). PGA=0.5 g is selected for the site.







Gravel Contents (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crit} range (m)	-	-	-	-	2.0 - 11.0
d_{crt} (m)	-	-	-	-	6.5
GWT (m)	-	-	-	-	1.3 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	131.9 ± 31.1
σ_v' (kPa)	-	-	-	-	80.3 ± 16.4
a_{max} (g)	-	-	-	-	0.500 ± 0.100
r_d	-	-	-	-	0.81 ± 0.087
CSR	-	-	-	-	0.435 ± 0.100
M_w	-	-	-	-	7.51
D_{50}	-	-	-	-	2.700 ± 1.106
% Fines	-	-	-	-	8.3 ± 3.5
% PI	-	-	-	-	0
N	-	-	-	-	11.4 ± 3.4
C_R	-	-	-	-	1.00
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.06
C_N	-	-	-	-	1.12
$(N_1)_{60}$	-	-	-	-	13.6 ± 4.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	162.2

EVENT PARAMETERS

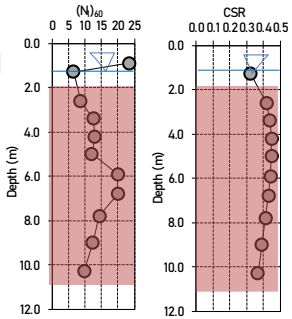
1999 Kocaeli Earthquake — fault length of 120km

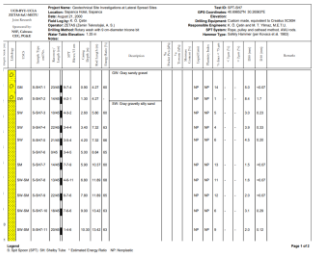
Magnitude: 7.51

Fault Type: Strike-slip (rigt — Z_{tor} (km): 0 — R_{rup} (km): 1.2

Dip: 83 — Width (km): 15 — R_{jb} (km): 1.2

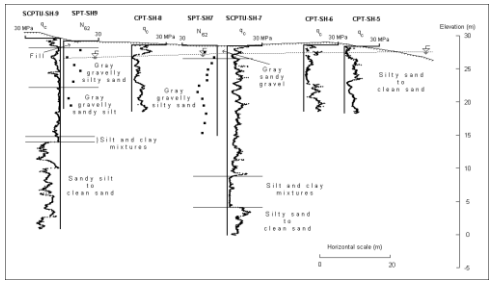
ACCELERATION TIME HISTORY





Depth (m)	Description
0	
2	GW: Gray sandy gravel
14	SW: Gray gravelly silty sand

GWT		
SPT-SH11	1.2	m
SPT-SH7	1.25	m
SPT-SH9	2.57	m



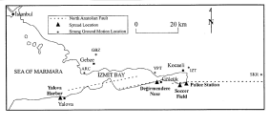
sand boils!		Depth (m)	Depth (ft)	CSR	N	C_N	rod length	C_R	$(N1)_{60}$	energy ratio	Depth (m)	USCS	Description	Liquid Limit	Plasticity Index	% fines < 75 µm	< 5 µm (%)	< 2 µm (%)	D_{50} (mm)	D_{10} (mm)
above GWT	SPT-SH7	0.9	3.0	NA	**11**	2.00	4.27	1.00	23	60	1.50	GM	GW	NP	NP	14	-	-	5	<0.07
inconsistent SPT gravel?? No ER.	SPT-SH7	1.3	4.3	0.325	**3**	2.00	4.27	1.00	6	-	2.62	GW	GW	NP	NP	1	-	-	8.4	1.7
	SPT-SH7	**2.6**	**8.5**	**0.417**	**5**	**1.63**	**5.80**	**1.00**	**9**	**60**	**3.50**	**SW**	**SW**	**NP**	**NP**	**5**	**-**	**-**	**3**	**0.23**
	SPT-SH7	**3.4**	**11.2**	**0.439**	**8**	**1.47**	**7.32**	**1.00**	**12**	**63**	**4.38**	**SW**	**SW**	**NP**	**NP**	**4**	**-**	**-**	**3.9**	**0.33**
	SPT-SH7	**4.2**	**13.8**	**0.449**	**9**	**1.35**	**7.32**	**1.00**	**13**	**66**	**5.26**	**SW**	**SW**	**NP**	**NP**	**6**	**-**	**-**	**4.5**	**0.2**
	SPT-SH7	**5.0**	**16.4**	**0.449**	**9**	**1.26**	**8.84**	**1.00**	**12**	**65**	**6.14**	**-**	**SW**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
	SPT-SH7	**5.9**	**19.4**	**0.442**	**16**	**1.17**	**10.37**	**1.00**	**20**	**60**	**7.02**	**SM**	**SW**	**NP**	**NP**	**13**	**-**	**-**	**1.5**	**<0.07**
	SPT-SH7	**6.8**	**22.3**	**0.430**	**17**	**1.10**	**11.89**	**1.00**	**20**	**68**	**7.90**	**SW-SM**	**SW**	**NP**	**NP**	**11**	**-**	**-**	**1.6**	**<0.07**
	SPT-SH7	**7.8**	**25.6**	**0.413**	**13**	**1.04**	**11.89**	**1.00**	**14**	**65**	**8.78**	**SW-SM**	**SW**	**NP**	**NP**	**12**	**-**	**-**	**2**	**<0.07**
	SPT-SH7	**9.0**	**29.5**	**0.390**	**12**	**0.97**	**13.42**	**1.00**	**12**	**63**	**9.66**	**SW-SM**	**SW**	**NP**	**NP**	**6**	**-**	**-**	**3.1**	**0.29**
	SPT-SH7	**10.3**	**33.8**	**0.365**	**10**	**0.91**	**13.42**	**1.00**	**10**	**63**	**10.54**	**SW-SM**	**SW**	**NP**	**NP**	**9**	**-**	**-**	**2**	**0.12**
								Mean:	**13.6**	**63.7**						**8.3**			**2.7**	**0.2**
								St. Dev.	**4.0**							**3.5**			**1.1**	**0.1**

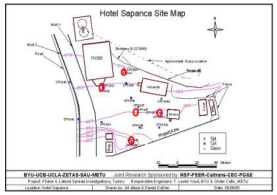
SW: Gray gravelly silty sand

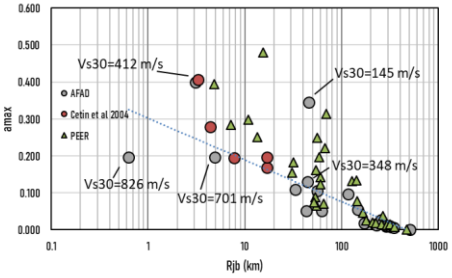
GW: Gray sandy gravel

**No short rod correctioons were applied as energy measurements were available.*

Case number:	305
Earthquake:	1999 Kocaeli Earthquake
Magnitude:	7.51
Location:	Hotel Sapanca SH-11 https://apps.peer.berkeley.edu/publications/turkey/adapazari/index.html
References:	Cetin et al (2004), PEER(2000a), Personal Com. with Prof. Dr. Kemal Onder Cetin
Nature of Failure:	10 cm vertical settlement SPT-SH11 Vertical settlement
GPS LAT	40.6987 SPT-SH7 Sand Boil
GPS LONG	30.2654 SPT-SH9 Lateral Spread
Liq. layer consist of:	Silty Sand (SM)
Geological Unit:	Alluvium young flood-plain-deposits of Sakarya River
Site Response Anlaysis:	No
Comments:	A rope and cathead system was used to perform the Standard Penetration Test. Event specific ground motion local model is contructed by using the available SMS data provided by AFAD. The fault rupture is measured as approximately as 1.2 km. The closest station to the site is called "5401" (Vs30=412 m/s, Rrup=6 km, PGA=0.399 g (only EW available). PGA=0.5 g is selected for the site.
Gravel Contents (%):	NAV
CPT available:	Yes
Vs available:	Yes





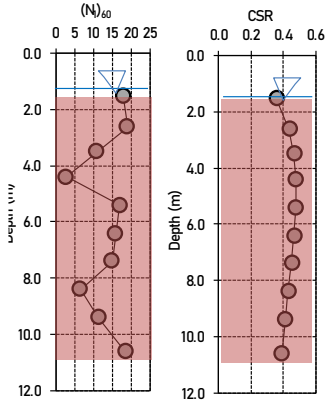




Summary of Input Data					
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crit} range (m)	-	-	-	-	1.2 - 11.2
d_{crit} (m)	-	-	-	-	6.2
GWT (m)	-	-	-	-	1.2 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	115.3 ± 31.6
σ_v' (kPa)	-	-	-	-	66.1 ± 15.3
a_{max} (g)	-	-	-	-	0.500 ± 0.100
r_d	-	-	-	-	0.83 ± 0.084
CSR	-	-	-	-	0.469 ± 0.108
M_w	-	-	-	-	7.51
D_{50}	-	-	-	-	2.290 ± 1.617
% Fines	-	-	-	-	17.6 ± 18.6
% PI	-	-	-	-	0
N	-	-	-	-	11.9 ± 3.5
C_R	-	-	-	-	1.00
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.00
C_N	-	-	-	-	1.24
$(N_1)_{60}$	-	-	-	-	14.7 ± 4.3
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	162.2

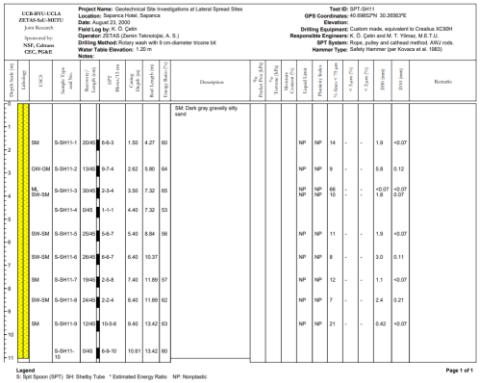
EVENT PARAMETERS		
1999 Kocaeli Earthquake	fault length of 120km	
Magnitude: 7.51		
Fault Type: Strike-slip (rigt	Z_{tor} (km): 0	R_{rup} (km): 1.2
Dip: 83	Width (km): 15	R_{jb} (km): 1.2

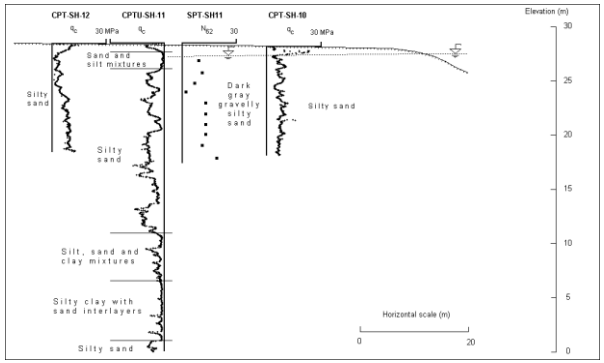
ACCELERATION TIME HISTORY



Depth (m)	Description
0-11.20	SM: Dark gray gravelly silty sand

GWT		
SPT-SH11	1.2	m
SPT-SH7	1.25	m
SPT-SH9	2.57	m





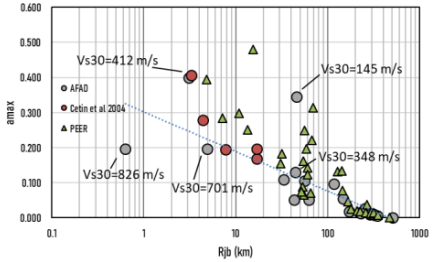
	Depth (m)	Depth (ft)	CSR	N	C_N	rod length	C_R	$(N1)_{60}$	energy ratio
SPT-SH11	*1.50*	*4.92*	*0.36*	*9*	*2.00*	*4.27*	*1.00*	*18*	*60*
SPT-SH11	*2.62*	*8.60*	*0.44*	*11*	*1.74*	*5.80*	*1.00*	*19*	*64*
SPT-SH11	*3.50*	*11.48*	*0.47*	*7*	*1.56*	*7.32*	*1.00*	*11*	*65*
SPT-SH11	4.40	14.44	0.48	**2**	1.43	7.32	1.00	3	53
SPT-SH11	*5.40*	*17.72*	*0.48*	*13*	*1.31*	*8.84*	*1.00*	*17*	*56*
SPT-SH11	*6.40*	*21.00*	*0.47*	*13*	*1.22*	*10.37*	*1.00*	*16*	*-*
SPT-SH11	*7.40*	*24.28*	*0.45*	*13*	*1.15*	*11.89*	*1.00*	*15*	*57*
SPT-SH11	*8.40*	*27.56*	*0.43*	*6*	*1.09*	*11.89*	*1.00*	*7*	*62*
SPT-SH11	*9.40*	*30.84*	*0.41*	*11*	*1.03*	*13.42*	*1.00*	*11*	*63*
SPT-SH11	*10.61*	*34.81*	*0.39*	*19*	*0.98*	*13.42*	*1.00*	*19*	*60*
							Mean:	**14.7**	**60.0**
							St. Dev.	**4.3**	

**No short rod correctioons were applied as energy measurements were available.*

Depth (m)	USCS	Description	Liquid Limit	Plasticity Index	% fines < 75 µm	< 5 µm (%)	< 2 µm (%)	D50 (mm)	D10 (mm)
1.50	*SM*	*SM*	*NP*	*NP*	*14*	*-*	*-*	*1.9*	*<0.07*
2.62	*GW-GM*	*SM*	*NP*	*NP*	*9*	*-*	*-*	*5.8*	*<0.07*
3.50	*ML*	*SM*	*NP*	*NP*	*66*	*-*	*-*	*<0.07*	*0.12*
3.50	*SW-SM*	*SM*	*NP*	*NP*	*10*	*-*	*-*	*1.8*	*0.07*
4.40	*-*	*SM*	*-*	*-*		*-*	*-*		
5.40	*SW-SM*	*SM*	*NP*	*NP*	*11*	*-*	*-*	*1.9*	*<0.07*
6.40	*SW-SM*	*SM*	*NP*	*NP*	*8*	*-*	*-*	*3*	*0.11*
7.40	*SM*	*SM*	*NP*	*NP*	*12*	*-*	*-*	*1.1*	*<0.07*
8.40	*SW-SM*	*SM*	*NP*	*NP*	*7*	*-*	*-*	*2.4*	*0.21*
9.40	*SM*	*SM*	*NP*	*NP*	*21*	*-*	*-*	*0.42*	*<0.07*
10.61	*-*	*SM*	*NP*	*NP*		*-*	*-*		
					17.6			**2.3**	**0.13**
					18.6			**1.6**	**0.06**

SM: Dark gray gravelly silty sand

Case number:	307
Earthquake:	1999 Kocaeli Earthquake
Magnitude:	7.51
Location:	Yalova Harbor https://apps.peer.berkeley.edu/publications/turkey/adapazari/index.html
References:	Cetin et al (2004), PEER (2000a), Moss et al. (2003)
Nature of Failure:	Cracks were observed at the harbor due to excessive settlement or possible lateral spreading
GPS LAT	40.6596
GPS LONG	29.2689
Liq. layer consist of:	Sand (SP-SM)
Geological Unit:	Alluvium, young flood-plain-deposits of Sakarya River
Site Response Anlaysis:	No
Comments:	A rope and cathead system was used to perform the Standard Penetration Test. Event specific local gorund motion model is contructed by using the available SMS data provided by AFAD. The fault rupture close to Yalova harbour is within the sea as a result Rjb may possibly has a range of 4-10 km which leads to 0.35-0.4 g for Yalova Harbour during 1999 Kocaeli EQ. 0.37 g is assigned to site.





Gravel Contents (%):	NAV
CPT available:	Yes
Vs available:	Yes

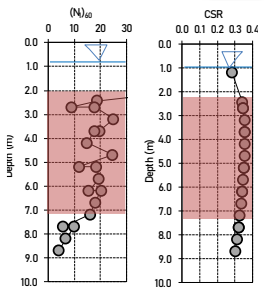
Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	Yes	-	Yes
Data Class	-	-	-	-	B
d_{rtr} range (m)	-	-	-	-	0.8 - 8.2
d_{rt} (m)	-	-	5.1	-	4.5
GWT (m)	-	-	0.8	-	0.8 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	93	-	91.6 ± 25.4
σ_v' (kPa)	-	-	51	-	55.3 ± 13.4
a_{max} (g)	-	-	0.3	-	0.370 ± 0.074
r_d	-	-	0.96	-	0.89 ± 0.064
CSR	-	-	0.340	-	0.354 ± 0.077
M_w	-	-	7.5	-	7.51
D_{50}	-	-	-	-	0.219 ± 0.068
% Fines	-	-	19	-	18.9 ± 16.7
% PI	-	-	-	-	0
N	-	-	10.2	-	9.9 ± 2.3
C_R	-	-	1	-	1.00
C_S	-	-	1	-	1.30
C_B	-	-	1	-	1.00
C_F	-	-	1.04	-	1.02
C_N	-	-	1.36	-	1.36
$(N_1)_{60}$	-	-	14.4	-	17.8 ± 4.2
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	158.0

EVENT PARAMETERS

1999 Kocaeli Earthquake — fault length of 120km
Magnitude: 7.51 — (due to uncert. in fault rupture plane)
Fault Type: Strike-slip (rigt — Z_{tor} (km): 0 — R_{rup} (km): 4--10
Dip: 83 — Width (km): 15 — R_{jb} (km): 4--10

ACCELERATION TIME HISTORY



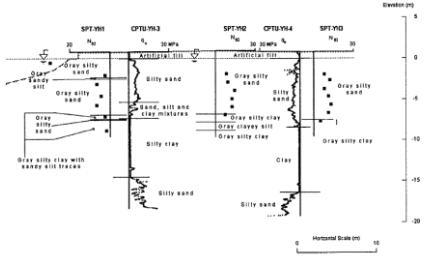
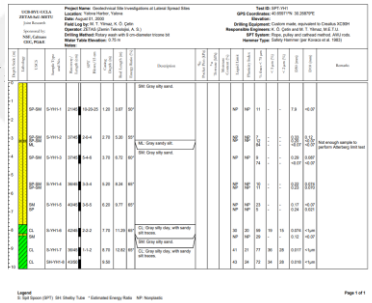
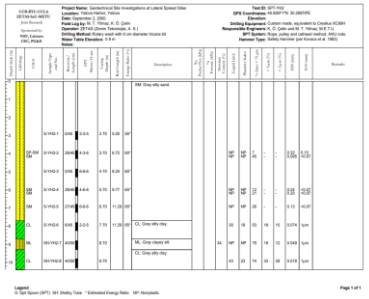


Fig. 13. Cross section I-I of Yalova Harbor site





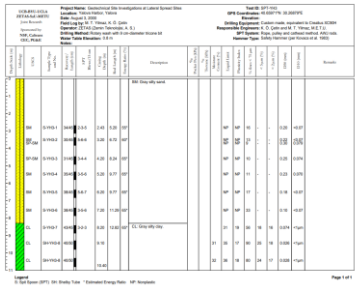
	Depth (m)	Depth (ft)	CSR	N	C_N	rod length	C_R	$(N1)_{60}$	energy ratio	Depth (m)	USCS	Description	Liquid Limit	Plasticity Index	% fines < 75 µm	< 5 µm (%)	< 2 µm (%)	D50 (mm)	D10 (mm)	
SPT-YH1	1.2	3.9	0.281	45	2.00	3.67	1.00	119.4	50	1.2	SP-SM	SM	NP	NP	11			7.9	<0.07	SPT-YH1
SPT-YH3	***2.43***	***8.0***	***0.340***	***8***	***1.76***	***5.2***	***1.00***	***18.7***	***55***	***2.43***	***SM***	***SM***	***NP***	***NP***	***16***	***-***	***-***	***0.2***	***<0.07***	***SPT-YH3***
SPT-YH1	***2.7***	***8.9***	***0.346***	***4***	***1.68***	***5.2***	***1.00***	***8.9***	***55***	***2.7***	***SP-SM***	***SM***	***NP***	***NP***	***7***			***0.33***	***0.12***	***SPT-YH1***
SPT-YH2	***2.7***	***8.9***	***0.346***	***8***	***1.68***	***5.2***	***1.00***	***17.9***	***55***	2.7	SP-SM	SM	NP	NP	12			0.2	<0.07	SPT-YH1
SPT-YH3	***3.2***	***10.5***	***0.352***	***12***	***1.57***	***6.72***	***1.00***	***25.0***	***60***	2.7	ML	SM	NP	NP	84			<0.07	<0.07	SPT-YH1
SPT-YH1	***3.7***	***12.1***	***0.355***	***10***	***1.48***	***6.72***	***1.00***	***19.6***	***60***	2.7		SM								SPT-YH2
SPT-YH2	***3.7***	***12.1***	***0.355***	***9***	***1.48***	***6.72***	***1.00***	***17.6***	***60***	***3.2***	***SM***	***SM***	***NP***	***NP***	***13***	***-***	***-***	***0.22***	***<0.07***	***SPT-YH3***
SPT-YH3	***4.2***	***13.8***	***0.355***	***8***	***1.40***	***8.24***	***1.00***	***14.8***	***65***	***3.2***	***SP-SM***	***SM***	***NP***	***NP***	***9***	***-***	***-***	***0.3***	***0.079***	***SPT-YH3***
SPT-YH2	***4.7***	***15.4***	***0.353***	***14***	***1.33***	***8.24***	***1.00***	***24.7***	***65***	***3.7***	***SP-SM***	***SM***	***NP***	***NP***	***9***			***0.29***	***0.087***	***SPT-YH1***
SPT-YH1	***5.2***	***17.1***	***0.350***	***7***	***1.27***	***8.24***	***1.00***	***11.8***	***65***	***3.7***					***74***			***<0.07***	***<0.07***	***SPT-YH1***
SPT-YH3	***5.2***	***17.1***	***0.350***	***11***	***1.27***	***9.77***	***1.00***	***18.6***	***65***	***3.7***	***SP-SM***	***SM***	***NP***	***NP***	***7***			***0.32***	***0.1***	***SPT-YH2***
SPT-YH2	***5.7***	***18.7***	***0.345***	***12***	***1.22***	***9.77***	***1.00***	***19.4***	***65***	***3.7***	***SM***	***SM***	***NP***	***NP***	***45***			***0.095***	***<0.07***	***SPT-YH2***
SPT-YH1	***6.2***	***20.3***	***0.339***	***10***	***1.17***	***9.77***	***1.00***	***15.6***	***65***	***4.2***	***SP-SM***	***SM***	***NP***	***NP***	***10***	***-***	***-***	***0.25***	***0.074***	***SPT-YH3***
SPT-YH3	***6.2***	***20.3***	***0.339***	***13***	***1.17***	***9.77***	***1.00***	***20.3***	***65***	***4.7***		***SM***			***12***					***SPT-YH2***
SPT-YH2	***6.7***	***22.0***	***0.332***	***12***	***1.13***	***11.29***	***1.00***	***18.1***	***65***	***5.2***	***SP-SM***	***SM***	***NP***	***NP***	***10***			***0.22***	***0.074***	***SPT-YH1***
SPT-YH3	***7.2***	***23.6***	***0.325***	***11***	***1.10***	***11.29***	***1.00***	***16.0***	***65***	***5.2***	***SP-SM***	***SM***	***NP***	***NP***	***11***			***0.23***	***0.07***	***SPT-YH1***
SPT-YH1	7.7	25.3	0.317	4	1.06	11.29	1.00	5.6	65	***5.2***	***SM***	***SM***	***NP***	***NP***	***11***	***-***	***-***	***0.23***	***0.07***	***SPT-YH3***
SPT-YH2	7.7	25.3	0.317	7	1.06	11.29	1.00	9.9	65	***5.7***	***SM***	***SM***	***NP***	***NP***				***0.24***	***<0.07***	***SPT-YH2***
SPT-YH3	8.2	26.9	0.309	5	1.03	12.82	1.00	6.9	65	***5.7***	***SM***	***SM***	***NP***	***NP***	***21***			***0.2***	***<0.07***	***SPT-YH2***
SPT-YH1	8.7	28.5	0.302	3	1.00	12.82	1.00	4.0	65	***6.2***	***SM***	***SM***	***NP***	***NP***	***23***			***0.17***	***<0.07***	***SPT-YH1***
							Mean:	17.8	61.3	***6.2***	***SP***	***SM***	***NP***	***NP***	***5***			***0.24***	***0.021***	***SPT-YH1***
							St. Dev.	4.2		***6.2***	***SM***	***SM***	***NP***	***NP***	***17***	***-***	***-***	***0.18***	***<0.07***	***SPT-YH3***
										6.7	***SM***	***SM***	***NP***	***NP***	***26***			***0.13***	***<0.07***	***SPT-YH2***
										7.2	***SM***	***SM***	***NP***	***NP***	***33***	***-***	***-***	***0.1***	***<0.07***	***SPT-YH3***
										7.7	CL	CL	30	20	59	19	15	0.074	<0.001	SPT-YH1
										7.7	SM	SM	NP	NP	29				<0.07	SPT-YH1
										7.7	CL	CL	30	19	53	18	15	0.074	0.001	SPT-YH2
										8.2	CL	CL	31	19	56	18	16	0.074	<0.001	SPT-YH3
										8.7	CL	CL	41	21	77	36	28	0.017	<0.001	SPT-YH1
										8.7	ML	ML	NP	NP	79	18	12	0.049	0.001	SPT-YH2
										9.1	CL	CL	35	17	90	25	18	0.026	<0.001	SPT-YH3
										9.5	CL	CL	43	24	72	34	28	0.018	<0.001	SPT-YH1
										9.7	CL	CL	43	23	74	33	28	0.018	0.001	SPT-YH3
										10.4	CL	CL	36	18	80	24	17	0.028	<0.001	SPT-YH3
														Mean:	18.9		**Mean:**	0.2		
														St. Dev.	16.7		**St. Dev.**	0.1		

**No short rod correctioons were applied as energy measurements were available.*

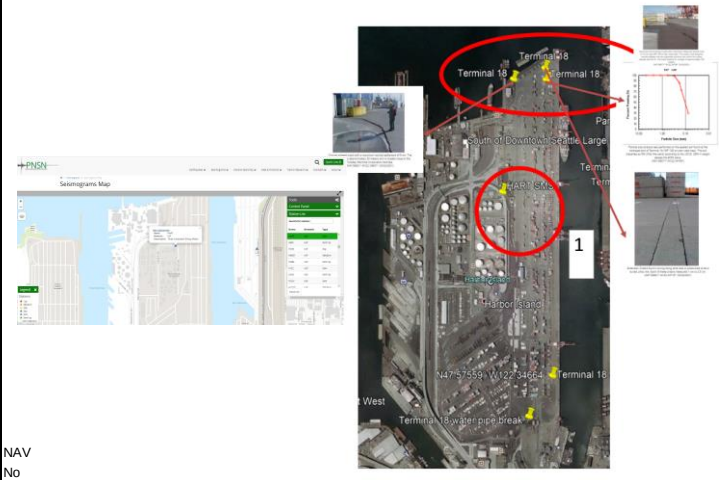
GWT

SPT-YH1	0.75 m
SPT-YH2	0.9 m
SPT-YH3	0.8 m

SM: Gray silty sand.
CL: Gray silty clay, with sandy silt traces.
ML: Gray clayey silt.



Case number:	332
Earthquake:	2001 Nisqually Earthquake
Magnitude:	6.8 (USGS)
Location:	Port of Seattle Terminal 18 Harbour Island Seattle, WA 98134, USA
References:	PEER 2001, Washington Geological Information Portal, https://geologyportal.dnr.wa.gov/
Nature of Failure:	Formation of a sand boil in the Port of Seattle on Harbor Island
GPS LAT:	47.58373
GPS LONG:	-122.350137
Liq. layer consist of:	Sand (SP)
Geological Unit:	artificial fill, including modified land, Holocene delta
Site Response Anlaysis:	No (digitial record can not be downloaded)
Comments:	The area consists of artificial fill. The sesimologist observed liquefaction at the site. UB-19 is the closest borehole to strong ground motion station. The earthquake moment magnitude (Mw) is 6.8. The preliminary mechanism for this earthquake is tensional (normal) faulting in the subducting. Based on the figure provided by "https://www.strongmotioncenter.org/vdc/scripts/plot.plx?stn=2112&evt=630", PGA is recorded as 0.216 and 0.187 g and the geometric mean of which is 0.201 g is used in the analysis. No information regarding hammer type was found. Hence it is assumed that a saftey hammer is used considering the other liquefaction sites in USA. An average value of 66% is assigned as hammer efficiency.
Gravel Contents (%):	NAV
CPT available:	No
Vs available:	Yes



Summary of Input Data					
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.1 - 3.7
d_{crt} (m)	-	-	-	-	2.9
GWT (m)	-	-	-	-	2.1 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	55.8 ± 5.4
σ_v' (kPa)	-	-	-	-	48.2 ± 3.1
a_{max} (g)	-	-	-	-	0.201 ± 0.010
r_d	-	-	-	-	0.82 ± 0.044
CSR	-	-	-	-	0.125 ± 0.010
M_w	-	-	-	-	6.80
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	11.0 ± 0.5
C_R	-	-	-	-	0.89
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.10
C_N	-	-	-	-	1.45
$(N_1)_{60}$	-	-	-	-	15.6 ± 0.7
$V_{s,30m}$ (m/s)	-	-	-	-	131.2
$V_{s,12m}$ (m/s)	-	-	-	-	109.7

EVENT PARAMETERS

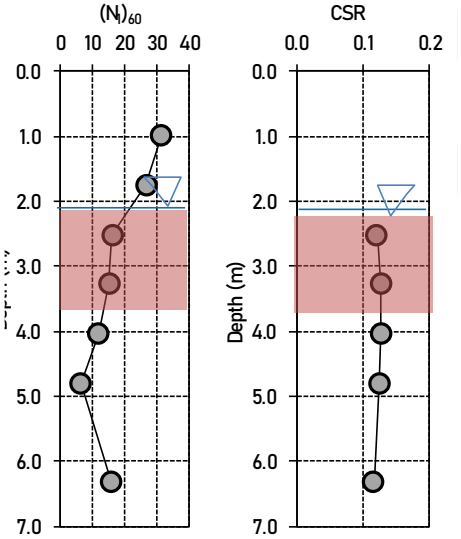
2001 Nisqually Earthquake Hypocentral Distance: 75.6 km

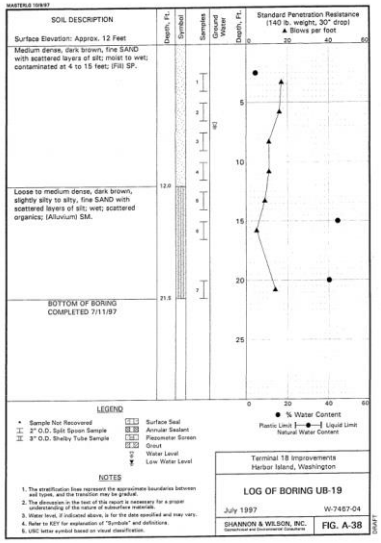
Magnitude: 6.80

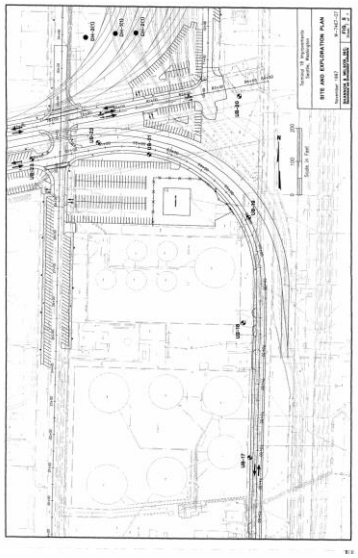
Fault Type: intraslab earth Z_{tor} (km): - R_{rup} (km): -

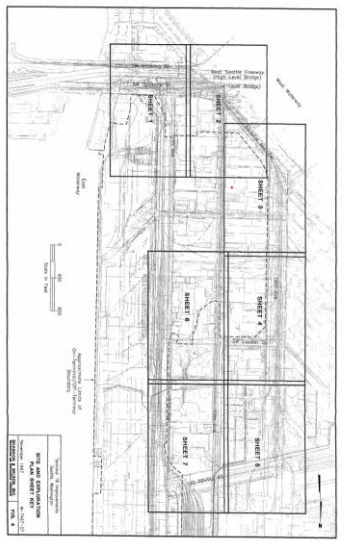
Dip: - Width (km): - R_{jb} (km): 39.0

ACCELERATION TIME HISTORY



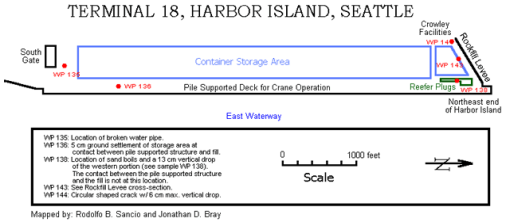






Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		FC	
1.0	3.2	NA	17	2.00	0.84	31.3	SP	<5	
1.8	5.8	NA	16	1.75	0.86	26.5	SP	<5	
2.5	***8.3***	***0.121***	***11***	***1.51***	***0.88***	***16.1***	***SP***	***<5***	
3.3	***10.8***	***0.127***	***11***	***1.39***	***0.90***	***15.1***	***SP***	***<5***	
4.0	13.3	0.127	9	1.29	0.91	11.7	SM	5--12	scattered organics
4.8	15.8	0.125	5	1.21	0.93	6.2	SM	5--12	scattered organics
6.3	20.8	0.116	14	1.09	0.95	15.9	SM	5--12	scattered organics
					Mean:	15.6			
					St. Dev.	0.7			

Case number:	333
Earthquake:	2001 Nisqually Earthquake
Magnitude:	6.8 (USGS)
Location:	Port of Seattle Terminal 18 Harbour Island, Seattle, WA 98134, USA
References:	PEER 2001, Washington Geological Information Portal, https://geologyportal.dnr.wa.gov/
Nature of Failure:	Liquefaction is observed
GPS LAT	47.58877
GPS LONG	-122.34706
Liq. layer consist of:	Sand-silt-gravel
Geological Unit:	Quaternary alluvial clay, silt, sand, gravel, and (or) cobble deposit locally includes modified land and artificial fill.
Site Response Anlaysis:	No
Comments:	Particle size analysis test performed on the ejected soil found at the northeast end of Terminal 18 (WP 138 on plan view map). The soil is classified as SM (Silty fine sand) according to the USCS. 29% in weight passes the #200 sieve. (N47.58877° W122.34706°). According to USGS map PGA is in the range of 0.12-0.16 g . Vs12m is estimated based on the correlation of Vs-SPT N. Based on the figure provided by https://www.strongmotioncenter.org/, PGA is recorded as 0.216 and 0.187 g at HART station and geometric mean of which is 0.201 g. The site is located 400 m away from the HART SMS however Vs measurements was not available at the site. It was decided to take amax as 0.201 g. No information regarding hammer type. Hence it is assumed that a saftey hammer is used considering the other liquefaction sites in USA. An average value of 66% is assigned as hammer efficieny value. Soil strata and SPT vealues are somewhat inconcistent. Gravel layers have unusally low values SPT- N=4-6. It is difficult to select a single susceptible layer hence gravel layers are assessed together.



Gravel Contents (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crit} range (m)	-	-	-	-	2.4 - 15.0
d_{m1} (m)	-	-	-	-	8.7
GWT (m)	-	-	-	-	2.4 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	175.1 ± 43.5
σ_v' (kPa)	-	-	-	-	113.0 ± 23.0
a_{max} (g)	-	-	-	-	0.201 ± 0.040
r_d	-	-	-	-	0.79 ± 0.112
CSR	-	-	-	-	0.160 ± 0.040
M_w	-	-	-	-	6.80
D_{50}	-	-	-	-	0.317 ± 0.118
% Fines	-	-	-	-	25.0 ± 11.2
% PI	-	-	-	-	0
N	-	-	-	-	10.3 ± 6.5
C_R	-	-	-	-	0.97
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.10
C_N	-	-	-	-	0.95
$(N_1)_{60}$	-	-	-	-	10.4 ± 6.6
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	177.9

EVENT PARAMETERS

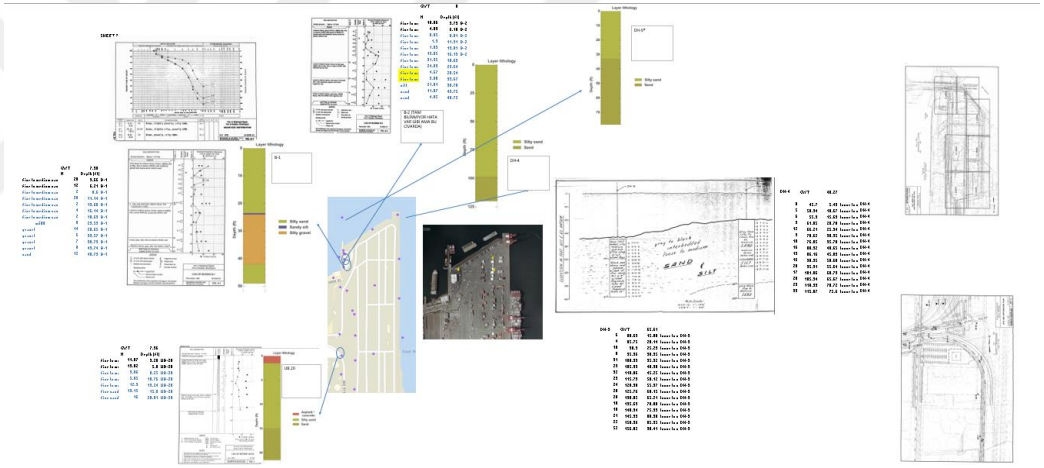
2001 Nisqually Earthquake

Magnitude: 6.80

Fault Type: intraslab earth | Z_{tor} (km): - | R_{rup} (km): -

Dip: - | Width (km): - | R_{jb} (km): 39.0

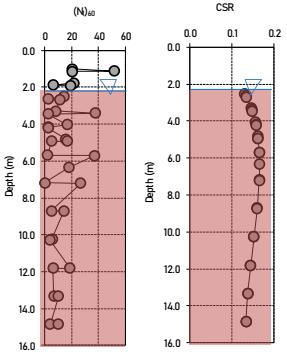
ACCELERATION TIME HISTORY

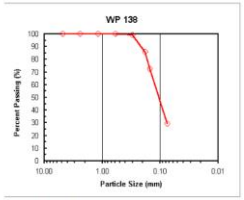


	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$			FC	GC
fine to medium sand	*1.0*	*3.3*	*NA*	*11*	*2.00*	*0.84*	*20.2*	*UB-20*		<5	
fine to medium sand	1.1	3.7	NA	28	2.00	0.84	51.8	B-1	Outlier		
fine to medium sand	*1.1*	*3.7*	*NA*	*11*	*2.00*	*0.84*	*20.4*	*B-2*		<5	
fine to medium sand	*1.8*	*5.8*	*NA*	*13*	*1.74*	*0.86*	*21.5*	*UB-20*		<5	
fine to medium sand	*1.9*	*6.2*	*NA*	*4*	*1.69*	*0.86*	*6.4*	*B-2*		<5	
fine to medium sand	*1.9*	*6.2*	*NA*	*12*	*1.69*	*0.86*	*19.2*	*B-1*		<5	
fine to medium sand	*2.5*	*8.3*	*0.131*	*10*	*1.48*	*0.88*	*14.3*	*UB-20*		<5	
fine to medium sand	*2.6*	*8.6*	*0.133*	*2*	*1.46*	*0.88*	*2.8*	*B-1*		<5	
fine to medium sand	*2.7*	*8.8*	*0.135*	*8*	*1.45*	*0.88*	*11.3*	*B-2*		<5	
fine to medium sand	*3.3*	*10.8*	*0.146*	*6*	*1.36*	*0.90*	*8.1*	*UB-20*		<5	
fine to medium sand	3.4	11.1	0.148	28	1.35	0.90	37.4	B-1	Outlier		
fine to medium sand	*3.4*	*11.3*	*0.148*	*2*	*1.34*	*0.90*	*2.7*	*B-2*		<5	
fine to medium sand	*4.0*	*13.2*	*0.155*	*13*	*1.27*	*0.91*	*16.6*	*UB-20*		<5	
fine to medium sand	*4.2*	*13.7*	*0.157*	*2*	*1.26*	*0.91*	*2.5*	*B-1*		<5	
fine to medium sand	*4.2*	*13.8*	*0.157*	*2*	*1.25*	*0.92*	*2.5*	*B-2*		<5	
fine sand	*4.8*	*15.8*	*0.162*	*13*	*1.19*	*0.93*	*15.8*	*UB-20*		<5	
fine to medium sand	*4.9*	*16.1*	*0.162*	*14*	*1.19*	*0.93*	*16.9*	*B-2*		<5	
fine to medium sand	*4.9*	*16.1*	*0.162*	*4*	*1.18*	*0.93*	*4.8*	*B-1*		<5	
fine to medium sand	*5.7*	*18.6*	*0.165*	*2*	*1.12*	*0.94*	*2.3*	*B-1*		<5	
fine to medium sand	5.7	18.7	0.165	32	1.12	0.94	37.0	B-2	Outlier		
fine sand	*6.3*	*20.8*	*0.166*	*16*	*1.08*	*0.95*	*17.9*	*UB-20*		<5	
silt	7.2	23.6	0.165	0	1.02	0.95	0.0	B-1	Outlier		
fine to medium sand	7.2	23.6	0.165	25	1.02	0.95	26.9	B-2	Outlier		
fine to medium sand2	*8.7*	*28.5*	*0.160*	*5*	*0.95*	*0.97*	*5.0*	*B-2*		<5	
gravel	*8.7*	*28.7*	*0.160*	*14*	*0.95*	*0.97*	*14.1*	*B-1*			
gravel	*10.2*	*33.6*	*0.152*	*6*	*0.88*	*0.98*	*5.7*	*B-1*			
fine to medium sand2	*10.3*	*33.7*	*0.152*	*4*	*0.88*	*0.98*	*3.8*	*B-2*		<5	
silt	*11.8*	*38.8*	*0.144*	*21*	*0.83*	*0.98*	*18.9*	*B-2*		>50	
gravel	*11.8*	*38.8*	*0.144*	*7*	*0.83*	*0.98*	*6.3*	*B-1*		<5	>50
gravel	*13.3*	*43.7*	*0.138*	*8*	*0.79*	*0.99*	*6.9*	*B-1*			>50
sand	*13.3*	*43.8*	*0.138*	*12*	*0.79*	*0.99*	*10.3*	*B-2*		<5	
sand	*14.8*	*48.7*	*0.133*	*5*	*0.75*	*0.99*	*4.1*	*B-2*		<5	
sand	*14.9*	*48.7*	*0.133*	*12*	*0.75*	*0.99*	*9.8*	*B-1*		<5	
						Mean:	10.4				
						St. Dev.	6.6				

GWT	
UB-20	7.96 ft
B-1	7.38 ft
B-2	8 ft
average	7.78

Pa
2116.22



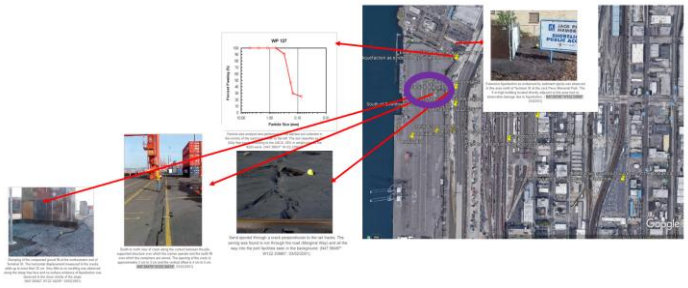


Particle size analysis test performed on the ejected soil found at the northeast end of Terminal 18 (WP 139 on plan view map). The soil classifies as SM (Silty fine sand) according to the USCS. 29% in weight passes the #200 sieve.
(N47.56877° W122.34708°)



Extension Cracks found running along what was is presumed to be a buried utility line. Each of these cracks measured 1 cm to 2.5 cm.
(N47.56831° W122.34715°, 03/02/2001)

Case number:	334
Earthquake:	2001 Nisqually Earthquake
Magnitude:	6.8 (USGS)
Location:	Port of Seattle Terminal 30
References:	PEER 2001, Washington Geological Information Portal, https://geologyportal.dnr.wa.gov/
Nature of Failure:	Sand ejecta and sand boils
GPS LAT	47.58637
GPS LONG	-122.33969
Liq. layer consist of:	Sand (SM)
Geological Unit:	Quaternary alluvial clay, silt, sand, gravel, and (or) cobble deposits; locally includes modified land and artificial fill.
Site Response Anlaysis:	No
Comments:	Borehole HC-16 is used in the analysis. The other boreholes either have organic, petroleum odor, or very close to sea. The site is located between 0.12-0.16 g contours of USGS shake map. However, Terminal 30 area is 300 m away a strong ground motion station where PGA is recorded as 0.343 g (the information is retrieved from USGS Shake map). Based on the figure provided by "https://www.strongmotioncenter.org", PGA is recorded as 0.216 and 0.187 g geometric mean of which is 0.201 g at HART strong ground motion station. The site is located 800 m away from the HART station hence PGA is selected as 0.201 g. No information regarding hammer type was found. Hence it is assumed that a saftey hammer is used considering the other liquefaction sites in USA. An average value of 66% is assigned as hammer efficiency.



Gravel Contents (%):	0
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.7 - 8.0
d_{crt} (m)	-	-	-	-	5.3
GWT (m)	-	-	-	-	2.7 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	20.0 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	108.5 ± 18.4
σ_v' (kPa)	-	-	-	-	82.4 ± 9.8
a_{max} (g)	-	-	-	-	0.201 ± 0.040
r_d	-	-	-	-	0.99 ± 0.074
CSR	-	-	-	-	0.170 ± 0.037
M_w	-	-	-	-	6.80
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	23.5 ± 1.5
% PI	-	-	-	-	0
N	-	-	-	-	14.5 ± 3.9
C_R	-	-	-	-	0.93
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.10
C_N	-	-	-	-	1.11
$(N_1)_{60}$	-	-	-	-	16.5 ± 4.5
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	240.0

EVENT PARAMETERS

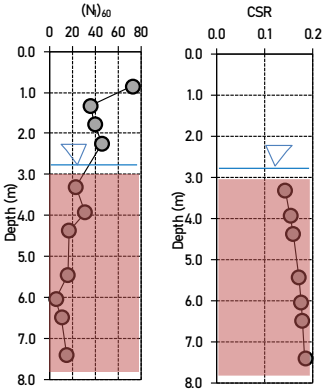
2001 Nisqually Earthquake

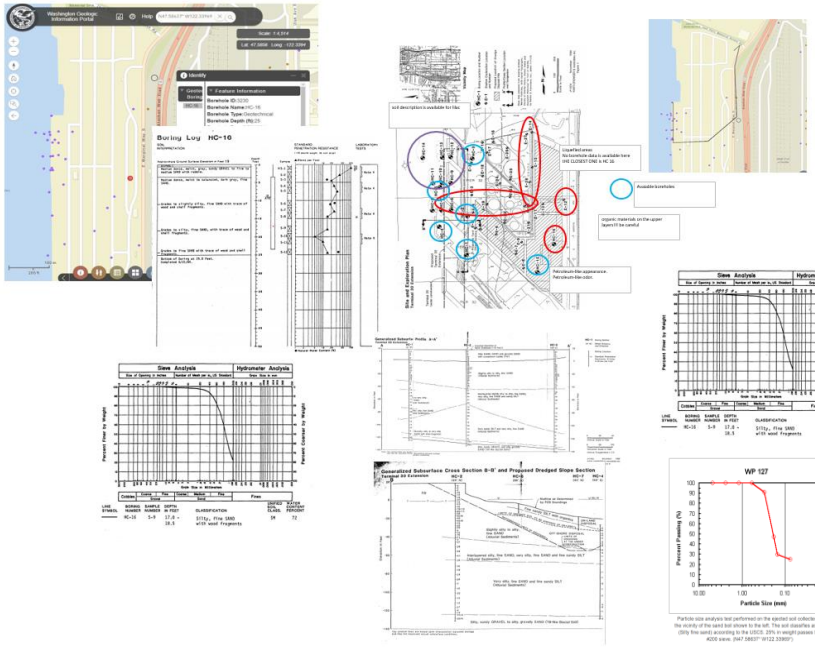
Magnitude: 6.80

Fault Type: intraslab earthq | Z_{tor} (km): - | R_{rup} (km): -

Dip: - | Width (km): - | R_{jb} (km): 39.5

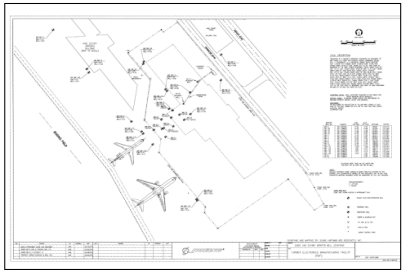
ACCELERATION TIME HISTORY

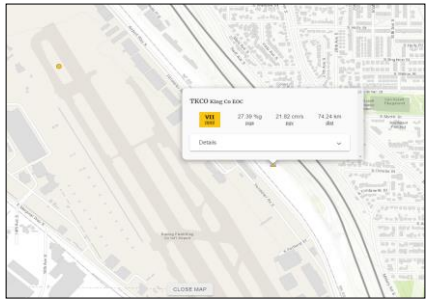




	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$			
Medium dense, moist, gray, sandy GRAVEL to fine to Medium sand with rubble	0.2	0.8	NA	50/5"	2.00	0.81	-	HC-16		
Medium dense, moist, gray, sandy GRAVEL to fine to Medium sand with rubble	0.9	2.8	NA	40	2.00	0.83	72.6	HC-16		OUTLIER
Medium dense, moist to saturated, dark gray, fine SAND	1.3	4.4	NA	20	1.96	0.85	36.2	HC-16	SM	
Medium dense, moist to saturated, dark gray, fine SAND	1.8	5.9	NA	25	1.69	0.86	39.8	HC-16	SM	
Medium dense, moist to saturated, dark gray, fine SAND	2.3	7.4	NA	32	1.50	0.87	46.3	HC-16	SM	OUTLIER
Medium dense, moist to saturated, dark gray, fine SAND	***3.3***	***10.9***	***0.143***	***18***	***1.30***	***0.90***	***23.0***	***HC-16***	***SM***	
Medium dense, moist to saturated, dark gray, fine SAND	3.9	12.9	0.153	25	1.23	0.91	31.2	HC-16	SM	OUTLIER
Medium dense, moist to saturated, dark gray, fine SAND	***4.4***	***14.4***	***0.160***	***14***	***1.19***	***0.92***	***17.4***	***HC-16***	***SM***	
Medium dense, moist to saturated, dark gray, fine SAND	***5.4***	***17.9***	***0.171***	***14***	***1.10***	***0.93***	***16.3***	***HC-16***	***SM***	
Medium dense, moist to saturated, dark gray, fine SAND	6.1	19.9	0.176	5	1.06	0.94	5.5	HC-16	SM	OUTLIER
Medium dense, moist to saturated, dark gray, fine SAND	***6.5***	***21.3***	***0.179***	***10***	***1.04***	***0.95***	***10.7***	***HC-16***	***SM***	
	7.4	***24.4***	***0.184***	***15***	***0.98***	***0.96***	***15.0***	***HC-16***	***SM***	
						Mean:	16.5			
						St. Dev.	4.5			

Case number:	336
Earthquake:	2001 Nisqually Earthquake
Magnitude:	6.8 (USGS)
Location:	King County International Airport, Boeing Field, Seattle
References:	PEER, Washington Geological Information Portal, https://geologyportal.dnr.wa.gov/
Nature of Failure:	Sand boils, cracks
GPS LAT:	47.536733
GPS LONG:	-122.30515
Liq. layer consist of:	Sand (SP-SM)
Geological Unit:	Holocene alluvium, undifferentiated, Quaternary deposits locally includes modified land and artificial fill.
Site Response Anlaysis:	No
Comments:	The site is located between 0.12-0.16 g PGA contours from the USGS shake map. Station: King County, WA - EOC; Boeing Field Station (47.5369, -122.3004) is located 355 m away from the site. PGA is recorded as 0.17 and 0.273 g geometric mean of which is 0.216 g is used in the analysis. No information regarding hammer type. Hence it is assumed that a saftey hammer is used considering the other liquefaction sites in USA. An average value of 66% is assigned as hammer efficiency value.





Gravel Contents (%):	<5
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.1 - 3.4
d_{crt} (m)	-	-	-	-	2.7
GWT (m)	-	-	-	-	2.1 ± 0.7
γ_{moist} (kN/m^3)	-	-	-	-	18.1 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	51.2 ± 4.7
σ_v' (kPa)	-	-	-	-	45.1 ± 5.7
a_{max} (g)	-	-	-	-	0.216 ± 0.043
r_d	-	-	-	-	0.87 ± 0.042
CSR	-	-	-	-	0.138 ± 0.035
M_w	-	-	-	-	6.80
D_{50}	-	-	-	-	0.149 ± 0.050
% Fines	-	-	-	-	8.0 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	12.2 ± 2.7
C_R	-	-	-	-	0.89
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.10
C_N	-	-	-	-	1.50
$(N_1)_{60}$	-	-	-	-	17.8 ± 4.0
V_{s30m} (m/s)	-	-	-	-	151.5
V_{s12m} (m/s)	-	-	-	-	121.9

EVENT PARAMETERS

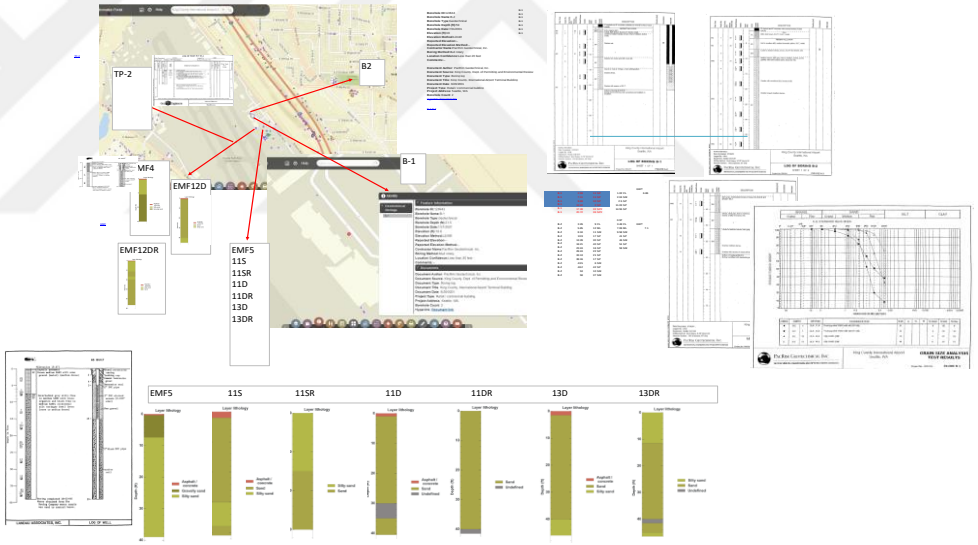
2001 Nisqually Earthquake

Magnitude: 6.80

Fault Type: intraslab earth | Z_{tor} (km): - | R_{rup} (km): -

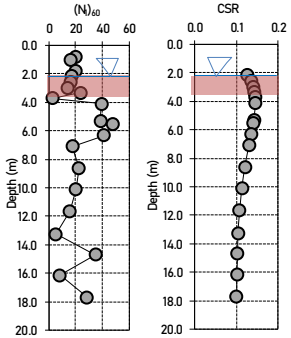
Dip: - | Width (km): - | R_{jb} (km): 37.1

ACCELERATION TIME HISTORY



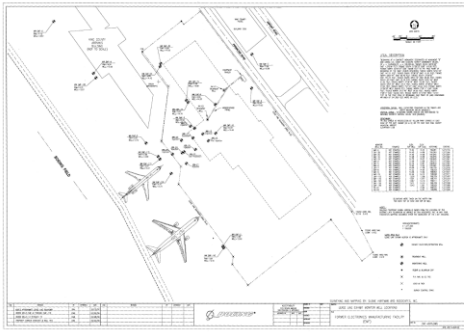
	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
B-1	0.8	2.6	NA	11	2.00	0.83	20.1	SP
B-2	1.0	3.3	NA	9	2.00	0.84	16.6	CL
B-2	1.8	5.9	NA	12	1.77	0.86	20.2	ML
B-1	***2.2***	***7.1***	***0.127***	***11***	***1.61***	***0.87***	***17.0***	***SP***
B-2	***2.5***	***8.3***	***0.135***	***11***	***1.54***	***0.88***	***16.4***	***SM***
B-1	***3.0***	***9.7***	***0.140***	***10***	***1.46***	***0.89***	***14.3***	***SP***
B-2	***3.3***	***10.9***	***0.143***	***17***	***1.41***	***0.90***	***23.6***	***SP***
B-1	3.7	12.2	0.145	2	1.35	0.91	2.7	SP
B-2	4.1	13.4	0.146	30	1.31	0.91	39.3	SP
B-1	5.3	17.4	0.142	32	1.18	0.93	38.8	SP2
B-2	5.6	18.2	0.141	40	1.16	0.94	47.8	SP
B-1	6.3	20.7	0.136	36	1.10	0.95	41.2	SP2
B-2	7.1	23.2	0.131	16	1.05	0.95	17.6	SP
B-2	8.6	28.2	0.121	22	0.97	0.97	22.6	SP
B-2	10.1	33.1	0.113	21	0.90	0.97	20.3	SP
B-2	11.6	38.2	0.108	17	0.85	0.98	15.6	SP
B-2	13.3	43.5	0.104	6	0.80	0.99	5.2	SM
B-2	14.7	48.2	0.102	42	0.76	0.99	34.9	SP
B-2	16.2	53.0	0.101	10	0.73	0.99	8.0	SM
B-2	17.7	58.0	0.101	37	0.70	0.99	28.4	SM
						Mean:	17.8	
						St. Dev.	4.0	

outlier



GWT		
	6.86	ft
	7.1	ft
average	6.98	ft

Case number:	337
Earthquake:	2001 Nisqually Earthquake
Magnitude:	6.8 (USGS)
Location:	King County International Airport, Boeing Field, Seattle
References:	PEER, Washington Geological Information Portal, https://geologyportal.dnr.wa.gov/
Nature of Failure:	4.5 m by 3.5 m sinkhole with a maximum depth of 1.2 m. Two sand boils were observed to the east and south of the sinkho
GPS LAT:	47.541817
GPS LONG:	-122.314031
Liq. layer consist of:	Sand (SP-SM)
Geological Unit:	Holocene alluvium, undifferentiated, Quaternary deposits locally includes modified land and artificial fill.
Site Response Anlaysis:	No
Comments:	The site is located between 0.12-0.16 g PGA contours of USGS Map. However, the site is 100 m away from a strong groun motion station where PGA is recorded as 0.2739 g (. Associated borehole is B-10 (47.5421, -122.3145) Station: King County, WA - EOC; Boeing Field Station Owner: University of Washington, Geophysics Program Station Latitude & Longitude: 47.5369, -122.3004 Earthquake: Nisqually 2001-02-28 18:54:31 UTC Hypocentral Distance: 74.5 km SMS is located 1 km away from the site. PGA is recorded as 0.17 and 0.273 g geometric mean of which is 0.216 g.



Gravel Contents (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.1 - 3.4
d_{crt} (m)	-	-	-	-	2.7
GWT (m)	-	-	-	-	2.1 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	48.5 ± 4.0
σ_v' (kPa)	-	-	-	-	42.5 ± 2.3
a_{max} (g)	-	-	-	-	0.216 ± 0.043
r_d	-	-	-	-	0.95 ± 0.042
CSR	-	-	-	-	0.152 ± 0.032
M_w	-	-	-	-	6.80
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	6-27.5 ± 5.0
% PI	-	-	-	-	0
N	-	-	-	-	7.5 ± 2.4
C_R	-	-	-	-	0.89
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.10
C_N	-	-	-	-	1.55
$(N_1)_{60}$	-	-	-	-	11.2 ± 3.6
V_{s30m} (m/s)	-	-	-	-	182.6
V_{s12m} (m/s)	-	-	-	-	159.7

EVENT PARAMETERS

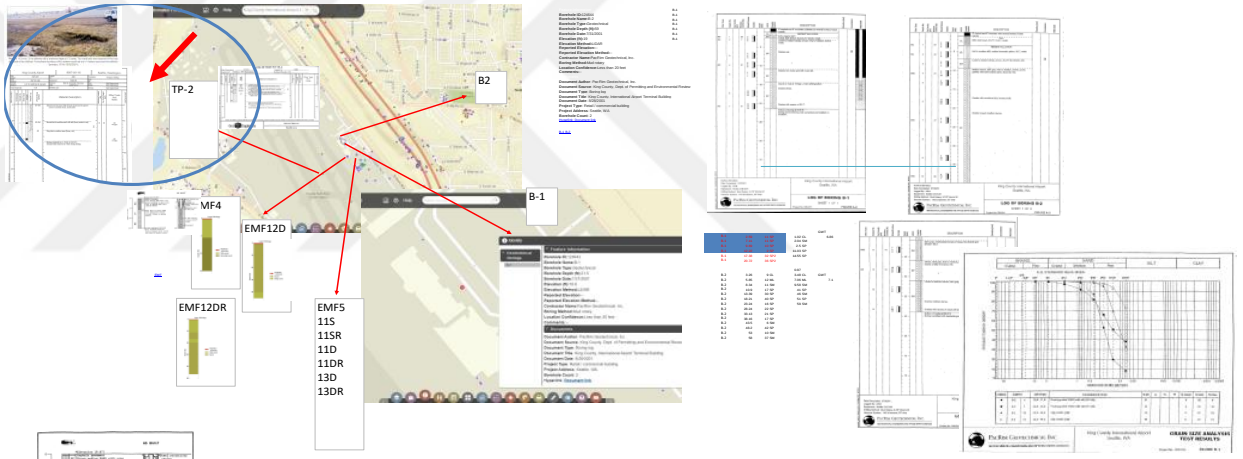
2001 Nisqually Earthquake

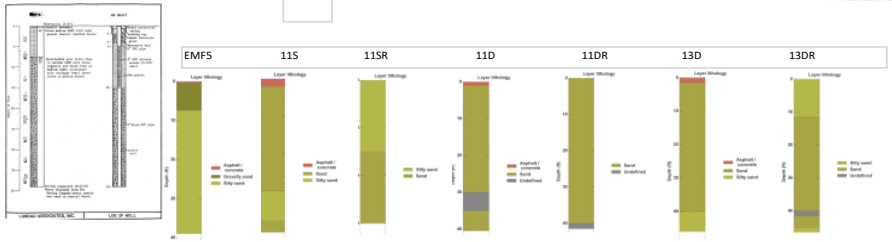
Magnitude: 6.80

Fault Type: intraslab earth | Z_{tor} (km): - | R_{rup} (km): -

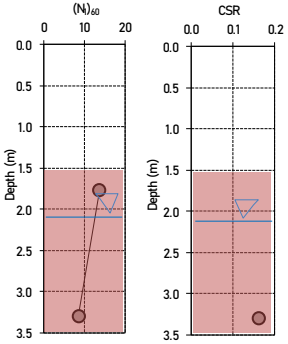
Dip: - | Width (km): - | R_{jb} (km): 37.0

ACCELERATION TIME HISTORY



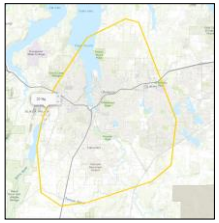


Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
1.8	*5.8*	*NA*	*8*	*1.82*	*0.86*	*13.8*	*SP-SM*
3.3	*10.8*	*0.162*	*6*	*1.46*	*0.90*	*8.7*	*SP-SM*
					Mean:	11.2	
					St. Dev.	3.6	



Case number:	338
Earthquake:	2001 Nisqually Earthquake
Magnitude:	6.8 (USGS)
Location:	Capitol Lake
References:	PEER, Washington Geological Information Portal, https://geologyportal.dnr.wa.gov/
Nature of Failure:	lateral spread/slumping of newly constructed shoreline along the east side of Capitol Lake. Sand boils found
GPS LAT:	47.0381
GPS LONG:	-122.90695
Liq. layer consist of:	Sand (SP-SM)
Geological Unit:	Pleistocene till modified land, and artificial fill.
Site Response Anlaysis:	No
Comments:	USGS PGA contour map suggest amax greate than 0.2 g for the site. USGS 2101 station (47.047, -122.899) is located 1.1 km away from the site and PGA is recorded as 0.222 g and 0.255 g, geometic mean of which is 0.238 g is used in the analysis. No information regarding hammer type. Hence it is assumed that a saftey hammer is used considering the other liquefaction sites in USA. An average value of 66% is assigned as hammer efficiency.

USGS PGA contour map



PEER webpage



Lateral spread/slumping of newly constructed shoreline along the side of Capitol Lake. Sand boils found in restricted access are beyond scope of this photo. (N47.03810° W122.90695°, 03/03/2001)



Cracking through recently placed fill (N47.03810° W122.90695°, 03/03/2001)

Gravel Contents (%):	10
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{cr1c} range (m)	-	-	-	-	2.6 - 3.6
d_{cr1} (m)	-	-	-	-	3.1
GWT (m)	-	-	-	-	1.5 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	58.6 ± 3.3
σ_v' (kPa)	-	-	-	-	43.1 ± 2.0
a_{max} (g)	-	-	-	-	0.238 ± 0.048
r_d	-	-	-	-	1.00 ± 0.047
CSR	-	-	-	-	0.210 ± 0.044
M_w	-	-	-	-	6.80
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	61.0 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	4.1 ± 1.3
C_R	-	-	-	-	0.89
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.10
C_N	-	-	-	-	1.54
$(N_1)_{60}$	-	-	-	-	6.1 ± 2.0
$V_{s,30m}$ (m/s)	-	-	-	-	344.6
$V_{s,12m}$ (m/s)	-	-	-	-	269.7

EVENT PARAMETERS

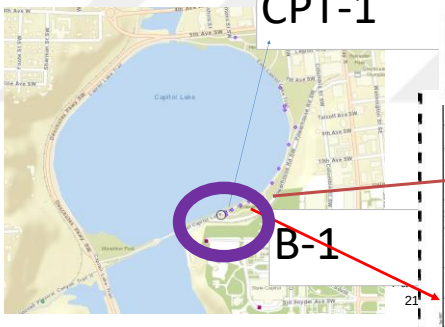
2001 Nisqually Earthquake

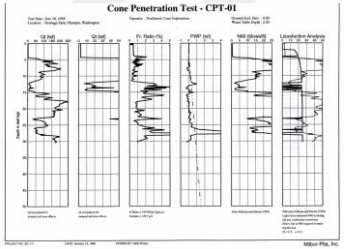
Magnitude: 6.80

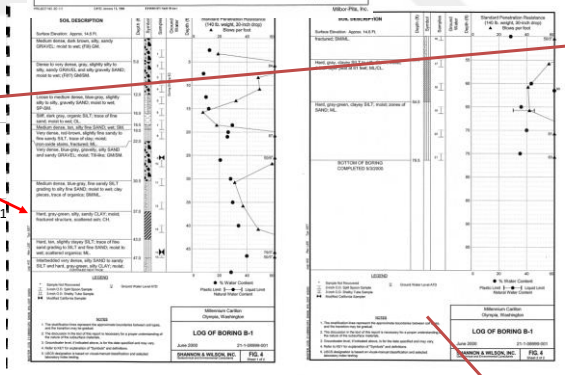
Fault Type: intraslab earth | Z_{tor} (km): - | R_{rup} (km): -

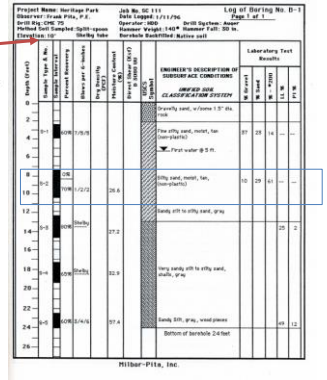
Dip: - | Width (km): - | R_{jb} (km): 11.2

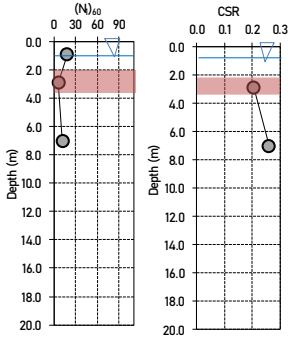
ACCELERATION TIME HISTORY







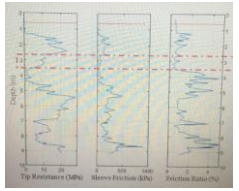




There are two borehole information; BH-1-1 and BH-1-2. Lateral spread/slumping of newly constructed shoreline along the east side of Capitol Lake. Sand boils found in restricted access area. Due to thick crust layer in BH-1-1, BH-1-2 is used in the analysis which is consistent with the CPT data at the site. Critical layer is selected as 2.6-3.6 m considering the CPT and SPT. After 3.6 m, CPT data shows a plastic layer. Hence lack of SPT data was compansated and one single SPT-N value is accepted.

BH-1-1

Depth (m)	N		
1.0	19	GM	
1.9	84	GM/SM	
2.6	***48***	GM/SM	
3.4	***49***	GM/SM	
4.1	32	SP-SM	
4.8	***8***	SP-SM	Organics
5.7	***18***	SM	Organics
6.4	87	ML	
7.9	50	GM/SM	CPT data by Can (2022)
8.2	58	GM/SM	
9.4	31	SM/ML	
11.0	37	SM/ML	
12.5	48	CH	
14.0	60	ML	
14.3	60	SM/ML	
16.9	60	SM/ML	
18.3	56	ML/CL	
19.5	41	ML/CL	
20.8	42	ML	
22.1	81	ML	
23.3	60	ML	



BH-1-2

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		Gravel	Sand	FC	PI
0.9	3.0	NA	10	2.00	0.83	18	Silty sand	37	23	14	NP
2.9	***9.5***	***0.205***	***4***	***1.57***	***0.89***	***6***	***Silty sand***	***10***	***29***	***61***	***NP***
7.0	23.0	0.259	10	1.14	0.95	12	sandy silt	-	-	-	2
					Mean:	6.1		10.0	29.0	61.0	
					St. Dev.	2.0	assigned	5.9	8.3	8.6	

Case number:	339
Earthquake:	2001 Nisqually Earthquake
Magnitude:	6.8 (USGS)
Location:	Port of Olympia
References:	PEER, Washington Geological Information Portal, https://geologyportal.dnr.wa.gov/
Nature of Failure:	At the Port of Olympia, liquefaction caused minor cracking of roads and of the banks of a marina (Bray and others, 2001).
GPS LAT:	47.05564
GPS LONG:	-122.89985
Liq. layer consist of:	Sand with silt content
Geological Unit:	Quaternary deposits, locally includes modified land and artificial fill.
Site Response Anlaysis:	No
Comments:	Vs12m is estimated based on the correlation of VS-SPTN USGS PGA contour map suggest amax>0.2 g. USGS 2101 strong ground motion station (47.047, -122.899) is located 1 km away from the site and PGA is recorded as 0.222 g and 0.255 g geometric mean of which is 0.238 g is used in the analysis. No information was available regarding hammer type. Hence it is assumed that a saftey hammer is used considering the other liquefaction sites in USA. An average value of 66% is assigned as hammer efficiency.
Gravel Contents (%):	0
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{cr1c} range (m)	-	-	-	-	2.3 - 6.0
d_{cr1} (m)	-	-	-	-	4.1
GWT (m)	-	-	-	-	2.3 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	17.3 ± 0.5
σ_v (kPa)	-	-	-	-	75.4 ± 10.8
σ_v' (kPa)	-	-	-	-	57.2 ± 4.9
a_{max} (g)	-	-	-	-	0.238 ± 0.048
r_d	-	-	-	-	0.89 ± 0.060
CSR	-	-	-	-	0.181 ± 0.040
M_w	-	-	-	-	6.80
D_{50}	-	-	-	-	0.320 ± 0.050
% Fines	-	-	-	-	3.0 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	4.1 ± 3.7
C_R	-	-	-	-	0.91
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.10
C_N	-	-	-	-	1.33
$(N_1)_{60}$	-	-	-	-	5.5 ± 4.9
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	153.0

EVENT PARAMETERS

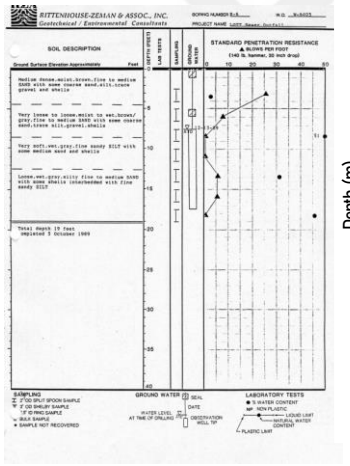
2001 Nisqually Earthquake

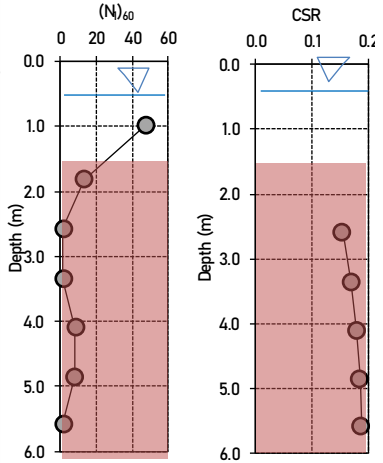
Magnitude: 6.80

Fault Type: intraslab earth | Z_{tor} (km): - | R_{rup} (km): -

Dip: - | Width (km): - | R_{jb} (km): 10.7

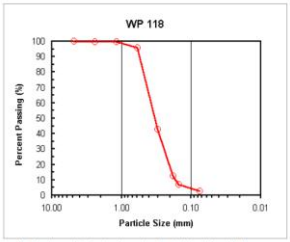
ACCELERATION TIME HISTORY







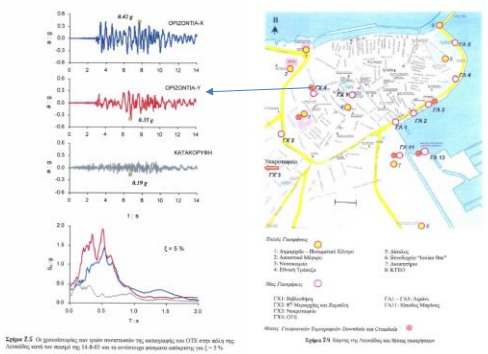
Cracking of road in the Port of Olympia due to liquefaction (N47.05564° W122.89985°; 03/01/2001)



Particle size analysis test performed on the ejected soil found in the vicinity of the crack shown in the photo to the left. The soil classifies as SP (Poorly graded fine sand) according to the USCS. The soil was rich in shells. (N47.05564° W122.89985°)

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
B-6	1.0	3.2	NA	26	2.00	0.84	47.8	Medium dense,moist,brown,fine to mediumSAND with some coarse sand,silt,tracegravel and shells
B-6	***1.8***	***6.0***	***NA***	***8***	***1.72***	***0.86***	***13.1***	***Very loose to loose.moist to wet,brown/gray . fine to medium SAND with some coarsesand.trace silt,gravel,shells***
B-6	***2.6***	***8.5***	***0.155***	***1***	***1.50***	***0.88***	***1.5***	***Very loose to loose.moist to wet,brown/gray . fine to medium SAND with some coarsesand.trace silt,gravel,shells***
B-6	***3.4***	***11.0***	***0.170***	***1***	***1.41***	***0.90***	***1.4***	***Very, soft,wet,gray,fine sandy SILT withsome medium sand and shells***
B-6	***4.1***	***13.4***	***0.180***	***6***	***1.34***	***0.91***	***8.1***	***Loose,wet,gray,silt y fine to medium S~ND with some shells interbedded with fine sandy SILT***
B-6	***4.9***	***15.9***	***0.186***	***6***	***1.27***	***0.93***	***7.8***	***Loose,wet,gray,silt y fine to medium S~ND with some shells interbedded with fine sandy SILT***
B-6	***5.6***	***18.3***	***0.188***	***1***	***1.22***	***0.94***	***1.3***	***Loose,wet,gray,silt y fine to medium S~ND with some shells interbedded with fine sandy SILT***
						Mean:	5.5	
						St. Dev.	4.9	

Case number:	324
Earthquake:	2003 Lefkada earthquake
Magnitude:	6.2
Location:	Lefkada town GL11-12
References:	Papathanassiou et al (2005), KEDE 2004, ITSAK 2003.
Nature of Failure:	No liquefaction was observed
GPS LAT	38.830639
GPS LONG	20.709072
Liq. layer consist of:	Silty Sand (SM)
Geological Unit:	Quaternay Formation
Site Response Anlaysis:	No
Comments:	An energy ratio (ER) of 60% was offered by the original source document. PGA was recorded at the LEF1 strong ground motion station which is situated at the center of Lefkada town as amax=0.42 g. OTE strong ground motion station is located in the middle of Lefkada town as well. Vs profile of the SMS was available and it indicates that SMS is located on a soil site (Vs30=180-300 m/s). The geometric mean of the two component 0.42 and 0.35 g which is 0.38 g is assigned to the site. No information regarding hammer type. Hence it is assumed that a saftey hammer is used with an average hammer efficiency value of 66% is assigned.



Gravel Contents (%):	3
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	6.0 - 11.6
d_{crt} (m)	-	-	-	-	8.8
GWT (m)	-	-	-	-	1.8 ± 0.8
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	21.2 ± 0.5
σ_v (kPa)	-	-	-	-	180.2 ± 20.4
σ_v' (kPa)	-	-	-	-	110.9 ± 12.0
a_{max} (g)	-	-	-	-	0.383 ± 0.077
r_d	-	-	-	-	0.84 ± 0.113
CSR	-	-	-	-	0.340 ± 0.084
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	31.0 ± 4.3
% PI	-	-	-	-	0
N	-	-	-	-	21.9 ± 0.9
C_R	-	-	-	-	0.97
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.10
C_N	-	-	-	-	0.96
$(N_1)_{60}$	-	-	-	-	22.3 ± 0.9
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	198.1

EVENT PARAMETERS

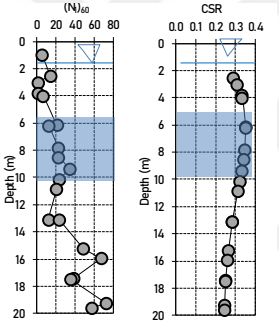
2003 Lefkada earthquake

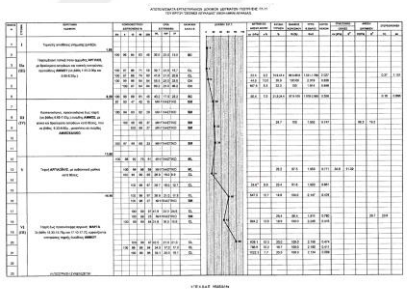
Magnitude: 6.20

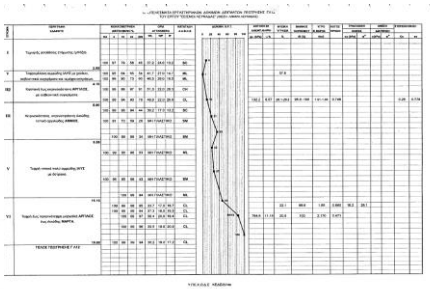
Fault Type: Strike Slip — Z_{tor} (km): 3.5 — R_{rup} (km): -

Dip: 84 — Width (km): 15 — R_{jb} (km): 6.9

ACCELERATION TIME HISTORY





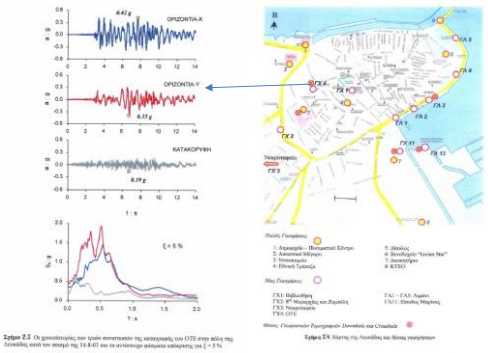


	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
GL11	1.01	3.3	NA	3	2.00	0.84	5.5	artificial fill
GL 12	2.5	8.2	0.29	9	1.62	0.88	14.1	artificial fill
GL11	3.01	9.9	0.3	1	1.51	0.89	1.5	CL soft layer with ver
GL 12	3.83	12.6	0.3	1	1.37	0.91	1.4	ML very thin
GL11	4	13.1	0.3	5	1.35	0.91	6.8	CL
GL11	***6.15***	***20.2***	***0.35***	***18***	***1.12***	***0.94***	***21.0***	SM
GL 12	6.23	20.4	0.35	11	1.12	0.94	12.8	CL
GL 12	***7.85***	***25.8***	***0.35***	***21***	***1.01***	***0.96***	***22.3***	SM
GL11	***8.51***	***27.9***	***0.34***	***22***	***0.97***	***0.97***	***22.7***	SM
GL 12	9.37	30.7	0.33	35	0.93	0.97	34.8	SM outlier
GL11	***10.12***	***33.2***	***0.32***	***24***	***0.90***	***0.98***	***23.1***	SM
GL 12	10.82	35.5	0.3	22	0.87	0.98	20.6	
GL11	13.07	42.9	0.3	14	0.80	0.99	12.1	
GL 12	13.12	43.0	0.3	27	0.80	0.99	23.3	
GL11	15.25	50.0	0.3	60	0.74	0.99	48.5	
GL 12	15.93	52.3	0.3	85	0.73	0.99	67.4	
GL 12	17.41	57.1	0.3	50	0.70	0.99	38.1	
GL11	17.5	57.4	0.3	47	0.69	0.99	35.7	
GL 12	19.26	63.2	0.2	100	0.66	1.00	72.7	
GL11	19.58	64.2	0.2	80	0.66	1.00	57.8	
						Mean:	22.3	
						St. Dev.	0.9	

The grain size distribution curve results indicated that the silty sandy layer, which lies beneath the artificial fill in the coastal zone in Lefkada town, had liquefied during the 14 August Earthquake.

Depth (m)	USCS	FC	WL	WP	IP	Borehole #	GC
1.71	SC	49	36	23	13	GL11	
3.22	CL	59	39.7	24	15.7	GL11	
3.7	CL	60	41.7	21	20.8	GL11	
4.2	CH	84	58.5	25	33.5	GL11	
4.68	CH	84	69.2	23	46.2	GL11	
5.7	SC	46	40.2	17	23.2	GL11	
6.16	GM	15				GL11	
7.17	**SM**	**29**				GL11	**6**
8.19	**SM**	**37**				GL11	**0**
8.7	**SM**	**27**				GL11	**0**
10.18	**SM**	**33**				GL11	**3**
11.71	ML	61				GL11	
12.7	ML	89				GL11	
13.18	CL	95	26.9	18	8.9	GL11	
14.21	CL	97	28.7	16	12.7	GL11	
15.19	CL	97	38.8	21	17.8	GL11	
15.69	ML	27				GL11	
16.7	CL	97	47.6	23	24.6	GL11	
17.2	ML	23				GL11	
17.7	CL	84	31.6	16	15.6	GL11	
19.68	CL	97	41	21	21	GL11	
20.15	CL	94	34	17	17	GL11	
20.72	CL	96	39.1	20	19.1	GL11	
2.73	SC	46	37.2	24	13.2	GL 12	
3.71	ML	54	41.7	27	14.7	GL 12	
4.2	ML	60	46.5	28	18.5	GL 12	
5.17	CH	91	51.3	22	29.3	GL 12	
6.18	CL	78	48.9	22	26.9	GL 12	
7.19	SC	44	30.2	17	13.2	GL 12	
8.15	***SM***	***26***				GL 12	**9**
9.65	***SM***	***34***				GL 12	**0**
11.17	ML	53				GL 12	
13.72	SM	43				GL 12	
15.23	ML	94				GL 12	
16.2	CL	95				GL 12	
16.71	CL	94				GL 12	
17.2	CL	97				GL 12	
18.19	CL	96				GL 12	
19.7	CL	94				GL 12	
		31.0					3.0
		4.3					3.8

Case number:	325
Earthquake:	2003 Lefkada earthquake
Magnitude:	6.2
Location:	Lefkada town GX5
References:	Papathanassiou et al (2005), KEDE 2004, ITSAK 2003.
Nature of Failure:	Sand boils and ground fissures with ejection of mud.
GPS LAT	38.835095
GPS LONG	20.711474
Liq. layer consist of:	Sand (SM)
Geological Unit:	Quaternay Formation Rondoyanni-Tsiambaou (1997)
Site Response Anlaysis:	No
Comments:	An energy ratio (ER) of 60% was offered by the original source document. PGA was recorded at the LEF1 strong ground motion station which is situated at the center of Lefkada town as amax=0.42 g. OTE strong ground motion station is located in the middle of Lefkada town as well. Vs profile of the SMS was available and it indicates that SMS is located on a soil site (Vs30=180-300 m/s). The geometric mean of the two component 0.42 and 0.35 g which is 0.38 g is assigned to the site. No information regarding hammer type. Hence it is assumed that a saftey hammer is used with an average hammer efficiency value of 66% is assigned. Vs12m is calculated based on SPT N-Vs correlations
Gravel Content (%):	2
CPT available:	No
Vs available:	No



Σχήμα 2.5 Οι χρονοϊστορίες των τριών συνιστωσών της επιτάχυνσης που ΟΤΕ στην αίθουσα της Λιτοσάθας κατά τον σεισμό της 14-8-03 και τα αντίστοιχα φάσματα απόκρισης για ξ = 5 %

Σχήμα 2.6 Χάρτης της Λιτοσάθας και θέσεις σεισμογράφων

Summary of Input Data					
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	4.6 - 10.3
d_{crt} (m)	-	-	-	-	7.5
GWT (m)	-	-	-	-	0.8 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	149.8 ± 19.9
σ_v' (kPa)	-	-	-	-	84.4 ± 10.7
a_{max} (g)	-	-	-	-	0.383 ± 0.077
r_d	-	-	-	-	0.97 ± 0.098
CSR	-	-	-	-	0.427 ± 0.096
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV
% Fines	-	-	-	-	30.3 ± 10.1
% PI	-	-	-	-	0
N	-	-	-	-	16.6 ± 3.4
C_R	-	-	-	-	0.96
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.10
C_N	-	-	-	-	1.10
$(N_1)_{60}$	-	-	-	-	19.2 ± 3.9
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	237.7

EVENT PARAMETERS

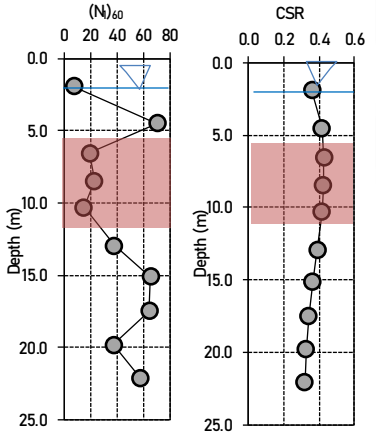
2003 Lefkada earthquake

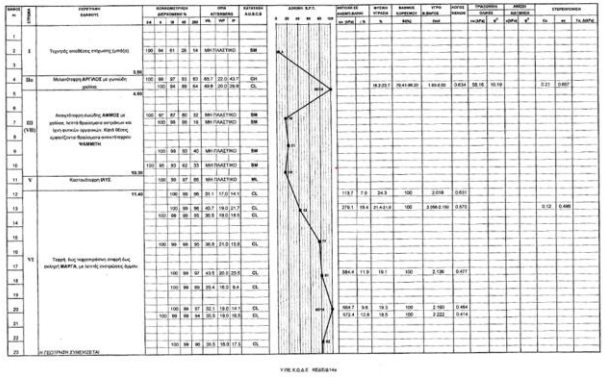
Magnitude: 6.20

Fault Type: Strike Slip | Z_{tor} (km): 3.5 | R_{rup} (km): -

Dip: 84 | Width (km): 15 | R_{jb} (km): 7.0

ACCELERATION TIME HISTORY



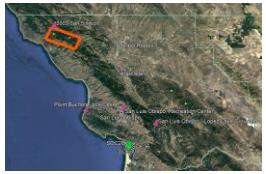


	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
GX5	1.92	6.3	0.359	4	2.00	0.86	7.6	SM, CN>2
GX5	4.50	14.8	0.42	50	1.39	0.92	70.4	Clay
GX5	***6.57***	***21.6***	***0.43***	***16***	***1.16***	***0.95***	***19.4***	***SM***
GX5	***8.46***	***27.8***	***0.42***	***21***	***1.03***	***0.96***	***23.0***	***SM***
GX5	***10.30***	***33.8***	***0.41***	***15***	***0.94***	***0.98***	***15.1***	***SM***
GX5	12.94	42.5	0.39	42	0.84	0.99	38.3	Clay
GX5	15.10	49.5	0.36	77	0.78	0.99	65.5	Clay
GX5	17.47	57.3	0.34	81	0.73	0.99	64.3	Clay
GX5	19.80	65.0	0.33	50	0.68	1.00	37.4	Clay
GX5	22.11	72.5	0.32	82	0.65	1.00	58.2	Clay
						Mean:	19.2	
						St. Dev.	3.9	

Depth (m)	USCS	FC	WL	WP	IP	GC
1.83	SM	14				6
3.83	CH	83	65.7	22	43.7	1
4.32	CL	64	49.8	20	29.8	0
6.33	***SM***	***32***				***3***
6.85	***SM***	***16***				***0***
8.84	***SM***	***40***				***0***
9.85	***SM***	***33***				***5***
10.84	ML	66				0
11.8	CL					0
12.81	CL					0
13.31	CL					0
15.38	CL					0
17.35	CL					0
18.34	CL					0
19.82	CL					0
20.31	CL					0
22.3	CL					0
	Mean:	30.3				2.0
	St. Dev.	10.1				2.4

The grain size distribution curve results indicated that the silty sandy layer, which lies beneath the artificial fill in the coastal zone in Lefkada town, had liquefied during the 14 August Earthquake.

Case number:	326
Earthquake:	2003 San Simeon Earthquake
Magnitude:	6.5
Location:	SOC 10, Oceano, California
References:	Holzer et al (2004, 2005), personal communication Prof. Dr. Robb Moss
Nature of Failure:	SOC 10 is outside the extension region hence nonliquefied.
GPS LAT	35.107468
GPS LONG	-120.624019
Liq. layer consist of:	Sand (SP)
Geological Unit:	artificial fill
Site Response Anlaysis:	No
Comments:	Holzer et al. (2004) "...The 22 December 2003 M 6.5 San Simeon, California, earthquake occurred on a reverse fault .. (Hardebeck et al., 2004)...", "Although the mainshock ground motion at Oceano was not recorded, peak ground acceleration was estimated to range from 0.25 and 0.28g on the basis of the liquefaction potential index and aftershock recordings."



Unit weight below GWT is assigned as the average value from the measured laboratory results.
Vs12m is calculated based on measured Vs values.
Based on locally calibrated event specific ground motion predicition equations amax is selected as 0.123 g.



SOC 10 is outside the extension region hence nonliquefied.
No information regarding hammer type. Hence it is assumed that a saftey hammer is used considering the other liquefaction sites in USA. An average value of 66% is assigned as hammer efficiency.

Gravel Contents (%):	0
CPT available:	Yes
Vs available:	Yes

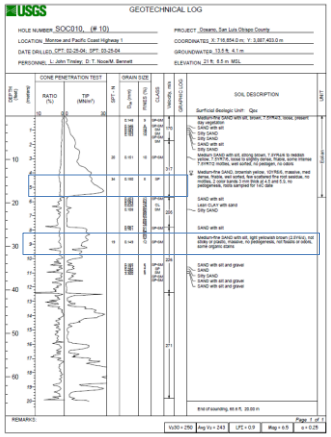
Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crtr} range (m)	-	-	-	-	4.1 - 5.6
d_{crt} (m)	-	-	-	-	4.9
GWT (m)	-	-	-	-	4.1 ± 0.0
γ_{moist} (kN/m^3)	-	-	-	-	16.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.7 ± 0.5
σ_v (kPa)	-	-	-	-	81.0 ± 5.1
σ_v' (kPa)	-	-	-	-	73.6 ± 3.0
a_{max} (g)	-	-	-	-	0.123 ± 0.025
r_d	-	-	-	-	0.99 ± 0.068
CSR	-	-	-	-	0.087 ± 0.019
M_w	-	-	-	-	6.50
D_{50}	-	-	-	-	0.149 ± 0.005
% Fines	-	-	-	-	3.6 ± 5.0
% PI	-	-	-	-	0
N	-	-	-	-	34.7 ± 1.7
C_R	-	-	-	-	0.93
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.10
C_N	-	-	-	-	1.17
$(N_1)_{60}$	-	-	-	-	41.5 ± 2.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	234.4

EVENT PARAMETERS

2003 San Simeon Earthquake	strike: 290 (WNW-ESE)	
Magnitude: 6.50	depth (km): 8	
Fault Type: reverse fault	Z_{tor} (km): 0	R_{rup} (km): **63.2**
Dip: 58	Width (km): 22	R_{jb} (km): **63.2**

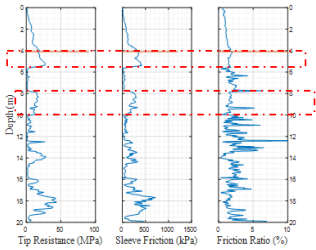
ACCELERATION TIME HISTORY

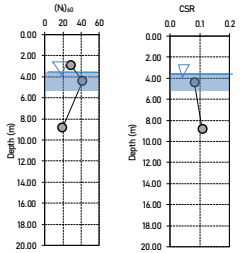


ORGANIC STAINS

Depth (m)	Vs (m/s)	Thickness (m)	time
1.38	170	1.38	0.008
5.32	317	3.94	0.012
7.45	206	2.13	0.010
12.04	226	4.59	0.020
20	271	7.96	0.029
		$V_{s\text{-}12m}$ (m/s)	234.392

Can (2022)





	Depth (m)	Depth (ft)	CSR	N	C_N	C_E	$(N1)_{60}$	
SP-SM	2.90	9.5	NA	20	1.47	0.89	28.7	
SP	*4.42*	*14.5*	*0.08*	*34*	*1.21*	*0.92*	*41.5*	
SM	8.84	29.0	0.1	19.0	1.0	1.0	19.5	organic stians
						Mean:	41.5	
						St. Dev.	2.0	

Critical layer selection is compared with nearby CPT. There is no other critical layer hence even though the SPT data is limited, the case is included.

Index #	Site	Sample number	Depth (m)	Depth (ft)	N	Gravel	Sand	FC	Silt	Clay	D50 mm	Cu	LL	PL	PI	LI	w	USC	Description	Density
	SOC010-0.1	***0-2***	***0.30***	***1***		***0***	***91***	***9***	***9***	***0***	***0.148***	***1.9***						***SP-SM***	***SAND with silt***	
2-4.5	***SOC010-1a***	***2-2.5***	***0.69***	***2.25***		***0***	***92***	***8***	***7***	***1***	***0.146***	***1.7***					***5.8***	***SP-SM***	***SAND with silt***	1.52
2-4.5	***SOC010-1b***	***2.5-3.05***	***0.84***	***2.75***		***0***	***87***	***0***			***0.15***						***6.8***	***SM***	***Silty SAND***	1.59
2-4.5	***SOC010-1c***	***3.05-3.6***	***0.99***	***3.25***		***0***	***86***	***0***			***0.143***						***8***	***SM***	***Silty SAND***	1.66
2-4.5	***SOC010-1d***	***3.6-4.05***	***1.14***	***3.75***		***0***	***90***	***10***	***9***	***1***	***0.154***	***2.3***					***10.6***	***SP-SM***	***SAND with silt***	1.71
2-4.5	***SOC010-1e***	***4.05-4.6***	***1.30***	***4.25***		***0***	***86***	***0***			***0.153***						***13.2***	***SM***	***Silty SAND***	1.77
	SOC010-2	***8.5-10***	***2.90***	***9.5***	***20***	***0***	***90***	***10***	***8***	***2***	***0.151***	***2.2***					***10.8***	***SP-SM***	***SAND with silt***	
	SOC010-3	***13.5-15***	***4.42***	***14.5***	***34***	***0***	***95***	***5***	***5***	***0***	***0.15***	***1.4***					***19.7***	***SP***	***SAND***	
19-22	***SOC010-4a1***	***19-19.15***	***5.81***	***19.075***		***0***	***88***	***0***			***0.153***							***SP-SM***	***SAND with silt***	
19-22	SOC010-4a2	19.15-19.3	5.86	19.225		0	47	53	30	23	0.063		27	18	9			CL	Sandy lean CLAY	
19-22	SOC010-4b1	19.3-19.55	5.92	19.435		0	22	78	46	32	0.02		42	21	21			CL	Lean CLAY with sand	
19-22	SOC010-4b2	19.55-19.75	5.99	19.65		0	26	73	56	17	0.045		33	26	7	-0.26	24.2	ML	SILT with sand	1.90
19-22	SOC010-4c	19.75-20.25	6.10	20		0	8	92	61	31	0.014		43	21	22	0.27	27	CL	Lean CLAY	1.89
19-22	SOC010-4d	20.25-20.95	6.28	20.6		0	4	96	58	38	0.015		44	23	21	0.37	30.7	CL	Lean CLAY	1.87
19-22	SOC010-4e1	20.95-21.10	6.41	21.025		0	16	84	56	28	0.016		45	25	20			CL	Lean CLAY with sand	
19-22	SOC010-4e2	21.1-21.4	6.48	21.25		0	35	65	52	13	0.05						32	CL	Sandy lean CLAY	1.91
19-22	SOC010-4f1	21.4-21.6	6.55	21.5		0	50	50	39	11	0.075							SM	Silty SAND	
19-22	SOC010-4f2	21.6-21.85	6.62	21.725		0	62	38	31	7	0.096	13	32	25	7	0.66	29.6	SM	Silty SAND	1.96
	SOC010-4.1	20.5	6.25	20.5		0	20	80	44	36	0.02		45	20	25	0.21	25.2	CL	Lean CLAY with sand	
23-25'7"	SOC010-5a1	23-23.1	7.04	23.1		0	32	68	51	17	0.046		36	20	16			CL	Sandy lean CLAY	
23-25'7"	SOC010-5a2	23-23.33	7.08	23.22		0	22	78	65	13	0.043							CL	Lean CLAY with sand	
23-25'7"	SOC010-5b1	23.33-23.83	7.17	23.52		0	23	77	62	15	0.04		35	25	10			ML	SILT with sand	
23-25'7"	SOC010-5b2	23.33-23.83	7.25	23.77		0	9	91	64	27	0.018		41	26	15	0.20	29	CL	Lean CLAY	1.90
23-25'7"	SOC010-5c	23.83-24.33	7.34	24.08		0	16	84	62	22	0.027		40	23	17	0.48	31.1	CL	Lean CLAY with sand	1.88
23-25'7"	SOC010-5d	24.33-24.83	7.49	24.58		0	3	97	47	50	0.005		59	27	32	0.32	37.3	CH	Fat CLAY	1.83
23-25'7"	SOC010-5e	24.83-25.33	7.64	25.08		0	11	89	55	34	0.01		45	26	19	0.37	33.1	CL	Lean CLAY	1.87
23-25'7"	SOC010-5f1	25.33-25.83	7.79	25.55		0	47	53	34	19	0.067		33	20	13	0.80	30.4	CL	Sandy lean CLAY	
23-25'7"	SOC010-5f2	25.33-25.83	7.85	25.77		0	93	7	7	0	0.161	1.7						SP-SM	SAND with silt	1.94
34-36.1	SOC010-6	28-29.5	8.84	29	19	0	88	12			0.149	2.7					25.7	SM	Silty SAND	
34-36.1	SOC010-7a	34-34.5	10.44	34.25		0	94	6	6	0	0.165	2.0						SP-SM	SAND with silt and gravel	
34-36.1	SOC010-7b	34.5-35	10.59	34.75		0	97	3	3	0	0.191	1.6					18.8	SP	SAND	1.95
34-36.1	SOC010-7c	35-35.5	10.74	35.25		6	87	7	7	0	0.28	3.3						SM	Silty SAND	2.02
34-36.1	SOC010-7d	35.5-36	10.90	35.75		31	63	6	5	1	2.15	20						SP-SM	SAND with silt and gravel	2.01
34-36.1	SOC010-7e	36-36.5	11.05	36.25		44	47	9	9	0	3.3	50						SP-SM	SAND with silt and gravel	2.05
					Mean:	0.0	88.2	3.6	8.0	1.0	0.149									
					St. Dev.	5.9	2.7	5.0	1.4	2.3	0.005									

Gravel >4.75 mm
Sand 4.75-0.075 mm
Silt 0.075-0.005 mm
Clay <0.005 mm
Cu D60/D10

Case number:	364
Earthquake:	2003 Tokachi-oki Earthquake
Magnitude:	8.3
Location:	HKD086
References:	Iai. et. al. (1989), Greenfield (2017, 2018), NGL project, Kinoshita (2008)
GPS LAT	42.8542
GPS LONG	143.8579
Liq. layer consist of:	Silt
Geological Unit:	Quaternary terrace deposits of the Shiranuka Formation
Site Response Anlaysis:	No
Nature of Failure:	Strong motion recorder tilted due to liquefaction and had to be replaced
Comments:	Tokachi-Oki earthquake occurred on September 26, 2003 on a subduction zone. The digital recordings of the ground motions recorded at the site are available. Liquefaction has occured at early stages hence it did not affcet the PGA levels and 0.784g is used. SPT procedures were not clearly documented. However, on page 66 in Iai et. al. for comparison with Seed et. al. 1985, an average Japanese SPT energy ratio of 73% was reported to be used. On the basis of this, with some uncertainty Iai et. al. N values may be adopted as N73 values. Note that Seed et. al. (1985) adopted an energy ratio of 73% for liquefied cases. The rationale behind this choice could be field data which is unknown to us or simply a conservative engineering judgement. Back in 2018 the site was rejected due to missing soil layering information, now it is available thus the site is included. Greenfield (2018) reported amax as 0.77g. Greenfield (2017) performed analysis to determine the time of liquefaction which in turn calculated as 35 s. The number of cycles and corresponding M is calculated. amax is determined form the a-t histories as 0.81g and 0.750 g geometric mean of whic is 0.784 g. This values is used in the analysis. This value is very high to perform deconvolution analysis (limitiation of EQL analysis) as a result CSR is estimated by simplified procedure. PI info were not available hence assigned based on USCS.
Gravel Content (%):	NAV
CPT available:	No
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.5 - 14.0
d_{crt} (m)	-	-	-	-	8.3
GWT (m)	-	-	-	-	1.6 ± 0.5
g_{moist} (kN/m^3)	-	-	-	-	18.1 ± 0.5
g_{sat} (kN/m^3)	-	-	-	-	19.6 ± 0.5
s_v (kPa)	-	-	-	-	159.9 ± 37.9
s_v' (kPa)	-	-	-	-	94.5 ± 19.6
a_{max} (g)	-	-	-	-	0.784 ± 0.039
r_d	-	-	-	-	0.57 ± 0.107
CSR	-	-	-	-	0.493 ± 0.100
M_w	-	-	-	-	8.30
D_{50}	-	-	-	-	NAV
% Fines	-	-	-	-	50.7 ± 41.6
% PI	-	-	-	-	NAV
N	-	-	-	-	9.1 ± 3.6
C_R	-	-	-	-	0.97
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.04
$(N_1)_{60}$	-	-	-	-	12.5 ± 4.9
V_{s30m} (m/s)	-	-	-	-	205.0
V_{s12m} (m/s)	-	-	-	-	127.4

EVENT PARAMETERS

2003 Tokachi-oki Earthquake https://earthquake.usgs.gov/earthquakes/eventpage/official2003092519500636

Magnitude: 8.30

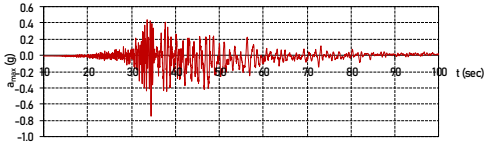
Fault Type: subduction-zon Z_{tor} (km): - R_{rup} (km): 59.0

Dip: 16-77 Width (km): - R_{jb} (km): -

ACCELERATION TIME HISTORY

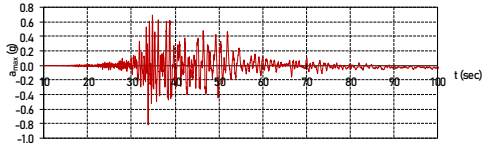
Full Record

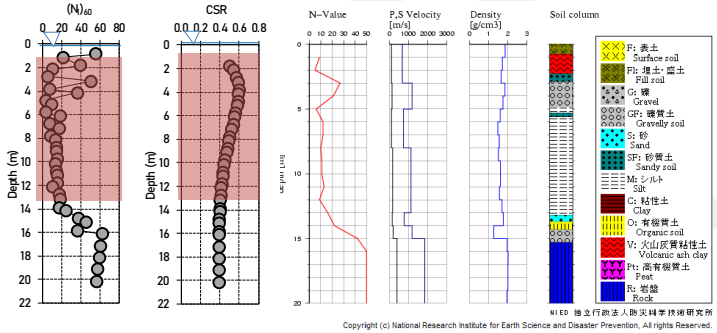
N_{H1}	13.6
N_{H2}	11.2
N_{gm}	12.4
PGA_{H1}	0.819
PGA_{H2}	0.750
PGA	0.784
M_w	8.3
$M_{w,cycle}$	3.2

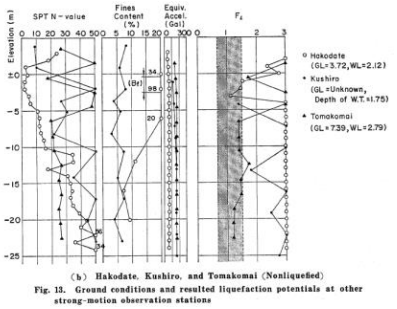


Untill Liquefaction

$N_{H1,L}$	4.0
$N_{H2,L}$	5.4
$N_{gm,L}$	4.7
PGA_{H1}	0.803
PGA_{H2}	0.735
PGA_L	0.768
$M_{w,eq}$	3.1
t_L	34.9







(b) Hakodate, Kushiro, and Tomakomai (Nonliquefied)

Fig. 13. Ground conditions and resulted liquefaction potentials at other strong-motion observation stations

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
lai. et. al. (1989)	0.86	2.81	NA	24	2.00	0.85	56	-	
From K-net boring log	1.15	3.77	NA	9	2.00	0.86	21	-	Volcanic Ash Clay
lai. et. al. (1989)	1.81	5.94	0.50	18	1.81	0.88	39	-	
From K-net boring log	2.15	7.05	0.54	5	1.72	0.89	10	-	Volcanic Ash Clay
lai. et. al. (1989)	*2.74*	*8.98*	*0.57*	*3*	*1.59*	*0.90*	*6*	*-*	
From K-net boring log	***3.15***	***10.33***	***0.59***	***27***	***1.51***	***0.91***	***51***	***-***	***Silty gravel*** outlier
lai. et. al. (1989)	*3.85*	*12.63*	*0.60*	*4*	*1.41*	*0.92*	*7*	*34*	
From K-net boring log	***4.15***	***13.62***	***0.60***	***21***	***1.37***	***0.92***	***36***	***-***	***Silty gravel*** outlier
lai. et. al. (1989)	*4.78*	*15.69*	*0.59*	*2*	*1.30*	*0.93*	*3*	*-*	
From K-net boring log	***5.15***	***16.90***	***0.58***	***6***	***1.26***	***0.94***	***10***	***-***	***Silt***
lai. et. al. (1989)	*5.79*	*19.00*	*0.57*	*2*	*1.20*	*0.95*	*3*	*98*	
From K-net boring log	***6.15***	***20.18***	***0.56***	***12***	***1.17***	***0.95***	***18***	***-***	***Silty Sand***
lai. et. al. (1989)	*6.75*	*22.16*	*0.54*	*5*	*1.13*	*0.96*	*7*	*-*	
From K-net boring log	***7.15***	***23.46***	***0.53***	***12***	***1.10***	***0.96***	***17***	***-***	***Silt***
lai. et. al. (1989)	*7.78*	*25.54*	*0.51*	*6*	*1.06*	*0.96*	*8*	*-*	
From K-net boring log	***8.15***	***26.74***	***0.50***	***10***	***1.04***	***0.97***	***14***	***-***	***Silt***
lai. et. al. (1989)	*8.81*	*28.91*	*0.48*	*11*	*1.01*	*0.97*	*15*	*-*	
From K-net boring log	***9.15***	***30.02***	***0.47***	***11***	***0.99***	***0.97***	***14***	***-***	***Silt***
lai. et. al. (1989)	*9.74*	*31.97*	*0.46*	*12*	*0.96*	*0.98*	*15*	*20*	
From K-net boring log	***10.15***	***33.30***	***0.45***	***11***	***0.95***	***0.98***	***14***	***-***	***Silt***
lai. et. al. (1989)	*10.81*	*35.46*	*0.44*	*12*	*0.92*	*0.98*	*15*	*-*	
From K-net boring log	***11.15***	***36.58***	***0.43***	***13***	***0.91***	***0.98***	***16***	***-***	***Silt***
lai. et. al. (1989)	*11.79*	*38.67*	*0.42*	*13*	*0.89*	*0.98*	*15*	*-*	
From K-net boring log	***12.15***	***39.86***	***0.42***	***9***	***0.87***	***0.99***	***11***	***-***	***Silt***
lai. et. al. (1989)	*12.80*	*42.00*	*0.41*	*15*	*0.85*	*0.99*	*17*	*-*	
From K-net boring log	***13.15***	***43.14***	***0.41***	***16***	***0.84***	***0.99***	***18***	***-***	***Silt***
lai. et. al. (1989)	*13.92*	*45.67*	*0.40*	*16*	*0.82*	*0.99*	*18*	*-*	
From K-net boring log	14.15	46.42	0.40	22	0.82	0.99	24	-	Organic soil
lai. et. al. (1989)	14.78	48.48	0.40	35	0.80	0.99	38	-	
From K-net boring log	15.15	49.70	0.40	42	0.79	0.99	45	-	Silty Gravel
lai. et. al. (1989)	15.83	51.94	0.39	35	0.77	0.99	37	-	
From K-net boring log	16.15	52.99	0.39	60	0.77	0.99	63	-	Rock
From K-net boring log	17.15	56.27	0.39	60	0.75	0.99	61	-	Rock
From K-net boring log	18.15	59.55	0.39	60	0.73	1.00	59	-	Rock
From K-net boring log	19.15	62.83	0.39	60	0.71	1.00	58	-	Rock
From K-net boring log	20.15	66.11	0.39	60	0.69	1.00	57	-	Rock
						Mean:	**12.5**	**50.7**	
						St. Dev.	**4.9**	**41.6**	

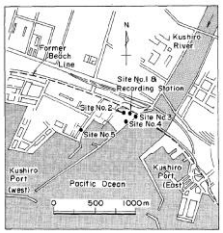
GWT (m)

1.6	lai et al Borehole
4	Inferred from increased P-wave velocity in B-1

Depth (m)	Vs (m/s)	Vp (m/s)	time (s)
1	105	670	0.0095
2	105	670	0.0095
3	105	670	0.0095
4	135	1180	0.0074
5	135	1180	0.0074
6	110	730	0.0091
7	110	730	0.0091
8	110	730	0.0091
9	170	1130	0.0059
10	170	1130	0.0059
11	170	1130	0.0059
12	170	1130	0.0059
13	170	1130	
14	150	770	
15	190	1180	
16	400	1850	
17	400	1850	
18	400	1850	
19	400	1850	
20	400	1850	
		$V_{S,12m}$ (m/s	127.4

Case number:	370
Earthquake:	2003 Tokachi-Oki earthquake
Magnitude:	8.3
Location:	Kushiro Port
References:	Iai et al. (1995), Greenfield (2017, 2018), Sasatani (1996), Kayen (2008), NGL Project.
GPS LAT:	42.999
GPS LONG:	144.355
Liq. layer consist of:	Sand
Geological Unit:	man-made fill
Site Response Anlaysis:	No
Nature of Failure:	No surface manifestation of liquefaction.
Comments:	Kushiro Port (Kushiro-G) recorded ground motions are provided by PARI. Greenfield (2018) "..The recording array included accelerographs at the ground surface and at a depth of 77 m… The test results indicate the average shear wave velocity in the upper 30 m of the site, Vs30, is about 290 m/s. …Sand (Fill): Based on three gradation tests, the sand fill has a median diameter, D50, between 0.6 to 0.8 mm and contains between 4% to 16% fine-grained particles…." PARI provides the following information "Kushiro-G, GB Latitude: 42.999N deg. Longitude: 144.355E deg. https://www.eq.pari.go.jp/kyosin/data/pnt/en/kushiro-g.htm. Greenfield (2018) ".. the nearest distance from Kushiro-G to the fault rupture, Rrup, was about 31 km. Kayen et al. (2013) indicate that no surficial manifestation of liquefaction was observed at the Kushiro Port office seismometer station.





Gravel Content (%):	<5
CPT available:	No
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	2.0 - 5.5
d_{crt} (m)	-	-	-	-	3.8
GWT (m)	-	-	-	-	2.0 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.6 ± 0.5
σ_v (kPa)	-	-	-	-	68.1 ± 11.0
σ_v' (kPa)	-	-	-	-	50.9 ± 5.4
a_{max} (g)	-	-	-	-	0.449 ± 0.022
r_d	-	-	-	-	0.99 ± 0.055
CSR	-	-	-	-	0.387 ± 0.037
M_w	-	-	-	-	8.30
D_{50}	-	-	-	-	0.350 ± 0.050
% Fines	-	-	-	-	5.0 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	15.8 ± 1.1
C_R	-	-	-	-	0.92
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.41
$(N_1)_{60}$	-	-	-	-	28.0 ± 1.9
V_{s30m} (m/s)	-	-	-	-	279.2
V_{s12m} (m/s)	-	-	-	-	222.4

EVENT PARAMETERS

2003 Tokachi-Oki earthquake

Magnitude: 8.30

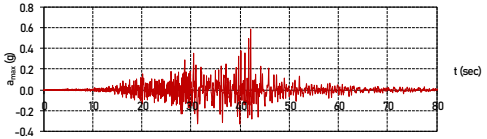
Fault Type: subduction-zon | Z_{tor} (km): - | R_{rup} (km): 31.0

Dip: 16-77 | Width (km): - | R_{jb} (km): -

ACCELERATION TIME HISTORY

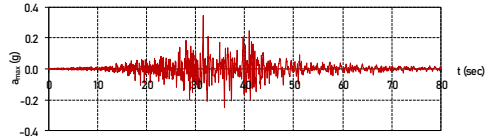
Full Record

N_{H1}	9.7
N_{H2}	9.5
N_{gm}	9.6
PGA_{H1}	0.345
PGA_{H2}	0.586
PGA	0.449
M_w	8.3
$M_{w,cycle}$	2.8



Untill Liquefaction

$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-



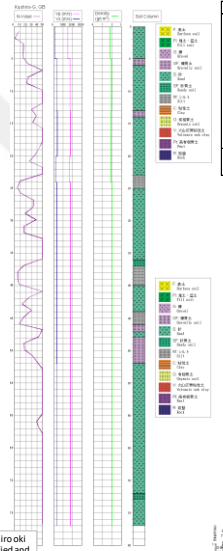
	Depth (m)	Depth (ft)	rd	CSR	N	C_N	C_{ER}	$(N1)_{60}$		
above GWT	1	3.3	0.998	NA	6	2.00	0.86	14.0	Sand	PARI
above GWT	2	6.6	0.996	NA	4	1.69	0.88	8.2	Sand	PARI
	3	9.8	0.993	0.354	16	1.52	0.90	30.0	Sand	PARI
	4	13.1	0.989	0.396	15	1.38	0.92	26.1	Sand	PARI
	5	16.4	0.983	0.424	17	1.28	0.94	27.9	Sand	PARI
	6	19.7	0.976	0.443	31	1.20	0.95	48.1	Gravelly sand	PARI
	7	23.0	0.966	0.456	42	1.13	0.96	62.1	Gravelly sand	PARI
	8	26.2	0.953	0.464	23	1.07	0.97	32.5	Gravelly sand	PARI
	9	29.5	0.937	0.467	27	1.02	0.97	36.6	Gravelly sand	PARI
	10	32.8	0.919	0.467	50	0.98	0.98	65.3	Gravelly sand	PARI
	11	36.1	0.898	0.464	50	0.94	0.98	63.0	Gravelly sand	PARI
	12	39.4	0.875	0.458	46	0.91	0.99	56.1	Gravelly sand	PARI
	13	42.7	0.853	0.452	32	0.87	0.99	37.8	Gravelly sand	PARI
	14	45.9	0.831	0.445	37	0.85	0.99	42.4	Gravelly sand	PARI
	15	49.2	0.811	0.438	36	0.82	0.99	40.1	Gravelly sand	PARI
	16	52.5	0.794	0.432	50	0.80	0.99	54.2	Gravelly sand	PARI
	17	55.8	0.781	0.428	50	0.78	0.99	52.8	Gravelly sand	PARI
	18	59.1	0.769	0.424	48	0.76	1.00	49.5	Gravelly sand	PARI
	19	62.3	0.761	0.422	42	0.74	1.00	42.3	Gravelly sand	PARI
	20	65.6	0.755	0.421	34	0.72	1.00	33.5	Gravelly sand	PARI
	21	68.9	0.750	0.420	32	0.71	1.00	30.8	Gravelly sand	PARI
	22	72.2	0.745	0.419	50	0.69	1.00	47.2	Gravelly sand	PARI
	23	75.5	0.741	0.418	39	0.68	1.00	36.1	Silt	PARI
	24	78.7	0.736	0.417	8	0.66	1.00	7.3	Silt	PARI
	25	82.0	0.732	0.416	6	0.65	1.00	5.3	Sand	PARI
	26	85.3	0.727	0.414	17	0.64	1.00	14.9	Sand	PARI
	27	88.6	0.722	0.413	34	0.63	1.00	29.2	Sand	PARI
	28	91.9	0.718	0.411	30	0.62	1.00	25.3	Sand	PARI
	29	95.1	0.713	0.410	23	0.61	1.00	19.1	Sand	PARI
	30	98.4	0.709	0.408	34	0.60	1.00	27.8	Sand	PARI
	31	101.7	0.704	0.406	17	0.59	1.00	13.7	Sand	PARI
	32	105.0	0.700	0.404	24	0.58	1.00	19.1	Sand	PARI
	33	108.3	0.695	0.403	50	0.57	1.00	39.1	Sand	PARI
	34	111.5	0.690	0.401	50	0.56	1.00	38.6	Sand	PARI
	35	114.8	0.686	0.399	50	0.56	1.00	38.0	Sand	PARI
	36	118.1	0.681	0.397	43	0.55	1.00	32.3	Sand	PARI
	37	121.4	0.677	0.394	14	0.54	1.00	10.4	Silt	PARI
	38	124.7	0.672	0.392	6	0.54	1.00	4.4	Silt	PARI
	39	128.0	0.667	0.390	6	0.53	1.00	4.3	Silt	PARI
	40	131.2	0.663	0.388	19	0.52	1.00	13.6	Sand	PARI
	41	134.5	0.658	0.386	45	0.52	1.00	31.8	Sand	PARI
	42	137.8	0.654	0.384	23	0.51	1.00	16.1	Sand	PARI
	43	141.1	0.649	0.381	17	0.50	1.00	11.7	Sand	PARI
	44	144.4	0.644	0.379	26	0.50	1.00	17.7	Silt	PARI
	45	147.6	0.640	0.377	14	0.49	1.00	9.5	Silt	PARI
	46	150.9	0.635	0.374	18	0.49	1.00	12.0	Sandy gravel	PARI
	47	154.2	0.631	0.372	48	0.48	1.00	31.7	Sandy gravel	PARI
	48	157.5	0.626	0.370	38	0.48	1.00	24.9	Sandy gravel	PARI
	49	160.8	0.621	0.367	17	0.47	1.00	11.0	Sandy gravel	PARI
	50	164.0	0.617	0.365	21	0.47	1.00	13.5	Sandy gravel	PARI
	51	167.3	0.612	0.362	34	0.47	1.00	21.6	Sandy gravel	PARI
	52	170.6	0.608	0.360	43	0.46	1.00	27.1	Sand	PARI
	53	173.9	0.603	0.357	50	0.46	1.00	31.2	Sand	PARI
	54	177.2	0.598	0.355	50	0.45	1.00	30.9	Sand	PARI
	55	180.4	0.594	0.353	50	0.45	1.00	30.7	Sand	PARI
	56	183.7	0.589	0.350	50	0.44	1.00	30.4	Sand	PARI
	57	187.0	0.585	0.348	50	0.44	1.00	30.1	Sand	PARI
	58	190.3	0.580	0.345	50	0.44	1.00	29.9	Sand	PARI
	59	193.6	0.576	0.342	50	0.43	1.00	29.6	Sand	PARI
	60	196.9	0.571	0.340	47	0.43	1.00	27.6	Sand	PARI
	61	200.1	0.566	0.337	40	0.43	1.00	23.3	Sand	PARI
	62	203.4	0.562	0.335	45	0.42	1.00	26.0	Sand	PARI
	63	206.7	0.557	0.332	50	0.42	1.00	28.7	Sand	PARI
	64	210.0	0.553	0.330	50	0.42	1.00	28.5	Sand	PARI
	65	213.3	0.548	0.327	50	0.41	1.00	28.3	Sand	PARI
	66	216.5	0.543	0.325	50	0.41	1.00	28.1	Sand	PARI
	67	219.8	0.539	0.322	50	0.41	1.00	27.9	Sand	PARI
	68	223.1	0.534	0.319	50	0.40	1.00	27.7	Sand	PARI
	69	226.4	0.530	0.317	50	0.40	1.00	27.5	Sand	PARI
	70	229.7	0.525	0.314	50	0.40	1.00	27.3	Sand	PARI
	71	232.9	0.520	0.311	50	0.40	1.00	27.1	Sand	PARI
	72	236.2	0.516	0.309	50	0.39	1.00	26.9	Sand	PARI
	73	239.5	0.511	0.306	50	0.39	1.00	26.7	Sand	PARI
	74	242.8	0.507	0.304	50	0.39	1.00	26.6	Sand	PARI
	75	246.1	0.502	0.301	50	0.39	1.00	26.4	Sand	PARI
	76	249.3	0.497	0.298	50	0.38	1.00	26.2	Sand	PARI
							Mean:	28.0		
							St. Dev.	1.9		

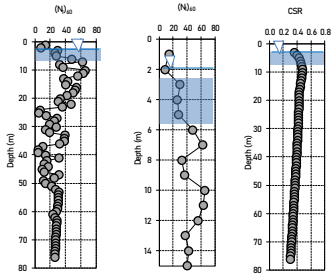
Cetin (2000) selected this layer. Greenfield (2017) selected dcrt as 2.3 m

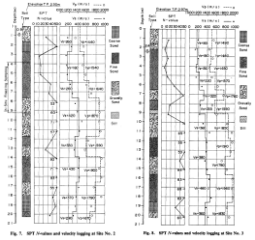
After 1993 Kushiro oki the site is liquefied and it was noted as "Liquefaction of the backfill sand of quay walls; displacements of quay walls." by Iai et al. (1994). Hence the above backfill sand kept as critical layer. The PI of this silt layer is unknown. CSR is decreased at deeper layers

B-2

Depth	Fines
1.15	16.4
2.15	4.2
2.15	4.5
3.15	5.1
3.15	55.6
4.15	15.6
5.15	7.1
6.15	10.5
6.15	6.2
7.15	10.2
Mean:	15.5
St. Dev.	18.4







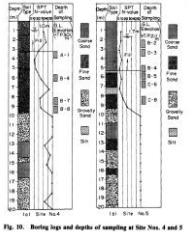


Fig. 10. Boring logs and depths of sampling at Site Nos. 4 and 5

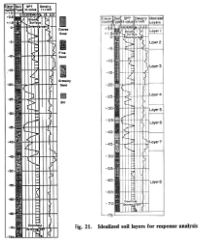


Fig. 21. Idealized soil layers for response analysis

Site no 1

Case number:	346
Earthquake:	2006 Kiholo Bay Earthquake
Magnitude:	6.7
Location:	Kawaihae Harbor_Pier-1
References:	Mahoney et al. (2008), Brandes et al. (2017), FEMA Report (2008)
Nature of Failure:	Extensive liquefaction occurred in the dredged fill
GPS LAT	20.037625
GPS LONG	-155.830069
Liq. layer consist of:	Sand and Gravel (SP-SM-GP-GM)
Geological Unit:	Dense Fill
Site Response Anlaysis:	No
Comments:	Brandes et al. (2007) "On October 15th, 2006, two earthquakes with magnitudes of Mw6.7 and Mw6.0 struck in close succession just off the Northwest coast of the Island of Hawai. ... Some of the worst damage occurred in Kawaihae Harbor, located only 24 km from the epicenter. Extensive liquefaction occurred in the dredged fill and in the natural calcareous deposits nearby, leading to lateral spreading and shifting of the pier-supported dock No.1." USGS shake map contours suggest amax in the range of 0.2-0.5 g hence 0.35 g is used. No information regarding hammer type. Hence it is assumed that a saftey hammer is used considering the other liquefaction sites in USA. An average value of 66% is assigned as hammer efficiency.





Gravel Content (%):	25-75
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.2 - 11.0
d_{crt} (m)	-	-	-	-	6.6
GWT (m)	-	-	-	-	2.2 ± 0.9
γ_{moist} (kN/m^3)	-	-	-	-	20.0 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	21.5 ± 0.5
σ_v (kPa)	-	-	-	-	139.2 ± 31.7
σ_v' (kPa)	-	-	-	-	96.0 ± 18.9
a_{max} (g)	-	-	-	-	0.400 ± 0.080
r_d	-	-	-	-	0.99 ± 0.089
CSR	-	-	-	-	0.375 ± 0.090
M_w	-	-	-	-	6.70
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	5-26.0 ± 5.0
% PI	-	-	-	-	0
N	-	-	-	-	20.8 ± 9.0
C_R	-	-	-	-	0.95
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.10
C_N	-	-	-	-	1.03
$(N_1)_{60}$	-	-	-	-	22.3 ± 9.7
V_{s30m} (m/s)	-	-	-	-	NA
V_{s12m} (m/s)	-	-	-	-	274.3

EVENT PARAMETERS

2006 Kiholo Bay Earthquake

Magnitude: 6.70

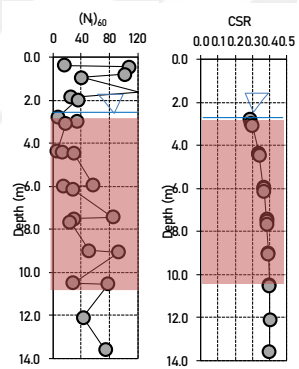
Fault Type: Normal Fault | Z_{tor} (km): 30?? | R_{rup} (km): 32??

Dip: 45-67 | Width (km): 20 | R_{jb} (km): 11.5

ACCELERATION TIME HISTORY

https://earthquake.usgs.gov/earthquakes/eventpage/hv5532127/executive#shakemap





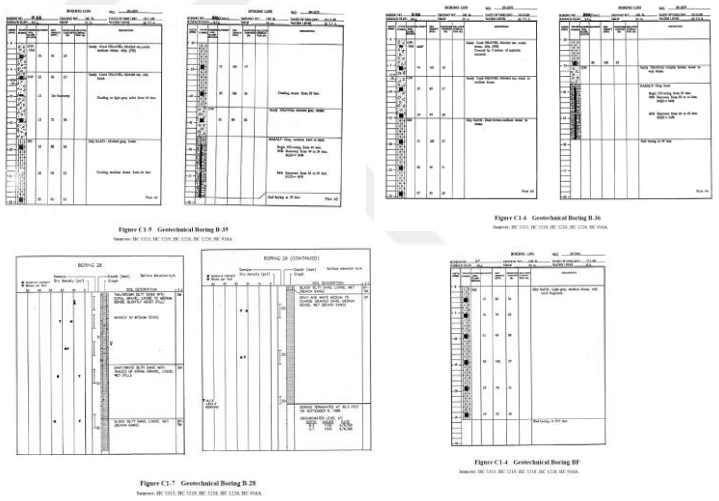


Figure C1-5 Geotechnical Boring B-35

Figure C1-6 Geotechnical Boring B-36

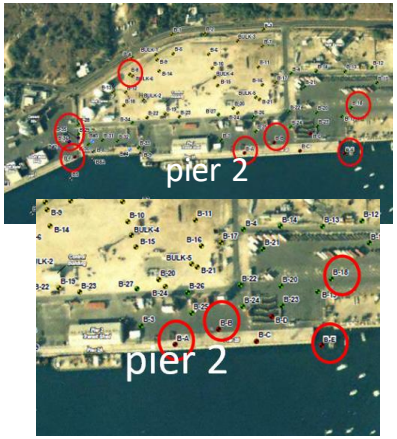
Figure C1-7 Geotechnical Boring B-28

Figure C1-4 Geotechnical Boring BF

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	Total Unit weight (pcf)	USCS
B-28	0.4	1.2	NA	9	2.00	0.81	16.1	115	SM-GM
B-36	0.5	1.5	NA	60	2.00	0.82	107.9	135	GP-SP
B-35	0.8	2.6	NA	56	2.00	0.83	102.2	135	GP-SP
B-28	0.9	3.1	NA	22	2.00	0.83	40.4	121	SM-GM
B-36	1.6	5.4	NA	74	1.76	0.86	122.5	135	GP-SP
B-28	***1.9***	***6.1***	***NA***	***16***	***1.65***	***0.86***	***25.1***	***115***	***SM-GM***
B-35	***2.0***	***6.5***	***NA***	***23***	***1.60***	***0.87***	***35.1***	***125***	***GP-SP***
B-28	***2.8***	***9.1***	***0.287***	***5***	***1.41***	***0.89***	***6.9***	***89***	***SM-GM***
B-36	***3.0***	***9.7***	***0.295***	***25***	***1.38***	***0.89***	***33.9***	***124***	***GP-SP***
B-35	***3.1***	***10.1***	***0.300***	***13***	***1.36***	***0.89***	***17.4***	***112***	***GP-SP***
B-28	***4.4***	***14.3***	***0.338***	***5***	***1.21***	***0.92***	***6.1***	***89***	***SM-GM***
B-35	***4.4***	***14.4***	***0.338***	***11***	***1.21***	***0.92***	***13.4***	***109***	***GP-SP***
B-36	***4.5***	***14.6***	***0.340***	***24***	***1.20***	***0.92***	***29.1***	***122***	***GP-SP***
B-36	5.9	19.5	0.366	51	1.07	0.94	56.7	137	SM-GM
B-35	***6.0***	***19.7***	***0.367***	***13***	***1.07***	***0.94***	***14.4***	***112***	***SM-GM***
B-28	***6.2***	***20.2***	***0.369***	***26***	***1.06***	***0.94***	***28.6***	***126***	***GP-SP***
B-36	7.4	24.4	0.383	82	0.98	0.96	84.6	135	SM-GM
B-35	***7.5***	***24.6***	***0.383***	***28***	***0.98***	***0.96***	***28.8***	***127***	***SM-GM***
B-28	***7.7***	***25.1***	***0.385***	***23***	***0.97***	***0.96***	***23.5***	***122***	***GP-SP***
B-35	9.0	29.5	0.394	53	0.91	0.97	51.1	138	SM-GM
B-36	9.1	29.7	0.394	97	0.90	0.97	93.3	135	SM-GM
B-35	***10.5***	***34.4***	***0.400***	***31***	***0.85***	***0.98***	***28.2***	***127***	***SM-GM***
B-36	10.5	34.6	0.400	86	0.85	0.98	78.1	135	SM-GM
B-35	12.1	39.7	0.403	50	0.80	0.98	43.0	135	SM-GM
B-35	13.6	44.6	0.401	91	0.76	0.99	74.7	135	GP-SP
						Mean:	**22.3**		
						St. Dev.	**9.7**		

GWT (ft)	B-28		
5.7	9/6/1988	11:30	
8.3	9/6/1988	15:15	
GWT (ft)	B-35		
7.7	10/11/1989		
GWT (ft)	B-35		
7.5	10/11/1989		

Case number:	347
Earthquake:	2006 Kiholo Bay Earthquake
Magnitude:	6.7
Location:	Kawaihae Harbor_Pier-2
References:	Mahoney et al. (2008), Brandes et al. (2017), FEMA Report (2008)
Nature of Failure:	Extensive liquefaction occurred in the dredged fill
GPS LAT	20.035094
GPS LONG	-155.827789
Liq. layer consist of:	Silty Sand (SM)
Geological Unit:	Fill
Site Response Anlaysis:	No
Comments:	Brandes et al. (2007) "On October 15th, 2006, two earthquakes with magnitudes of Mw6.7 and Mw6.0 struck in close succession just off the Northwest coast of the Island of Hawai. ... Some of the worst damage occurred in Kawaihae Harbor, located only 24 km from the epicenter. Extensive liquefaction occurred in the dredged fill and in the natural calcareous deposits nearby, leading to lateral spreading and shifting of the pier-supported dock No.1." USGS shake map contours suggest amax in the range of 0.2-0.5 g hence 0.35 g is adapted. No information regarding hammer type. Hence it is assumed that a saftey hammer is used considering the other liquefaction sites in USA. An average value of 66% is assigned as hammer efficiency.



Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.5 - 5.0
d_{crt} (m)	-	-	-	-	3.8
GWT (m)	-	-	-	-	2.2 ± 0.5
γ_{moist} (kN/m^3)	-	-	-	-	20.0 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	76.0 ± 8.7
σ_v' (kPa)	-	-	-	-	60.6 ± 6.5
a_{max} (g)	-	-	-	-	0.350 ± 0.070
r_d	-	-	-	-	1.00 ± 0.055
CSR	-	-	-	-	0.284 ± 0.064
M_w	-	-	-	-	6.70
D_{50}	-	-	-	-	NAV
% Fines	-	-	-	-	31.0 ± 10.0
% PI	-	-	-	-	0
N	-	-	-	-	17.3 ± 2.7
C_R	-	-	-	-	0.91
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.10
C_N	-	-	-	-	1.30
$(N_1)_{60}$	-	-	-	-	22.3 ± 3.5
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	248.6

EVENT PARAMETERS

2006 Kiholo Bay Earthquake

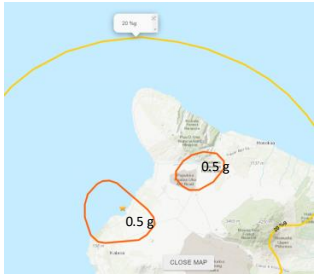
Magnitude: 6.70

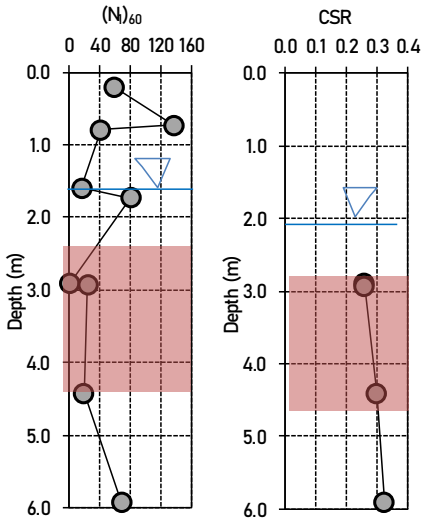
Fault Type: Normal Fault | Z_{tor} (km): 30?? | R_{rup} (km): 32??

Dip: 45-67 | Width (km): 20 | R_{jb} (km): 11.4

ACCELERATION TIME HISTORY

https://earthquake.usgs.gov/earthquakes/eventpage/hv5532127/executive#shakemap





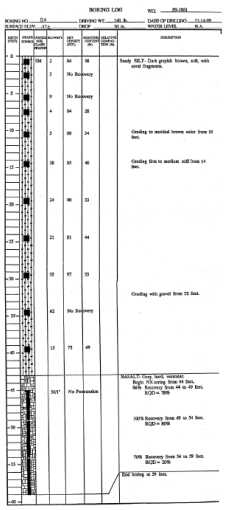


Figure C1-1 Geotechnical Boring BA

Sources: HC 5313; HC 5219; HC 5218; HC 1226; HC 916A.

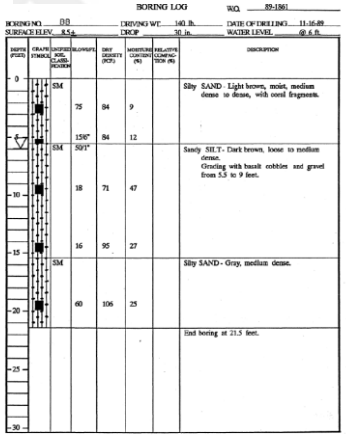


Figure C1-2 Geotechnical Boring BB

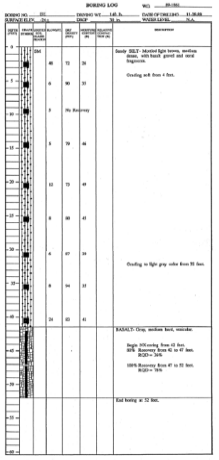


Figure C1-3 Geotechnical Boring BE

Sources: HC 5313; HC 5219; HC 5218; HC 1226; HC 916A.

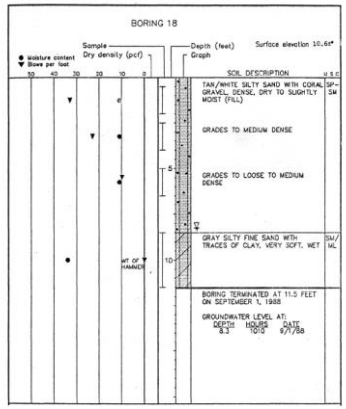


Figure C1-9 Geotechnical Boring B-18

Sources: HC 5313; HC 5219; HC 5218; HC 1226; HC 916A.

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	Total Unit weight (pcf)	USCS		
B-18	0.2	0.76	NA	33	2.00	0.81	58.6		SP-SM	above GWT	
BB	0.7	2.4	NA	75	2.00	0.83	136.5		SM	above GWT	
B-18	0.8	2.7	NA	23	2.00	0.83	42.0		SP-SM	above GWT	
B-18	1.6	5.4	NA	10	1.76	0.86	16.5		SP-SM	above GWT	
BB	1.7	5.7	NA	50	1.71	0.86	80.8		SM (Basalt cobble?)	above GWT	
B-18	2.9	9.6	0.259	1	1.40	0.89	1.4		SM-ML (trace of clay)	wt of hammer	
BB	***2.9***	***9.6***	***0.259***	***18***	***1.40***	***0.89***	***24.7***		***SM***		
BB	***4.4***	***14.5***	***0.299***	***16***	***1.22***	***0.92***	***19.8***		***SM***		
BB	5.9	19.4	0.323	60	1.10	0.94	68.3		SM		
						Mean:	**22.3**				
						St. Dev.	**3.5**				

	GWT (ft)
B18	8.3
BB	6.00

Case number:	365
Earthquake:	2007 Chuetsu-oki Earthquake
Magnitude:	6.8
Location:	Kashiwazaki, Niigata Prefecture, NIG018
References:	Kayen et al (2007), Greenfield (2017, 2018), Yoshida et al (2007), K-net, NGL Project
GPS LAT	37.3724
GPS LONG	138.5579
Liq. layer consist of:	Sand
Geological Unit:	sand dunes of the U River that run parallel to the coast
Site Response Anlaysis:	No
Nature of Failure:	Liquefaction modified ground motions. No surface manifestation
Comments:	"Liquefaction modified ground motions." Greenfield (2017)
	Kayen et al. (2007) performed a reconnaissance between July 20 and 24, 2007,
	which included a visit to the NIG018 recording station and the surrounding neighborhood.
	They did not observe any evidence liquefaction at the ground surface immediately surrounding NIG018
	Greenfield (2017, 2018) performed analysis to determine the time of liquefaction which in turn calculated as 19 s.
	The PGA is recorded as 0.522 and 0.681 g geometric mean of which is 0.6 g.
	This value is very high to perform deconvolution analysis (limitiation of EQL analysis)
	as a result CSR is estimated by simplified procedure. The PGA is recorded as 0.41 g and the site is liquefied.
	Based on our protocol, it is necessary to use PGApredicted that had not liquefied. PGA is taken as 0.65 g as liquefaction seems to decrease the PGA levels at the site.
	PGA is taken as 0.65 g as liquefaction seems to decrease the PGA levels at the site.
	Liquefaction occurred but no surface manifestation was observed at the site.
	FC and PI info were not available.
Gravel Content (%):	NAV
CPT available:	No
Vs available:	Yes



Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No or Yes
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	4.0 - 7.5
d_{crt} (m)	-	-	-	-	5.8
GWT (m)	-	-	-	-	4.0 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	111.7 ± 12.2
σ_v' (kPa)	-	-	-	-	94.5 ± 6.7
a_{max} (g)	-	-	-	-	0.650 ± 0.033
r_d	-	-	-	-	0.85 ± 0.079
CSR	-	-	-	-	0.424 ± 0.048
M_w	-	-	-	-	6.60
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	15.0 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	21.3 ± 3.5
C_R	-	-	-	-	0.95
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.04
$(N_1)_{60}$	-	-	-	-	28.5 ± 4.7
$V_{s,30m}$ (m/s)	-	-	-	-	188.0
$V_{s,12m}$ (m/s)	-	-	-	-	169.6

EVENT PARAMETERS

2007 Niigata Chuetsu-oki Earthquake

Magnitude: 6.60 https://earthquake.usgs.gov/earthquakes/eventpage/usp00

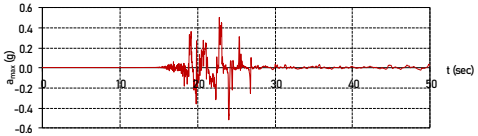
Fault Type: Reverse Fault Z_{tor} (km): 3.1 R_{rup} (km): 10.8

Dip: 33-58 Width (km): 20 R_{jb} (km): 0.0

ACCELERATION TIME HISTORY

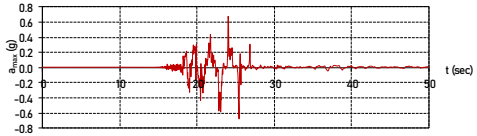
Full Record

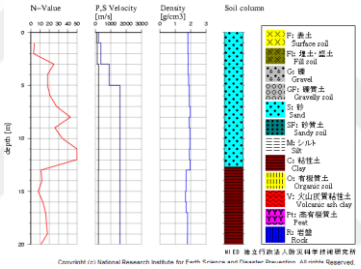
N_{H1}	6.5
N_{H2}	6.3
N_{gm}	6.4
PGA_{H1}	0.522
PGA_{H2}	0.681
PGA	0.596
M_w	6.6
$M_{w,cycle}$	1.1



Untill Liquefaction

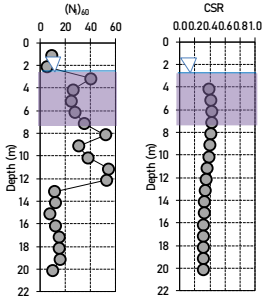
$N_{H1,L}$	0.9
$N_{H2,L}$	1.5
$N_{gm,L}$	1.2
PGA_{H1}	0.328
PGA_{H2}	0.277
PGA_L	0.301
$M_{w,eq}$	0.196
t_L	19.0





Depth (m)	Depth (m)	Soil Layer
0	12.7	Sand
12.7	20.45	Clay

Depth (m)	Vs (m/s)	Vp (m/s)	time (s)
1	80	200	0.0125
2	130	360	0.0077
3	130	360	0.0077
4	210	900	0.0048
5	210	900	0.0048
6	210	1600	0.0048
7	210	1600	0.0048
8	210	1600	0.0048
9	210	1600	0.0048
10	210	1600	0.0048
11	210	1600	0.0048
12	210	1600	0.0048
13	210	1600	
14	190	1600	
15	190	1600	
16	190	1600	
17	190	1600	
18	190	1600	
19	190	1600	
20	190	1600	
		$V_{s,12m}$ (m/s):	169.6



	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
Sand	1.15	3.8	NA	4	2.00	0.86	9.4
Sand	2.15	7.1	NA	3	1.58	0.89	5.7
Sand	3.15	10.3	NA	25	1.31	0.91	40.5
Sand	*4.15*	*13.6*	*0.393*	*18*	*1.15*	*0.92*	*26.1*
Sand	*5.15*	*16.9*	*0.417*	*18*	*1.07*	*0.94*	*24.8*
Sand	*6.15*	*20.2*	*0.426*	*21*	*1.01*	*0.95*	*27.6*
Sand	*7.15*	*23.5*	*0.424*	*28*	*0.96*	*0.96*	*35.3*
Sand	8.15	26.7	0.414	43	0.92	0.97	52.2
Sand	9.15	30.0	0.399	26	0.88	0.97	30.4
Sand	10.15	33.3	0.382	34	0.85	0.98	38.4
Sand	11.15	36.6	0.365	50	0.82	0.98	54.7
Sand	12.15	39.9	0.350	50	0.79	0.99	53.1
Clay	13.15	43.1	0.337	11	0.76	0.99	11.3
Clay	14.15	46.4	0.327	12	0.74	0.99	12.0
Clay	15.15	49.7	0.320	8	0.72	0.99	7.8
Clay	16.15	53.0	0.315	13	0.70	0.99	12.4
Clay	17.15	56.3	0.312	16	0.68	0.99	14.9
Clay	18.15	59.5	0.310	17	0.67	1.00	15.4
Clay	19.15	62.8	0.309	18	0.65	1.00	16.0
Clay	20.15	66.1	0.308	11	0.64	1.00	9.6
						Mean:	28.5
						St. Dev.	4.7

Fines content was given as 15 % by Yoshida et al. (2007) by Greenfield (2017).

Case number:	433
Earthquake:	2010 Maule Earthquake
Magnitude:	8.8
Location:	Constitución ID 15
References:	Montalva et al. (2022)
Nature of Failure:	No visible surface manifestations of liquefaction
GPS LAT	-35.335446
GPS LONG	-72.404316
Liq. layer consist of:	SP
Geological Unit:	Early Jurassic
Site Response Anlaysis:	No
Comments:	Free-field level ground SPT is located 75 m away from the site Stick-up is given as 1.5 m by Montalva et al. (2022)



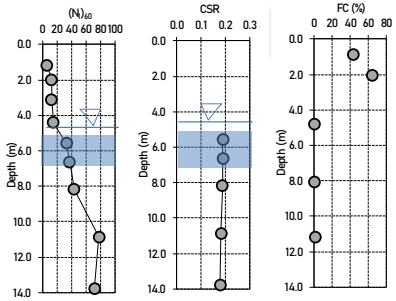
Gravel Content (%):	0.00
CPT available:	No
Vs available:	Yes

Summary of Input Data

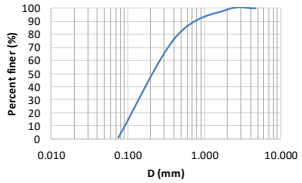
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	5.1 - 7.2
d_{crt} (m)	-	-	-	-	6.1
GWT (m)	-	-	-	-	4.6 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	21.5 ± 0.5
σ_v (kPa)	-	-	-	-	119.6 ± 8.0
σ_v' (kPa)	-	-	-	-	104.7 ± 4.8
a_{max} (g)	-	-	-	-	0.347 ± 0.069
r_d	-	-	-	-	0.74 ± 0.083
CSR	-	-	-	-	0.191 ± 0.044
M_w	-	-	-	-	8.80
D_{50}	-	-	-	-	0.200 ± 0.050
% Fines	-	-	-	-	1.0 ± 8.6
% PI	-	-	-	-	NP
N	-	-	-	-	38.0 ± 3.0
C_R	-	-	-	-	0.94
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.00
C_N	-	-	-	-	0.98
$(N_1)_{60}$	-	-	-	-	35.3 ± 2.8
V_{s30m} (m/s)	-	-	-	-	249.0
V_{s12m} (m/s)	-	-	-	-	127.1

EVENT PARAMETERS

2010 Maule Earthquake		Montalva et al. (202		epicenter	Latitude	Longitude
Magnitude:	8.80	February 27, 2010			-36.22	-73.174
Fault Type:	Subduction Inte	Z_{tor} (km):			R_{rup} (km):	38.7
Dip:		Width (km):			R_{jb} (km):	



D (mm)	M-3
4.750	100.00
2.000	99.00
0.425	78.00
0.075	1.00



	GWT (m)	CPT_ID	Latitude	Longitude
SPT	4.60	1	-35.3350	-72.4050

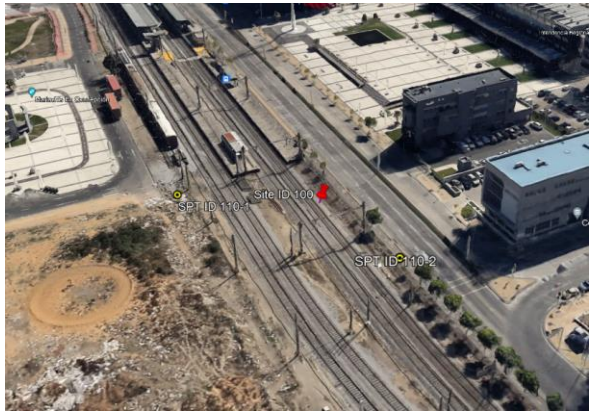
Initial Depth (m)	Final Depth (m)	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
0.85	1.53	1.2	3.9	NA	4	2.00	0.84	6.7
1.53	2.45	2.0	6.5	NA	9	1.64	0.87	12.8
2.45	3.78	3.1	10.2	NA	11	1.31	0.89	12.9
3.78	5.05	4.4	14.5	NA	15	1.10	0.92	15.2
5.05	*6.10*	*5.6*	*18.3*	*0.189*	*35*	*1.02*	*0.94*	*33.3*
6.10	*7.18*	*6.6*	*21.8*	*0.191*	*41*	*0.96*	*0.95*	*37.2*
7.18	9.21	8.2	26.9	0.188	51	0.89	0.96	43.6
9.21	12.52	10.9	35.6	0.182	100	0.80	0.98	77.9
12.52	15.07	13.8	45.2	0.179	100	0.72	0.99	71.4
15.07	17.67	16.4	53.7	0.181	100	0.67	0.99	66.7
17.67	19.36	18.5	60.7	0.183	100	0.64	1.00	63.4
19.36	21.17	20.3	66.5	0.185	100	0.61	1.00	61.0
21.17	23.05	22.1	72.5	0.186	100	0.59	1.00	58.8
23.05	24.90	24.0	78.7	0.188	100	0.57	1.00	56.7
24.90	26.69	25.8	84.6	0.190	100	0.55	1.00	54.9
26.69	28.07	27.4	89.8	0.191	100	0.54	1.00	53.5
28.07	30.05	29.1	95.3	0.192	100	0.52	1.00	52.1
							Mean:	35.3
							St. Dev.	2.8

	Gravel Content (%)	Sand Content (%)	FC (%)
Mean:	0.0	99.0	1.0
St. Dev.	5.9	assigned	8.6

Percentage Passing (%)

Sample_ID	Initial Depth (m)	Final Depth (m)	Sieve Nº4	Sieve Nº10	Sieve Nº 40	Sieve Nº 200	USCS Class.	w (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Gs	γ_{sat} (g/cm^3)
M-1	0.85	2.05	100.00	100.00	99.00	44.00	SM	22.90	-	-	NP	-	-
M-2	2.05	4.83	100.00	100.00	98.00	64.00	ML	36.60	25.00	0.00	NP	-	-
M-3	*4.83*	*8.06*	*100.00*	*99.00*	*78.00*	*1.00*	*SP*	*22.30*	*-*	*-*	*NP*	*-*	*-*
M-4	8.06	11.17	100.00	100.00	85.00	1.00	SP	16.70	-	-	NP	-	-
M-5	11.17	14.42	100.00	100.00	87.00	2.00	SP	16.20	-	-	NP	-	-
M-6	14.42	18.53	100.00	99.00	82.00	1.00	SP	18.40	-	-	NP	-	-
M-7	18.53	21.42	100.00	100.00	83.00	1.00	SP	18.10	-	-	NP	-	-
M-8	21.42	23.73	100.00	99.00	85.00	2.00	SP	17.90	-	-	NP	-	-
M-9	23.73	25.13	100.00	100.00	82.00	2.00	SP	18.50	-	-	NP	-	-
M-10	25.13	27.54	100.00	99.00	84.00	1.00	SP	18.30	-	-	NP	-	-
M-11	27.54	28.90	100.00	95.00	83.00	1.00	SP	17.90	-	-	NP	-	-
M-12	28.90	30.05	100.00	100.00	86.00	2.00	SP	18.10	-	-	NP	-	-
								22.3			NP		

Case number:	445
Earthquake:	2010 Maule Earthquake
Magnitude:	8.8
Location:	Concepción ID 100
References:	Montalva et al. (2022)
Nature of Failure:	No visible surface manifestations of liquefaction
GPS LAT	-36.831361
GPS LONG	-73.060169
Liq. layer consist of:	SM-ML
Geological Unit:	Pleistocene-Holocene
Site Response Anlaysis:	No
Comments:	Free-field level ground



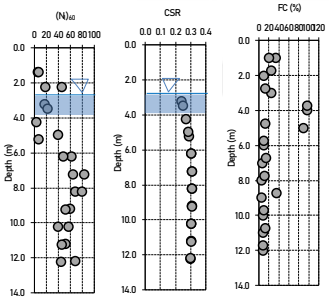
Gravel Content (%):	0.00
CPT available:	No
Vs available:	Yes

Summary of Input Data

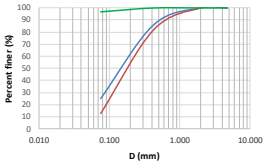
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
$d_{crt.c}$ range (m)	-	-	-	-	3.0 - 4.2
$d_{crt.}$ (m)	-	-	-	-	3.6
GWT (m)	-	-	-	-	3.0 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	64.3 ± 4.6
σ_v' (kPa)	-	-	-	-	58.0 ± 2.8
a_{max} (g)	-	-	-	-	0.360 ± 0.072
r_d	-	-	-	-	0.98 ± 0.053
CSR	-	-	-	-	0.254 ± 0.053
M_w	-	-	-	-	8.80
D_{50}	-	-	-	-	0.150 ± 0.050
% Fines	-	-	-	-	45.0 ± 45.4
% PI	-	-	-	-	5.00
N	-	-	-	-	19.9 ± 3.3
C_R	-	-	-	-	0.90
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	0.85
C_N	-	-	-	-	1.32
$(N_1)_{60}$	-	-	-	-	20.2 ± 3.4
V_{s30m} (m/s)	-	-	-	-	217.8
V_{s12m} (m/s)	-	-	-	-	192.8

EVENT PARAMETERS

2010 Maule Earthquake	Montalva et al. (20	epicenter	Latitude	Longitude
Magnitude: 8.80	February 27, 2010		-36.22	-73.174
Fault Type: Subduction Inte	Z_{tor} (km):		R_{rup} (km): 35.6	
Dip:	Width (km):		R_{jb} (km):	



D (mm)	BH-1	BH-2	BH-2
	M-3	M-3	M-4
4.750	100	100	100
2.000	100	100	100
0.425	86	82	100
0.075	25	13	97



GWT (m)		Latitude	Longitude	Hammer Energy (%)	Bar Diameter (mm)
SPT	2.9	-36.8314	-73.0606	51	110
SPT	3	-36.8316	-73.0600	51	110

Initial Depth (m)	Final Depth (m)	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
1.00	1.73	1.4	4.5	NA	4	2.00	0.85	5.8
1.73	2.73	2.2	7.3	NA	15	1.62	0.87	18.1
2.73	3.73	3.2	10.6	0.241	17	1.37	0.90	17.8
3.73	4.73	4.2	13.9	0.271	4	1.25	0.92	3.9
4.73	5.73	5.2	17.1	0.290	8	1.16	0.93	7.3
5.73	6.73	6.2	20.4	0.302	71	1.08	0.94	61.8
6.73	7.71	7.2	23.7	0.308	78	1.02	0.95	64.7
7.71	8.71	8.2	26.9	0.310	85	0.97	0.96	67.5
8.71	9.69	9.2	30.2	0.309	78	0.93	0.97	59.5
9.69	10.72	10.2	33.5	0.306	78	0.89	0.98	57.3
10.72	11.71	11.2	36.8	0.301	73	0.85	0.98	51.7
11.71	12.73	12.2	40.1	0.297	65	0.82	0.98	44.6
1.00	1.73	1.4	4.5	NA	5	2.00	0.85	7.2
1.73	2.73	2.2	7.3	NA	38	1.62	0.87	45.8
2.73	4.23	3.5	11.4	0.250	22	1.34	0.90	22.6
4.23	5.73	5.0	16.3	0.286	42	1.18	0.93	39.1
5.73	6.73	6.2	20.4	0.302	55	1.08	0.94	47.8
6.73	7.73	7.2	23.7	0.308	100	1.02	0.95	82.9
7.73	8.73	8.2	27.0	0.310	100	0.97	0.96	79.4
8.73	9.73	9.2	30.3	0.309	68	0.92	0.97	51.8
9.73	10.73	10.2	33.5	0.306	54	0.88	0.98	39.6
10.73	11.73	11.2	36.8	0.301	65	0.85	0.98	46.0
11.73	12.62	12.2	39.9	0.297	100	0.82	0.98	68.6
							Mean:	20.2
							St. Dev.	3.4

	Gravel Content (%)	Sand Content (%)	FC (%)
BH-1	0.0	66.0	34.0
BH-1	0.0	90.0	10.0
BH-1	0.0	75.0	25.0
BH-1	0.0	3.0	97.0
BH-1	0.0	11.0	89.0
BH-1	0.0	90.0	10.0
BH-1	0.0	93.0	7.0
BH-1	0.0	94.0	6.0
BH-1	0.0	95.0	5.0
BH-1	0.0	91.0	9.0
BH-1	0.0	91.0	9.0
BH-1	0.0	91.0	9.0
BH-2	3.0	77.0	20.0
BH-2	0.0	75.0	25.0
BH-2	0.0	87.0	13.0
BH-2	0.0	3.0	97.0
BH-2	0.0	87.0	13.0
BH-2	0.0	90.0	10.0
BH-2	0.0	86.0	14.0
BH-2	0.0	89.0	11.0
BH-2	0.0	65.0	35.0
BH-2	0.0	90.0	10.0
BH-2	0.0	87.0	13.0
BH-2	0.0	91.0	9.0
Mean:	0.0	55.0	45.0
St. Dev.	5.9	45.4	45.4

Sample_ID
M-1
M-2
M-3
M-4
M-5
M-6
M-7
M-8
M-9
M-10
M-11
M-12
M-1
M-2
M-3
M-4
M-5
M-6
M-7
M-8
M-9
M-10
M-11
M-12

Percentage Passing (%)

	Initial Depth (m)	Final Depth (m)	Sieve Nº4	Sieve Nº10	Sieve Nº 40	Sieve Nº 200	USCS Class.
BH-1	1.00	1.45	100	92	63	34	SM
BH-1	2.00	2.45	100	100	68	10	SP-SM
BH-1	3.00	3.45	100	100	86	25	SM
BH-1	4.00	4.45	100	100	99	97	ML
BH-1	5.00	5.45	100	100	98	89	ML
BH-1	6.00	6.45	100	100	53	10	SW-SM
BH-1	7.00	7.42	100	99	57	7	SP-SM
BH-1	8.00	8.42	100	97	44	6	SP-SM
BH-1	9.00	9.37	100	97	40	5	SP-SM
BH-1	10.00	10.43	100	92	82	9	SW-SM
BH-1	11.00	11.41	100	99	61	9	SP-SM
BH-1	12.00	12.45	100	96	42	9	SW-SM
BH-2	1.00	1.73	97	88	44	20	SM
BH-2	1.73	2.73	100	100	79	25	SM
BH-2	2.73	3.73	100	100	82	13	SM
BH-2	3.73	4.75	100	100	100	97	ML
BH-2	4.75	5.73	100	100	81	13	SM
BH-2	5.73	6.73	100	100	60	10	SP-SM
BH-2	6.73	7.73	100	100	76	14	SM
BH-2	7.73	8.73	100	100	56	11	SW-SM
BH-2	8.73	9.73	100	100	84	35	SM
BH-2	9.73	10.73	100	99	72	10	SP-SM
BH-2	10.73	11.73	100	100	86	13	SM
BH-2	11.73	12.62	100	99	61	9	SP-SM

	w (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Gs	γ_{sat} (g/cm³)	wc/LL	
BH-1	18.10	34.00	0.00	NP	2.37	1.96		
BH-1	17.00	-	-	NP	2.60	2.11		
BH-1	23.30	-	-	NP	2.61	2.00		
BH-1	58.70	39.00	29.00	10.00	2.29	1.55	1.51	not susceptible
BH-1	61.90	31.00	26.00	5.00	2.47	1.58	2.00	not susceptible
BH-1	21.70	-	-	NP	2.70	2.07		
BH-1	23.60	-	-	NP	2.72	2.05		
BH-1	21.80	-	-	NP	2.69	2.07		
BH-1	21.30	-	-	NP	2.70	2.08		
BH-1	20.70	-	-	NP	2.60	2.04		
BH-1	23.00	-	-	NP	2.70	2.05		
BH-1	19.00	-	-	NP	2.72	2.13		
BH-2	21.10	-	-	5.00	2.55	2.01		
BH-2	23.80	-	-	NP	2.67	2.02		
BH-2	22.10	-	-	NP	2.69	2.06		
BH-2	59.90	45.00	30.00	15.00	2.34	1.56	1.33	moderately susceptible
BH-2	22.90	-	-	NP	2.69	2.05		
BH-2	21.10	-	-	NP	2.72	2.09		
BH-2	20.20	-	-	NP	2.72	2.11		
BH-2	20.20	-	-	NP	2.70	2.10		
BH-2	22.70	-	-	NP	2.72	2.06		
BH-2	21.40	-	-	NP	2.74	2.10		
BH-2	22.60	-	-	NP	2.72	2.07		
BH-2	20.60	-	-	NP	2.73	2.11		
Mean:	35.1			5.00				
St. Dev.	21.5							

Case number:	258
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	20 Corhampton Street (VSVP 57194)
References:	McLaughlin (2017), NZGD
Nature of Failure:	None to minor
GPS LAT	-43.511608
GPS LONG	172.711428
Liq. layer consist of:	Sand
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	SPT data is retrieved from New Zealand Geotechnical database.
	The site initially studied by McLaughlin (2017). CPT and Vs are available at the site.
	amax is reported as 0.18 g by McLaughlin (2017) after 2011 Christchurch Earthquake based on the conditional distributions
	described by Green et al. (2014) and Bradley (2014). amax=0.147 g is calculated by site response analysis.
	rd=0.85 is used based on site response analysis. rd=0.95 is calculated based on Cetin and Seed (2004).
	Vs,12m is calculated based on the mesaured Vs values.
	Vs30m could not be calculated since there were not direct measurements until depth of 30 m.
	Vs data that has been used in site reponse analysis was attained from a nearby measurement considering
	the stratigraphy. Vs30m used in the 1D site reponse analysis is 249.7 m/s. GWT is retrieved from SPT.
	The standard deviation of GWT is calculated based on Vs and SPT data.
	FC<5 and PI=0 are assigned based on the SP classification from USCS.
	Hammer energy is assigned as 82% for PQDT/Auto SPT.



After McLaughlin (2017)

Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	A
d_{cr1c} range (m)	-	-	-	-	2.5 - 7.0
d_{cr1} (m)	-	-	-	-	4.7
GWT (m)	-	-	-	-	1.9 ± 0.5
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	88.2 ± 15.9
σ_v' (kPa)	-	-	-	-	60.4 ± 8.8
a_{max} (g)	-	-	-	-	0.180 ± 0.027
r_d	-	-	-	-	0.85 ± 0.033
CSR	-	-	-	-	0.145 ± 0.026
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	10.9 ± 4.2
C_R	-	-	-	-	0.92
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.30
$(N_1)_{60}$	-	-	-	-	17.8 ± 6.8
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	189.8

EVENT PARAMETERS

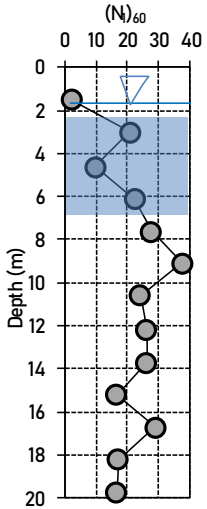
2010 Darfield Earthquake

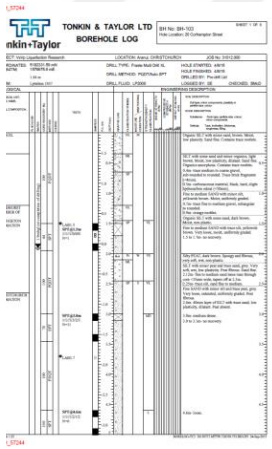
Magnitude: 7.10

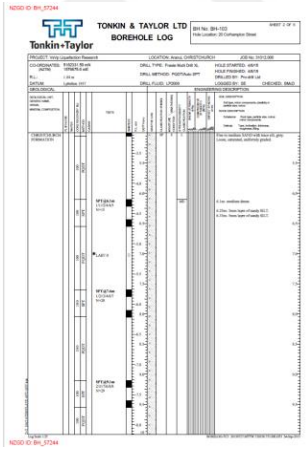
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 21.7

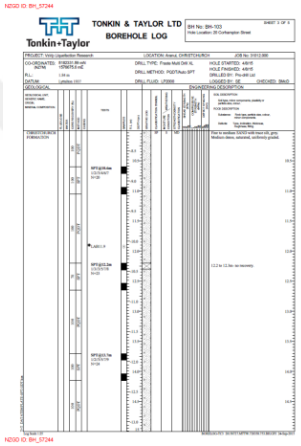
Dip: 82 | Width (km): 10 | R_{jb} (km): 21.7

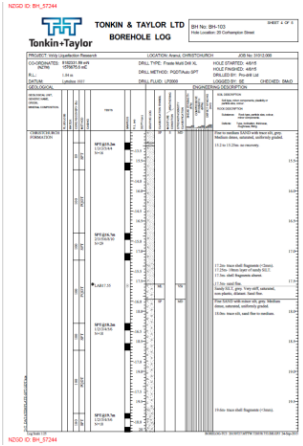
ACCELERATION TIME HISTORY











	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
SP	1.5	4.9		1	2.00	0.85	2.3	above GWT - outlier
SP	***3***	***9.8***		***11***	***1.56***	***0.89***	***20.9***	
SP	***4.6***	***15.1***		***6***	***1.31***	***0.92***	***9.9***	
SP	***6.1***	***20.0***		***15***	***1.16***	***0.94***	***22.5***	
SP	*7.6*	*24.9*	Site Response is performed	*20*	*1.05*	*0.96*	*27.6*	
SP	*9.1*	*29.9*		*29*	*0.97*	*0.97*	*37.3*	
SP	*10.6*	*34.8*		*20*	*0.91*	*0.98*	*24.2*	
SP	*12.2*	*40.0*		*23*	*0.85*	*0.98*	*26.2*	
SP	*13.7*	*44.9*		*24*	*0.80*	*0.99*	*26.0*	
SP	*15.2*	*49.9*		*16*	*0.76*	*0.99*	*16.6*	
SP	*16.7*	*54.8*		*29*	*0.73*	*0.99*	*28.8*	
SP	*18.2*	*59.7*		*18*	*0.70*	*1.00*	*17.2*	
SP	*19.7*	*64.6*		*18*	*0.68*	*1.00*	*16.6*	
						Mean:	17.8	
						St. Dev.	6.8	

GWT (m)	
by Vs	2.79
by Vs	2.86
SPT	1.90

Case number:	259
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1 Beyzaei (2017), NZGD, NGL Project, Original reference
Location:	EQC-4 - Avondale EQC-4 (Silty Soils Project and Ground Improvement Trials).
References:	Beyzaei et al. (2020), Beyzaei et al. (2018 a, b), and Bradley, B.A. and Hughes, M. (2012a and b),
Nature of Failure:	Moderate-to-severe liquefaction manifestations, including lateral spread and ejecta, were observed at EQC-4 following both the Darfield and Christchurch earthquakes.
GPS LAT	-43.5014
GPS LONG	172.6857
Liq. layer consist of:	Fine SAND with minor silt, grey, loose. (SP)
Geological Unit:	Alluvium
Site Response Anlaysis:	No
Comments:	The site is located 80 m away from the Avon River The site consists of silt sand layer followed by clean sands. The upper silty sand contain organic material. Clean sand specimens were tested with cyclic testing by Beyzaei (2017). amax is calculated as 0.18 g by conditional distribution of PGA (Bradley and Hughes, 2012a and b). Vs12m is calculated based on the correlation between SPTN and Vs The regional groundwater maps were updated over time by cross-correlating water level records from piezometers installed before and after the Canterbury earthquake sequence. As more post-event data (including seasonal fluctuations) were obtained, the groundwater models were refined. A backward extrapolation was done to estimate the groundwater levels immediately prior to the earthquake events (groundwater maps developed/updated by Tonkin + Taylor). GWT is taken as 1.88 m based on personel communication with Dr. Beyzaei"
Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes





Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crit} range (m)	-	-	-	-	2.0 - 8.0
d_{crt} (m)	-	-	-	-	5.0
GWT (m)	-	-	-	-	1.9 ± 0.3
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	94.0 ± 20.7
σ_v' (kPa)	-	-	-	-	63.3 ± 11.0
a_{max} (g)	-	-	-	-	0.180 ± 0.036
r_d	-	-	-	-	0.97 ± 0.070
CSR	-	-	-	-	0.169 ± 0.037
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	0.200 ± 0.050
% Fines	-	-	-	-	7.1 ± 6.9
% PI	-	-	-	-	0
N	-	-	-	-	12.1 ± 1.6
C_R	-	-	-	-	0.93
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.27
$(N_1)_{60}$	-	-	-	-	19.4 ± 2.5
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	213.4

EVENT PARAMETERS

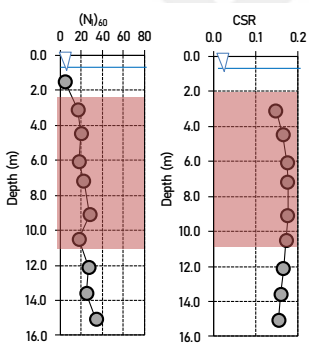
2010 Darfield Earthquake

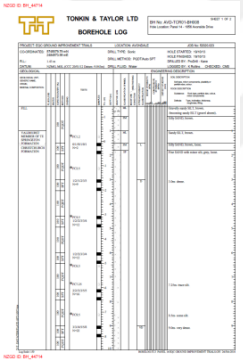
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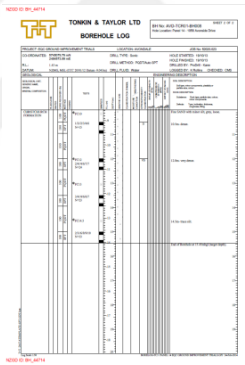
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 19.9

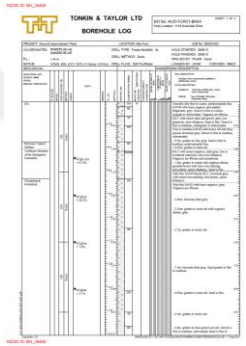
Dip: 82 | Width (km): 10 | R_{jb} (km): 19.9

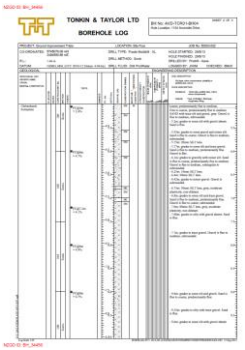
ACCELERATION TIME HISTORY

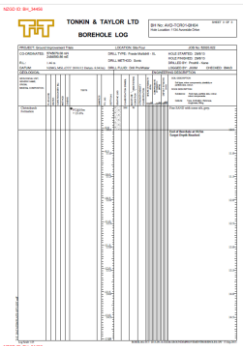












	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	NZGD ID: BH_44714 PQDT/Auto SPT	
ML	1.50	4.92	NA	2	2.00	0.85	4.7	Sandy SILT, brown.	
SP	***3.10***	***10.17***	***0.15***	***9***	***1.54***	***0.89***	***16.9***	***Fine SAND with minor silt, grey, loose***	
SP	***4.50***	***14.76***	***0.17***	***12***	***1.32***	***0.92***	***20.0***	***Fine SAND with minor silt, grey, loose.***	
SP	***6.10***	***20.01***	***0.17***	***12***	***1.16***	***0.94***	***18.0***	***Fine SAND with minor silt, grey, loose.***	
SP	***7.20***	***23.62***	***0.18***	***16***	***1.08***	***0.95***	***22.5***	***Fine SAND with minor silt, grey, loose.***	
SP	9.10	29.86	0.18	22	0.97	0.97	28.3	**Fine SAND with minor silt, grey, loose.**	outlier
SP	10.50	34.45	0.17	15	0.91	0.98	18.2	**Fine SAND with minor silt, grey, loose.**	
SP	12.10	39.70	0.17	24	0.85	0.98	27.5	**Fine SAND with minor silt, grey, loose.**	
SP	13.60	44.62	0.16	23	0.81	0.99	25.0	**Fine SAND with minor silt, grey, loose.**	
SP	15.10	49.54	0.16	33	0.77	0.99	34.3	**Fine SAND with minor silt, grey, loose.**	
						Mean:	19.4		
						St. Dev.	2.5		

BH21495 is located at the same location with CPT which is detailly studied by Beyzaei et al. and it indicates to organic material in the upper silty laye
That borehole did not have SPT measurements. NZGD ID: BH_44714
BH_34456 indicates some organic materail in the upper silt layers although 34456 is closer to CPT location
a few meters away 44714 was taken into account as that borehole did not indicate organic material similar with CPT.

The GWT information is retrieved from NGL Database

GWT (m)	Date
1.3	5/20/2013
0.9	9/19/2013
0.9	11/21/2013
1.4	1/10/2014
0.7	3/22/2014
0.3	4/23/2014
0.6	5/20/2014
0.8	7/28/2014
1.5	8/25/2014
1.0	12/10/2014
1.0	1/20/2015
1.1	2/17/2015
0.9	3/17/2015
0.8	4/16/2015
0.9	5/21/2015
0.9	6/18/2015
0.9	7/17/2015
1.0	8/25/2015
1.0	9/26/2015
1.0	10/29/2015
Mean:	0.9
St. Dev.	0.3

Case number:	260
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	Site 14-Barrington
References:	Beyzaei et al. (2020), Beyzaei et al. (2018 a, b), Beyzaei (2017), NZGD, NGL,
Nature of Failure:	No surface manifestations observed. Bradley and Hughes (2012a and b), original reference "Site 14" (Silty S
GPS LAT	-43.554
GPS LONG	172.61773
Liq. layer consist of:	Sand (SP-SW)
Geological Unit:	Alluvium
Site Response Anlaysis:	No
Comments:	amax=0.23 g is calculated based on conditional distribution of PGA (Bradley and Hughes, 2012a and b)
	Vs12m is caluclated based the correlation VS-SPTN
	The regional groundwater maps were updated over time by cross-correlating water level records from piezometers installed before and after the Canterbury earthquake sequence. As more post-event data (including seasonal fluctuations) were obtained, the groundwater models were refined. A backward extrapolation was done to estimate the groundwater levels immediately prior to the earthquake events (groundwater maps developed/updated by Tonkin + Taylor). GWT is taken as 0.10 m based on personel communication with Dr. Beyzaei" Hammer energy is given as 87%.
Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes



Summary of Input Data					
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crt} range (m)	-	-	-	-	2.5 - 5.5
d_{crt} (m)	-	-	-	-	4.0
GWT (m)	-	-	-	-	0.1 ± 0.2
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	75.4 ± 9.6
σ_v' (kPa)	-	-	-	-	37.1 ± 5.1
a_{max} (g)	-	-	-	-	0.230 ± 0.046
r_d	-	-	-	-	1.00 ± 0.058
CSR	-	-	-	-	0.303 ± 0.065
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	0.100 ± 0.050
% Fines	-	-	-	-	30.0 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	8.2 ± 2.0
C_R	-	-	-	-	0.91
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.45
C_N	-	-	-	-	1.65
$(N_1)_{60}$	-	-	-	-	17.8 ± 4.3
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	253.0

EVENT PARAMETERS

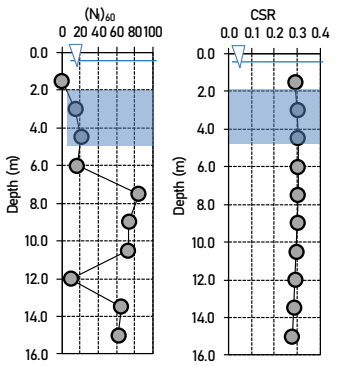
2010 Darfield Earthquake

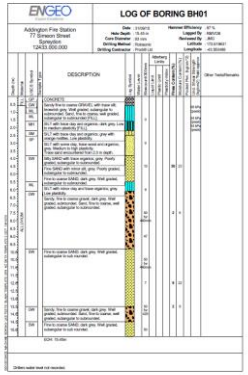
Magnitude: 7.10

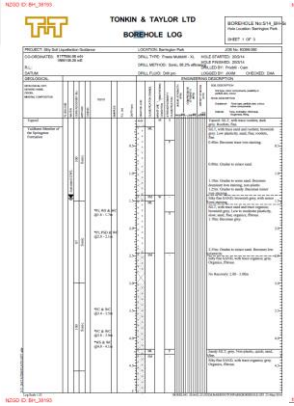
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 13.6

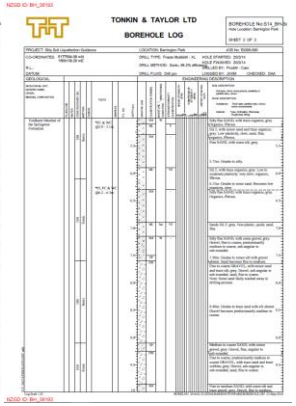
Dip: 82 | Width (km): 10 | R_{jb} (km): 13.6

ACCELERATION TIME HISTORY









Personel coomunication with Dr. Beyzaei

	Event Specific GWT (m)	
	Sept. 2010	Feb. 2011
Gainsborough	0.57	1.36
Barrington	0.10	0.10
Caulfield	0.10	0.10
Riccarton	0.59	0.59
Clarence	0.7	0.7
Cashmere	0.76	0.90
EQC-3	1.92	1.85
EQC-4	1.88	1.88
EQC-6	1.58	1.53

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	NZGD ID: BH_57630
ML	1.50	4.92	0.292	0	2.00	0.85	0.0		SILT with trace clay and organics; dark grey. Low to medium plasticity [FILL].
SP	***3.00***	***9.84***	***0.301***	***6***	***1.90***	***0.89***	***14.8***		***Fine SAND with minor silt; grey. Poorly graded, subangular to subrounded.Trace sand encountered from 2.0 m depth.***
SW	***4.50***	***14.76***	***0.303***	***10***	***1.56***	***0.92***	***20.8***	***30.0***	***Fine to coarse SAND; dark grey. Well graded, subangular to subrounded***
ML	6.00	19.69	0.304	9	1.36	0.94	16.7		SILT with minor clay and trace organics; grey. Low plasticity
GW	7.50	24.61	0.303	50	1.21	0.96	84.3	2.0	Sandy, fine to coarse gravel; dark grey. Well graded, subrounded. Sand, fine to coarse, well graded, subangular to subrounded.
GW	9.00	29.53	0.301	47	1.11	0.97	73.3		Sandy, fine to coarse gravel; dark grey. Well graded, subrounded. Sand, fine to coarse, well graded, subangular to subrounded.
SW	10.50	34.45	0.297	50	1.03	0.98	72.8		Fine to coarse SAND; dark grey. Well graded, subangular to sub rounded.
SW	12.00	39.37	0.291	7	0.96	0.98	9.6	9.0	Fine to coarse SAND; dark grey. Well graded, subangular to sub rounded.
GW	13.50	44.29	0.284	50	0.91	0.99	65.0	2.0	Sandy, fine to coarse gravel; dark grey. Well graded, subrounded. Sand, fine to coarse, well graded, subangular to subrounded.
SW	15.00	49.21	0.277	50	0.86	0.99	61.9		Fine to coarse SAND; dark grey. Well graded, subangular to sub rounded.
						Mean:	17.8	30.0	
						St. Dev.	4.3	8.6	assigned

*the given hammer efficiency is considered as the mean of the asymptotic values at depths >10 m hence short rod correction was applied.
If energy measurement were provided at depths no short rod correction would be applied.

Case number:	261
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	Normans Road/Papanui Road (VSVP 57200)
References:	McLaughlin (2017), NZGD
Nature of Failure:	None to minor
GPS LAT	-43.506153
GPS LONG	172.615603
Liq. layer consist of:	Sand (SP)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. Acceleration value 0.21 g is used which is based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Hammer energy is assigned as 82% for PQDT/Auto SPT. Vs values were available up to 6 m. Vs12m is calculated based on SPT-N values. GWT is 3.2 m by SPT. FC<5 and PI=0 are assigned based on the SP and GW classification from USCS. Sand in the gravel matrix liquefiable





After McLaughlin (2017)

Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crt_c} range (m)	-	-	-	-	4.4 - 8.0
d_{crt} (m)	-	-	-	-	6.2
GWT (m)	-	-	-	-	2.7 ± 0.4
γ_{moist} (kN/m^3)	-	-	-	-	18.9
γ_{sat} (kN/m^3)	-	-	-	-	20.6
σ_v (kPa)	-	-	-	-	123.3 ± 12.6
σ_v' (kPa)	-	-	-	-	88.7 ± 7.7
a_{max} (g)	-	-	-	-	0.210 ± 0.032
r_d	-	-	-	-	0.81 ± 0.042
CSR	-	-	-	-	0.153 ± 0.026
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	8.6 ± 0.2
C_R	-	-	-	-	0.94
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.07
$(N_1)_{60}$	-	-	-	-	11.8 ± 0.3
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	198.1

EVENT PARAMETERS

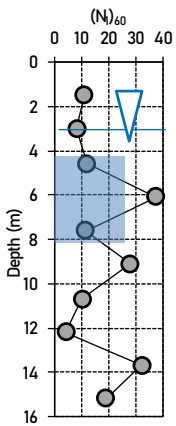
2010 Darfield Earthquake

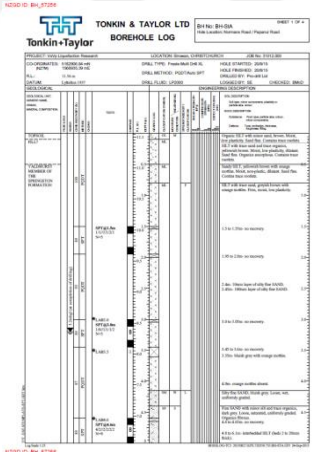
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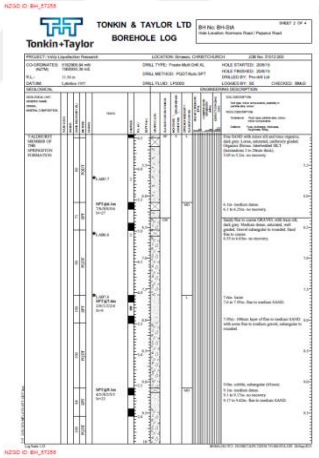
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 14.3

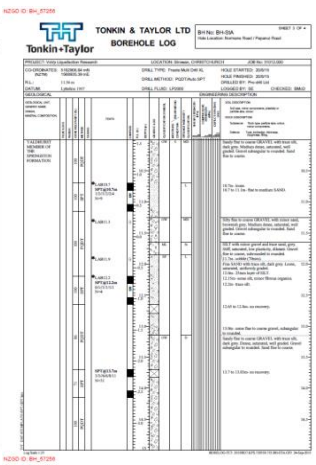
Dip: 82 | Width (km): 10 | R_{jb} (km): 14.3

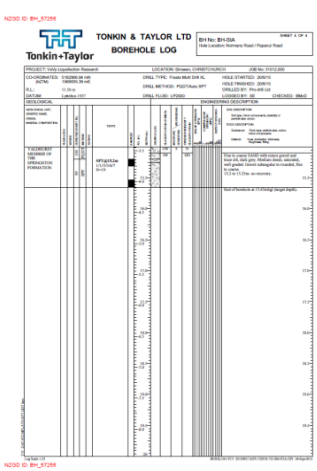
ACCELERATION TIME HISTORY











	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		
ML	1.5	4.9		5	1.89	0.85	11.0	CPT suggests plastic material	
ML	3	9.8		5	1.37	0.89	8.4	CPT suggests plastic material	
SP (organic trace_interbedded SILT ?)	**4.6**	**15.1**		**8**	**1.19**	**0.92**	**12.0**	CPT did not confirm organic traces	
SP	6.1	20.0		27	1.08	0.94	37.5	immeadiately before Gravel excluded	
GW?	***7.6***	***24.9***	Site	***9***	***0.99***	***0.96***	***11.7***	fine to medium sand	
GW	9.1	29.9	Response	23	0.92	0.97	28.0	excluded	
Sand band	10.7	35.1		9	0.86	0.98	10.3	fine to medium sand	CPT indicates plastic material
SP (fibrous organics)	12.2	40.0		4	0.81	0.98	4.4	some silt	CPT indicates plastic material
GW	13.7	44.9		31	0.77	0.99	32.4		
SW	15.2	49.9		19	0.74	0.99	19.0		
						Mean:	11.8		
						St. Dev.	0.3	assigned	

GWT	
Vs	2.81 m
Vs	2.86 m
SPT	3.2 m
CPT	2 m
Mean:	2.68 m

Case number:	262
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	EQC-6 - Bexley NGL, Original reference EQC-4 (Silty Soils Project and Ground Improvement Trials).
References:	Beyzaei et al. (2020), Beyzaei et al. (2018 a, b), and Bradley, B.A. and Hughes, M. (2012a and b), Beyzaei 2017, NZGD.
Nature of Failure:	Minor-to-moderate liquefaction manifestations.
GPS LAT:	-43.5102
GPS LONG:	172.7215
Liq. layer consist of:	Sand and silt
Geological Unit:	Alluvium
Site Response Anlaysis:	No
Comments:	amax=0.18 g is calculated based on the conditional distribution of PGA (Bradley and Hughes, 2012a and b) The regional groundwater maps were updated over time by cross-correlating water level records from piezometers installed before and after the Canterbury earthquake sequence. As more post-event data (including seasonal fluctuations) were obtained, the groundwater models were refined. A backward extrapolation was done to estimate the groundwater levels immediately prior to the earthquake events (groundwater maps developed/updated by Tonkin + Taylor). GWT is taken as 1.58 m based on personel communication with Dr. Beyzaei. PI is assigned as 0-7 considering sand and silt layers based on USCS. Estimated hammer energy is given as 85%. Since there is no direct energy measurements available with depth CR is applied



Free field



Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
$d_{crit.}$ range (m)	-	-	-	-	2.1 - 5.0
$d_{crt.}$ (m)	-	-	-	-	3.6
GWT (m)	-	-	-	-	1.6 ± 0.3
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	67.1 ± 9.2
σ_v' (kPa)	-	-	-	-	47.7 ± 5.4
a_{max} (g)	-	-	-	-	0.180 ± 0.036
r_d	-	-	-	-	0.99 ± 0.052
CSR	-	-	-	-	0.163 ± 0.036
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	13.0 ± 8.7
% PI	-	-	-	-	0-7
N	-	-	-	-	5.3 ± 4.7
C_R	-	-	-	-	0.90
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.42
C_N	-	-	-	-	1.46
$(N_1)_{60}$	-	-	-	-	9.8 ± 8.8
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	219.5

EVENT PARAMETERS

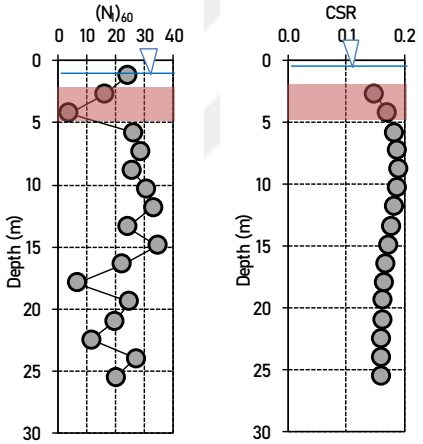
2010 Darfield Earthquake

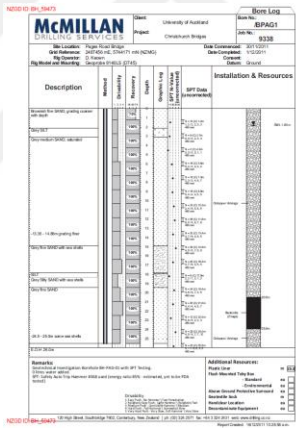
Magnitude: 7.10

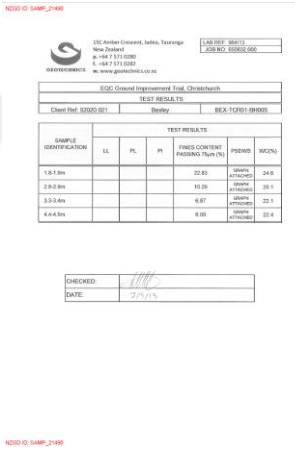
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 22.4

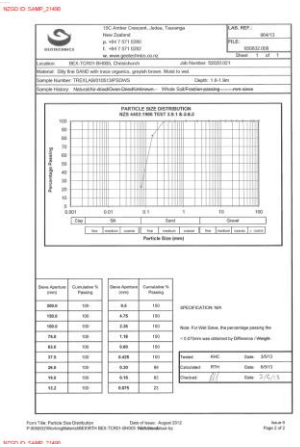
Dip: 82 | Width (km): 10 | R_{jb} (km): 22.4

ACCELERATION TIME HISTORY









	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	NZGD ID: BH_59473
CN>2	1.2	3.9	NA	10	2.00	0.84	23.9	Brownish fine SAND, grading coarser with depth
	2.7	***8.9***	***0.148***	***8***	***1.59***	***0.88***	***16.0***	***Grey SILT-Grey medium SAND; saturated***
	4.2	***13.8***	***0.171***	***2***	***1.38***	***0.92***	***3.6***	***Grey medium SAND; saturated***
	5.8	19.0	0.183	16	1.22	0.94	26.0	Grey medium SAND; saturated
	7.3	24.0	0.188	19	1.11	0.96	28.7	Grey medium SAND; saturated
	8.8	28.9	0.190	18	1.03	0.97	25.5	Grey medium SAND; saturated
	10.3	33.8	0.187	23	0.97	0.98	30.7	Grey medium SAND; saturated
	11.8	38.7	0.183	26	0.91	0.98	32.9	Grey medium SAND; saturated
	13.4	44.0	0.177	20	0.86	0.99	24.1	Grey medium SAND; saturated
	14.9	48.9	0.172	30	0.82	0.99	34.6	Grey medium SAND; saturated
	16.4	53.8	0.167	20	0.79	0.99	22.1	Grey fine SAND with sea shells
	17.9	58.7	0.164	6	0.76	0.99	6.4	Grey fine SAND with sea shells
	19.4	63.6	0.162	24	0.73	1.00	24.7	Grey fine SAND
	21	68.9	0.161	20	0.70	1.00	19.8	Grey fine SAND
	22.5	73.8	0.161	12	0.68	1.00	11.5	Grey fine SAND
	24	78.7	0.161	29	0.66	1.00	27.1	Grey fine SAND
	25.5	83.7	0.161	22	0.64	1.00	20.0	Grey fine SAND
						Mean:	9.8	
						St. Dev.	8.8	

*the given hammer efficiency is estimated as 85% for automatic trip hammer no direct measurements was available hence short rod correction was applied.
If energy measurement were provided at depths no short rod correction would be applied.

Case number:	264
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	Avondale Park (VSVP 57187)
References:	McLaughlin (2017), NZGD
Nature of Failure:	None to minor
GPS LAT:	-43.505578
GPS LONG:	172.690892
Liq. layer consist of:	Sand-Silt (SP-ML)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.18 g by McLaughlin (2017) after 2011 Christchurch Earthquake. Test results are retrieved from NGZD. Hammer energy is assigned as 82% for PQDT/Auto SPT. Vs,12m is calculated based on the mesaured Vs values. GWT is estimated based on Vs measurement Acceleration values is based on the conditional distributions described by Green et al. (2014) and Bradley (2014). 0.146 g and 0.149 g is calcuated based on site reponse analysis. FC is assigned based on the SP classification from USCS.



Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	A
d_{crit}, range (m)	-	-	-	-	1.4 - 5.0
d_{crt} (m)	-	-	-	-	3.2
GWT (m)	-	-	-	-	1.4 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	58.3 ± 11.4
σ_v' (kPa)	-	-	-	-	40.6 ± 5.7
a_{max} (g)	-	-	-	-	0.180 ± 0.027
r_d	-	-	-	-	0.93 ± 0.024
CSR	-	-	-	-	0.156 ± 0.026
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	30-70 ± 10.0
% PI	-	-	-	-	0-7
N	-	-	-	-	4.7 ± 2.6
C_R	-	-	-	-	0.90
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.58
$(N_1)_{60}$	-	-	-	-	9.1 ± 5.0
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	162.9

EVENT PARAMETERS

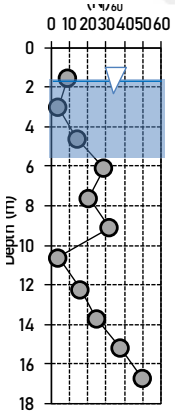
2010 Darfield Earthquake

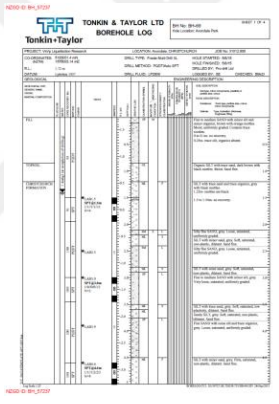
Magnitude: 7.10

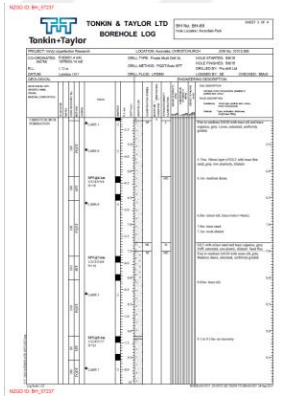
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 20.1

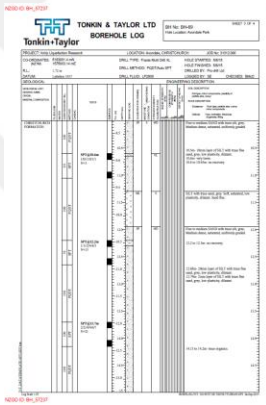
Dip: 82 | Width (km): 10 | R_{jb} (km): 20.1

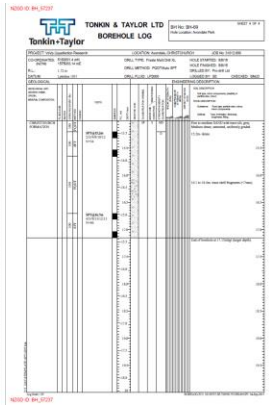
ACCELERATION TIME HISTORY











	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
ML	*1.5*	*4.9*		*4*	*2.00*	*0.85*	*9.3*	non plastic
SP	*3*	*9.8*		*2*	*1.62*	*0.89*	*3.9*	non plastic
ML	*4.6*	*15.1*		*8*	*1.38*	*0.92*	*13.9*	non plastic
SP	6.1	20.0		18	1.23	0.94	28.6	
SP	7.6	24.9	site response	14	1.12	0.96	20.6	
SP	9.1	29.9		23	1.04	0.97	31.7	
SP	10.6	34.8		3	0.97	0.98	3.9	plastic material from CPT
SP	12.2	40.0		13	0.91	0.98	15.9	
SP	13.7	44.9		21	0.86	0.99	24.5	
SP	15.2	49.9		34	0.82	0.99	38.0	
SP	16.7	54.8		46	0.79	0.99	49.3	
						Mean:	9.1	
						St. Dev.	5.0	

GWT	
by Vs	1.6 m
by Vs	1.68 m

One sand l5.1-7.35 Fine to medium SAND with trace silt and trace organics, grey. Loose, saturated, uniformly graded

the second layer undeneath 7.5-17.15 with a silt layer in it 11.30-11.95 m SILT with trace sand, grey. Soft, saturated, low plasticity, dilatant. Sand fine.

Case number:	268
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	29 Charles Street (VSVP 57196)
References:	McLaughlin (2017), NZGD
Nature of Failure:	None to minor
GPS LAT	-43.5432
GPS LONG	172.657544
Liq. layer consist of:	Sand (SP)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	No
Comments:	CPT and Vs are available at the site. amax is reported as 0.22 g by McLaughlin (2017) after 2010 Darfield Earthquake. Test results are retrieved from NGZD. Hammer energy is assigned as 82% for PQDT/Auto SPT. Vs,12m is calculated based on the mesaured Vs values. GWT is estimated based on SPT measurement amax=0.22 g is calculated based on the conditional distributions described by Green et al. (2014) and Bradley (2014). FC<5 is assigned based on the SP classification from USCS. PI is assigned as 0 for the SP layer.



After McLaughlin (2017)

Gravel Content (%):	0
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crit} range (m)	-	-	-	-	3.0 - 10.0
d_{crt} (m)	-	-	-	-	6.5
GWT (m)	-	-	-	-	1.4 ± 0.5
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	127.4 ± 24.3
σ_v' (kPa)	-	-	-	-	77.0 ± 13.0
a_{max} (g)	-	-	-	-	0.220 ± 0.044
r_d	-	-	-	-	0.78 ± 0.087
CSR	-	-	-	-	0.186 ± 0.044
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	14.2 ± 3.0
C_R	-	-	-	-	0.95
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.15
$(N_1)_{60}$	-	-	-	-	21.1 ± 4.4
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	152.4

EVENT PARAMETERS

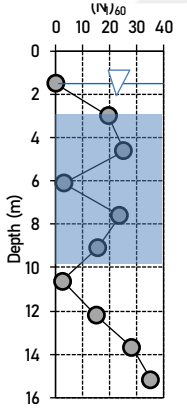
2010 Darfield Earthquake

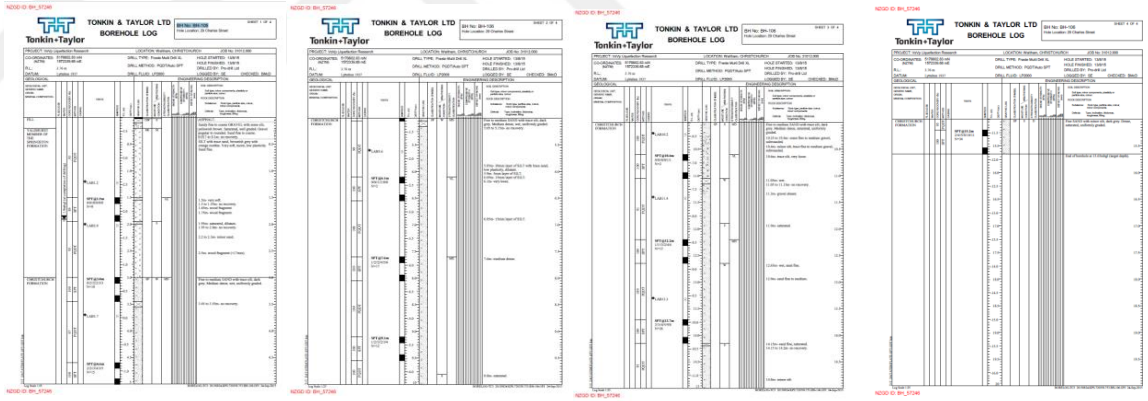
Magnitude: 7.10

Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 16.8

Dip: 82 | Width (km): 10 | R_{jb} (km): 16.8

ACCELERATION TIME HISTORY





	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
ML	1.5	4.9		0	2.00	0.85	0.0	very shallow CN>2, not saturated above GWT
SP	***3***	***9.8***		***10***	***1.61***	***0.89***	***19.6***	
SP	***4.6***	***15.1***		***15***	***1.34***	***0.92***	***25.3***	
SP	6.1	20.0		2	1.18	0.94	3.0	very thin layer of silt layer (35 cm) SPTN 0/0/1/1/0/0 qt = 7 - 8 MPa
SP	***7.6***	***24.9***	site	***17***	***1.07***	***0.96***	***23.8***	
SP	***9.1***	***29.9***	response	***12***	***0.98***	***0.97***	***15.6***	
SP	10.6	34.8		2	0.92	0.98	2.4	trace silt very thin within sand layer SPTN 0/0/1/1/0/0 qt = 2 - 3 MPa very thin layer about 4 cm according to CPT
SP	12.2	40.0		13	0.86	0.98	15.0	
SP	13.7	44.9		26	0.81	0.99	28.4	
SP	15.2	49.9		34	0.77	0.99	35.5	outlier within the layer very dense
						Mean:	21.1	
						St. Dev.	4.4	

GWT (m)	
by Vs	1.22
by Vs	1.03
SPT	1.9
CPT	1.1

Case number:	265
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	Avondale Playground
References:	McLaughlin (2017), NZGD
Nature of Failure:	None to minor
GPS LAT	-43.508503
GPS LONG	172.686906
Liq. layer consist of:	Sand (SP)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.18 g by McLaughlin (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD. Hammer energy is assigned as 82% for PQDT/Auto SPT. amax is calculated as 0.146g and 0.147 g based on site response analysis. Vs,12m is calculated based on the mesaured Vs values. GWT is estimated based on SPT FC is assigned based on the SP classification from USCS.
Gravel Content (%)	NAV
CPT available:	Yes
Vs available:	Yes



After McLaughlin (2017)

Summary of Input Data					
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crit} range (m)	-	-	-	-	2.4 - 6.0
d_{crt} (m)	-	-	-	-	4.2
GWT (m)	-	-	-	-	0.9 ± 0.7
γ_{moist} (kN/m^3)	-	-	-	-	15.7
γ_{sat} (kN/m^3)	-	-	-	-	18.9
σ_v (kPa)	-	-	-	-	76.1 ± 11.8
σ_v' (kPa)	-	-	-	-	43.9 ± 7.4
a_{max} (g)	-	-	-	-	0.180 ± 0.027
r_d	-	-	-	-	0.83 ± 0.030
CSR	-	-	-	-	0.168 ± 0.035
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	7.2 ± 2.2
C_R	-	-	-	-	0.92
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.52
$(N_1)_{60}$	-	-	-	-	13.6 ± 4.2
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	158.7

EVENT PARAMETERS

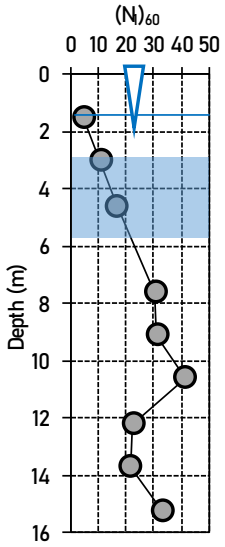
2010 Darfield Earthquake

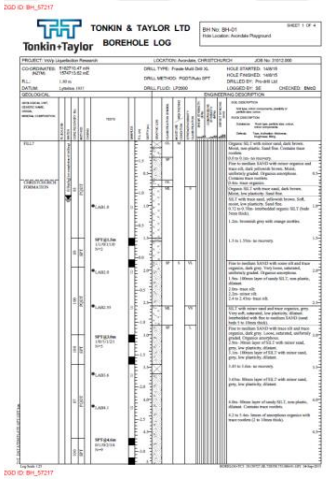
Magnitude: 7.10

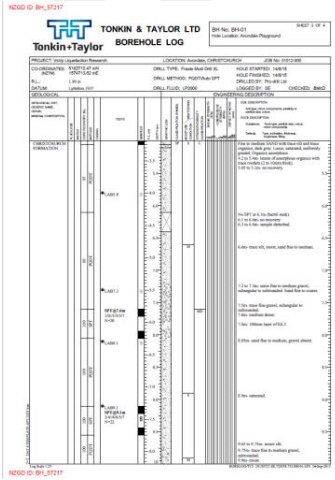
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 19.8

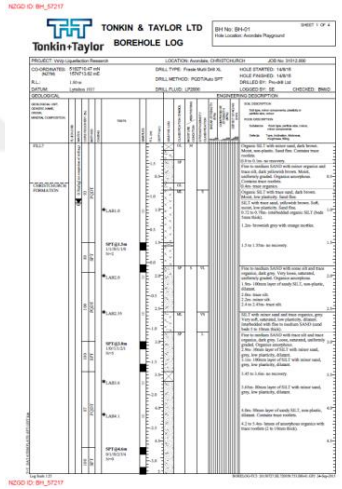
Dip: 82 | Width (km): 10 | R_{jb} (km): 19.8

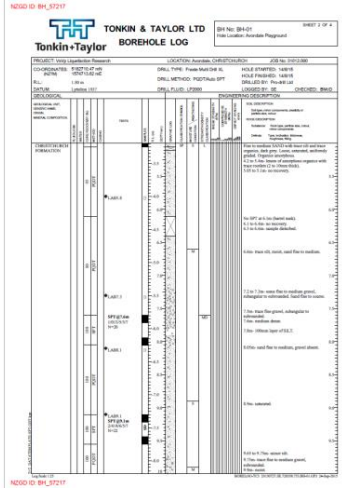
ACCELERATION TIME HISTORY











	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
ML	1.5	4.9		2	2.00	0.85	4.7	organics
SP	*3*	*9.8*		*5*	*1.75*	*0.89*	*10.7*	
SP	*4.6*	*15.1*		*9*	*1.46*	*0.92*	*16.5*	
SP	7.6	24.9	Site	20	1.16	0.96	30.5	
SP	9.1	29.9	Response	22	1.07	0.97	31.2	
SP	10.6	34.8	Analysis	31	1.00	0.98	41.3	
SP	12.2	40.0		18	0.93	0.98	22.6	
SP	13.7	44.9		18	0.88	0.99	21.5	
SP	15.2	49.9		29	0.84	0.99	33.0	
						Mean:	13.6	
						St. Dev.	4.2	

GWT	
by Vs	2.05 m
by Vs	2.14 m
SPT	0.9 m

Case number:	267
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	Carisbroke Playground (57193)
References:	McLaughlin (2017), NZGD
Nature of Failure:	None to minor
GPS LAT	-43.511014
GPS LONG	172.709708
Liq. layer consist of:	Sand (SP)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.18 g by McLaughlin (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD. Hammer energy is assigned as 80% for PQLT/Auto SPT. Vs,12m and Vs,30 m are calculated based on the mesaured Vs values. GWT is estimated based on SPT FC<5 is assigned based on the SP classification from USCS. amax is calculated as 0.133 g and 0.136 g, geometric mean of which is 0.134 g based on site response analysis. PI is assigned as 0 for the SP.



Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	3.0 - 5.0
d_{crt} (m)	-	-	-	-	4.0
GWT (m)	-	-	-	-	1.8 ± 0.6
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	76.6 ± 7.3
σ_v' (kPa)	-	-	-	-	54.9 ± 5.6
a_{max} (g)	-	-	-	-	0.180 ± 0.027
r_d	-	-	-	-	0.90 ± 0.029
CSR	-	-	-	-	0.147 ± 0.027
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	15.4 ± 1.4
C_R	-	-	-	-	0.91
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.36
$(N_1)_{60}$	-	-	-	-	26.0 ± 2.4
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	218.2

EVENT PARAMETERS

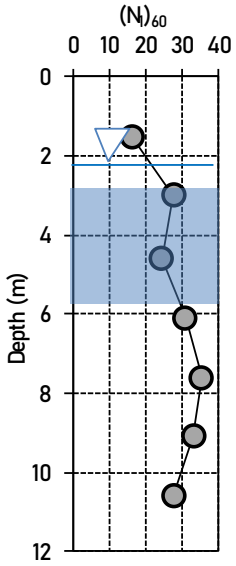
2010 Darfield Earthquake

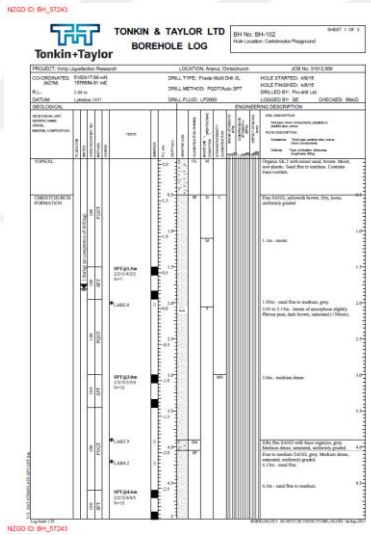
Magnitude: 7.10

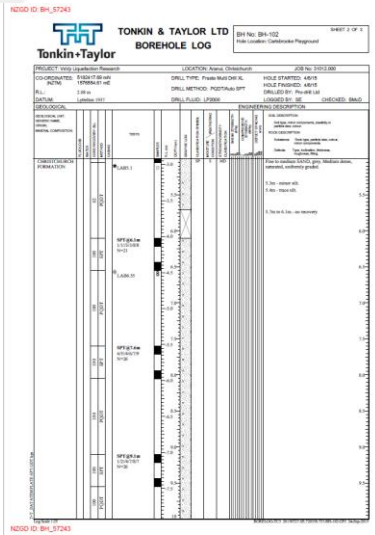
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 21.5

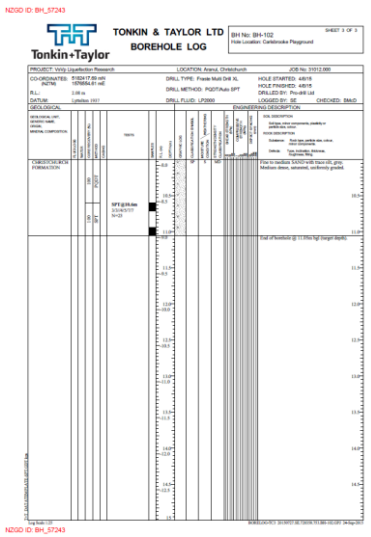
Dip: 82 | Width (km): 10 | R_{jb} (km): 21.5

ACCELERATION TIME HISTORY









	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
SP	1.5	4.9		7	1.98	0.85	16.1	surficial layer excluded
SP	**3**	**9.8**		**15**	**1.52**	**0.89**	**27.7**	
SP	***4.6***	***15.1***	Site Response	***15***	***1.29***	***0.92***	***24.3***	
SP	6.1	20.0		21	1.14	0.94	31.0	
SP	7.6	24.9		26	1.04	0.96	35.4	
SP	9.1	29.9		26	0.96	0.97	33.1	
SP	10.6	34.8		23	0.90	0.98	27.6	
						Mean:	26.0	
						St. Dev.	2.4	

GWT	
by Vs	2.91 m
by Vs	2.87 m
SPT	1.8 m

0.5-3.9 Fine SAND, yellowish brown. Dry, loose, uniformly graded.

4.05-11.05 Fine to medium SAND, grey. Medium dense, saturated, uniformly graded.

Case number:	269
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	Harrington Park (VSVP 57141)
References:	McLaughlin (2017), NZGD
Nature of Failure:	None to minor
GPS LAT	-43.5345
GPS LONG	172.590233
Liq. layer consist of:	Sand (SP)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.22 g by McLaughlin (2017) after 2011 Christchurch Earthquake. Test results are retrieved from NGZD. Hammer energy is assigned as 82% for PQDT/Auto SPT. Critical layer is selected from the CPT as 3.5-5 m and the SPT blowcount at 4.6m is assigned to that critical layer. Vs,12m and Vs30m are calculated based on the mesaured Vs values. GWT is estimated based on Vs measurement amax=0.22g is calculated based on the conditional distributions described by Green et al. (2014) and Bradley (2014). FC<5 and PI=0 are assigned based on the SP classification from USCS. amax is calculated as 0.201 g and 0.249 g goemetric mean of which is 0.224 g based on site response analysis
Gravel Content (%)	NAV
CPT available:	Yes
Vs available:	Yes



After McLaughlin (2017)

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crit} range (m)	-	-	-	-	4.4 - 6.1
d_{crt} (m)	-	-	-	-	5.2
GWT (m)	-	-	-	-	1.0 ± 0.4
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	95.1 ± 5.9
σ_v' (kPa)	-	-	-	-	53.8 ± 4.4
a_{max} (g)	-	-	-	-	0.220 ± 0.033
r_d	-	-	-	-	0.80 ± 0.036
CSR	-	-	-	-	0.201 ± 0.035
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	10.5 ± 1.1
C_R	-	-	-	-	0.93
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.37
$(N_1)_{60}$	-	-	-	-	18.3 ± 2.0
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	170.2

EVENT PARAMETERS

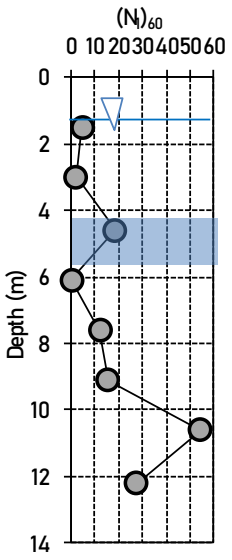
2010 Darfield Earthquake

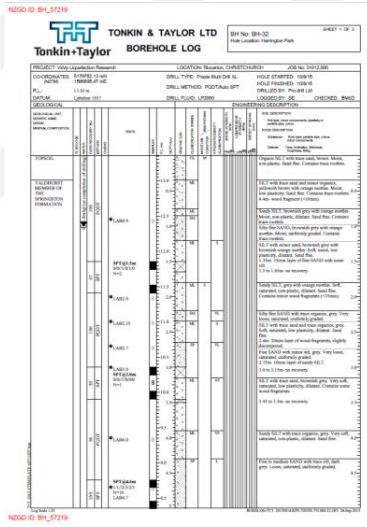
Magnitude: 7.10

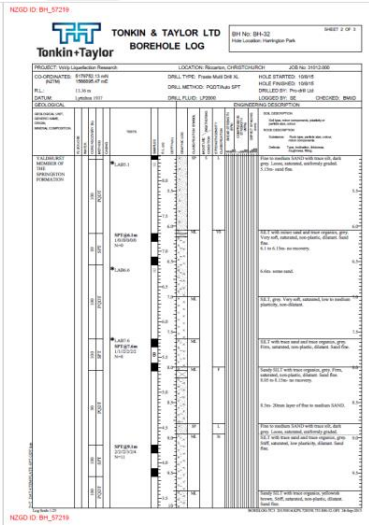
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 11.5

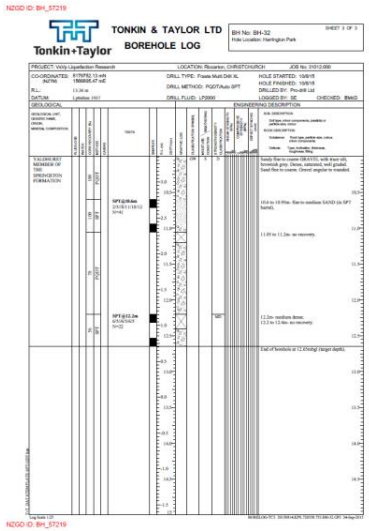
Dip: 82 | Width (km): 10 | R_{jb} (km): 11.5

ACCELERATION TIME HISTORY





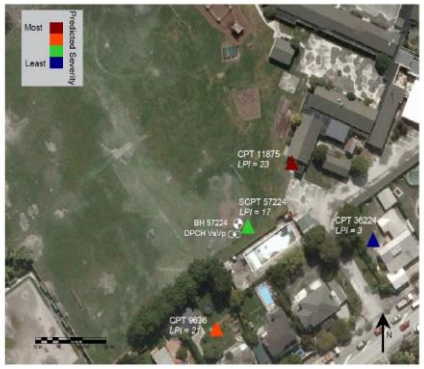




	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
ML	1.5	4.9		2	2.00	0.85	4.7	organic content
SP or ML	3	9.8		1	1.73	0.89	2.1	organic content
SP	***4.6***	***15.1***		***10***	***1.45***	***0.92***	***18.3***	single SPT suspicious but confirmed with consistent with CPT
ML	6.1	20.0	Site	0	1.28	0.94	0.0	based on CPT RF=4% plastic? saturated below 3 m based on Vp/Vs
ML	7.6	24.9	Response	8	1.16	0.96	12.1	
ML	9.1	29.9		11	1.07	0.97	15.5	
GW	10.6	34.8		41	0.99	0.98	54.4	
GW	12.2	40.0		22	0.93	0.98	27.5	
						Mean:	18.3	
						St. Dev.	2.0	

	GWT
by Vs	1.74 m
by Vs	1.78 m
SPT	1 m

Case number:	270
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	Heaton Normal Intermediate School (57181)
References:	McLaughlin (2017), NZGD
Nature of Failure:	Moderate
GPS LAT	-43.510556
GPS LONG	172.614753
Liq. layer consist of:	Sand and Silt (SP-ML)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.21 g by McLaughlin (2017) after 2011 Christchurch Earthquake. Test results are retrieved from NGZD.
	Hammer energy is assigned as 82% for PQDT/Auto SPT.
	Vs,12m is calculated based on the mesaured Vs values.
	GWT is estimated based on SPT measurement
	Acceleration values is based on the conditional distributions described by Green et al. (2014) and Bradley (2014).
	FC values for SP and ML layer are assigned as 5% and 50-60 % based on the classification from USCS.
	Lab data is asked to Tonkin and Taylor.
	Based upon available CPT logs following conclusions were made: 0-3 m clayey soil, 3-6 m sand silt mixtures (nonplastic) hence on the SPT borelog sand and silt interlayering were chosen as the suspect layer



After McLaughlin (2017)

Gravel Content (%)	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crit} range (m)	-	-	-	-	6.0 - 8.0
d_{crt} (m)	-	-	-	-	7.0
GWT (m)	-	-	-	-	1.2 ± 0.2
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	128.5 ± 6.9
σ_v' (kPa)	-	-	-	-	71.5 ± 4.4
a_{max} (g)	-	-	-	-	0.210 ± 0.032
r_d	-	-	-	-	0.74 ± 0.047
CSR	-	-	-	-	0.181 ± 0.030
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	25-55 ± 7.0
% PI	-	-	-	-	0-7
N	-	-	-	-	7.1 ± 1.8
C_R	-	-	-	-	0.95
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.19
$(N_1)_{60}$	-	-	-	-	11.0 ± 2.8
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	143.0

EVENT PARAMETERS

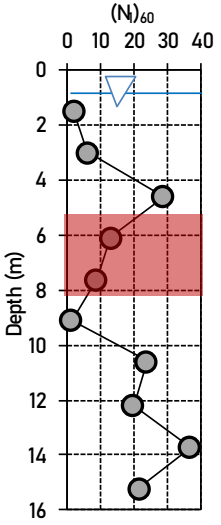
2010 Darfield Earthquake

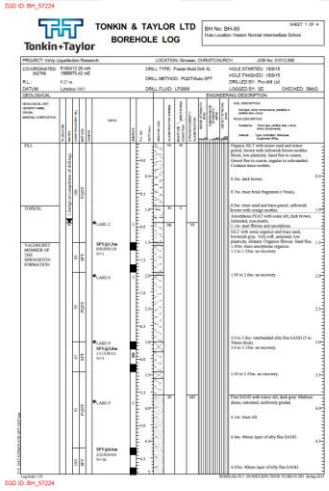
Magnitude: 7.10

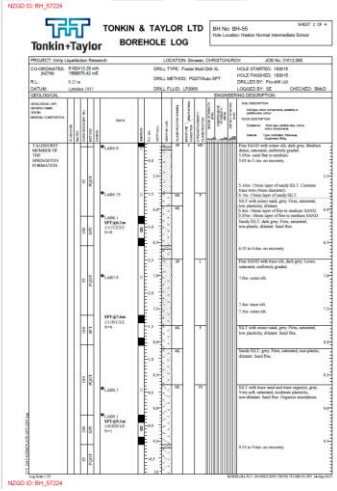
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 14.1

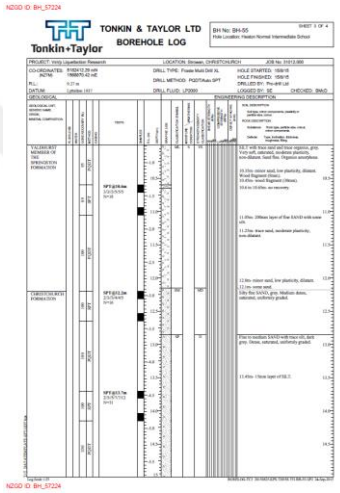
Dip: 82 | Width (km): 10 | R_{jb} (km): 14.1

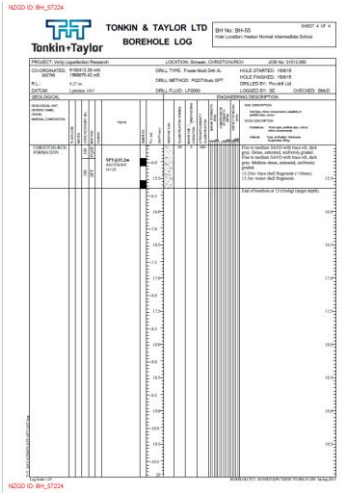
ACCELERATION TIME HISTORY











	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
ML	1.5	4.9	0.149	1	2.00	0.85	2.3	trace organic content
ML	3	9.8	0.19	3	1.70	0.89	6.2	within same layer with the above one
SP	4.6	15.1	0.192	16	1.43	0.92	28.8	
ML	***6.1***	***20.0***	***0.184***	***8***	***1.27***	***0.94***	***13.1***	non plastic
SP	***7.6***	***24.9***	***0.172***	***6***	***1.15***	***0.96***	***9.0***	
ML	9.1	29.9	0.159	1	1.06	0.97	1.4	trace organic content
ML	10.6	34.8	0.149	18	0.99	0.98	23.7	trace organic content
SM	12.2	40.0	0.141	16	0.93	0.98	19.9	
SP	13.7	44.9	0.136	31	0.88	0.99	36.7	
SP	15.2	49.9	0.133	19	0.83	0.99	21.5	
						Mean:	11.0	
						St. Dev.	2.8	

GWT	
by Vs	1.42 m
by Vs	1.63 m
SPT	1.2 m

Case number:	271
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	Hillmerton Highschool (57201)
References:	McLaughlin (2017), NZGD
Nature of Failure:	Moderate
GPS LAT	-43.556233
GPS LONG	172.593325
Liq. layer consist of:	Silt (ML)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.24 g by McLaughlin (2017) after 2011 Christchurch Earthquake. Test results are retrieved from NGZD.
	Hammer energy is assigned as 82% for PQDT/Auto SPT.
	amax is calculated as 0.179g and 0.213g geometrci mean of which is 0.195 g based on site response analysis
	Vs,12m is calculated based on the mesaured Vs values.
	GWT is estimated based on SPT measurement
	Acceleration values is based on the conditional distributions described by Green et al. (2014) and Bradley (2014).
	FC is assigned based on the SM classification from USCS.
	Lab data is asked to Tonkin and Taylor.
	PI is assigned as 0-7. Silt is nonplastic mostly according to borehole description.



After McLaughlin (2017)

Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	A
d_{crr} range (m)	-	-	-	-	3.5 - 8.5
d_{cr1} (m)	-	-	-	-	6.0
GWT (m)	-	-	-	-	1.9 ± 0.5
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	17.3 ± 0.5
σ_v (kPa)	-	-	-	-	100.9 ± 14.6
σ_v' (kPa)	-	-	-	-	60.7 ± 7.7
a_{max} (g)	-	-	-	-	0.240 ± 0.036
r_d	-	-	-	-	0.75 ± 0.041
CSR	-	-	-	-	0.195 ± 0.035
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	>50 ± 12.5
% PI	-	-	-	-	0-7
N	-	-	-	-	2.0 ± 0.1
C_R	-	-	-	-	0.94
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.29
$(N_1)_{60}$	-	-	-	-	3.3 ± 0.2
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	143.7

EVENT PARAMETERS

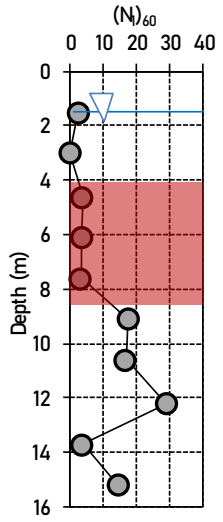
2010 Darfield Earthquake

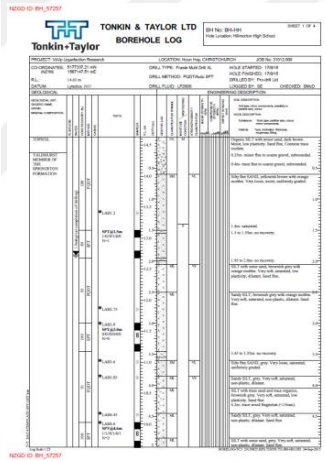
Magnitude: 7.10

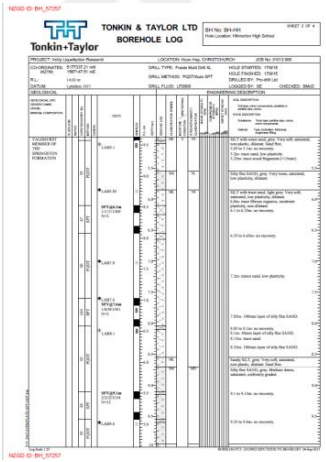
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 11.6

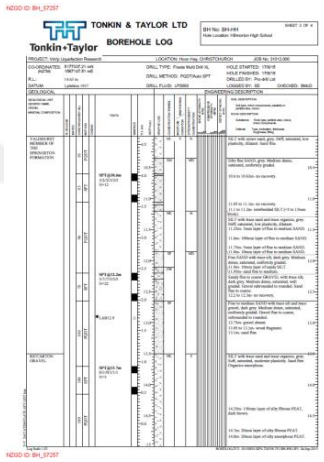
Dip: 82 | Width (km): 10 | R_{jb} (km): 11.6

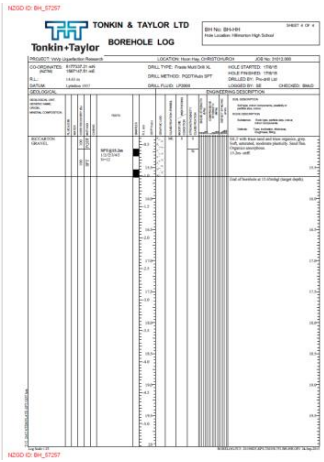
ACCELERATION TIME HISTORY











	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
SM	1.5	4.9	NA	1	2.00	0.85	2.3	above GWT
ML	3	9.8	0.182	0	1.63	0.89	0.0	excluded
ML	***4.6***	***15.1***	***0.201***	***2***	***1.42***	***0.92***	***3.6***	
ML	***6.1***	***20.0***	***0.200***	***2***	***1.29***	***0.94***	***3.3***	
ML	***7.6***	***24.9***	***0.191***	***2***	***1.18***	***0.96***	***3.1***	
SM	*9.1*	*29.9*	*0.180*	*12*	*1.10*	*0.97*	*17.5*	
SM	*10.6*	*34.8*	*0.171*	*12*	*1.03*	*0.98*	*16.6*	
GW	12.2	40.0	0.163	22	0.97	0.98	28.8	
ML	13.7	44.9	0.158	3	0.93	0.99	3.8	
ML	15.2	49.9	0.156	12	0.89	0.99	14.4	
						Mean:	3.3	
						St. Dev.	0.2	

GWT	
by VS	2.78 m
by VS	2.64 m
spt	1.9 m

Case number:	272
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	Hillsborough Park (VSVP 57202)
References:	McLaughlin (2017), NZGD
Nature of Failure:	None to minor
GPS LAT	-43.560664
GPS LONG	172.673108
Liq. layer consist of:	Sand (SP)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	No
Comments:	CPT and Vs are available at the site. amax is reported as 0.25 g by McLaughlin (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD.
	Hammer energy is assigned as 82% for PQDT/Auto SPT.
	Vs,12m is calculated based on the mesaured Vs values.
	GWT is estimated based on Vs measurement
	FC<5 is assigned based on the SP classification from USCS.
	Lab data is asked to Tonkin and Taylor.
	PI is assigned as 0. Silt is nonplastic mostly according to borehole description.





After McLaughlin (2017)

Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	3.9 - 5.0
d_{crt} (m)	-	-	-	-	4.5
GWT (m)	-	-	-	-	0.9 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	19.6 ± 0.5
σ_v (kPa)	-	-	-	-	85.5 ± 4.0
σ_v' (kPa)	-	-	-	-	50.4 ± 2.6
a_{max} (g)	-	-	-	-	0.250 ± 0.050
r_d	-	-	-	-	0.93 ± 0.063
CSR	-	-	-	-	0.256 ± 0.054
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	15.0 ± 1.1
C_R	-	-	-	-	0.92
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.42
$(N_1)_{60}$	-	-	-	-	26.7 ± 2.0
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	174.5

EVENT PARAMETERS

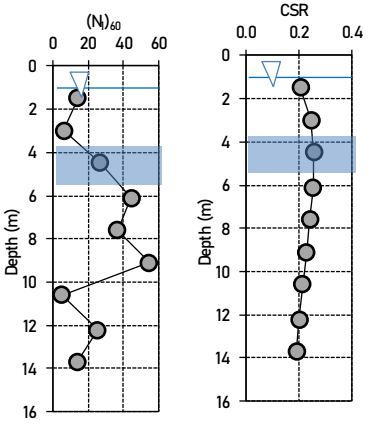
2010 Darfield Earthquake

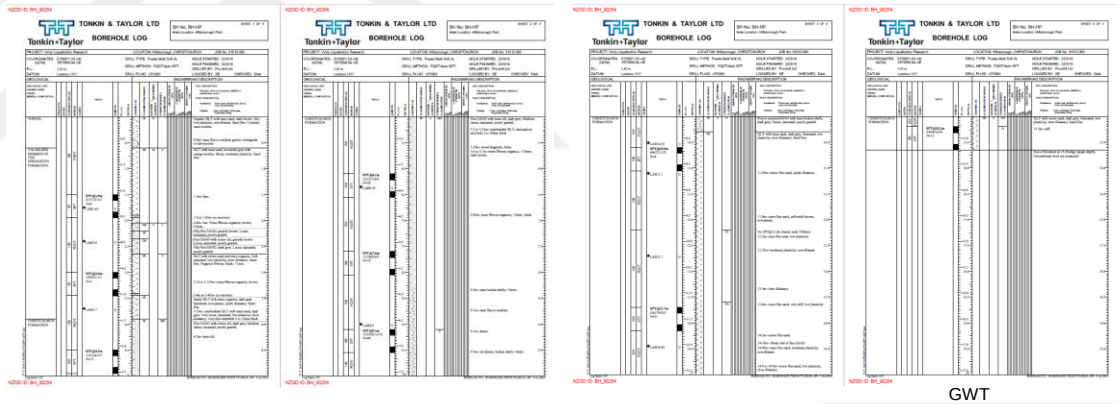
Magnitude: 7.10

Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 18.1

Dip: 82 | Width (km): 10 | R_{jb} (km): 18.1

ACCELERATION TIME HISTORY

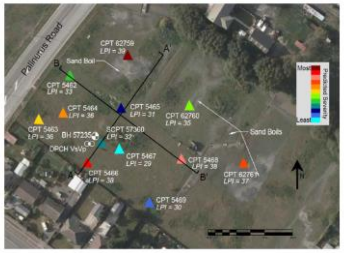




	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
OL	1.5	4.9	0.206	6	2.00	0.85	14.0	SILT with trace sand,
ML	3	9.8	0.247	3	1.68	0.89	6.1	SILT with minor sand and trace organics
SP	***4.5***	***14.8***	***0.256***	***15***	***1.41***	***0.92***	***26.7***	***Fine SAND with minor silt, dark grey. Medium dense, saturated, poorly graded.***
SP	6.1	20.0	0.253	28	1.23	0.94	44.5	Fine SAND with trace silt, dark grey. Medium dense, saturated, poorly graded. some fibrous organics
SP	7.6	24.9	0.242	25	1.12	0.96	36.6	Fine SAND with trace silt, dark grey. Medium dense, saturated, poorly graded. some fibrous organics
SP	9.1	29.9	0.228	40	1.03	0.97	54.4	Fine SAND with trace silt, dark grey. Medium dense, saturated, poorly graded. some fibrous organics
SP	***10.6***	***34.8***	***0.214***	***4***	***0.96***	***0.98***	***5.1***	***SILT with trace sand, dark grey. Saturated, low plasticity, slow dilatancy. Sand fine CPT indicates plastic material RF=4%***
SP	12.2	40.0	0.200	21	0.90	0.98	25.3	SILT with trace sand, dark grey. Saturated, low plasticity, slow dilatancy. Sand fine.
SP	13.7	44.9	0.191	12	0.85	0.99	13.7	SILT with minor sand, dark grey. Saturated, low plasticity, slow dilatancy. Sand fine.
						Mean:	26.7	
						St. Dev.	2.0	assigned

	GWT
by VS	0.89 m
by VS	0.86 m
SPT	NA m

Case number:	273
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	Palinurus Road (VSVP 57185)
References:	McLaughlin (2017), NZGD
GPS LAT	-43.551286
GPS LONG	172.688208
Liq. layer consist of:	SP
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Nature of Failure:	No liquefaction was observed at this site
Comments:	CPT and Vs are available at the site. amax is reported as 0.24 g by McLaughlin (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD. amax is calculated as 0.13g and 0.143 g geometric mean of which is 0.137g based on the site response analysis. Vs,12m is calculated based on the mesaured Vs values. GWT is estimated based on SPT measurement FC<5 is assigned based on the SPL classification from USCS.
Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes



After McLaughlin (2017)

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	1.2 - 5.0
d_{crt} (m)	-	-	-	-	3.1
GWT (m)	-	-	-	-	1.2 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	58.1 ± 13.1
σ_v' (kPa)	-	-	-	-	39.4 ± 6.9
a_{max} (g)	-	-	-	-	0.240 ± 0.036
r_d	-	-	-	-	0.91 ± 0.023
CSR	-	-	-	-	0.210 ± 0.034
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	15
N	-	-	-	-	11.2 ± 0.1
C_R	-	-	-	-	0.89
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.61
$(N_1)_{60}$	-	-	-	-	22.0 ± 0.2
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	162.8

EVENT PARAMETERS

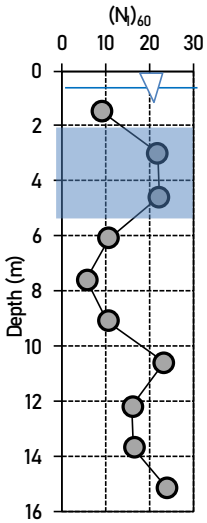
2010 Darfield Earthquake

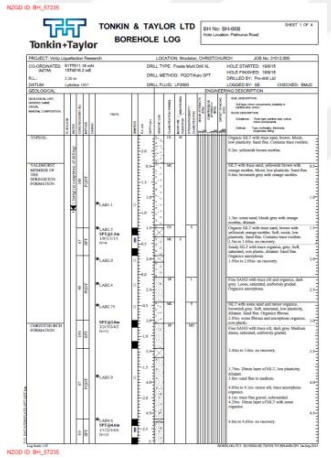
Magnitude: 7.10

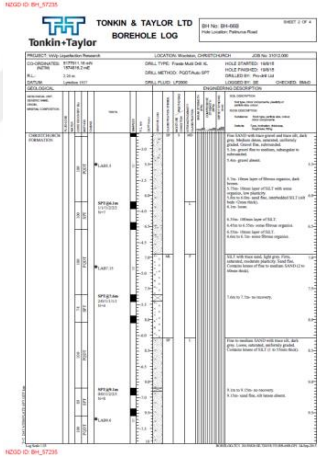
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 19.4

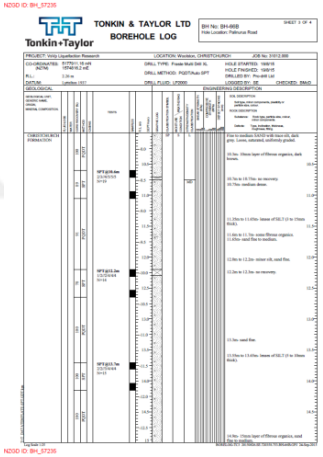
Dip: 82 | Width (km): 10 | R_{jb} (km): 19.4

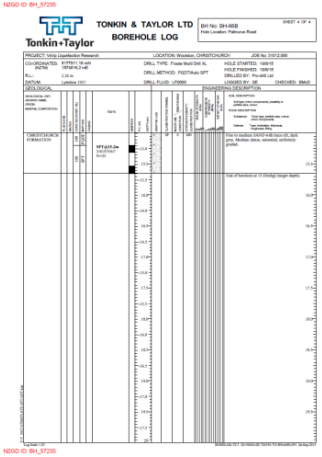
ACCELERATION TIME HISTORY











	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
-	1.5	4.9		4	2.00	0.85	9.3	organic silt up to 3 m depth
SP	***3***	***9.8***		***11***	***1.63***	***0.89***	***21.8***	
SP	***4.6***	***15.1***		***13***	***1.35***	***0.92***	***22.1***	
SP	***6.1***	***20.0***	Site Response Analysis	***7***	***1.19***	***0.94***	***10.7***	interbedded silt possibly high plastic according to CPT RF>3%
ML	***7.6***	***24.9***		***4***	***1.07***	***0.96***	***5.6***	moderate plasticity possibly high plastic according to CPT RF>3%
SP	***9.1***	***29.9***		***8***	***0.99***	***0.97***	***10.5***	contains lenses of silt possibly high plastic according to CPT RF>3%
SP	10.6	34.8		19	0.92	0.98	23.3	
SP	12.2	40.0		14	0.86	0.98	16.2	
SP	13.7	44.9		15	0.81	0.99	16.5	
SP	15.2	49.9		23	0.77	0.99	24.1	
						Mean:	22.0	
						St. Dev.	0.2	

GWT	
by Vs	1.34 m
by Vs	1.23 m
SPT	1.2 m

Case number:	274
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	Rawhiti Domain (VSVP 57188)
References:	McLaughlin (2017), NZGD
Nature of Failure:	None to Minor
GPS LAT:	-43.506536
GPS LONG:	172.720961
Liq. layer consist of:	Sand (SP)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.18 g by McLaughlin (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD. Hammer energy is assigned as 82% for PQDT/Auto SPT. Vs,12m is calculated based on the mesaured Vs values. GWT is estimated based on SPT measurement amax is calculated as 0.138 g and 0.141 g geometric mean of which is 0.140 g based on site response analysis. FC is assigned based on the SP classification from USCS.
Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes



After McLaughlin (2017)

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	A
$d_{crit.c}$ range (m)	-	-	-	-	2.5 - 11.1
d_{crit} (m)	-	-	-	-	6.8
GWT (m)	-	-	-	-	1.5 ± 0.6
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	137.2 ± 29.5
σ_v' (kPa)	-	-	-	-	85.4 ± 16.4
a_{max} (g)	-	-	-	-	0.180 ± 0.027
r_d	-	-	-	-	0.79 ± 0.045
CSR	-	-	-	-	0.148 ± 0.026
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	20.3 ± 3.5
C_R	-	-	-	-	0.95
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.09
$(N_1)_{60}$	-	-	-	-	28.7 ± 5.0
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	197.6

EVENT PARAMETERS

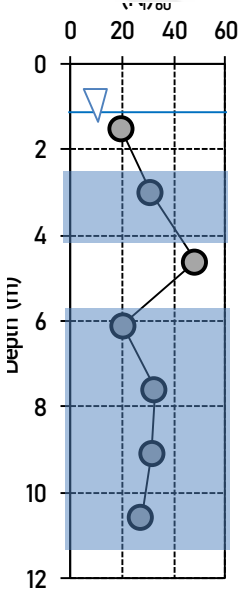
2010 Darfield Earthquake

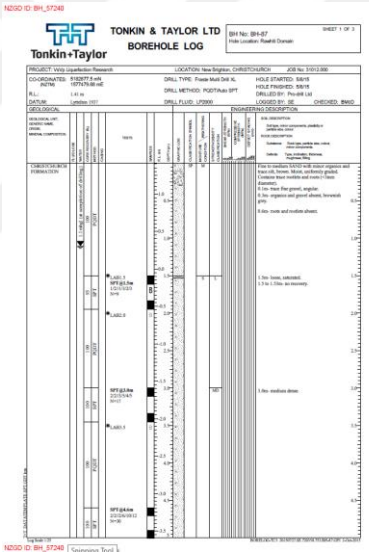
Magnitude: 7.10

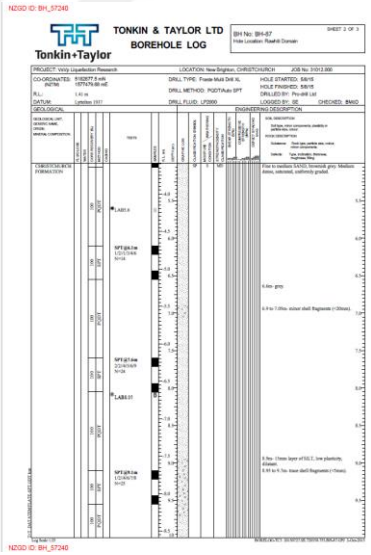
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 22.5

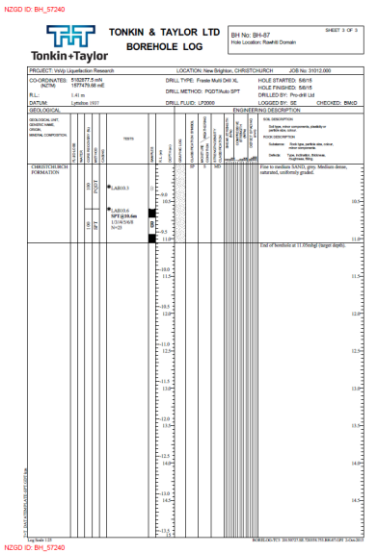
Dip: 82 | Width (km): 10 | R_{jb} (km): 22.5

ACCELERATION TIME HISTORY









	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
SP	1.5	4.9		9	1.89	0.85	19.8	surfacial CN>2.0
SP	***3***	***9.8***		***17***	***1.51***	***0.89***	***31.3***	saturated below 2.5 m according to VP/VS data
SP	4.6	15.1	***site***	30	1.28	0.92	48.4	outlier SPT-N values
SP	***6.1***	***20.0***	***response***	***14***	***1.14***	***0.94***	***20.6***	
SP	***7.6***	***24.9***	***analysis***	***24***	***1.04***	***0.96***	***32.6***	
SP	***9.1***	***29.9***		***25***	***0.96***	***0.97***	***31.8***	
SP	***10.6***	***34.8***		***23***	***0.90***	***0.98***	***27.5***	
						Mean:	28.7	
						St. Dev.	5.0	

GWT	
by Vs	1.23 m
by Vs	1.22 m
SPT	1.1 m
CPT	2.2 m
Mean:	1.51 m

Case number:	275
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	Rydal Reserve (VSVP 57190)
References:	McLaughlin (2017), NZGD
Nature of Failure:	Moderate
GPS LAT	-43.565975
GPS LONG	172.608153
Liq. layer consist of:	Sand-Silt-Gravel (ML-SP-GW)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	No
Comments:	CPT and Vs are available at the site. amax is reported as 0.24 g by McLaughlin (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD. Hammer energy is assigned as 82% for PQDT/Auto SPT. Vs,12m is calculated based on SPT-N values. Vs values were available up to 6 m. GWT is estimated based on SPT measurement FC is assigned based on the SP classification from USCS.



After McLaughlin (2017)

Gravel Content (%):	12.0-60.0
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.0 - 9.5
d_{crt} (m)	-	-	-	-	5.8
GWT (m)	-	-	-	-	1.6 ± 0.2
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	113.3 ± 25.9
σ_v' (kPa)	-	-	-	-	72.5 ± 13.7
a_{max} (g)	-	-	-	-	0.240 ± 0.048
r_d	-	-	-	-	0.98 ± 0.079
CSR	-	-	-	-	0.239 ± 0.053
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	6.0-16.0 ± 2.5
% PI	-	-	-	-	0-4
N	-	-	-	-	12.4 ± 3.3
C_R	-	-	-	-	0.94
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.18
$(N_1)_{60}$	-	-	-	-	18.8 ± 5.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	228.60

EVENT PARAMETERS

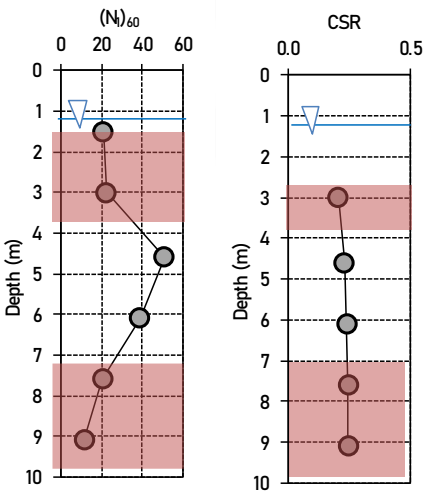
2010 Darfield Earthquake

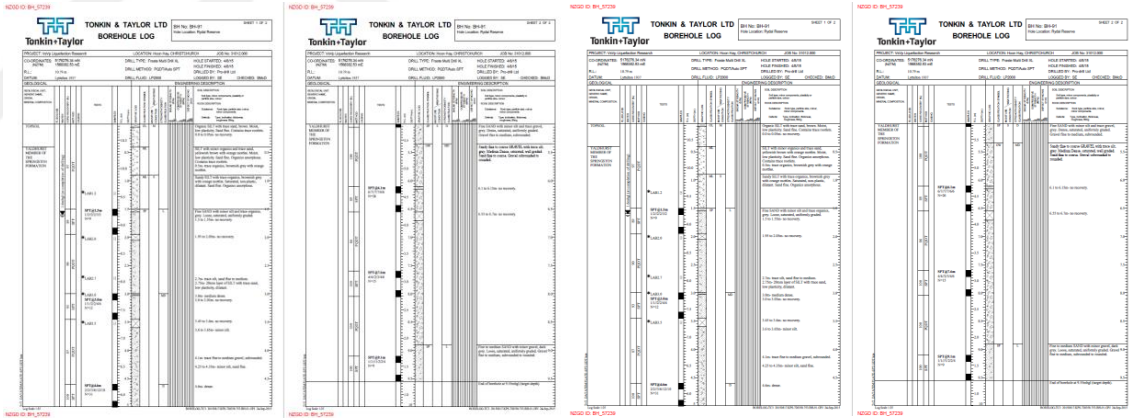
Magnitude: 7.10

Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 12.9

Dip: 82 | Width (km): 10 | R_{jb} (km): 12.9

ACCELERATION TIME HISTORY





	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
ML-SP band	*1.5*	*4.9*	*NA*	*9*	*1.98*	*0.85*	*20.7*	saturated below 2 m according to Vp/Vs
SP	*3*	*9.8*	*0.20*	*12*	*1.54*	*0.89*	*22.5*	
SP	4.6	15.1	0.229	31	1.30	0.92	50.8	outlier
GW	6.1	20.0	0.241	26	1.15	0.94	38.7	outier
GW	*7.6*	*24.9*	*0.25*	*15*	*1.05*	*0.96*	*20.6*	
SP	*9.1*	*29.9*	*0.246*	*9*	*0.97*	*0.97*	*11.5*	
						Mean:	18.8	
						St. Dev.	5.0	

	GWT
by Vs	1.72 m
by Vs	1.32 m
SPT	1.6 m

Case number:	276
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	Sabina Playground (VSVP 57192)
References:	McLaughlin (2017), NZGD
Nature of Failure:	None to minor
GPS LAT	-43.504394
GPS LONG	172.660661
Liq. layer consist of:	Sand-Gravel (SP-GW)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.18 g by McLaughlin (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD.
	Hammer energy is assigned as 82% for PQDT/Auto SPT.
	amax is calculated as 0.129 g and 0.160 g geometric mean of which is 0.143 g based on Site response analysis.
	Vs,12m is calculated based on the mesaured Vs values.
	GWT is estimated based on SPT measurement
	FC is assigned based on the SP classification from USCS.
	Lab data is asked to Tonkin and Taylor.
	Gravel Content is assigned according to USCS



After McLaughlin (2017)

Gravel Content (%):	25-75
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

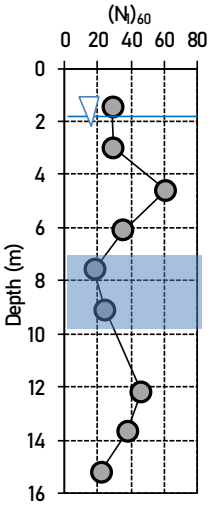
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crit} range (m)	-	-	-	-	7.0 - 9.5
d_{crt} (m)	-	-	-	-	8.3
GWT (m)	-	-	-	-	1.6 ± 0.3
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	167.4 ± 9.2
σ_v' (kPa)	-	-	-	-	102.1 ± 5.9
a_{max} (g)	-	-	-	-	0.180 ± 0.027
r_d	-	-	-	-	0.71 ± 0.054
CSR	-	-	-	-	0.137 ± 0.023
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	15.8 ± 3.5
C_R	-	-	-	-	0.96
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.00
$(N_1)_{60}$	-	-	-	-	20.8 ± 4.6
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	184.1

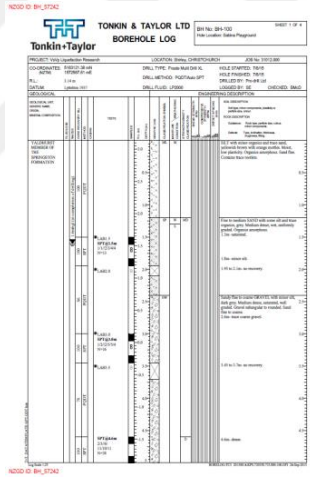
EVENT PARAMETERS

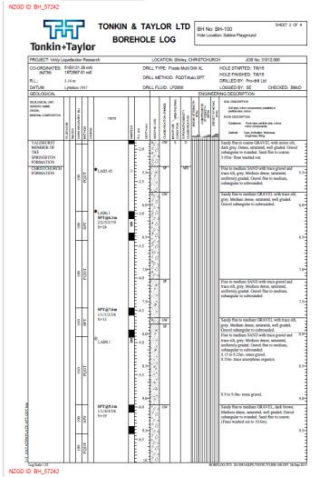
2010 Darfield Earthquake

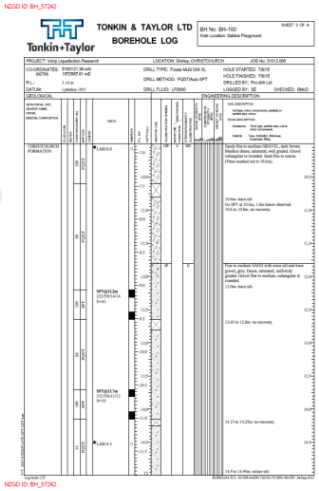
Magnitude: 7.10			
Fault Type: Strike Slip	Z_{tor} (km): 0	R_{rup} (km): 17.9
Dip: 82	Width (km): 10	R_{jb} (km): 17.9

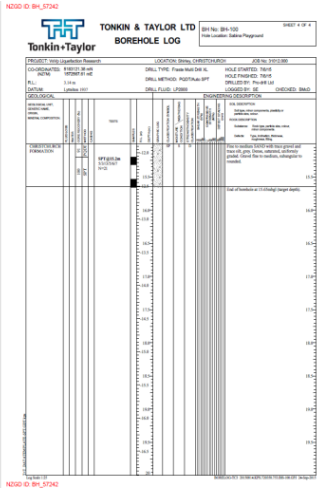
ACCELERATION TIME HISTORY











	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
SP	1.5	4.9		13	1.89	0.85	28.7	
GW	3	9.8		16	1.50	0.89	29.2	
GW	4.6	15.1		38	1.27	0.92	61.0	outlier
GW	6.1	20.0	***site***	24	1.14	0.94	35.1	outlier
SP	***7.6***	***24.9***	***response***	***13***	***1.03***	***0.96***	***17.6***	more critical when
GW	***9.1***	***29.9***	***analysis***	***19***	***0.96***	***0.97***	***24.0***	compared to upper
SP	12.2	40.0		41	0.84	0.98	46.2	outlier
SP	13.7	44.9		35	0.79	0.99	37.5	outlier
SP	15.2	49.9		21	0.76	0.99	21.5	
						Mean:	20.8	
						St. Dev.	4.6	

SP - GW matrix

GWT	
by Vs	1.08 m
by Vs	1.25 m
SPT	1.6 m

Case number:	277
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	Shirley Intermediate School (VSVP 57203)
References:	McLaughlin (2017), NZGD
Nature of Failure:	None to minor
GPS LAT	-43.510356
GPS LONG	172.661992
Liq. layer consist of:	Sand (SP)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.19 g by McLaughlin (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD. Hammer energy is assigned as 82% for PQDT/Auto SPT. Vs,12m is calculated based on the mesaured Vs values. GWT is estimated based onVs and CPT measurement FC is assigned based on the SP classification from USCS. amax is calculated as 0.123 g and 0.156 g geometric mean of which is 0.139 g based on Site response analysis. Top silt layer has organic content. Sand is suspectible to liquefaction.



After McLaughlin (2017)

Gravel Content (%)	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	A
$d_{crit.c}$ range (m)	-	-	-	-	4.0 - 9.4
$d_{crt.}$(m)	-	-	-	-	6.7
GWT (m)	-	-	-	-	2.4 ± 0.4
γ_{moist} (kN/m^3)	-	-	-	-	17.4 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	130.6 ± 18.8
σ_v' (kPa)	-	-	-	-	88.6 ± 10.3
a_{max} (g)	-	-	-	-	0.190 ± 0.029
r_d	-	-	-	-	0.77 ± 0.045
CSR	-	-	-	-	0.140 ± 0.024
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	13.5 ± 2.8
C_R	-	-	-	-	0.95
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.07
$(N_1)_{60}$	-	-	-	-	18.8 ± 3.9
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	175.9

EVENT PARAMETERS

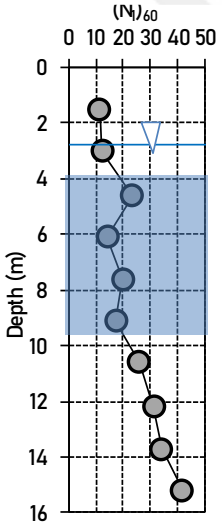
2010 Darfield Earthquake

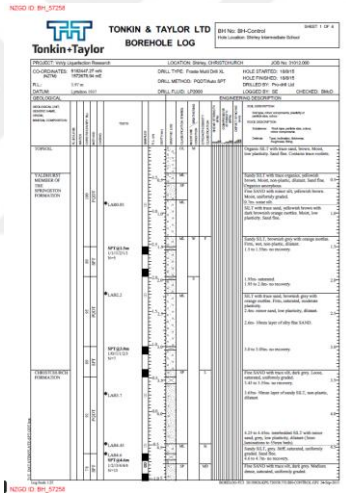
Magnitude: 7.10

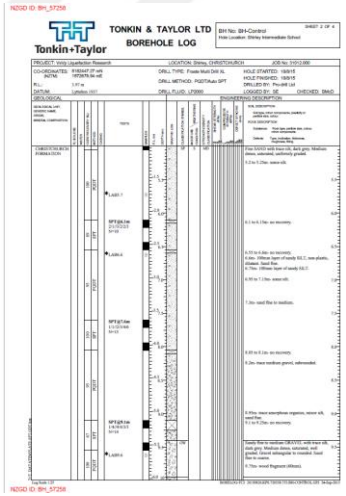
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 17.8

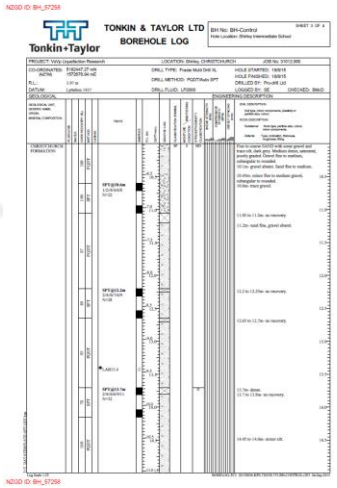
Dip: 82 | Width (km): 10 | R_{jb} (km): 17.8

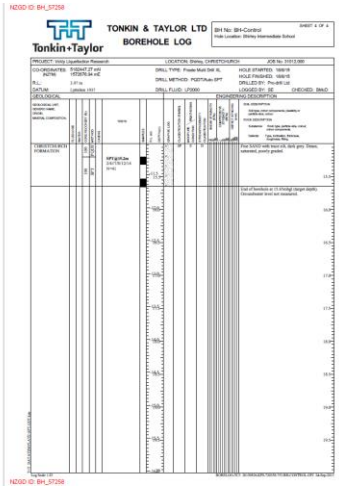
ACCELERATION TIME HISTORY











802

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
ML	1.5	4.9		5	1.97	0.85	11.5	not fully saturated
ML	3	9.8		7	1.45	0.89	12.3	moderate plasticity
ML-SP BAND	***4.6***	***15.1***		***15***	***1.24***	***0.92***	***23.5***	sandy silt
SP	***6.1***	***20.0***		***10***	***1.11***	***0.94***	***14.3***	
SP	***7.6***	***24.9***	site response analysis	***15***	***1.02***	***0.96***	***20.0***	
SP	***9.1***	***29.9***		***14***	***0.94***	***0.97***	***17.5***	
SP	10.6	34.8		22	0.88	0.98	25.9	
SP	12.2	40.0		28	0.83	0.98	31.2	
SP	13.7	44.9		32	0.79	0.99	34.0	
SP	15.2	49.9		41	0.75	0.99	41.7	
						Mean:	18.8	
						St. Dev.	3.9	

CPT FR>2% plastic

GWT	
by Vs	2.8 m
by Vs	2.7 m
CPT	2 m
CPT	2.2 m

Case number:	278
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	St. Albans Catholic School (VSVP 57180)
References:	McLaughlin (2017), NZGD
Nature of Failure:	None to minor
GPS LAT	-43.507189
GPS LONG	172.629139
Liq. layer consist of:	Sand- Silt (SP-SM-ML)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.21 g by McLaughlin (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD.
	Hammer energy is assigned as 82% for PQDT/Auto SPT.
	amax is calculated as 0.140 g and 0.147 g geometric mean of which is 0.144 g based on Site response analysis.
	Vs,12m is calculated based on the mesaured Vs values.
	GWT is estimated based on SPT measurement
	FC is assigned based on the SP-SM-ML classification from USCS. A large unceratinty is assigned.
	SP <5
	SM >12
	ML >50



After McLaughlin (2017)

Gravel Content:	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	A
d_{crit} range (m)	-	-	-	-	4.4 - 8.5
d_{crt} (m)	-	-	-	-	6.4
GWT (m)	-	-	-	-	1.7 ± 0.4
γ_{moist} (kN/m^3)	-	-	-	-	17.4 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	119.1 ± 13.0
σ_v' (kPa)	-	-	-	-	72.3 ± 7.3
a_{max} (g)	-	-	-	-	0.210 ± 0.032
r_d	-	-	-	-	0.88 ± 0.043
CSR	-	-	-	-	0.198 ± 0.033
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	20.0-50.0 ± 7.5
% PI	-	-	-	-	0-7
N	-	-	-	-	5.4 ± 0.8
C_R	-	-	-	-	0.95
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.19
$(N_1)_{60}$	-	-	-	-	8.3 ± 1.3
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	159.1

EVENT PARAMETERS

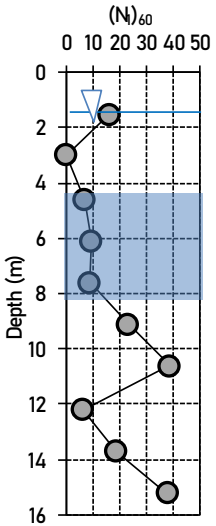
2010 Darfield Earthquake

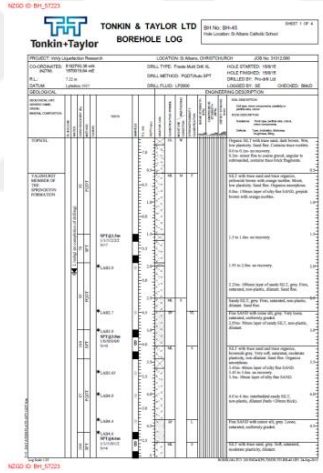
Magnitude: 7.10

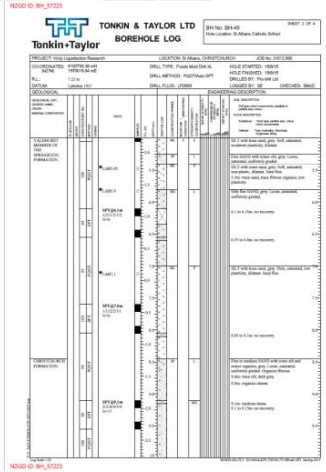
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 15.3

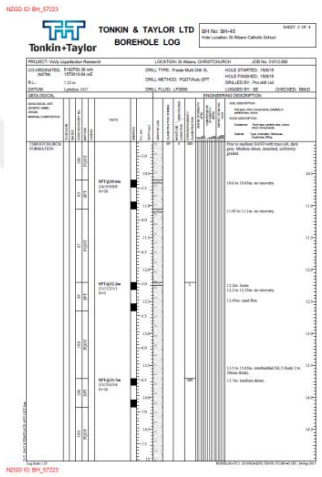
Dip: 82 | Width (km): 10 | R_{jb} (km): 15.3

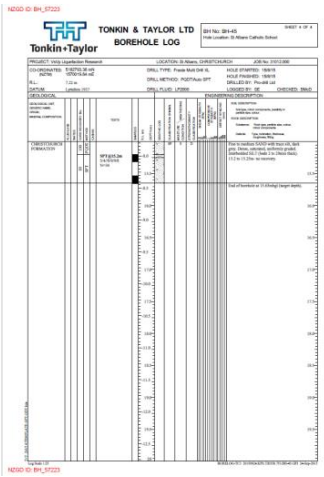
ACCELERATION TIME HISTORY











	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
ML	1.5	4.9		7	1.97	0.85	16.1	above GWT
SP	3	9.8		0	1.57	0.89	0.0	outlier
SP	***4.6***	***15.1***		***4***	***1.35***	***0.92***	***6.8***	
SM	***6.1***	***20.0***	site response analysis	***6***	***1.21***	***0.94***	***9.4***	
ML	***7.6***	***24.9***		***6***	***1.11***	***0.96***	***8.7***	low plasticity
SP	9.1	29.9		17	1.03	0.97	23.1	
SP	10.6	34.8		30	0.96	0.98	38.5	
SP	12.2	40.0		5	0.90	0.98	6.1	outlier
SP	13.7	44.9		16	0.86	0.99	18.5	
SP	15.2	49.9		34	0.82	0.99	37.7	
						Mean:	8.3	
						St. Dev.	1.3	

just below there is an organic ML layer

GWT	
by Vs	1.3 m
by Vs	1.27 m
SPT	2.1 m

Case number:	279
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	St. Teresa's School (VSVP 57191)
References:	McLaughlin (2017), NZGD
GPS LAT	-43.529833
GPS LONG	172.59205
Liq. layer consist of:	Silt (ML)-Sand
Geological Unit:	Natural Deposit
Site Response Anlaysis:	No
Nature of Failure:	No observations of surficial liquefaction manifestation were noted at this site.
Comments:	"The depth to the water table at this site fluctuated very little from September 2010 to February 2011, ranging from 0.96 m to 1.04 m. Thus, the Vp profile indicates that the soil is not fully saturated for about 4.5 m below the hydrostatic water table. The grain size distributions were determined for eight samples in the top 10 m using laser diffraction. None of these samples had a FC less than 44%, with most ranging between 50-90%...." (Quoted from McLaughlin (2017). CPT and Vs are available at the site. amax is reported as 0.22 g by McLaughlin (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD.
	Hammer energy is taken as 80% and 95.6 % for the two borehole respectively.
	Vs,12m is calculated based on the mesaured Vs values.
	GWT is estimated based on two SPT measurements
	FC is assigned based on the SM-ML classification from USCS. A large uncertaity is assigned
	There exist 2 borehole data at the site having the same soil layering. ER is given as 95.6% for one of the borehole.
Gravel Content	NAV
CPT available:	Yes
Vs available:	Yes





After McLaughlin (2017)

Summary of Input Data					
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	C
$d_{crt.}$ range (m)	-	-	-	-	2.0 - 4.5
d_{crt} (m)	-	-	-	-	3.3
GWT (m)	-	-	-	-	2.0 ± 1.6
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	19.0 ± 0.5
σ_v (kPa)	-	-	-	-	55.4 ± 9.6
σ_v' (kPa)	-	-	-	-	43.2 ± 11.3
a_{max} (g)	-	-	-	-	0.220 ± 0.044
r_d	-	-	-	-	0.91 ± 0.049
CSR	-	-	-	-	0.167 ± 0.067
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	12.5-62.5 ± 7.5
% PI	-	-	-	-	0-4
N	-	-	-	-	6.0 ± 1.8
C_R	-	-	-	-	0.90
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.00
C_N	-	-	-	-	1.53
$(N_1)_{60}$	-	-	-	-	8.3 ± 2.5
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	146.4

EVENT PARAMETERS

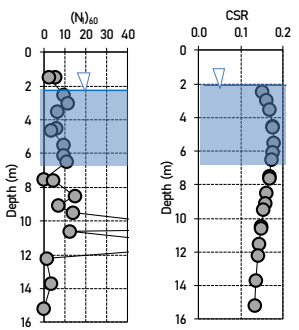
2010 Darfield Earthquake

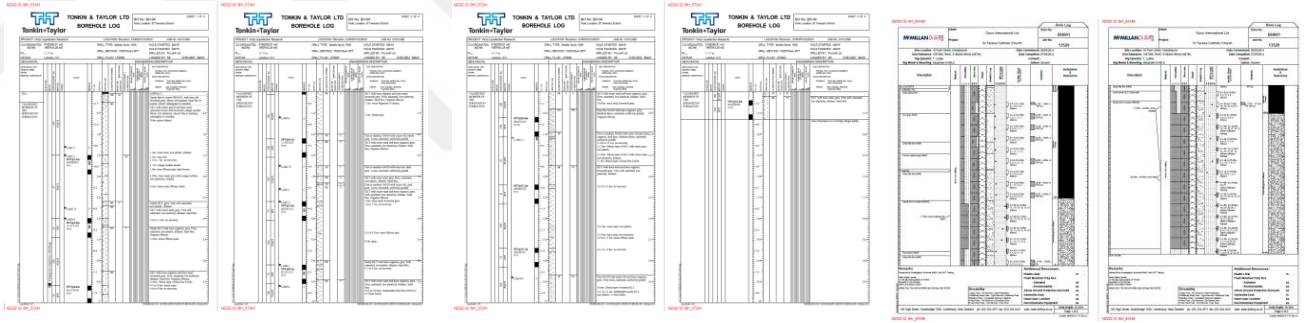
Magnitude: 7.10

Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 11.8

Dip: 82 | Width (km): 10 | R_{jb} (km): 11.8

ACCELERATION TIME HISTORY



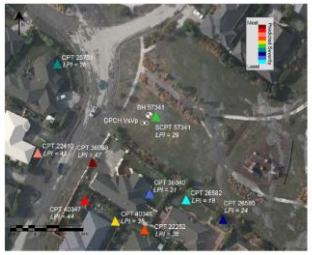


	Depth (m)	Depth (ft)	CSR	N_{60}	C_N	C_R	$(N1)_{60}$	Borehole Name	
Grey Sandy SILT	1.5	4.9	NA	3	2.00	0.85	5.4	45186	
ML	1.5	4.9	NA	1	2.00	0.85	2.3	57241	outlier
Fine grey SAND	***2.5***	***8.2***	***0.151***	***6***	***1.67***	***0.88***	***9.4***	45186	
ML	***3***	***9.8***	***0.162***	***8***	***1.58***	***0.89***	***11.3***	57241	
Fine grey SAND	***3.5***	***11.5***	***0.170***	***5***	***1.50***	***0.90***	***6.4***	45186	
Fine grey SAND	***4.5***	***14.8***	***0.177***	***5***	***1.36***	***0.92***	***6.0***	45186	
ML	4.6	15.1	0.177	3	1.35	0.92	3.3	57241	organics
Grey Silty fine SAND	***5.5***	***18.0***	***0.178***	***8***	***1.26***	***0.94***	***9.4***	**45186**	*CPT indicates plastic material*
SP	***6.1***	***20.0***	***0.176***	***8***	***1.21***	***0.94***	***9.1***	**57241**	*RF>3-4% hence upper layer is*
Fine to medium grey SAND	***6.5***	***21.3***	***0.174***	***10***	***1.18***	***0.95***	***10.7***	**45186**	*selected*
Grey Silty fine SAND	7.5	24.6	0.168	0	1.11	0.96	0.0	45186	outlier
ML	7.6	24.9	0.168	4	1.10	0.96	4.2	57241	organics
Grey Silty fine SAND	8.5	27.9	0.162	14	1.05	0.97	14.6	45186	
ML	9.1	29.9	0.157	7	1.02	0.97	6.6	57241	organics
Grey Silty fine SAND	9.5	31.2	0.155	14	1.00	0.97	14.0	45186	
Sandy fine to coarse GRAVEL	10.5	34.4	0.149	88	0.96	0.98	82.3	45186	
SM	10.6	34.8	0.148	13	0.96	0.98	12.5	57241	
Sandy fine to coarse GRAVEL	11.5	37.7	0.144	86	0.92	0.98	77.9	45186	
ML	12.2	40.0	0.141	**1**	0.90	0.98	1.2	57241	
ML	13.7	44.9	0.137	**4**	0.85	0.99	3.4	57241	**plastic material based on CPT**
ML	15.2	49.9	0.134	**0**	0.81	0.99	0	57241	
						Mean:	8.3		
						St. Dev.	2.5		

	Depth (m)	N	Borehole Name	ER	CE	N60		
Grey Sandy SILT	*1.5*	*2*	45186	0.956	1.59	3	GWT	3.1
Fine grey SAND	*2.5*	*4*	45186	0.956	1.59	6	(m)	
Fine grey SAND	*3.5*	*3*	45186	0.956	1.59	5		
Fine grey SAND	*4.5*	*3*	45186	0.956	1.59	5		
Grey Silty fine SAND	*5.5*	*5*	45186	0.956	1.59	8		
Fine to medium grey SAND	*6.5*	*6*	45186	0.956	1.59	10		
Grey Silty fine SAND	*7.5*	*0*	45186	0.956	1.59	0		
Grey Silty fine SAND	*8.5*	*9*	45186	0.956	1.59	14		
Grey Silty fine SAND	*9.5*	*9*	45186	0.956	1.59	14		
Sandy fine to coarse GRAVEL	10.5	55	45186	0.956	1.59	88		
Sandy fine to coarse GRAVEL	11.5	54	45186	0.956	1.59	86		
ML	*1.5*	*1*	57241	0.82	1.37	1	GWT	4.6
ML	*3*	*6*	57241	0.82	1.37	8	(m)	
ML	*4.6*	*2*	57241	0.82	1.37	3		
SP	*6.1*	*6*	57241	0.82	1.37	8		
ML	*7.6*	*3*	57241	0.82	1.37	4		
ML	*9.1*	*5*	57241	0.82	1.37	7		
SM	10.6	10	57241	0.82	1.37	14		
ML	12.2	1	57241	0.82	1.37	1		
ML	13.7	3	57241	0.82	1.37	4		
ML	15.2	0	57241	0.82	1.37	0		

N60 values were calculated

Case number:	280
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	Ti Rakau Reserve (VSVP 57186)
References:	McLaughlin (2017), NZGD
Nature of Failure:	None to minor
GPS LAT	-43.548878
GPS LONG	172.695286
Liq. layer consist of:	Sand (SP) and minor silt
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.23 g by McLaughlin (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD.
	Hammer energy is assigned as 82% for PQDT/Auto SPT.
	Vs,12m is calculated based on the mesaured Vs values.
	GWT is estimated based on SPT measurement
	amax is calculated as 0.122 g and 0.137 g geometric mean of which is 0.129 g based on Site response analysis.
	FC is assigned based on the SP classification from USCS.





After McLaughlin (2017)

Gravel Content:	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	3.3 - 15.7
d_{crt} (m)	-	-	-	-	9.5
GWT (m)	-	-	-	-	1.9 ± 1.7
γ_{moist} (kN/m^3)	-	-	-	-	17.4 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	189.0 ± 43.1
σ_v' (kPa)	-	-	-	-	114.6 ± 25.3
a_{max} (g)	-	-	-	-	0.230 ± 0.035
r_d	-	-	-	-	0.75 ± 0.060
CSR	-	-	-	-	0.185 ± 0.040
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	20.3 ± 3.0
C_R	-	-	-	-	0.97
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	0.94
$(N_1)_{60}$	-	-	-	-	25.4 ± 3.8
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	155.8

EVENT PARAMETERS

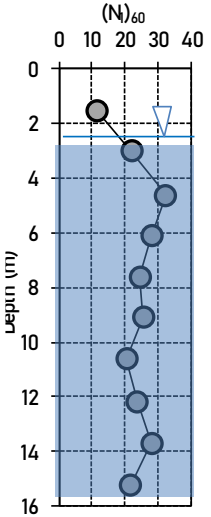
2010 Darfield Earthquake

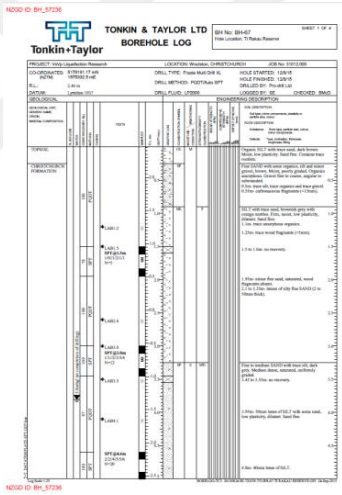
Magnitude: 7.10

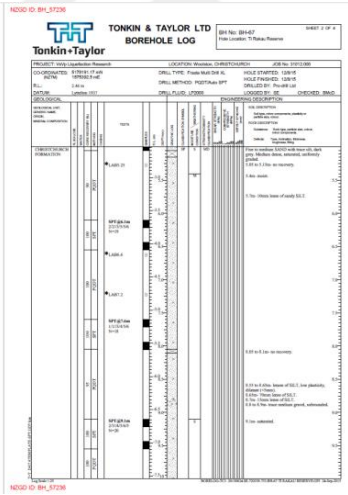
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 20

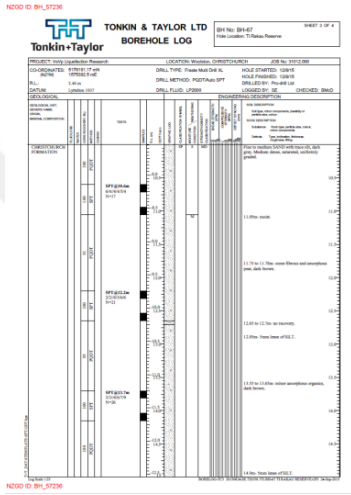
Dip: 82 | Width (km): 10 | R_{jb} (km): 20.0

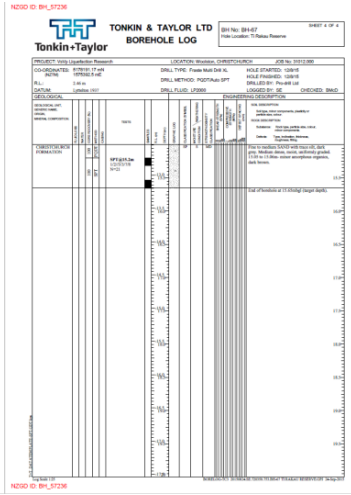
ACCELERATION TIME HISTORY











	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
ML	1.5	4.9	site response analysis	5	1.97	0.85	11.5	above GWT
ML	3	9.8		12	1.50	0.89	22.0	trace wood and organics
SP	***4.6***	***15.1***		***20***	***1.28***	***0.92***	***32.2***	
SP	***6.1***	***20.0***		***19***	***1.14***	***0.94***	***27.9***	
SP	***7.6***	***24.9***		***18***	***1.04***	***0.96***	***24.4***	
SP	***9.1***	***29.9***		***20***	***0.96***	***0.97***	***25.4***	
SP	***10.6***	***34.8***		***17***	***0.89***	***0.98***	***20.3***	
SP	***12.2***	***40.0***		***21***	***0.84***	***0.98***	***23.7***	
SP	***13.7***	***44.9***		***26***	***0.80***	***0.99***	***27.9***	
SP	***15.2***	***49.9***		***21***	***0.76***	***0.99***	***21.6***	
						Mean:	25.4	
						St. Dev.	3.8	

GWT	
by Vs	0.59 m
by Vs	0.67 m
SPT	3.8 m
CPT	1.2 m
Mean	1.88 m

Case number:	281
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	Wharenui School (VSVP 57165)
References:	McLaughlin (2017), NZGD
Nature of Failure:	None to minor
GPS LAT	-43.53611
GPS LONG	172.597625
Liq. layer consist of:	Sand - Silt (SM-ML)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	No
Comments:	CPT and Vs are available at the site. amax is reported as 0.22 g by McLaughlin (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD.
	Hammer energy is assigned as 82% for PQDT/Auto SPT.
	Vs,12m is calculated based on the mesaured Vs values.
	GWT is estimated based on SPT measurement
	FC is assigned based on the SM classification from USCS.



After McLaughlin (2017)

Gravel Content	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	4.5 - 6.7
d_{crt} (m)	-	-	-	-	5.6
GWT (m)	-	-	-	-	1.6 ± 0.4
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	19.0 ± 0.5
σ_v (kPa)	-	-	-	-	100.9 ± 7.3
σ_v' (kPa)	-	-	-	-	61.9 ± 4.8
a_{max} (g)	-	-	-	-	0.220 ± 0.044
r_d	-	-	-	-	0.79 ± 0.077
CSR	-	-	-	-	0.184 ± 0.042
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	31.0 ± 10.0
% PI	-	-	-	-	0-7
N	-	-	-	-	7.8 ± 5.6
C_R	-	-	-	-	0.94
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.28
$(N_1)_{60}$	-	-	-	-	12.8 ± 9.1
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	141.9

EVENT PARAMETERS

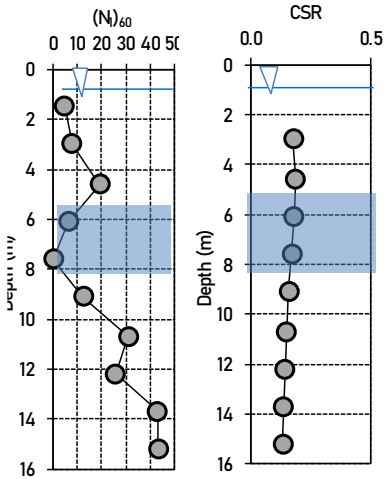
2010 Darfield Earthquake

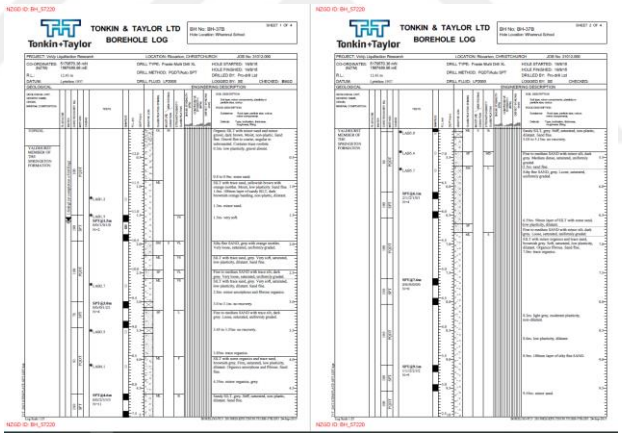
Magnitude: 7.10

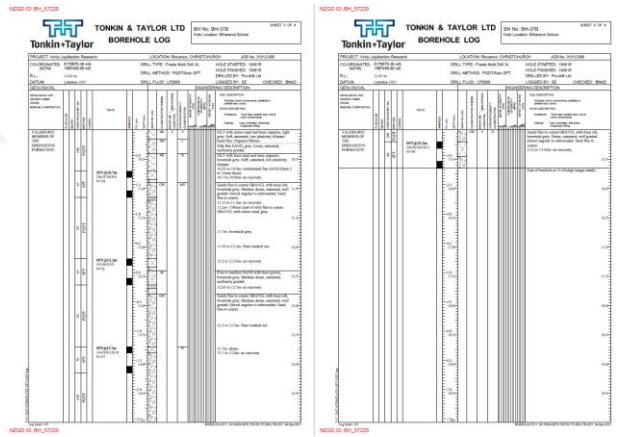
Fault Type: Strike Slip — Z_{tor} (km): 0 — R_{rup} (km): 12.1

Dip: 82 — Width (km): 10 — R_{jb} (km): 12.1

ACCELERATION TIME HISTORY







	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
ML	1.5	4.9	NA	2	2.00	0.85	4.7	nonplastic-above GWT
ML	3	9.8	0.18	4	1.63	0.89	8.0	minor organics
ML	***4.6***	***15.1***	***0.186***	***11***	***1.39***	***0.92***	***19.2***	nonplastic, CPT suggest to combine these two sublayers
SM	***6.1***	***20.0***	***0.181***	***4***	***1.23***	***0.94***	***6.4***	
ML	7.6	24.9	0.170	0	1.12	0.96	0.0	organics
ML	9.1	29.9	0.158	9	1.04	0.97	12.4	minor organics
-	10.7	35.1	0.148	24	0.96	0.98	30.9	
GW	12.2	40.0	0.141	21	0.91	0.98	25.7	
GW	13.7	44.9	0.136	37	0.86	0.99	43.0	
GW	15.2	49.9	0.134	39	0.82	0.99	43.4	
						Mean:	12.8	
						St. Dev.	9.1	

GWT	
by Vs	2.32 m
by Vs	2.35 m
SPT	1.6 m

Case number:	283
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	SW KAN 09
References:	Wood et al (2017), NZGD
Nature of Failure:	Small isolated sand boils with limited liquefaction ejecta.
GPS LAT:	-43.38136667
GPS LONG:	172.6614833
Liq. layer consist of:	SP-SM-SW
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.239 g by Wood et al (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD.
	Hammer energy is assigned as 82% for PQDT/Auto SPT.
	Gravel layer is sandy there exist interlayering of sand and gravel layer hence gravel and sand layer are combined.
	Site response analysis is performed and amax is calculated as 0.299 g and 0.363 g geometric mean of which is 0.330 g.



Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crLc} range (m)	-	-	-	-	1.5 - 3.5
d_{crt} (m)	-	-	-	-	2.5
GWT (m)	-	-	-	-	1.5 ± 0.3
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	49.1 ± 7.0
σ_v' (kPa)	-	-	-	-	38.7 ± 4.5
a_{max} (g)	-	-	-	-	0.239 ± 0.036
r_d	-	-	-	-	0.83 ± 0.019
CSR	-	-	-	-	0.163 ± 0.029
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	25.3 ± 9.7
% PI	-	-	-	-	0
N	-	-	-	-	7.6 ± 1.4
C_R	-	-	-	-	0.88
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.62
$(N_1)_{60}$	-	-	-	-	14.7 ± 2.8
$V_{s,30m}$ (m/s)	-	-	-	-	245.9
$V_{s,12m}$ (m/s)	-	-	-	-	163.8

EVENT PARAMETERS

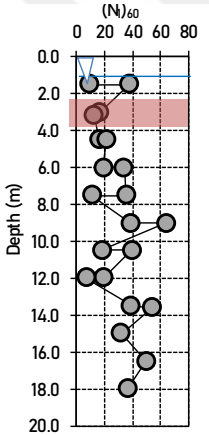
2010 Darfield Earthquake

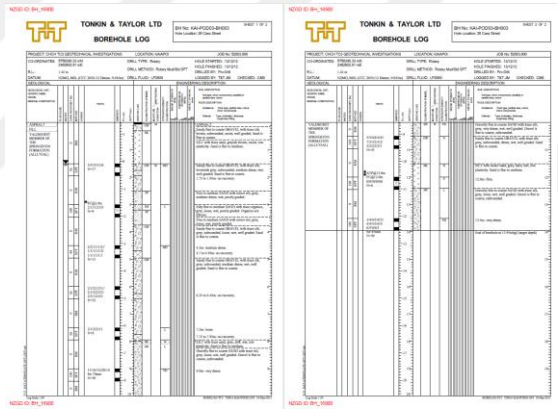
Magnitude: 7.10

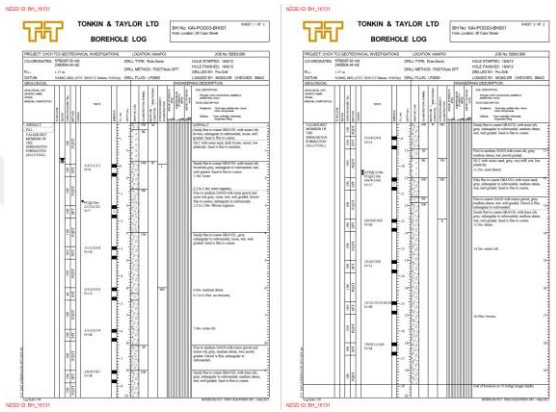
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 25.6

Dip: 82 | Width (km): 10 | R_{jb} (km): 25.6

ACCELERATION TIME HISTORY







	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	Borehole	N	FC	LL	PL	PI	
GW	1.50	4.92		4	1.91	0.85	8.89	16131						
GW	1.50	4.92		17	1.91	0.85	37.76	16900						
SP-SM	***3.00***	***9.84***		***9***	***1.52***	***0.89***	***16.64***	***16900***		***32.14***	***outlier FC***			SP 0-5 % inconsistent FC info
SW	***3.20***	***10.50***		***7***	***1.48***	***0.90***	***12.70***	***16131***		***18.37***	***for average this FC was include***			SW 0-5 % inconsistent FC info
GW	4.50	14.76		10	1.30	0.92	16.32	16131		0.00				
GW	4.50	14.76		13	1.30	0.92	21.22	16900		0.00				
GW	6.00	19.69		13	1.15	0.94	19.27	16131		0.00				
GW	6.00	19.69		23	1.15	0.94	34.10	16900						outlier gravel influence
GW	7.50	24.61		26	1.05	0.96	35.59	16131						
GW	7.50	24.61	site	8	1.05	0.96	10.95	16900						outlier gravel?
SP-GW	9.00	29.53	response	30	0.97	0.97	38.34	16131						
SW	9.00	29.53	analysis	50	0.97	0.97	63.91	16900	>50					
GW	10.50	34.45		15	0.90	0.98	18.04	16131						
GW	10.50	34.45		33	0.90	0.98	39.69	16900						
ML-GW	12.00	39.37		17	0.85	0.98	19.36	16131		46.22	24.00	16.00	8.00	
ML	12.00	39.37		6	0.85	0.98	6.83	16900		90.32	40.00	30.00	10.00	multile suspect but PI=10
GW	13.50	44.29		36	0.80	0.99	39.01	16131						hence the upper layer is claimed
SW	13.60	44.62		50	0.80	0.99	54.01	16900	>50					to be more critical
GW	15.00	49.21		31	0.76	0.99	32.10	16131						
GW	16.50	54.13		50	0.73	0.99	49.63	16131						
GW	18.00	59.06		38	0.70	1.00	36.27	16131						
						Mean:	14.7			25.3				
						St. Dev.	2.8			9.7				

Case number:	284
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	SW KAN 19
References:	Wood et al (2017), NZGD
Nature of Failure:	Limited liquefaction ejecta along edge of road (a few cm thick at most). No apparent impact on road, buried utilities or houses.
GPS LAT	-43.380567
GPS LONG	172.668707
Liq. layer consist of:	SP-SM
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.234 g by Wood et al (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD.
	Hammer energy is assigned as 82% for PQDT/Auto SPT.
	Vs,12m is calculated based on the mesaured Vs values.
	amax is calculated as 0.212 g and 0.205 g geometric mean of which is 0.209 g based on site response analysis.



After Wood et al (2017)

Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	2.0 - 10.5
d_{crt} (m)	-	-	-	-	6.3
GWT (m)	-	-	-	-	1.2 ± 0.3
γ_{moist} (kN/m^3)	-	-	-	-	17.4 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	125.2 ± 29.3
σ_v' (kPa)	-	-	-	-	75.5 ± 15.6
a_{max} (g)	-	-	-	-	0.234 ± 0.035
r_d	-	-	-	-	0.86 ± 0.042
CSR	-	-	-	-	0.216 ± 0.036
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	5.5 ± 2.7
% PI	-	-	-	-	0-4
N	-	-	-	-	13.8 ± 5.1
C_R	-	-	-	-	0.94
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.16
$(N_1)_{60}$	-	-	-	-	20.6 ± 7.6
$V_{s,30m}$ (m/s)	-	-	-	-	202.3
$V_{s,12m}$ (m/s)	-	-	-	-	142.69

EVENT PARAMETERS

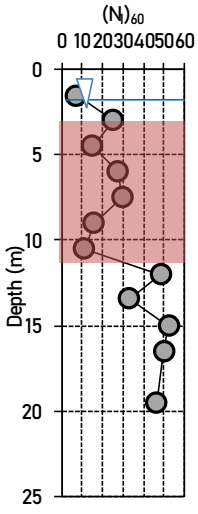
2010 Darfield Earthquake

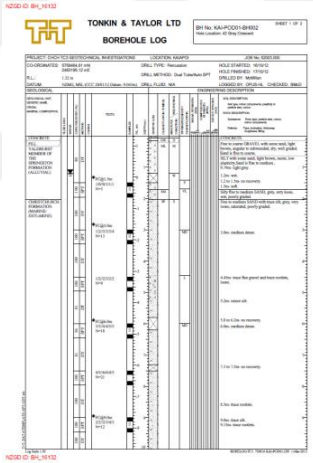
Magnitude: 7.10

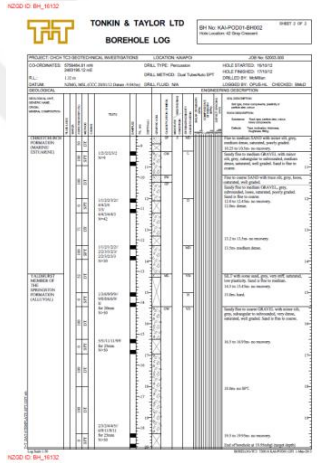
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 26

Dip: 82 | Width (km): 10 | R_{jb} (km): 26

ACCELERATION TIME HISTORY









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LAB REF: 884/12
JOB NO: 720018.575

TC3 GEOTECHNICAL LABORATORY TESTING, CHRISTCHURCH

TEST RESULTS	
42 Gray Crescent	Kaiapoi

SAMPLE IDENTIFICATION	TEST RESULTS				
	LL	PL	PI	FINES CONTENT PASSING 75μm (%)	WATER CONTENT (%)
1.5m*				54.48	24.5
3.0m				3.55	24.4
6.0m				9.50	27.4
9.0m				4.45	28.7

* Sample insufficiently cohesive to prepare for liquid limit and plastic limit tests.

CHECKED:
DATE: 23/01/13

BH-16132	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		FC
ML	1.5	4.9	site response analysis	3	2.00	0.85	7.0		54.5
SP	***3***	***9.8***		***13***	***1.59***	***0.89***	***25.1***		***3.6***
SP	***4.5***	***14.8***		***9***	***1.34***	***0.92***	***15.2***		***4.5***
SP-SM	***6***	***19.7***		***18***	***1.18***	***0.94***	***27.4***		***9.5***
SP	***7.5***	***24.6***		***21***	***1.07***	***0.96***	***29.3***		
SP	***9***	***29.5***		***12***	***0.98***	***0.97***	***15.6***		***4.5***
SP-GW	***10.5***	***34.4***		***9***	***0.91***	***0.98***	***11.0***		
GP	12	39.4		42	0.86	0.98	48.5		
GP	13.4	44.0		30	0.82	0.99	33.0		
??	15	49.2		50	0.77	0.99	52.3	N>50	
GW	16.5	54.1		50	0.74	0.99	50.1	N>50	
GW	19.5	64.0		50	0.68	1.00	46.4	N>50	
						Mean:	20.6		5.5
						St. Dev.	7.6		2.7

Case number:	286
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	SW Z2-4 (the Borehole is located closer to Z2-2)
References:	Wood et al (2017), NZGD
Nature of Failure:	No surficial evidence of liquefaction
GPS LAT	-43.52833333
GPS LONG	172.6353167
Liq. layer consist of:	Sand-Gravel
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.21 g by Wood et al (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD. Energy Ratio is calculated as 0.9425 based on energy measurements of 97-92-93-95%. Vs,12m is calculated based on the mesaured Vs values. amax is calculated as 0.16 g and 0.164 g geometric mean of which is 0.162 g based on Site response analysis



After Wood et al (2017)

Gravel Content (%):	>11
CPT available:	Yes (Z2-11 Can (2021))
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	6.0 - 15.5
d_{crt} (m)	-	-	-	-	10.8
GWT (m)	-	-	-	-	1.0 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	220.0 ± 33.0
σ_v' (kPa)	-	-	-	-	124.2 ± 17.7
a_{max} (g)	-	-	-	-	0.210 ± 0.032
r_d	-	-	-	-	0.76 ± 0.067
CSR	-	-	-	-	0.185 ± 0.032
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	16.1 ± 2.8
C_R	-	-	-	-	0.97
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.57
C_N	-	-	-	-	0.90
$(N_1)_{60}$	-	-	-	-	22.2 ± 3.9
V_{s30m} (m/s)	-	-	-	-	201.7
V_{s12m} (m/s)	-	-	-	-	163.74

EVENT PARAMETERS

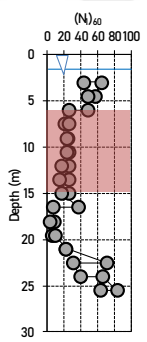
2010 Darfield Earthquake

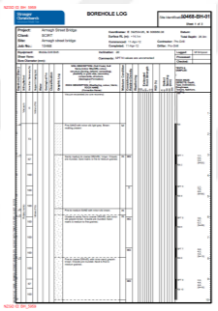
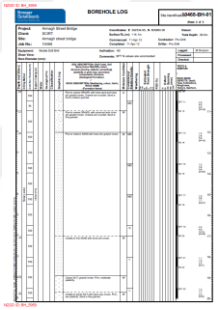
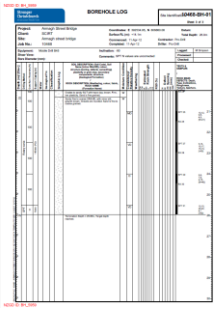
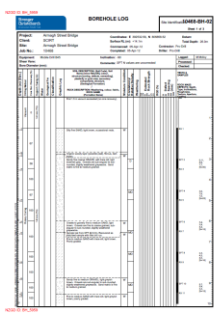
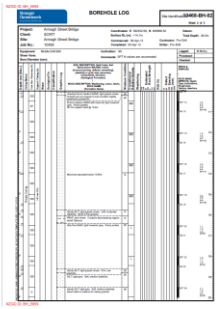
Magnitude: 7.10

Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 15.2

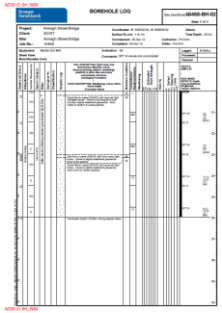
Dip: 82 | Width (km): 10 | R_{jb} (km): 15.2

ACCELERATION TIME HISTORY



	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		
bh-1	3	9.8		20	1.58	0.86	42.9	Sandy medium to coarse GRAVEL	
bh-2	3	9.8		30	1.58	0.86	64.3	Sandy fine-coarse GRAVEL	
bh-1	4.5	14.8		30	1.34	0.90	56.7	Sandy medium to coarse GRAVEL	
bh-2	4.5	14.8		25	1.34	0.90	47.2	Sandy fine-coarse GRAVEL	
bh-1	6	19.7		28	1.18	0.93	48.0	Fine to medium SAND	
bh-2	***6***	***19.7***		***15***	***1.18***	***0.93***	***25.7***	***Grades to gravelly fine to medium SAND***	
bh-1	***7.5***	***24.6***		***13***	***1.07***	***0.95***	***20.6***	***Fine to medium SAND***	
bh-2	***7.5***	***24.6***		***16***	***1.07***	***0.95***	***25.4***	***Fine to medium SAND***	
bh-1	***9***	***29.5***		***16***	***0.98***	***0.96***	***23.7***	***Fine to coarse GRAVEL***	
bh-2	***9***	***29.5***		***15***	***0.98***	***0.96***	***22.2***	***Sandy fine to medium GRAVEL***	
bh-1	***10.5***	***34.4***		***18***	***0.91***	***0.97***	***25.1***	***Fine to coarse GRAVEL***	
bh-2	***10.5***	***34.4***		***16***	***0.91***	***0.97***	***22.3***	***Fine to medium SAND***	
bh-1	***12***	***39.4***		***19***	***0.86***	***0.98***	***25.1***	***Fine to medium SAND***	
bh-2	***12***	***39.4***		***13***	***0.86***	***0.98***	***17.2***	***Fine to medium SAND***	
bh-1	***13.5***	***44.3***	site	***20***	***0.81***	***0.98***	***25.1***	***Fine to medium SAND***	
bh-2	***13.5***	***44.3***	response	***11***	***0.81***	***0.98***	***13.8***	***Fine to medium SAND***	
bh-1	***15***	***49.2***	analysis	***21***	***0.77***	***0.99***	***25.2***	***Fine to medium SAND***	
bh-2	***15***	***49.2***		***14***	***0.77***	***0.99***	***16.8***	***Fine to medium SAND***	
bh-1	16.5	54.1		32	0.74	0.99	36.8	Fine to medium SAND	Outlier
bh-2	16.5	54.1		6	0.74	0.99	6.9	Silty fine SAND	
bh-1	18	59.1		7	0.71	0.99	7.7	Grades to fine SAND	
bh-2	18	59.1		3	0.71	0.99	3.3	Silty fine SAND	
bh-1	19.5	64.0		5	0.68	1.00	5.3	Clayey SILT-Grades to sandy SILT	
bh-2	19.5	64.0		8	0.68	1.00	8.5	Sandy SILT	
bh-1	21	68.9		21	0.66	1.00	21.6	Sandy fine to coarse GRAVEL	
bh-2	21	68.9		21	0.66	1.00	21.6	Sandy fine to coarse GRAVEL	
bh-1	22.5	73.8		71	0.64	1.00	70.8	Sandy fine to coarse GRAVEL	*
bh-2	22.5	73.8		30	0.64	1.00	29.9	Sandy fine to coarse GRAVEL	
bh-1	24	78.7		41	0.62	1.00	39.6	Sandy fine to coarse GRAVEL	
bh-2	24	78.7		68	0.62	1.00	65.7	Sandy fine to coarse GRAVEL	*
bh-1	25.5	83.7		88	0.60	1.00	82.6	Sandy fine to coarse GRAVEL	*
bh-2	25.5	83.7		67	0.60	1.00	62.9	Sandy fine to coarse GRAVEL	*
						Mean:	22.2		
						St. Dev.	3.9		



** Hammer efficiency values were measured and provided around 10 m depth, the hammer efficiency is considered as the average of these values hence short rod correction was applied.*
**It was stated on the borehole data that 1 ft should be added for total rod length.*

Case number:	287
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	SW Z4-4
References:	Wood et al (2017), NZGD
Nature of Failure:	No surficial evidence of liquefaction
GPS LAT	-43.52867
GPS LONG	172.64241
Liq. layer consist of:	silty fine sand
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.215 g by Wood et al (2017) after 2011 Christchurch Earthquake. Test results are retrieved from NGZD. Acceleration value 0.215 g is based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Two borehole data are available. The efficiency of the SPT hammer is given as 99 % for BH 49057. The drilling method is same hence ER is taken as 99 % for both borehole. FC is assigned for SM-ML layers accordingly with USCS. FC is considered as >50 and FC>12 for ML and SM layers. A large unceratinty is assigned. Vs,12m is calculated based on the mesaured Vs values.



After Wood et al (2017)

Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crit} range (m)	-	-	-	-	2.0 - 3.3
d_{crt} (m)	-	-	-	-	2.6
GWT (m)	-	-	-	-	2.0 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.4 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	19.0 ± 0.5
σ_v (kPa)	-	-	-	-	46.9 ± 4.1
σ_v' (kPa)	-	-	-	-	40.7 ± 2.3
a_{max} (g)	-	-	-	-	0.215 ± 0.032
r_d	-	-	-	-	1.01 ± 0.020
CSR	-	-	-	-	0.163 ± 0.026
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	12.0-50.0 ± 10.0
% PI	-	-	-	-	0-7
N	-	-	-	-	7.7 ± 0.9
C_R	-	-	-	-	0.88
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.65
C_N	-	-	-	-	1.58
$(N_1)_{60}$	-	-	-	-	17.7 ± 2.0
$V_{s,30m}$ (m/s)	-	-	-	-	208.9
$V_{s,12m}$ (m/s)	-	-	-	-	178.5

EVENT PARAMETERS

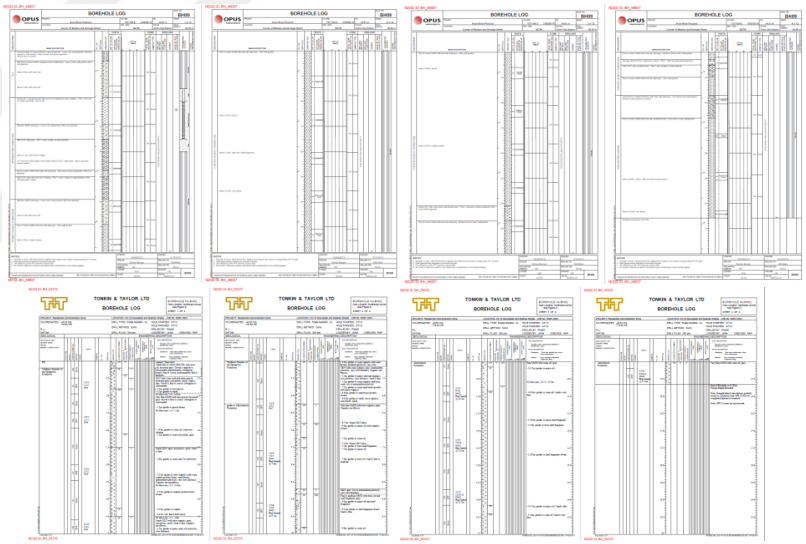
2010 Darfield Earthquake

Magnitude: 7.10

Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 15.8

Dip: 82 | Width (km): 10 | R_{jb} (km): 15.8

ACCELERATION TIME HISTORY



	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	C_E	$(N1)_{60}$		
55378	0.7	2.3	NA	4	2.00	0.83	1.37	9.0	ML	
49057	1.6	5.2	NA	4	1.91	0.86	1.65	10.8	Silty fine to coarse sand	
55378	1.7	5.6	NA	4	1.85	0.86	1.37	8.7	SM	
49057	***3.1***	***10.2***	***0.167***	***8***	***1.50***	***0.89***	***1.65***	***17.7***	***silty fine sand***	*CPT data confirm this selection*
55378	3.25	10.7	0.170	4	1.48	0.90	1.37	7.2	ML	trace organics
49057	4.7	15.4	0.188	0	1.30	0.92	1.65	0.0	clay	
55378	4.85	15.9	0.189	2	1.29	0.93	1.37	3.3	ML	trace organics
49057	6.2	20.3	0.194	5	1.17	0.94	1.65	9.1	silty fine sand	trace organics??
55378	6.35	20.8	0.194	7	1.16	0.95	1.37	10.5	SM	trace organics
55378	7.6	24.9	0.192	21	1.08	0.96	1.37	29.8	SP	
49057	7.7	25.3	0.19	18	1.08	0.96	1.65	30.7	fine to coarse sand	
49057	9.2	30.2	0.185	29	1.00	0.97	1.65	46.4	fine to coarse sand	
55378	9.35	30.7	0.18	22	0.99	0.97	1.37	29.0	SP	
49057	10.7	35.1	0.177	31	0.94	0.98	1.65	47.0	fine to coarse sand	
55378	10.9	35.8	0.18	32	0.93	0.98	1.37	39.9	SM	
49057	12.3	40.4	0.168	33	0.88	0.98	1.65	47.4	fine to coarse sand	
55378	12.35	40.5	0.17	35	0.88	0.98	1.37	41.5	SM	
49057	13.8	45.3	0.162	58	0.84	0.99	1.65	79.5	fine to coarse sand	
55378	13.9	45.6	0.16	43	0.84	0.99	1.37	48.7	SM	
49057	15.3	50.2	0.157	51	0.80	0.99	1.65	67.0	fine to coarse sand	
55378	15.4	50.5	0.16	39	0.80	0.99	1.37	42.3	SM	
49057	16.8	55.1	0.155	36	0.77	0.99	1.65	45.4	fine to coarse sand	
49057	18.4	60.4	0.15	48	0.74	1.00	1.65	58.2	fine to coarse sand	
49057	19.9	65.3	0.153	16	0.71	1.00	1.65	18.7	fine to coarse sand	
49057	21.4	70.2	0.15	25	0.69	1.00	1.65	28.4	fine to coarse sand	
49057	22.9	75.1	0.153	15	0.67	1.00	1.65	16.5	fine to coarse sand	
49057	24.4	80.1	0.15	10	0.65	1.00	1.65	10.7	peat	
49057	25.9	85.0	0.154	60	0.63	1.00	1.65	62.4	gravel	60+
49057	27.3	89.6	0.15	60	0.62	1.00	1.65	60.9	fine to coarse sand	60+
49057	28.9	94.8	0.155	44	0.60	1.00	1.65	43.5	fine to coarse sand	
49057	30.4	99.7	0.16	60	0.58	1.00	1.65	57.9	fine to coarse sand	60+
						Mean:	1.65	17.7		
						St. Dev.		2.0	assigned	

*the given hammer efficiency is considered as the mean of the asymptotic values at depths >10 m hence short rod correction was applied.
If energy measurement were provided at depths no short rod correction would be applied.

Case number:	289
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	SW Z2-6
References:	Wood et al (2017), NZGD
Nature of Failure:	None No surficial evidence of liquefaction
GPS LAT	-43.52763333
GPS LONG	172.6369667
Liq. layer consist of:	Sand (SW)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.214 g by Wood et al (2017) abased on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD. Hammer energy is assigned as 99% for "Sonic" based on energy mesaurement by a previous borehole by Tonkin and Taylor. (BH49047 ER=99%) GWT is averaged from measurements based on Vs and CPT. FC is assigned accordingly with USCS, SP <5, Silty fine sand >12, SW <5, ML >50. A large unceratinty is assigned. Vs,12m is calculated based on the mesaured Vs values. amax is calculated as 0.165 g and 0.174 g geometric mean of which is 0.169 g based on site response analysis.



After Wood et al. (2017)

Gravel Conetnt (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
$d_{crt.}$ range (m)	-	-	-	-	2.0 - 4.6
d_{crt} (m)	-	-	-	-	3.3
GWT (m)	-	-	-	-	1.3 ± 0.7
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	60.3 ± 8.3
σ_v' (kPa)	-	-	-	-	41.0 ± 7.2
a_{max} (g)	-	-	-	-	0.214 ± 0.032
r_d	-	-	-	-	0.92 ± 0.025
CSR	-	-	-	-	0.188 ± 0.043
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	4.9 ± 0.4
C_R	-	-	-	-	0.90
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.57
$(N_1)_{60}$	-	-	-	-	9.4 ± 0.8
$V_{s,30m}$ (m/s)	-	-	-	-	207.0
$V_{s,12m}$ (m/s)	-	-	-	-	162.6

EVENT PARAMETERS

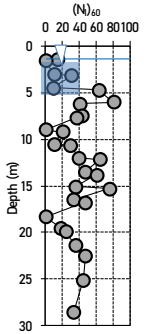
2010 Darfield Earthquake

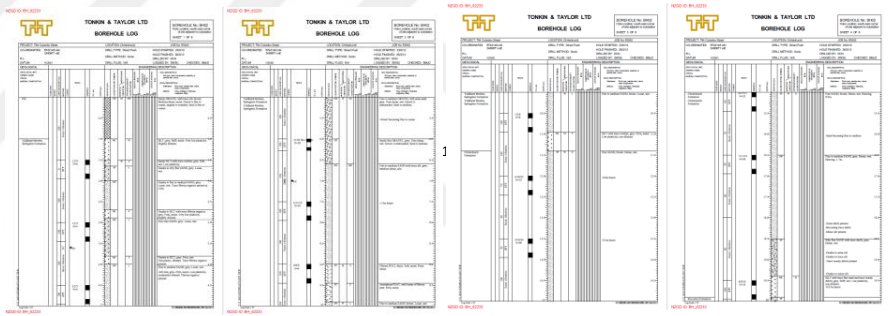
Magnitude: 7.10

Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 15.4

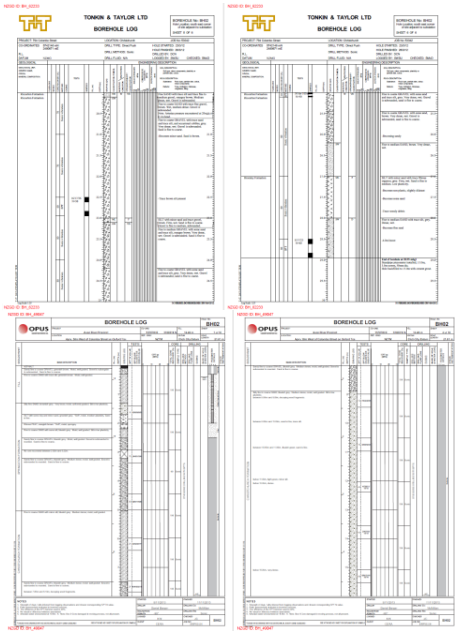
Dip: 82 | Width (km): 10 | R_{jb} (km): 15.4

ACCELERATION TIME HISTORY





	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	C_E	$(N1)_{60}$	
SP-ML	1.5	4.9		6	2.00	0.85	1.37	13.98	62233 CN>2 excluded
Silty fine sand	1.6	5.2		0	1.99	0.86	1.65	0.00	49047 outlier
SW	***3***	***9.8***		***5***	***1.63***	***0.89***	***1.37***	***9.93***	***62233***
no core recovery	3.2	10.5		13	1.59	0.90	1.65	30.61	49047 outlier
SW	***4.5***	***14.8***		***5***	***1.40***	***0.92***	***1.37***	***8.80***	***62233***
sandy fine to coarse gravel	4.7	15.4		30	1.38	0.92	1.65	62.91	49047
GP	6	19.7		50	1.25	0.94	1.37	80.17	62233 >50
Fine to coarse sand	6.2	20.3		21	1.23	0.94	1.65	40.20	49047
SW	7.5	24.6		29	1.13	0.96	1.37	43.00	62233
sandy fine to coarse gravel	7.7	25.3		21	1.12	0.96	1.65	37.24	49047
PT	9	29.5		0	1.05	0.97	1.37	0.00	62233
silty fine to coarse sand	9.2	30.2		12	1.04	0.97	1.65	19.91	49047
SW	10.5	34.4		8	0.98	0.98	1.37	10.44	62233
silty fine to coarse sand	10.7	35.1	site	19	0.97	0.98	1.65	29.72	49047
SP-ML	12	39.4	response	32	0.92	0.98	1.37	39.58	62233
silty fine to coarse sand	12.2	40.0	analysis	43	0.91	0.98	1.65	63.77	49047
SP-ML	13.5	44.3		40	0.87	0.99	1.37	47.10	62233
silty fine to coarse sand	13.8	45.3		43	0.86	0.99	1.65	60.56	49047
SP-ML	15.1	49.5		32	0.83	0.99	1.37	35.91	62233
silty fine to coarse sand	15.3	50.2		56	0.82	0.99	1.65	75.43	49047
SW-SP LIMIT	16.5	54.1		30	0.80	0.99	1.37	32.38	62233
silty fine to coarse sand	16.8	55.1		36	0.79	0.99	1.65	46.54	49047
clayey silt	18.3	60.0		0	0.76	1.00	1.65	0.00	49047
ML	19.5	64.0		18	0.74	1.00	1.37	18.02	62233
silty fine to coarse sand	19.9	65.3		20	0.73	1.00	1.65	23.95	49047
silty fine to coarse sand	21.4	70.2		31	0.70	1.00	1.65	35.91	49047
GW	22.5	73.8		50	0.69	1.00	1.37	46.87	62233 >50
GW	25.1	82.3		50	0.65	1.00	1.37	44.53	62233 >50
SW	28.5	93.5		40	0.61	1.00	1.37	33.54	62233
						Mean:	1.37	9.4	
						St. Dev.	0.00	0.8	



**the given hammer efficiency for BH 49047 (99%) is considered as the mean of the asymptotic values at depths >10 m hence short rod correction was applied. Hammer eff. is assigned as 82% for BH62233*

Case number:	290
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	Christchurch Botanical Garden (CBGS) - SMS
References:	Wotherspoon et al. (2014), Network NSMN, GeoNet, NZGD
GPS LAT	-43.52933938
GPS LONG	172.6198776
Liq. layer consist of:	Sand (SP)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Deconvolution Analysis
Nature of Failure:	No clear manifestation of liquefaction effects at the ground surface in the immediate vicinity of the SMS or evidence of liquefaction in the acceleration record following the Darfield earthquake.
Comments:	CPT and Vs are available at the site. amax is reported as 0.16 g by Wotherspoon et al (2014). Based on the acceleration record data dowloaded from Geonet (2013) 0.150 g and 0.174 g is determined for two component geometric mean of which is 0.161 g is used in the analysis. SPT values are given as N60 so ER is taken as 60%. GWT is determined from the figure provided by Wotherspoon et al (2014), probably interpreted from CPT. FC is assigned accordingly with USCS, SP <5. Vs,12m, Vs,30 m are calculated based on the mesaured Vs values. Rrup 14.1 km , Rjb=13.9 km Bradley 2012 Deconvolution analysis were performed succesfully at the site which suggest rd =0.81 and Cetin and Seed (2004) suggest rd 0.68. amax is calculated as 0.161 g which is same with the measured value at the SMS.

Nearby Geotechnical Site Investigation

Table 10 CBGS geotechnical site investigation summary

Investigation Method	Number	Notes
CPT (CPT)	1	Predrilled through surface gravel
Borehole/SPT (BH)	1	
V_S – surface wave (SW)	1	
H/V Spectral Ratio (HV)	1	

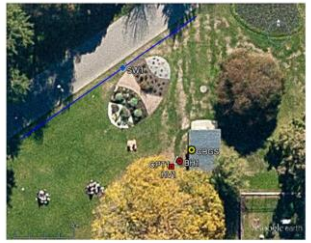


Figure 65 CBGS geotechnical site investigation location plan

After Wotherspoon et al. (2014)

Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	A
d_{crit} range (m)	-	-	-	-	8.9 - 12.5
d_{crt} (m)	-	-	-	-	10.7
GWT (m)	-	-	-	-	3.2 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	19.6 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	21.2 ± 0.5
σ_v (kPa)	-	-	-	-	222.3 ± 13.4
σ_v' (kPa)	-	-	-	-	148.7 ± 7.9
a_{max} (g)	-	-	-	-	0.161 ± 0.008
r_d	-	-	-	-	0.79 ± 0.067
CSR	-	-	-	-	0.124 ± 0.012
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	3.2 ± 2.1
% PI	-	-	-	-	0
N	-	-	-	-	16.9 ± 2.5
C_R	-	-	-	-	0.98
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.00
C_N	-	-	-	-	0.83
$(N_1)_{60}$	-	-	-	-	13.7 ± 2.0
$V_{s,30m}$ (m/s)	-	-	-	-	196.8
$V_{s,12m}$ (m/s)	-	-	-	-	161.6

EVENT PARAMETERS

2010 Darfield Earthquake

Magnitude: 7.10

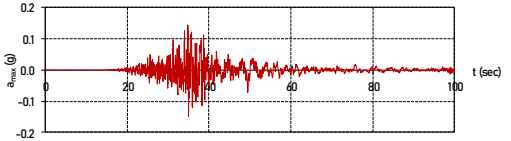
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 13.9

Dip: 82 | Width (km): 10 | R_{jb} (km): 13.9

ACCELERATION TIME HISTORY

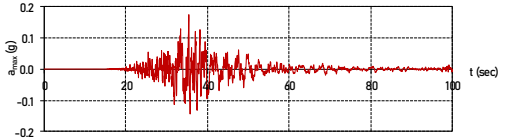
Full Record

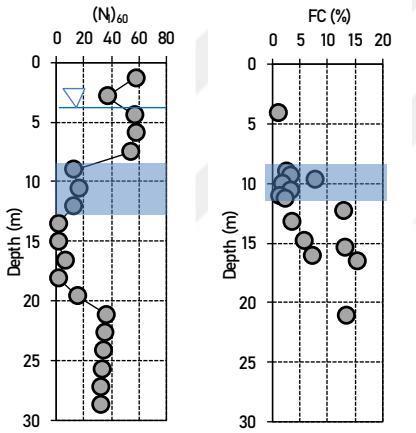
N_{H1}	19.5
N_{H2}	11.7
N_{gm}	15.1
PGA_{H1}	0.150
PGA_{H2}	0.174
PGA	0.161
M_w	7.1
$M_{w,cyc}$	6.3

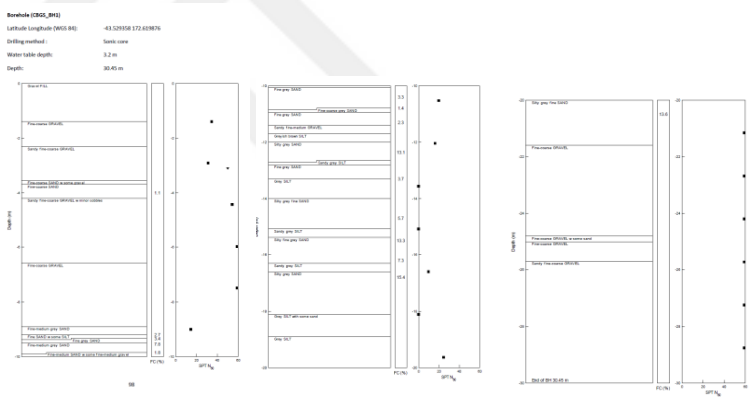


Untill Liquefaction

$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-





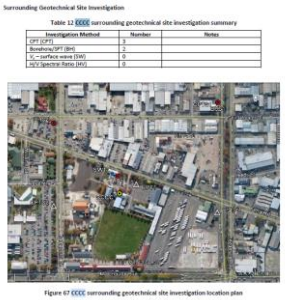


	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
Gravel Fill	1.33	4.4		34	1.97	0.85	57.6	Gravel fill
GW	2.88	9.4		31	1.34	0.89	36.8	Sandy fine coarse gravel
GW	4.46	14.6		54	1.15	0.92	57.3	Sandy fine coarse gravel w minor cobbles
GW	5.96	19.6		59	1.04	0.94	57.5	Sandy fine coarse gravel w minor cobbles
GW	7.51	24.6		59	0.95	0.96	53.9	Fine coarse gravel
SP	***9.03***	***29.6***		***15***	***0.89***	***0.97***	***12.5***	***Fine medium grey sand***
SP	***10.53***	***34.5***		***20***	***0.83***	***0.98***	***16.0***	***Fine grey sand***
ML (sand?)	***12.02***	***39.4***		***16***	***0.79***	***0.98***	***12.5***	***Silty grey sand***
ML	*13.55*	*44.5*	Site	*1*	*0.75*	*0.99*	*0.8*	*Grey silt*
SM-ML	*15.07*	*49.4*	Response	*1*	*0.71*	*0.99*	*0.7*	*Sandy grey fine sand*
SM-ML	*16.62*	*54.5*	Analysis	*10*	*0.69*	*0.99*	*6.5*	*Sandy grey silt*
SM-ML	*18.06*	*59.3*		*1*	*0.66*	*1.00*	*0.7*	*Silty grey sand*
ML	19.61	64.3		24	0.64	1.00	15.5	Grey silt
SM	21.11	69.3		59	0.62	1.00	36.2	Silty grey fine sand
GW	22.66	74.3		59	0.60	1.00	35.2	Fine coarse gravel
GW	24.18	79.3		59	0.58	1.00	34.1	Fine coarse gravel
GW	25.71	84.4		59	0.56	1.00	33.3	Sandy fine coarse gravel
GW	27.2	89.2		59	0.55	1.00	32.4	Sandy fine coarse gravel
GW	28.73	94.3		59	0.54	1.00	31.5	Sandy fine coarse gravel
						Mean:	13.7	
						St. Dev.	2.0	

Depth (m)	FC
4	1.1
9	***2.7***
9.3	***3.4***
9.6	***7.8***
10	***1.8***
10.5	***3.3***
11	***1.4***
11.2	***2.3***
12.2	13.1
13.2	3.7
14.8	5.7
15.3	13.3
16	7.3
16.5	15.4
21	13.6
Mean:	3.2
St. Dev.	2.1

Depth (m)	Soil Layering
0	
1.36	Gravel Fill
3.66	GW
4.21	SW
8.89	GW
9.92	***SP***
10.06	***SW***
11.41	***SP***
11.66	*GW*
12.71	*ML*
13.3	*SP*
13.99	*ML*
18.09	SM-ML
20.06	ML
21.61	SM
30	GW

Case number:	291
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	Christchurch Cathedral College (CCCC)
References:	Wotherspoon et al. (2014), Cannet, NZGD
GPS LAT	-43.538085
GPS LONG	172.647427
Liq. layer consist of:	Sand with some silt
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Deconvolution Analysis
Nature of Failure:	There was no clear manifestation of liquefaction effects at the ground surface in the immediate area surrounding the SMS following the Darfield earthquake.
Comments:	CPT and Vs are available at the site. amax is reported as 0.22 g by Wotherspoon et al (2014). Based on the acceleration record data dowloaded from Geonet (2013) 0.229 g and 0.202 g is determined for two component geometric mean of which is 0.215 g is used.
	Wotherspoon et al. (2014) provided SPT boreholes BH1 and BH2 which are 240 and 320 m away from the station. However closer two borehole (76451 and 76452) data were retrieved from NZGD located 30 m away. ER=85% is measured for these two borehole. They have been used to represent the site for this SMS. BH1 and BH2 were also processed where the average SPT value for the sand layer is lower when compared to 76451 and 76452. CPT data and the close borehole inditaces that surficial layers consist of clayey material underlying by a potenatially liquefiable sand layer having silt content.
	Hammer energy is given as 85% on the borehiole data.
	GWT is determined from the figure provided by Wotherspoon et al (2014), from SPT.
	Vs,12m is calculated based on the mesaured Vs values.
	Rrup 15.9 km , Rjb=16.2 km Bradley 2012
	Deconvolution analysis were performed succesfully at the site for one component which suggest rd =0.62 and Cetin and Seed (2004) suggest rd 0.55. amax is calculated as 0.229 g by site response analysis which is the same measured value at the SMS for one component.



After Wotherspoon et al. (2014)

Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	6.2 - 14.0
d_{crt} (m)	-	-	-	-	10.1
GWT (m)	-	-	-	-	1.2 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	19.6 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	21.2 ± 0.5
σ_v (kPa)	-	-	-	-	212.8 ± 28.0
σ_v' (kPa)	-	-	-	-	125.4 ± 15.5
a_{max} (g)	-	-	-	-	0.215 ± 0.011
r_d	-	-	-	-	0.62 ± 0.064
CSR	-	-	-	-	0.146 ± 0.017
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	3.9 ± 2.2
% PI	-	-	-	-	0
N	-	-	-	-	17.5 ± 6.5
C_R	-	-	-	-	0.97
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.42
C_N	-	-	-	-	0.90
$(N_1)_{60}$	-	-	-	-	21.7 ± 8.1
V_{s30m} (m/s)	-	-	-	-	186.6
V_{s12m} (m/s)	-	-	-	-	137.8

EVENT PARAMETERS

2010 Darfield Earthquake

Magnitude: 7.10

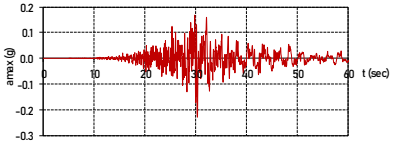
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 15.9

Dip: 82 | Width (km): 10 | R_{jb} (km): 15.9

ACCELERATION TIME HISTORY

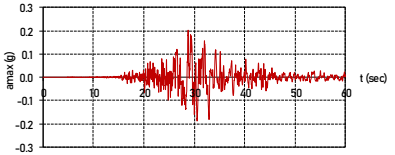
Full Record

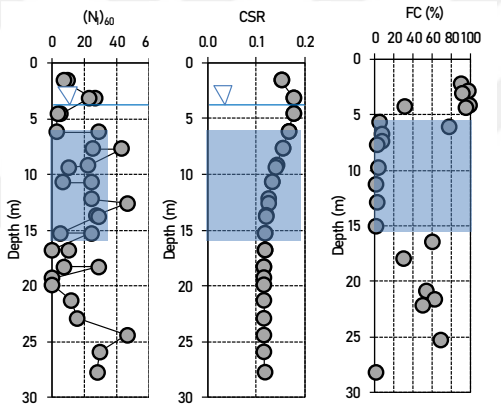
N_{H1}	9.4
N_{H2}	17.8
N_{gm}	12.9
PGA_{H1}	0.229
PGA_{H2}	0.202
PGA	0.215
M_w	7.1
$M_{w,cycle}$	5.5

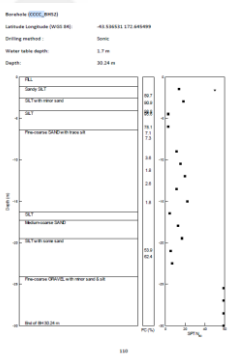


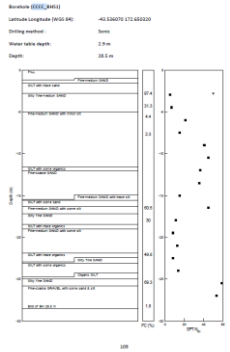
Untill Liquefaction

$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-









GWT		
BHS1	2.9	m
BHS2	1.7	m
76451	1.20	m
76452	1.20	m
avrg.	2.3	m

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		
Clay	1.6	5.2	0.15	4	1.90	0.86	9	76451	
CLAY with minor silt	1.6	5.2	0.15	3	1.90	0.86	7	76452	
Silty fine to medium SAND	3.2	10.5	0.177	14	1.48	0.90	26	76451	
SILT with some clay; grey	3.2	10.5	0.177	12	1.48	0.90	23	76452	
Silty Clay	4.6	15.1	0.176	3	1.27	0.92	5	76451	
Silty CLAY;	4.6	15.1	0.176	2	1.27	0.92	3	76452	
Fine to medium SAND	6.2	20.3	0.166	2	1.12	0.94	3	76451	outlier
Fine SAND with trace silt	**6.2**	**20.3**	**0.166**	**19**	**1.12**	**0.94**	**28**	**76452**	
Fine to medium SAND	**7.7**	**25.3**	**0.153**	**18**	**1.02**	**0.96**	**25**	**76451**	
Fine SAND with trace silt	7.7	25.3	0.153	31	1.02	0.96	43	76452	outlier
Fine to medium SAND	**9.2**	**30.2**	**0.142**	**17**	**0.94**	**0.97**	**22**	**76451**	
Fine SAND with trace silt	**9.4**	**30.8**	**0.140**	**8**	**0.93**	**0.97**	**10**	**76452**	
Fine to medium SAND	**10.7**	**35.1**	**0.132**	**5**	**0.88**	**0.98**	**6**	**76451**	
Fine SAND with trace silt	**10.7**	**35.1**	**0.132**	**20**	**0.88**	**0.98**	**24**	**76452**	
Fine to medium SAND	**12.2**	**40.0**	**0.126**	**21**	**0.82**	**0.98**	**24**	**76451**	
Fine SAND with trace silt	12.6	41.3	0.124	41	0.81	0.99	46	76452	outlier
Fine SAND with trace silt	**13.7**	**44.9**	**0.121**	**25**	**0.78**	**0.99**	**27**	**76452**	
Fine to medium SAND	**13.8**	**45.3**	**0.121**	**26**	**0.78**	**0.99**	**28**	**76451**	
Silty fine sand	**15.3**	**50.2**	**0.118**	**5**	**0.74**	**0.99**	**5**	**76451**	very thin layer
Fine SAND with trace silt	15.3	50.2	0.118	23	0.74	0.99	24	76452	
Silt	16.8	55.1	0.117	0	0.71	0.99	0	76451	0/ sunk under
Fine to coarse SAND;	16.8	55.1	0.117	10	0.71	0.99	10	76452	weight of
Sand	18.3	60.0	0.116	7	0.68	1.00	7	76451	hammer.
Fine to coarse SAND;	18.3	60.0	0.116	30	0.68	1.00	29	76452	
Sandy Silt	19.3	63.3	0.116	0	0.66	1.00	0	76451	
SILT moderate plasticity	19.9	65.3	0.116	0	0.65	1.00	0	76452	
Becomes CLAY with minor silt	21.3	69.9	0.116	13	0.63	1.00	12	76452	
Medium to coarse SAND	22.9	75.1	0.116	18	0.61	1.00	16	76452	
Fine to coarse SAND	24.4	80.1	0.116	55	0.59	1.00	46	76452	
Sandy fine to coarse GRAVEL	25.9	85.0	0.116	36	0.58	1.00	29	76452	
Becomes gravelly fine to coarse SAND	27.8	91.2	0.116	35	0.56	1.00	27.6	76452	
						Mean:	21.7		

Depth (m)	FC	
2.18	89.70	BHS2
2.86	97.40	BHS1
3.11	90.90	BHS2
4.12	98.80	BHS2
4.26	31.30	BHS1
4.41	95.00	BHS2
5.67	***4.40***	***BHS1***
6.06	78.10	BHS2
6.75	***7.10***	***BHS2***
7.36	***7.30***	***BHS2***
7.69	***2.30***	***BHS1***
9.74	***3.60***	***BHS2***
11.24	1.80	BHS2
12.86	2.60	BHS2
15.08	1.80	BHS2
16.47	60.60	BHS1
17.92	30.00	BHS1
20.90	53.90	BHS2
21.63	62.40	BHS2
22.14	49.80	BHS1
25.34	69.30	BHS1
28.24	1.80	BHS1
Mean:	3.9	
St. Dev.	2.2	

Case number:	292
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	Christchurch Hospital (CHHC)
References:	Wotherspoon et al. (2014), Cannet, NZGD
GPS LAT	-43.53592591
GPS LONG	172.6275195
Liq. layer consist of:	Gravel (GW)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Deconvolution Analysis
Nature of Failure:	There was no clear manifestation of liquefaction effects at the ground surface in the immediate area surrounding the SMS following the Darfield earthquake. The acceleration record from the Darfield earthquake showed no indication of the occurrence of liquefaction in the underlying soils.
Comments:	CPT and Vs are available at the site. amax is reported as 0.17 g by Wotherspoon et al (2014). However, based on the acceleration record data dowloaded from Geonet (2013) 0.198 g and 0.153 g is determined for two component geometric mean of which is 0.174 g. Very close values. 0.174 g is used.
	Hammer energy is taken as 60% since Wotherspoon et al. (2014) presents SPTN values as N60.
	GWT is determined from the figure provided by Wotherspoon et al (2014), probably interpreted from CPT.
	FC data is available.
	Vs,12m is calculated based on the mesaured Vs values.
	Rrup 14.7 km , Rjb=14.3 km Bradley 2012
	Deconvolution analysis were performed succesfully at the SMS. rd is suggested as 0.93 by site response and 0.90 by Cetin and Seed (2004). amax by site response is same with the recorded value (amax=0.174 g)

C.4 Christchurch Hospital (CHHC)

Nearby Geotechnical Site Investigations

Table 13 CHHC geotechnical site investigation summary

Investigation Method	Number	Notes
CPT (CPT)	2	
Borehole/SPT (BH)	2	
V_s – surface wave (SW)	1	
H/V Spectral Ratio (HV)	1	



Figure 60 CHHC geotechnical site investigation location plan

Gravel Conetnt (%):	50.0-100.0
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	5.5 - 7.0
d_{crt} (m)	-	-	-	-	6.3
GWT (m)	-	-	-	-	3.1 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	21.5 ± 0.5
σ_v (kPa)	-	-	-	-	126.8 ± 5.8
σ_v' (kPa)	-	-	-	-	95.3 ± 3.7
a_{max} (g)	-	-	-	-	0.174 ± 0.009
r_d	-	-	-	-	0.90 ± 0.042
CSR	-	-	-	-	0.135 ± 0.009
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	5.0 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	22.0 ± 3.3
C_R	-	-	-	-	0.94
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.00
C_N	-	-	-	-	1.03
$(N_1)_{60}$	-	-	-	-	21.5 ± 3.2
$V_{s,30m}$ (m/s)	-	-	-	-	193.4
$V_{s,12m}$ (m/s)	-	-	-	-	163.9

EVENT PARAMETERS

2010 Darfield Earthquake

Magnitude: 7.10

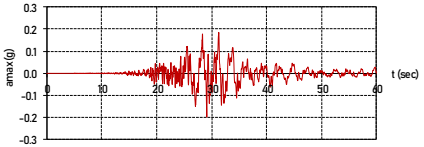
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 14.3

Dip: 82 | Width (km): 10 | R_{jb} (km): 14.3

ACCELERATION TIME HISTORY

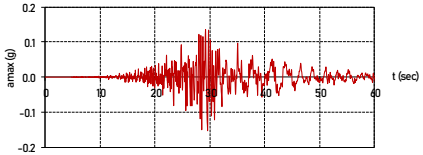
Full Record

N_{H1}	14.3
N_{H2}	24.2
N_{gm}	18.6
PGA_{H1}	0.198
PGA_{H2}	0.153
PGA	0.174
M_w	7.1
$M_{w,cycle}$	7.0



Untill Liquefaction

$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-





0-4 m Silts with organics

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N_1)_{60}$		
BH-2	1.44	4.7	NA	18	1.93	0.85	29.6	GW	not saturated
BH-1	1.55	5.1	NA	14	1.86	0.85	22.3	ML	organics
BH-1	2.99	9.8	NA	8	1.34	0.89	9.6	SM	not saturated
BH-2	2.99	9.8	NA	21	1.34	0.89	25.1	SP-GW	not saturated
BH-2	4.44	14.6	0.12	46	1.17	0.92	49.6	GW	
BH-1	4.47	14.7	0.122	44	1.17	0.92	47.3	GW	
BH-1	***5.95***	***19.5***	***0.127***	***24***	***1.05***	***0.94***	***23.8***	***GW***	
BH-2	***6.48***	***21.3***	***0.127***	***20***	***1.02***	***0.95***	***19.3***	***GW***	
BH-1	7.54	24.7	0.125	49	0.96	0.96	45.0	SW	
BH-2	7.99	26.2	0.124	37	0.94	0.96	33.3	GW	
BH-1	9.01	29.6	0.120	41	0.89	0.97	35.4	GW	
BH-2	9.51	31.2	0.118	37	0.87	0.97	31.4	GW	
BH-1	10.49	34.4	0.115	58	0.84	0.98	47.4	GW	
BH-1	12.01	39.4	0.110	38	0.79	0.98	29.5	GW	
BH-2	***12.46***	***40.9***	***0.108***	***46***	***0.78***	***0.98***	***35.2***	***SP***	
BH-1	***13.49***	***44.3***	***0.106***	***14***	***0.75***	***0.99***	***10.4***	***SP***	***N1,60,average=35 the upper layer is more critic***
BH-2	***13.98***	***45.9***	***0.105***	***46***	***0.74***	***0.99***	***33.6***	***SP***	
BH-1	***15.04***	***49.3***	***0.104***	***58***	***0.72***	***0.99***	***41.1***	***SP***	
BH-2	***15.46***	***50.7***	***0.103***	***58***	***0.71***	***0.99***	***40.6***	***SP***	
BH-1	***16.55***	***54.3***	***0.102***	***58***	***0.69***	***0.99***	***39.5***	***SP***	
BH-2	***16.97***	***55.7***	***0.102***	***58***	***0.68***	***0.99***	***39.1***	***SP***	
BH-1	17.99	59.0	0.102	25	0.66	1.00	16.4	SM-ML	
BH-2	18.45	60.5	0.102	42	0.65	1.00	27.3	SP	
BH-1	19.47	63.9	0.102	5	0.64	1.00	3.2	SP	
BH-2	20	65.6	0.102	1	0.63	1.00	0.6	SM-ML-OL-PT	
BH-1	20.95	68.7	0.102	25	0.62	1.00	15.4	ML	
BH-1	22.5	73.8	0.102	57	0.60	1.00	33.9	GW	
BH-2	23.06	75.7	0.102	58	0.59	1.00	34.1		
BH-2	24.44	80.2	0.103	58	0.57	1.00	33.2		
BH-2	25.88	84.9	0.103	58	0.56	1.00	32.4		
						Mean:	21.5		
						St. Dev.	3.2		

Depth (m)	FC	
2.7	58.5	BH-1
3.8	52.2	BH-1
4.8	8.5	BH-1
10.2	13.9	BH-1
16.7	3.1	BH-1
18.0	72.5	BH-1
18.6	88.3	BH-1
	-	
	-	

Case number:	293
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	Cashmere High School (CMHS)
References:	Wotherspoon et al. (2014), Cannet, NZGD
GPS LAT	-43.56561744
GPS LONG	172.6241694
Liq. layer consist of:	Sand-Silt (SM-ML)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Nature of Failure:	There was no clear manifestation of liquefaction at the ground surface across the entire school site following the Darfield earthquake. The acceleration record from the Darfield event did not show any clear indication of liquefaction of the underlying soils. (Bradley & Cubrinovski 2011).
Comments:	CPT and Vs are available at the site. amax is reported as 0.24 g by Wotherspoon et al (2014). Based on the acceleration record data dowloaded from Geonet (2013) 0.248g and 0.237 g is determined for two component geometric mean of which is 0.243 g. Very close values. 0.243 g is used.
	Hammer energy is taken as 60% since N values are given as N60 by Wotherspoon et al. (2014).
	GWT is determined from the figure provided by Wotherspoon et al (2014), probably interpreted from CPT.
	FC data is available for the critical layer.
	Vs,12m is calculated based on the mesaured Vs values.
	Rrup 14 km , Rjb=13.9 km Bradley 2012
	Site response analysis suggests rd =0.67, Cetin and Seed (2004) suggest the same value. amax by site response analysis is 0.190 g. The measured value at the station is 0.243 g is used.



Figure 69 CMHS geotechnical site investigation location plan

After Wotherspoon et al. (2014)

Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	7.0 - 11.0
d_{crt} (m)	-	-	-	-	9.0
GWT (m)	-	-	-	-	2.0 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	20.0 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	21.5 ± 0.5
σ_v (kPa)	-	-	-	-	191.0 ± 14.8
σ_v' (kPa)	-	-	-	-	122.2 ± 8.6
a_{max} (g)	-	-	-	-	0.243 ± 0.012
r_d	-	-	-	-	0.67 ± 0.058
CSR	-	-	-	-	0.164 ± 0.017
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	23.0 ± 5.6
% PI	-	-	-	-	0-7
N	-	-	-	-	13.4 ± 6.3
C_R	-	-	-	-	0.97
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.00
C_N	-	-	-	-	0.91
$(N_1)_{60}$	-	-	-	-	11.8 ± 5.6
V_{s30m} (m/s)	-	-	-	-	199.4
V_{s12m} (m/s)	-	-	-	-	152.5

EVENT PARAMETERS

2010 Darfield Earthquake

Magnitude: 7.10

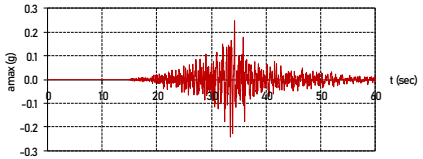
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 13.9

Dip: 82 | Width (km): 10 | R_{jb} (km): 13.9

ACCELERATION TIME HISTORY

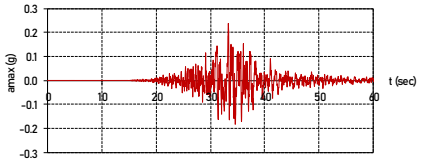
Full Record

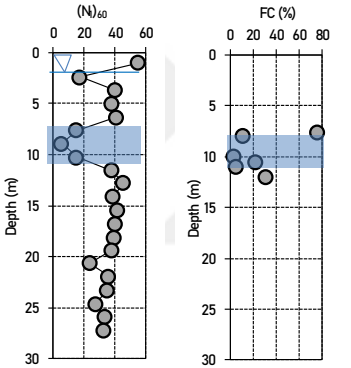
N_{H1}	16.2
N_{H2}	11.5
N_{gm}	13.6
PGA_{H1}	0.248
PGA_{H2}	0.237
PGA	0.243
M_w	7.1
$M_{w,cycle}$	5.9

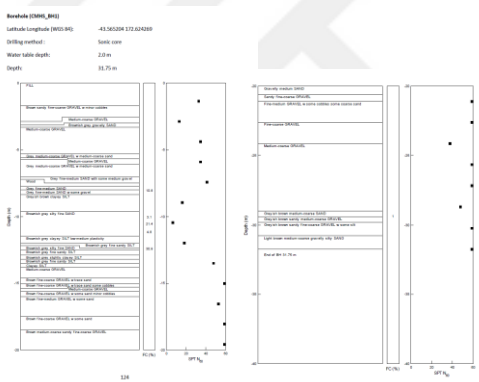


Untill Liquefaction

$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-



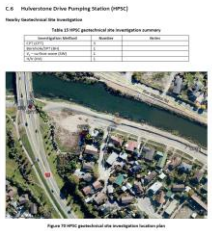




	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
	1.0	3.3	NA	33	2.00	0.84	55.2	Fill
GW	***2.4***	***7.8***	***0.162***	***13***	***1.51***	***0.88***	***17.2***	***Medium coarse gravel*** lower layer is more critical
GW	3.7	12.0	0.182	34	1.31	0.91	40.2	Medium coarse gravel
GW	5.0	16.6	0.187	35	1.16	0.93	37.6	Medium coarse gravel
SP	6.3	20.8	0.183	41	1.06	0.95	41.0	Grey fine-medium sand with some medium gravel
ML	**7.6**	**25.0**	**0.175**	**16**	**0.98**	**0.96**	**15.0**	**Greyish fine-medium sand**
SM	**8.9**	**29.2**	**0.166**	**6**	**0.92**	**0.97**	**5.3**	**Brownish grey silty fine sand**
SM-ML	**10.2**	**33.6**	**0.157**	**18**	**0.86**	**0.98**	**15.1**	**Brownish grey fine sandy silt**
SM-ML	11.6	37.9	0.149	47	0.82	0.98	37.7	Brownish grey fine sandy silt
GW-GP	12.8	42.0	0.144	59	0.78	0.99	45.4	Brown fine-coarse gravel w trace sand
GW-GP	14.1	46.4	0.140	52	0.75	0.99	38.4	Brown fine-medium gravel with some sand
GW-GP	15.5	50.7	0.137	59	0.72	0.99	41.9	Brown fine-medium gravel with some sand
GW-GP	16.8	55.1	0.136	59	0.69	0.99	40.4	Brown medium-coarse sandy fine-coarse gravel
GW-GP	18.1	59.3	0.135	59	0.67	1.00	39.1	fine-medium gravel with some cobbles some coarse sand
GW-GP	19.4	63.5	0.135	59	0.65	1.00	37.9	fine-medium gravel with some cobbles some coarse sand
GW-GP	20.6	67.7	0.135	38	0.63	1.00	23.7	Medium coarse gravel
GW-GP	21.9	71.9	0.135	59	0.61	1.00	35.8	Medium coarse gravel
GW-GP	23.3	76.3	0.135	59	0.59	1.00	34.9	Medium coarse gravel
GW-GP	24.6	80.8	0.135	48	0.58	1.00	27.6	Medium coarse gravel
GW-GP	25.9	85.0	0.136	59	0.56	1.00	33.2	Greyish brown sandy fine-coarse
GW-GP	27.2	89.4	0.136	59	0.55	1.00	32.4	Light brown medium-coarse gravelly silty sand
						Mean:	11.8	
						St. Dev.	5.6	

Depth (m)	FC	
7.60	***75.0***	***ML*** ***guesstimated***
8.00	***10.8***	***Grey fine-medium sand with some medium gravel***
10.00	***3.1***	***Brownish grey silty fine sand***
10.50	***21.4***	***Brownish grey silty fine sand***
11.00	***4.8***	***Brownish grey silty fine sand***
12.00	30.9	Brownish grey silty fine sand
Mean:	23.0	
St. Dev.	29.9	

Case number:	294
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	Hulverone Drive Pumping Station (HPSC)
References:	Wotherspoon et al. (2014), Cannet, NZGD
GPS LAT	-43.50157144
GPS LONG	172.7021909
Liq. layer consist of:	Sand (SM-SP-SW)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Nature of Failure:	There was clear manifestation of liquefaction effects at the ground surface in a large area surrounding the SMS. The acceleration record from the Darfield earthquake showed some indication of the occurrence of liquefaction.
Comments:	CPT and Vs are available at the site. amax is reported as 0.15 g by Wotherspoon et al (2014). However, based on the acceleration record data dowloaded from Geonet (2013) 0.156 g and 0.113 g is determined for two component geometric mean of which is 0.132 g which is used in the analysis. Hammer energy is taken as 60 % since N values are presented as N60. GWT is determined from the figure provided by Wotherspoon et al (2014), probably interpreted from CPT. FC is assigned accordingly with USCS, SP <5. Vs,12m is calculated based on the mesaured Vs values. Rrup 21.7 km , Rjb=21 km Bradley and Cubrinovski 2011. Borehole is located 75 m away from the SMS and it is not consistent with CPT at the SMS. So the site is taken as a regular site not SMS. Deconvolution Analysis were performed for one component of 2010 Darfield Earthquake which suggests rd = 0.838 with amax of 0.113g. However the other component of Darfield suggest a higher amax value of 0.16 g. Forward analysis with CACS suggested amax as 0.138 g and 0.1304 g geometric mean of which is 0.134 g which is very close to measured value at the station. The recorded PGA is 0.132 g and the site is liquefied. Based on the protocol, it is necessary to use PGApredicted that had not liquefied. As a result forward site response analysis is used. Cetin and Seed (2004) suggest rd as 0.76.
Free field	
Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes



After Wotherspoon et al. (2014)

N_{H1}	16.2
N_{H2}	17.8
N_{gm}	17.0
PGA_{H1}	0.156
PGA_{H2}	0.113
PGA	0.132
M_w	7.1
$M_{w,cycle}$	6.5
Untill Liquefaction	
$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	1.5 - 11.0
d_{crt} (m)	-	-	-	-	6.3
GWT (m)	-	-	-	-	1.5 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	126.3 ± 32.7
σ_v' (kPa)	-	-	-	-	79.7 ± 17.3
a_{max} (g)	-	-	-	-	0.134 ± 0.007
r_d	-	-	-	-	0.71 ± 0.042
CSR	-	-	-	-	0.099 ± 0.009
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	7.0 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	8.4 ± 3.6
C_R	-	-	-	-	0.94
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.00
C_N	-	-	-	-	1.13
$(N_1)_{60}$	-	-	-	-	9.0 ± 3.8
$V_{s,30m}$ (m/s)	-	-	-	-	207.0
$V_{s,12m}$ (m/s)	-	-	-	-	128.0

EVENT PARAMETERS

2010 Darfield Earthquake

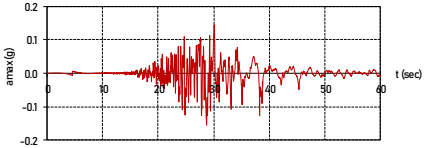
Magnitude: 7.10

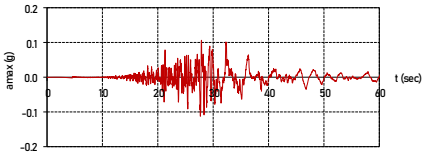
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 21.0

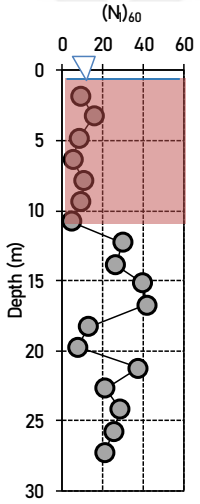
Dip: 82 | Width (km): 10 | R_{jb} (km): 21.0

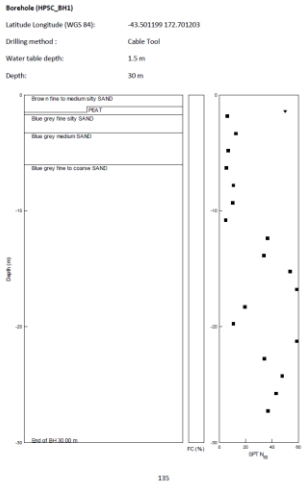
ACCELERATION TIME HISTORY

Full Record









FC is assigned according to USCS

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
SM	***1.8***	***6.0***		***6***	***1.79***	***0.86***	***9.2***	***>12***	Blue grey fien silty sand
SM	***3.3***	***10.8***		***12***	***1.46***	***0.90***	***15.7***	***>12***	blue grey medium sand
SP	***4.9***	***15.9***		***7***	***1.25***	***0.93***	***8.1***	***0-5***	blue grey medium sand
SW	***6.4***	***20.9***		***5***	***1.12***	***0.95***	***5.3***	***0-5***	blue grey fine to coarse sand
SW	***7.9***	***25.8***		***11***	***1.02***	***0.96***	***10.8***	***0-5***	blue grey fine to coarse sand
SW	***9.3***	***30.5***		***10***	***0.95***	***0.97***	***9.2***	***0-5***	blue grey fine to coarse sand
SW	***10.8***	***35.3***		***5***	***0.89***	***0.98***	***4.4***	***0-5***	blue grey fine to coarse sand
SW	12.3	40.4	***Site Response Analysis***	36	0.84	0.98	29.7		blue grey fine to coarse sand
SW	13.9	45.6		34	0.79	0.99	26.6		blue grey fine to coarse sand
SW	15.2	49.8		53	0.76	0.99	39.9		blue grey fine to coarse sand
SW	16.8	55.0		58	0.73	0.99	41.8		blue grey fine to coarse sand
SW	18.3	60.0		19	0.70	1.00	13.2		blue grey fine to coarse sand
SW	19.7	64.6		11	0.67	1.00	7.4		blue grey fine to coarse sand
SW	21.2	69.7		58	0.65	1.00	37.5		blue grey fine to coarse sand
SW	22.7	74.4		34	0.63	1.00	21.3		blue grey fine to coarse sand
SW	24.2	79.4		47	0.61	1.00	28.6		blue grey fine to coarse sand
SW	25.8	84.6		43	0.59	1.00	25.4		blue grey fine to coarse sand
SW	27.3	89.5		36	0.58	1.00	20.7		blue grey fine to coarse sand
						Mean:	9.0		
						St. Dev.	3.8		

Depth (m)	Soil Layering
0	
2	SM
2	PT
3	SM
6	SP
30	SW

Case number:	295
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	Kaiapoi North School (KPOC)
References:	Wotherspoon et al. (2014), Cannet, NZGD
GPS LAT	-43.37646016
GPS LONG	172.6637603
Liq. layer consist of:	Gravel (GW)-Sand (SW)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Deconvolution Analysis
Nature of Failure:	Acceleration records from the Darfield and Christchurch earthquakes had no indication of the occurrence of liquefaction in the underlying soils. There was no clear manifestation of liquefaction effects at the ground surface in the immediate area surrounding the SMS following any of the major earthquakes in the Canterbury earthquake sequence.
Comments:	Vs is available at the site. amax was not reported by Wotherspoon et al (2014). However, based on the acceleration record data dowloaded from Geonet (2013) 0.300 g and 0.344 g is determined for two component geometric mean of which is 0.321 g. 0.321 g is used in the analysis. 0.34 g is suggested by Bradley (2012). Hammer energy is assigned as 60% since SPTN values are presented as N60. GWT is determined from the figure provided by Wotherspoon et al (2014), interpreted from SPT. FC is assigned accordingly with USCS, GW <5. Vs,12m is calculated based on the mesaured Vs values. Rrup 27.6 km , Rjb=25.7 km Bradley and Cubrinovski 2011. Deconvolution analysis were performed succesfully at the site. Site response analysis and measured amax values are determined to be as 0.32 g. rd suggested by the site response analysis is 0.49, Cetin and Seed (2004) suggest rd value of 0.56.
Gravel Content (%):	50.0-100.0
CPT available:	No
Vs available:	Yes

C.8 Kaiapoi North School (KPOC)

Nearby Geotechnical Site Investigation

Table 17 KPOC geotechnical site investigation summary

Investigation Method	Number	Notes
CPT (CPT)	0	Gravelly site
Borehole/SPT (Bh)	1	
V_s - surface wave (SW)	1	
H/V (HV)	1	



Figure 72 KPOC geotechnical site investigation location plan

After Wotherspoon et al. (2014)

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	2.5 - 30.0
d_{crt} (m)	-	-	-	-	16.3
GWT (m)	-	-	-	-	1.2 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	21.5 ± 0.5
σ_v (kPa)	-	-	-	-	345.5 ± 99.1
σ_v' (kPa)	-	-	-	-	197.6 ± 54.3
a_{max} (g)	-	-	-	-	0.321 ± 0.016
r_d	-	-	-	-	0.49 ± 0.075
CSR	-	-	-	-	0.178 ± 0.029
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	57.3 ± 8.6
C_R	-	-	-	-	0.99
C_S	-	-	-	-	1.00
C_R	-	-	-	-	1.00
C_E	-	-	-	-	1.00
C_N	-	-	-	-	0.72
$(N_1)_{60}$	-	-	-	-	40.8 ± 6.1
$V_{s,30m}$ (m/s)	-	-	-	-	257.0
$V_{s,12m}$ (m/s)	-	-	-	-	164.4

EVENT PARAMETERS

2010 Darfield Earthquake

Magnitude: 7.10

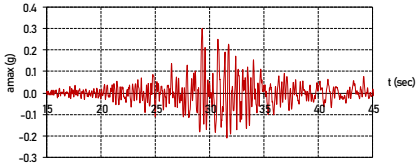
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 25.7

Dip: 82 | Width (km): 10 | R_{jb} (km): 25.7

ACCELERATION TIME HISTORY

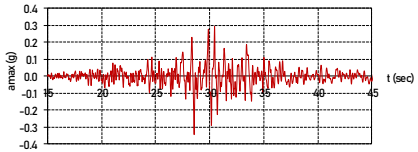
Full Record

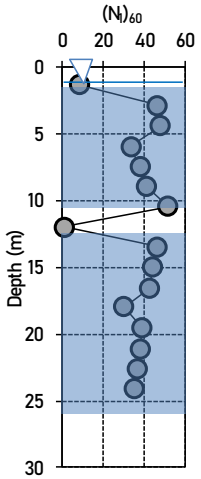
N_{H1}	12.5
N_{H2}	11.6
N_{gm}	12.0
PGA_{H1}	0.300
PGA_{H2}	0.344
PGA	0.321
M_w	7.1
$M_{w,cycle}$	4.8

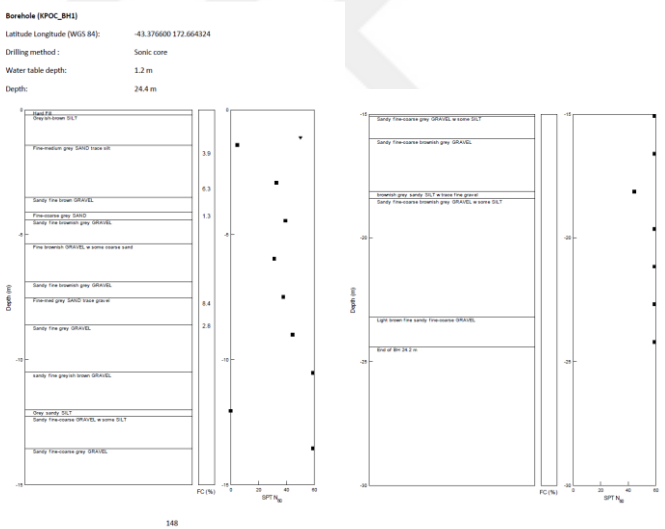


Untill Liquefaction

$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-







	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N_1)_{60}$	
SP	1.3	4.4		5	2.00	0.85	8.4	shallow CN<2.0 very 10 cm below GWT
SP	***2.9***	***9.4***		***33***	***1.59***	***0.89***	***46.4***	
GW	***4.4***	***14.5***		***40***	***1.32***	***0.92***	***48.1***	
GW	***5.9***	***19.5***		***31***	***1.15***	***0.94***	***33.5***	
GW	***7.5***	***24.5***		***38***	***1.04***	***0.96***	***37.8***	
GW	***9.0***	***29.5***	site	***45***	***0.95***	***0.97***	***41.1***	
GW	***10.5***	***34.3***	response	***60***	***0.89***	***0.98***	***51.9***	
ML	12.0	39.3	analysis	1	0.83	0.98	0.9	very thin ML layer about 10 cm
GW	***13.5***	***44.2***	were	***60***	***0.78***	***0.99***	***46.5***	
GW	***15.0***	***49.3***	performed	***60***	***0.74***	***0.99***	***44.3***	
GW	***16.6***	***54.4***	.	***60***	***0.71***	***0.99***	***42.3***	
GW	***18.0***	***59.0***		***45***	***0.68***	***1.00***	***30.3***	
GW	***19.5***	***64.1***		***60***	***0.66***	***1.00***	***39.2***	
GW	***21.1***	***69.2***		***60***	***0.63***	***1.00***	***37.8***	
GW	***22.6***	***74.1***		***60***	***0.61***	***1.00***	***36.6***	
GW	***24.1***	***79.1***		***60***	***0.59***	***1.00***	***35.5***	
						Mean:	40.8	
						St. Dev.	6.1	

Depth (m)	Soil Layering
0.0	
0.2	
1.3	ML
3.5	SP
4.1	GW
4.4	SW
7.4	GW
8.6	SP
11.9	GW
12.3	ML
18.0	GW
18.3	ML
24.4	GW
30.0	

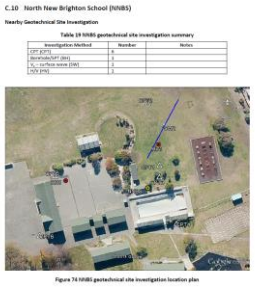
Case number:	296
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	North New Brighton School (NNBS)
References:	Wotherspoon et al. (2014), Cannet, McLaughlin (2017), NZGD
GPS LAT	-43.49541878
GPS LONG	172.7179969
Liq. layer consist of:	Sand (SP)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Nature of Failure:	There was no clear manifestation of liquefaction effects. The acceleration record from the Darfield earthquakedo not indicate liquefaction.
Comments:	CPT and Vs are available at the site. amax is recorded as 0.194 g and 0.187g geometric mean of which is 0.191 g at the SMS which is used in the analysis. amax is reported as 0.21 g by Bradley (2012) and Wotherspoon et al (2014). Bradley and Cubrinovski (2011) suggest amax as 0.194 g. Additionally the figure by Wotherspoon et al (2014) suggests amax=0.187 g but the table in the same study suggest amax= 0.191 g. Acceleration value of 0.20 g is calculated based on the conditional distributions described by Green et al. (2014) and Bradley (2014). amax is determined as 0.144 g by site repsonse analysis which is slightly lower than the measured value of 0.191 g. Site response analysis suggest rd=0.53, Cetin and Seed (2004) suggest rd=0.50. GWT is determined based on SPT soundings. FC is assigned accordingly with USCS, SP <5. Vs,12m is calculated based on the mesaured Vs values. Rrup 23.1 km , Rjb=22.4 km Bradley 2012. Test results are retrieved from NGZD. Probably BH1 and BH30210 are the same where ER is measured as 85%. Based on the detailed description of the site by Wotherspoon et al. (2014), the SMS is located in the elevated portion where no manifestation occured due to liquefaction. However, strong ground motion indicated liquefaction after 2011 Christchurch events. The deep sand layer which has relatively lower SPT-N values are claimed to caused that behavior so that layer was selected as potentially liquefiable layer.





Free field





After Wotherspoon et al. (2014)

CPT available:	Yes
Vs available:	Yes
Gravel Content:	NAV

N_{H1}	19.6
N_{H2}	10.4
N_{gm}	14.3
PGA_{H1}	0.194
PGA_{H2}	0.187
PGA	0.191
M_w	7.1
$M_{w,cycle}$	5.7
Untill Liquefaction	
$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	14.5 - 18.5
d_{crt} (m)	-	-	-	-	16.5
GWT (m)	-	-	-	-	2.3 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	336.4 ± 15.3
σ_v' (kPa)	-	-	-	-	196.9 ± 10.0
a_{max} (g)	-	-	-	-	0.191 ± 0.010
r_d	-	-	-	-	0.53 ± 0.075
CSR	-	-	-	-	0.113 ± 0.017
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	4.5 ± 2.8
% PI	-	-	-	-	0
N	-	-	-	-	14.4 ± 4.3
C_R	-	-	-	-	0.99
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.42
C_N	-	-	-	-	0.72
$(N_1)_{60}$	-	-	-	-	14.6 ± 4.3
V_{s30m} (m/s)	-	-	-	-	211.7
V_{s12m} (m/s)	-	-	-	-	144.7

EVENT PARAMETERS

2010 Darfield Earthquake

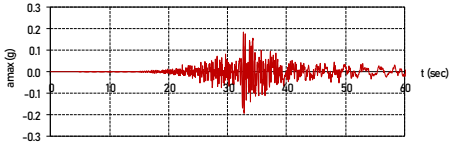
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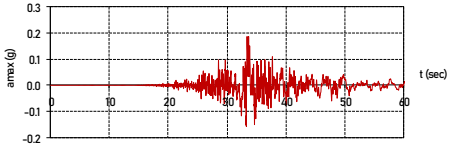
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 22.4

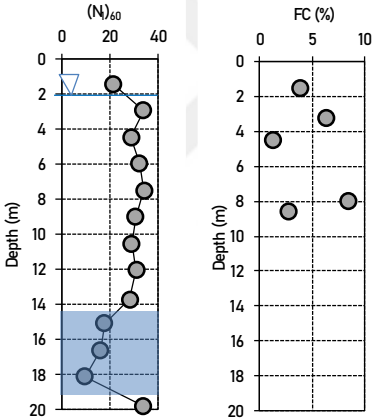
Dip: 82 | Width (km): 10 | R_{jb} (km): 22.4

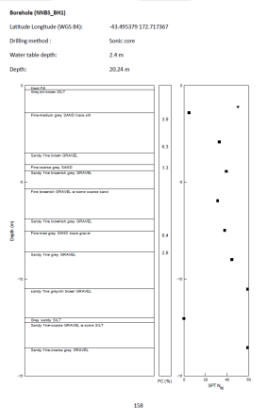
ACCELERATION TIME HISTORY

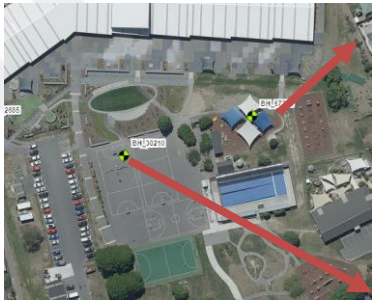
Full Record

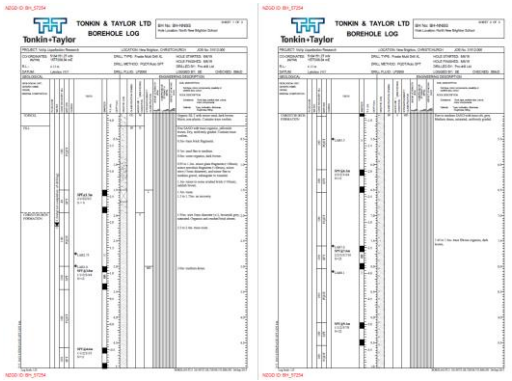


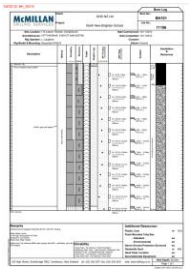












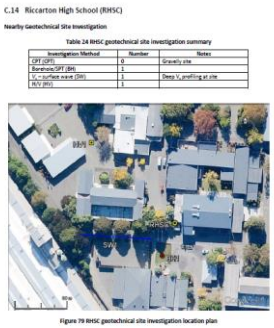
based on borhole retrieved from NZGD

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N_1)_{60}$		FC
SP	1.4	4.6		9	1.96	0.85	21.2	Sand	0-5
SP	2.9	9.6		19	1.42	0.89	34.1	Sand	0-5
SP	4.4	14.6		18	1.24	0.92	29.0	Sand	0-5
SP	6.0	19.6		22	1.11	0.94	32.5	Sand	0-5
SP	7.5	24.5	site response analysis were performed	25	1.01	0.96	34.3	Sand	0-5
SP	9.0	29.5		24	0.94	0.97	30.8	Sand	0-5
SP	10.5	34.5		24	0.88	0.98	29.1	Sand	0-5
SP	12.0	39.5		27	0.83	0.98	31.1	Sand	0-5
SP	13.7	45.0		26	0.78	0.99	28.4	Sand	0-5
SP	***15.1***	***49.5***		***17***	***0.75***	***0.99***	***17.9***	Sand	0-5
SP	***16.6***	***54.5***		***16***	***0.72***	***0.99***	***16.1***	Sand	0-5
SP	***18.1***	***59.4***		***10***	***0.69***	***1.00***	***9.7***	Sand	0-5
SP	19.8	64.9		36	0.66	1.00	33.6	Sand	0-5
						Mean:	14.6		
						St. Dev.	4.3		

Depth (m)	FC
1.5	3.9
3.2	6.3
4.5	1.3
8.0	8.4
8.6	2.8
Mean:	4.5
St. Dev.	2.8

Same layer consistent info this FC is used

Case number:	300
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	Riccarton High School (RHSC)
References:	Wotherspoon et al. (2014), Cannet, NZGD
GPS LAT	-43.536172
GPS LONG	172.564404
Liq. layer consist of:	Gravel (GW)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Deconvolution Analysis
Nature of Failure:	There was no clear manifestation of liquefaction. Acceleration records from the Darfield event did not indicate liquefaction.
Comments:	Vs measurement were available at the site. amax was not reported by Wotherspoon et al (2014). However, based on the acceleration record data dowloaded from Geonet (2013) 0.189 g and 0.219 g is determined for two component, geometric mean of which is 0.203 g which is used in the analysis. 0.21 g is suggested by Bradley (2012). GWT is determined from the figure provided by Wotherspoon et al (2014), interpreted from SPT. FC is assigned accordingly with USCS, GW <5. Vs,12m is calculated based on the mesaured Vs values. Rrup 10 km , Rjb=9.4 km Bradley 2012. Site response analysis suggest rd value of 0.70.



After Wotherspoon et al. (2014)

Gravel Content (%):	***50.0-100.0***
CPT available:	***No***
Vs available:	***Yes***

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	10.0 - 17.0
d_{crt} (m)	-	-	-	-	13.5
GWT (m)	-	-	-	-	6.4 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	21.5 ± 0.5
σ_v (kPa)	-	-	-	-	274.1 ± 25.6
σ_v' (kPa)	-	-	-	-	204.4 ± 14.4
a_{max} (g)	-	-	-	-	0.203 ± 0.010
r_d	-	-	-	-	0.70 ± 0.075
CSR	-	-	-	-	0.124 ± 0.015
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	44.4 ± 9.3
C_R	-	-	-	-	0.99
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.00
C_N	-	-	-	-	0.71
$(N_1)_{60}$	-	-	-	-	30.9 ± 6.5
$V_{s,30m}$ (m/s)	-	-	-	-	285.3
$V_{s,12m}$ (m/s)	-	-	-	-	205.0

EVENT PARAMETERS

2010 Darfield Earthquake

Magnitude: 7.10

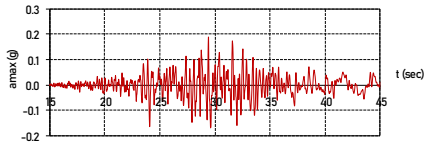
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 9.4

Dip: 82 | Width (km): 10 | R_{jb} (km): 9.4

ACCELERATION TIME HISTORY

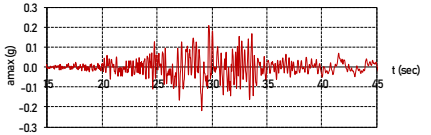
Full Record

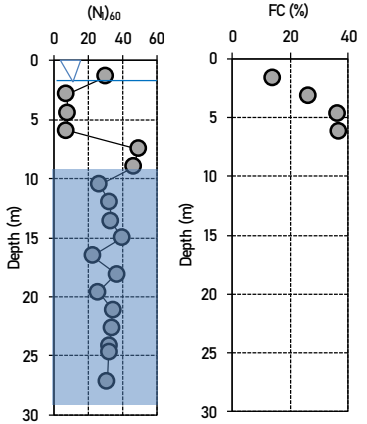
N_{H1}	23.4
N_{H2}	19.1
N_{gm}	21.1
PGA_{H1}	0.189
PGA_{H2}	0.219
PGA	0.203
M_w	7.1
$M_{w,cycle}$	7.8

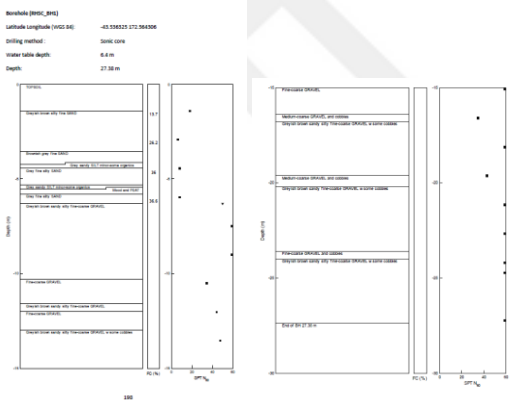


Untill Liquefaction

$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-



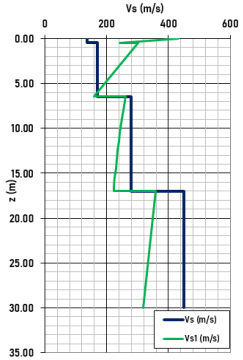




	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
top soil	1.33	4.4		18	2.00	0.85	30.5	SM
grayish brown silty fine sand	2.86	9.4		6	1.37	0.89	7.3	SM
grey sandy silt minor some organics	4.39	14.4		8	1.11	0.92	8.1	CL
ghrey fine silty sand	5.93	19.5		8	0.95	0.94	7.2	SM
grayish brown sandy silt fine-coarse gravel	7.46	24.5		59	0.87	0.96	49.3	GW
grayish brown sandy silt fine-coarse gravel	8.99	29.5		59	0.82	0.97	46.8	GW
fine-coarse gravel	**10.48**	**34.4**		**35**	**0.78**	**0.98**	**26.5**	**GW**
fine-coarse gravel	**12.02**	**39.4**		**45**	**0.74**	**0.98**	**32.6**	**GW**
grayish brown sandy silt fine-coarse gravel with some cobbles	**13.55**	**44.5**	Site response analysis	**48**	**0.70**	**0.99**	**33.4**	**GW**
fine-coarse gravel	**15.04**	**49.3**		**59**	**0.68**	**0.99**	**39.5**	**GW**
medium-coarse gravel and cobbles	**16.53**	**54.2**		**35**	**0.65**	**0.99**	**22.6**	**GW**
greyish brown sandy silty fine-coarse gravel w some cobbles	18.11	59.4		59	0.63	1.00	36.8	GW
greyish brown sandy silty fine-coarse gravel w some cobbles	19.60	64.3		43	0.61	1.00	26.0	GW
greyish brown sandy silty fine-coarse gravel w some cobbles	21.09	69.2		59	0.59	1.00	34.6	GW
greyish brown sandy silty fine-coarse gravel w some cobbles	22.67	74.4		59	0.57	1.00	33.6	GW
greyish brown sandy silty fine-coarse GRAVEL w some cobblesEnd	24.16	79.3		59	0.56	1.00	32.7	GW
greyish brown sandy silty fine-coarse GRAVEL w some cobblesEnd	24.74	81.2		59	0.55	1.00	32.4	GW
greyish brown sandy silty fine-coarse GRAVEL w some cobblesEnd	27.22	89.3		59	0.53	1.00	31.1	GW
						Mean:	30.9	
						St. Dev.	6.5	

Vs profile indicates a sub layer in gravel

This layer has sligthly higher N1,60



Depth (m)	FC
1.55	13.7
3.08	26.2
4.65	36.0
6.15	36.6
Mean:	
St. Dev.	

Case number:	302
Earthquake:	2010 Darfield Earthquake
Magnitude:	7.1
Location:	Styx Mill Transfer Station (SMTC)
References:	Wotherspoon et al. (2014), Cannet, NZGD
GPS LAT	-43.4675293
GPS LONG	172.6138611
Liq. layer consist of:	fine-coarse gravel w minor cobbles
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Nature of Failure:	There was no clear manifestation of liquefaction. Acceleration records from the Darfield event did not indicate liquefaction.
Comments:	Vs is available at the site. amax was not reported by Wotherspoon et al (2014). However, based on the acceleration record data dowloaded from Geonet (2013) 0.160 g and 0.186 g is determined for two component geometric mean of which is 0.172 g which is used the analysis. 0.18 g is suggested by Bradley (2012). Site response analysis suggest rd =0.92 and Cetin and Seed (2004) suggest rd as 0.81. amax is calculated as 0.117 g by site respose which is lower than the measured value at the SMS (0.172 g) GWT is determined from the figure provided by Wotherspoon et al (2014), interpreted from SPT. Vs,12m is calculated based on the mesaured Vs values. Rrup 10.7 km , Rjb=10.8 km Bradley and Cubrinovski (2011). FC info was insonsistent for ML layer hence FC is assigned as >50.

C.16 Styx Mill Transfer Station (SMTC)

Nearby Geotechnical Site Investigation

Table 26 SMTC geotechnical site investigation summary

Investigation Method	Number	Notes
CPT (CPT)	0	Gravelly site
Borehole/SPT (BH)	1	
V_s = surface wave (SW)	1	
H/V (HV)	1	



Figure 81 SMTC geotechnical site investigation location plan

After Wotherspoon et al. (2014)

Gravel Content (%):	50.0-100.0
CPT available:	No
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	7.0 - 11.0
d_{crt} (m)	-	-	-	-	9.0
GWT (m)	-	-	-	-	1.0 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	20.0 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	21.5 ± 0.5
σ_v (kPa)	-	-	-	-	192.6 ± 14.9
σ_v' (kPa)	-	-	-	-	114.0 ± 8.8
a_{max} (g)	-	-	-	-	0.172 ± 0.026
r_d	-	-	-	-	0.92 ± 0.058
CSR	-	-	-	-	0.174 ± 0.028
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	5.9 ± 5.8
% PI	-	-	-	-	0
N	-	-	-	-	47.2 ± 6.2
C_R	-	-	-	-	0.97
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.00
C_N	-	-	-	-	0.94
$(N_1)_{60}$	-	-	-	-	43.2 ± 5.7
$V_{s,30m}$ (m/s)	-	-	-	-	222.1
$V_{s,12m}$ (m/s)	-	-	-	-	183.2

EVENT PARAMETERS

2010 Darfield Earthquake

Magnitude: 7.10

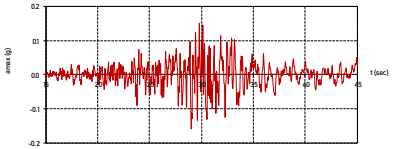
Fault Type: Strike Slip | Z_{tor} (km): 0 | R_{rup} (km): 16

Dip: 82 | Width (km): 10 | R_{jb} (km): 16.0

ACCELERATION TIME HISTORY

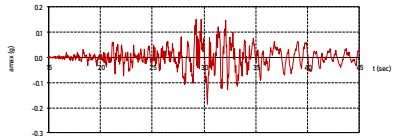
Full Record

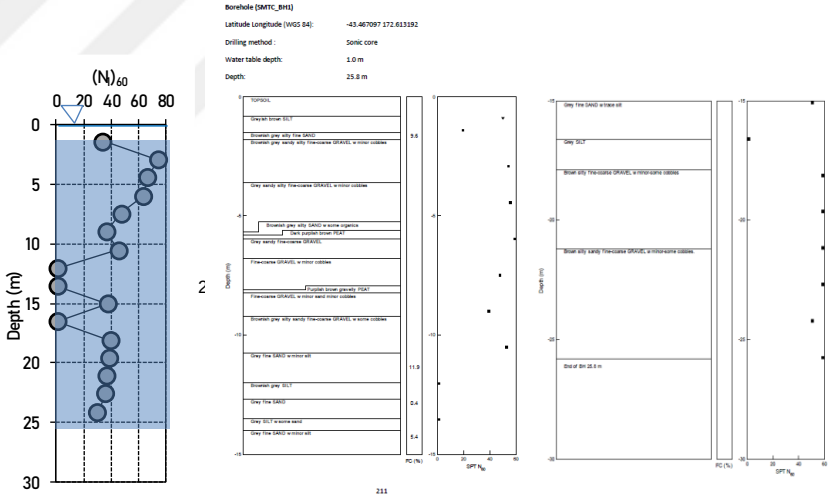
N_{H1}	23.5
N_{H2}	12.2
N_{gm}	16.9
PGA_{H1}	0.160
PGA_{H2}	0.186
PGA	0.172
M_w	7.1
$M_{w,cycle}$	6.7



Untill Liquefaction

$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-





		Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
ML	greyish brown silt	1.4	4.4	0.127	20	2.00	0.85	33.9	CN>2 exclude
GW	***brownish grey sandy fine-coarse gravel w cobbles***	***2.9***	***9.5***	***0.157***	***54***	***1.55***	***0.89***	***74.4***	
GW	***grey sandy silt fine-coarse gravel w minor cobbles***	***4.4***	***14.5***	***0.165***	***56***	***1.30***	***0.92***	***66.9***	
GW	***grey sandy fine-coarse gravel***	***6.0***	***19.6***	***0.166***	***59***	***1.14***	***0.94***	***63.2***	
GW	***fine-coarse gravel w minor cobbles***	***7.4***	***24.3***	***0.161***	***48***	***1.03***	***0.96***	***47.4***	
GW	***fine-coarse gravel w minor cobbles***	***9.0***	***29.4***	***0.154***	***40***	***0.95***	***0.97***	***36.6***	
GW	***brownish grey silty sandy fine-coarse gravel w some cobbles***	***10.5***	***34.4***	***0.145***	***53***	***0.88***	***0.98***	***45.5***	
ML-GP	brownish grey silt	12.0	39.5	0.137	1	0.82	0.98	0.8	plastic material
ML-GP	grey silt w some sand	13.5	44.4	0.131	1	0.78	0.99	0.8	plastic material
GW	***grey fine sand w minor silt***	***15.0***	***49.3***	***0.126***	***51***	***0.74***	***0.99***	***37.5***	
ML	grey silt	16.5	54.2	0.123	1	0.71	0.99	0.7	plastic material
GW	***brown silty fine-coarse gravel w minor some cobbles***	***18.12***	***59.4***	***0.121***	***59***	***0.68***	***1.00***	***39.8***	
GW	***brown silty fine-coarse gravel w minor some cobbles***	***19.56***	***64.2***	***0.120***	***59***	***0.65***	***1.00***	***38.4***	
GW	***brown silty sandy fine-coarse gravel w minor some***	***21.09***	***69.2***	***0.119***	***59***	***0.63***	***1.00***	***37.1***	
GW	***brown silty sandy fine-coarse gravel w minor some***	***22.57***	***74.0***	***0.119***	***59***	***0.61***	***1.00***	***35.9***	low CSR
GW	***brown silty sandy fine-coarse gravel w minor some***	***24.13***	***79.2***	***0.119***	***51***	***0.59***	***1.00***	***30.1***	low CSR
GW	***brown silty sandy fine-coarse gravel w minor some***	***26***	***85.3***	***0.119***	***59***	***0.57***	***1.00***	***33.5***	low CSR
							Mean:	43.2	
							St. Dev.	5.7	

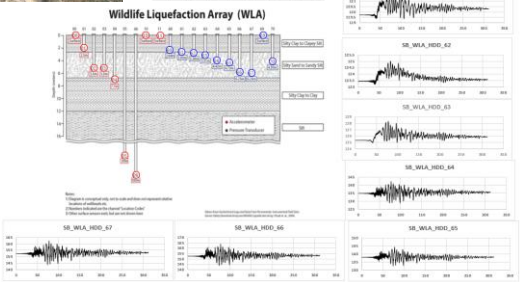
inconsisten FC info for ML

Depth (m)	FC
1.67	***9.6***
11.33	***11.9***
12.81	***0.4***
14.25	***5.4***
	5.9
	5.8

Case number:	362
Earthquake:	2010 El Mayor-Cucapah (Baja) Earthquake
Magnitude:	7.2
Location:	Wildlife Array
References:	Greenfield (2018), El-Sekelly et al 2017, Mccrink et al 2011, USGS, NGL. Bennett et al. (1984) and Fear et al. (1995), Youd and Wieczorek (1984),Bierschwale (1984),
Nature of Failure:	No liquefaction manifestation. Co-located piezometric recordings indicates non liquefaction.
GPS LAT	33.0976
GPS LONG	-115.5306
Liq. layer consist of:	Silty Sand
Geological Unit:	Holocene floodplain
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much ad 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The site is very closely monitored. Strong ground motion seismometers were installed at the surface and at 6.7 m depth. Piezometers were installed almost at every meter along the potentially liquefiable layer of thickness 4 m. A: very loose and very soft interbedded micaceous sandy silt, silt and clayey silts (0-2.5 m) flood plain deposits B: very loose to loose moderately sorted sandy silt (2.5-6.8m); point bar deposits C: silty clay (medium to very stiff) and clayey silt (medium to stiff); lacustrine deposit. Vs1=145–155 m/s. Energy ratio ~68 %" Upper silty clayye layer is very soft (SPT-N=1) hence it is difficult to estimate rd. As a result site response analysis is performed to estimate rd.
Gravel Content (%):	0
CPT available:	Yes
Vs available:	Yes



http://www.nees.ucsb.edu/facilities/wla



Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	2.7 - 7.0
d_{crt} (m)	-	-	-	-	4.9
GWT (m)	-	-	-	-	1.2 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	87.9 ± 13.7
σ_v' (kPa)	-	-	-	-	52.0 ± 6.8
a_{max} (g)	-	-	-	-	0.129 ± 0.006
r_d	-	-	-	-	0.72 ± 0.034
CSR	-	-	-	-	0.102 ± 0.008
M_w	-	-	-	-	7.20
D_{50}	-	-	-	-	0.089 ± 0.012
% Fines	-	-	-	-	27.4 ± 9.0
% PI	-	-	-	-	0
N	-	-	-	-	8.0 ± 3.5
C_R	-	-	-	-	0.92
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.13
C_N	-	-	-	-	1.40
$(N_1)_{60}$	-	-	-	-	11.6 ± 5.1
$V_{s,30m}$ (m/s)	-	-	-	-	179.0
$V_{s,12m}$ (m/s)	-	-	-	-	131.0

EVENT PARAMETERS

2010 El Mayor-Cucapah (Baja) Earthquake

Magnitude: 7.20

Fault Type: strike-slip fault | Z_{tor} (km): 0 | R_{rup} (km): 58.0

Dip: 63 | Width (km): 20 | R_{jb} (km): 58.0

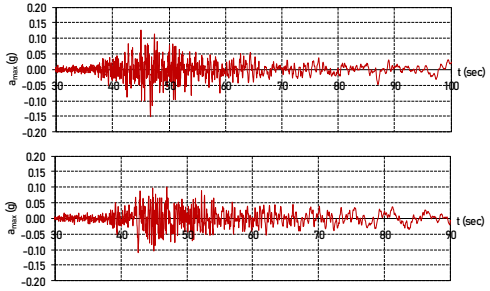
ACCELERATION TIME HISTORY

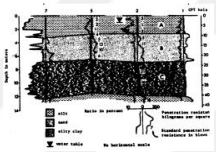
Full Record

N_{H1}	31.7
N_{H2}	14.1
N_{gm}	21.1
PGA_{H1}	0.110
PGA_{H2}	0.151
PGA	0.129
M_w	7.2
$M_{w,cycle}$	6.8

Untill Liquefaction

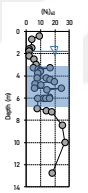
$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-

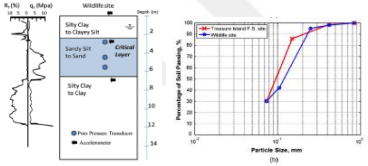






El-Sekelly et al. (2017)





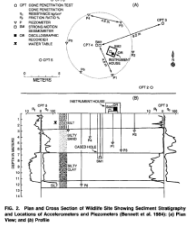


FIG. 2. Plan and Cross Section of Wildlife Site Showing Sediment Stratigraphy and Locations of Accelerometers and Piezometers (Bennett et al. 1998): (a) Plan View; and (b) Profile

	Depth (m)	Depth (ft)	CSR	N	C_N	C_E	$(N1)_{60}$		
A	0.42	1.3		2	2.00	0.80	9.1	silt, ML	2Ng1
	0.69	2.3		2	2.00	0.81	3.7	silty to silty sand	5Ng
	1.45	4.8		2	2.00	0.84	3.8	clayey silt	5Ng
B	1.58	5.2		1	2.00	0.85	1.9	silty clay, ML	2Ng1
A	1.75	5.8		1	2.00	0.85	1.9	silt	1Ns
	1.75	5.8		1	2.00	0.85	1.9	silt	3Ns
	2.21	7.3		1	1.90	0.86	1.9	silt	5Ng
C	2.59	8.2		3	1.82	0.87	5.4	sandy silt, ML	2Ng1
	2.97	9.8		4	1.70	0.88	6.8	sandy silt	5Ng
B	3.28	10.8		3	1.64	0.89	5.0	sand to silty sand	1Ns
	3.28	10.8		10	1.64	0.89	16.6	sand to silty sand	3Ns
C	3.43	11.2		5	1.61	0.89	8.2	sand, SM	2Ng1
	3.48	11.4		6	1.60	0.90	9.8	silty sand	2Ng3
	3.58	11.8		6	1.58	0.90	9.7	silty sand	2Ng2
	3.73	12.3		8	1.56	0.90	8.0	very fine sand	5Ng
B	4.19	13.8		5	1.49	0.91	7.7	sand to silty sand	1Ns
	4.19	13.8		9	1.49	0.91	13.8	sand to silty sand	3Ns
	4.35	14.2		11	1.47	0.91	16.7	sand, SM	2Ng1
	4.50	14.8		13	1.44	0.92	19.5	very fine sand	5Ng
	4.70	15.4		4	1.42	0.92	5.9	silty sand	2Ng3
	4.80	15.8		7	1.40	0.92	10.3	silty sand	2Ng2
B	5.11	16.8		4	1.37	0.93	5.7	sand to silty sand	1Ns
	5.11	16.8		17	1.37	0.93	24.4	sand to silty sand	3Ns
	5.26	17.3		10	1.35	0.93	14.2	very fine sand	5Ng
	5.91	19.4		12	1.28	0.94	16.4	silty sand	2Ng3
B	6.02	19.8		9	1.27	0.94	12.2	sand to silty sand	1Ns
	6.02	19.8		10	1.27	0.94	13.5	silty sand	2Ng2
	6.02	19.8		12	1.27	0.94	16.3	sand to silty sand	3Ns
	6.02	19.8		6	1.27	0.94	8.1	silty sand	5Ng
	6.93	22.8		6	1.20	0.95	7.7	sand, SM	2Ng1
	7.12	23.4		11	1.18	0.95	14.0	clayey silt	2Ng3
	7.24	23.8		14	1.17	0.95	17.7	silty sand	2Ng2
	8.46	27.8		21	1.09	0.96	25.1	silty clay, CH	2Ng1
	9.98	32.8		24	1.02	0.97	26.9	clayey silt, MH	2Ng1
	12.73	41.8		18	0.91	0.98	18.2	silt, ML	2Ng1
						Mean:	11.6		
						St. Dev.	5.1		

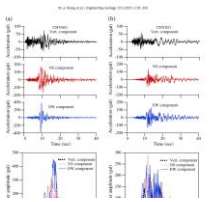
	Depth (ft)	FC	Sand	Silt	Clay	D_{50}		wn	wl	PI	LI
sandy silt, ML	0.6	82.0	18.0	72.0	10.0	0.046	2Ng1				
silt ML	1.3	99.0	1.0	87.0	12.0	0.015	2Ng1	32.0			
silt	4.3	98.0	2.0	76.0	22.0	0.011	2Ng1	28.0			
silt ML	4.7	93.0	7.0	76.0	17.0	0.038	2Ng1	31.0	30.0	5.0	1.6
silty clay ML	5.2	99.0	1.0	41.0	58.0	0.003	2Ng1	33.0	38.0	11.0	0.4
silt ML	7.5	89.0	11.0	76.0	13.0	0.034	2Ng1				
sandy silt ML	8.2	70.0	30.0	66.0	4.0	0.052	2Ng1				
silty sand ML	*10.5*	*34.0*	*66.0*	*34.0*	*0.0*	*0.076*	*2Ng1*				
sand SM	*11.2*	*17.0*	*83.0*	*17.0*	*0.0*	*0.096*	*2Ng1*				
silty sand SM	*13.5*	*27.0*	*73.0*	*26.0*	*1.0*	*0.090*	*2Ng1*				
sand SM	*14.2*	*20.0*	*80.0*	*20.0*	*0.0*	*0.100*	*2Ng1*				
silty sand SM	*18.3*	*33.0*	*67.0*	*29.0*	*4.0*	*0.082*	*2Ng1*				
sand SM	*22.8*	*18.0*	*82.0*	*17.0*	*1.0*	*0.102*	*2Ng1*				
silty clay CH	27.9	100.0	0.0	34.0	66.0	0.002	2Ng1	26.0	64.0	26.0	-0.5
clayey silt MH	32.8	100.0	0.0	57.0	43.0	0.005	2Ng1	24.0	57.0	22.0	-0.5
silt ML	41.8	100.0	1.0	84.0	16.0	0.026	2Ng1	24.0	30.0	4.0	-0.5
clayey silt, SYR 4/2, (CL-ML)	1.3	87.0	13.0	69.0	18.0	0.020	3Ag	27.0	26.0	5.0	1.2
clayey silt, SY 4.5/1	3.0	89.0	11.0	89.0	0.0		3Ag	31.0			
silt, SY 4.5/1	3.5	97.0	3.0	75.0	22.0	0.016	3Ag				
silt, SY 4.5/1, (CL-ML)	4.5	98.0	2.0	78.0	20.0	0.020	3Ag	43.0	28.0	6.0	3.5
sandy silt, 2.5Y 3/2, (ML)	5.8	56.0	44.0	44.0	12.0	0.056	3Ag	28.0			
silt, 2.5Y 3/2, (CL)	7.3	96.0	4.0	78.0	18.0	0.025	3Ag	34.0	30.0	9.0	1.6
sandy silt, 10YR 4/2, ML	9.0	63.0	37.0	53.0	10.0	0.056	3Ag				
sandy silt, 10YR 4/2, ML	9.5	56.0	44.0	46.0	10.0	0.057	3Ag				
silty sand, 10YR 4/2, SM	*11.4*	*31.0*	*69.0*	*26.0*	*5.0*	*0.086*	*3Ag*				
sand, 10YR 4/2, (SM)	*13.5*	*22.0*	*78.0*	*19.0*	*3.0*	*0.095*	*3Ag*				
silty sand, 10YR 4/2, SM	*15.0*	*26.0*	*74.0*	*23.0*	*3.0*	*0.088*	*3Ag*				
silty sand, 10YR 4/2, SM	*18.0*	*31.0*	*69.0*	*26.0*	*5.0*	*0.086*	*3Ag*				
silty sand, 10YR 3/3,SM	*19.5*	*49.0*	*51.0*	*43.0*	*6.0*	*0.063*	*3Ag*				
sand, 10YR 3/3, (SM)	*21.0*	*21.0*	*79.0*	*18.0*	*3.0*	*0.109*	*3Ag*				
clayey silt, 10YR 4/2, CL	22.8	96.0	4.0	66.0	30.0	0.012	3Ag	30.0	36.0	16.0	0.6
clayey silt, 10YR 4/2	24.5	97.0	3.0	71.0	26.0	0.013	3Ag	30.0			
silty clay, SYR 4/2	25.5	97.0	3.0	41.0	56.0	0.003	3Ag	28.0			
silty clay, SYR 4/2	27.5	99.0	1.0	28.0	71.0	0.001	3Ag	29.0			
clay, SYR 4/2, (CH)	30.0	98.0	2.0	23.0	75.0	0.001	3Ag	27.0	68.0	41.0	0.0
silty clay, SYR 4/2	33.0	98.0	2.0	29.0	69.0	0.002	3Ag	28.0			
clay, SYR 4/2, (CH)	36.0	99.0	1.0	11.0	88.0	0.001	3Ag	26.0	68.0	39.0	-0.1
silty clay, SYR 4/2	37.0	92.0	8.0	26.0	66.0	0.002	3Ag	31.0			
silt, (ML)	40.0	88.0	12.0	75.0	13.0	0.046	3Ag	26.0			
clayey silt	41.0	98.0	2.0	56.0	42.0	0.007	3Ag	25.0			
silt, 5Y 4/2, (ML)	44.0	97.0	3.0	79.0	18.0	0.023	3Ag	27.0	28.0	4.0	1.0
silt, 5Y 4/2, (ML)	46.5	96.0	4.0	86.0	10.0	0.030	3Ag	28.0			
clayey silt, 10YR 3.5/2	49.0	88.0	12.0	74.0	14.0	0.028	3Ag	30.0			
silt, 10YR 3.5/2, (ML)	51.5	96.0	4.0	84.0	12.0	0.022	3Ag	31.0			
silt, 10YR 3.5/2, (ML)	53.3	95.0	5.0	82.0	13.0	0.028	3Ag	29.0			
sandy silt, 10YR 3.5/2,	56.0	85.0	15.0	71.0	14.0	0.034	3Ag				
sandy silt, 10YR 3.5/2,	58.0	66.0	34.0	56.0	10.0	0.050	3Ag				
silty clay, SYR 4/2	58.8	95.0	5.0	31.0	64.0	0.002	3Ag				
silty sand, SYR 4/3, (SM)	59.5	49.0	51.0	39.0	10.0	0.063	3Ag				
clayey silt, SYR 4/2.5,	61.0	94.0	6.0	66.0	28.0	0.015	3Ag	24.0			
clayey silt, SYR 4/2.5	62.5	97.0	3.0	73.0	24.0	0.018	3Ag	28.0			
sand, (SM)	66.0	14.0	86.0	14.0		0.114	3Ag				
silty sand, 7. SYR 4/2, (SM)	68.0	34.0	66.0	28.0	6.0	0.088	3Ag				
silty sand, 7. SYR 4/2, (SM)	70.0	53.0	47.0	41.0	12.0	0.056	3Ag				
silt, 7. SYR 4/2, (ML)	72.0	96.0	4.0	82.0	14.0	0.023	3Ag	31.0			
clayey silt, 7. SYR 4/2	73.0	96.0	4.0	69.0	27.0	0.013	3Ag	31.0			
clayey silt, SYR 4/2.5, (CL)	74.5	95.0	5.0	61.0	34.0	0.009	3Ag	31.0	33.0	12.0	0.8
clayey silt, SYR 4/2.5	76.5	90.0	10.0	61.0	29.0	0.013	3Ag				
sandy silt, (ML)	78.0	80.0	20.0	66.0	14.0	0.041	3Ag	24.0			
silty sand, (SM)	80.0	29.0	71.0	23.0	6.0	0.088	3Ag				
clayey silt	82.0	85.0	15.0	65.0	20.0	0.036	3Ag	25.0			
silty clay, 7. SYR 4/2	83.0	96.0	4.0	42.0	54.0	0.003	3Ag	33.0			
clayey silt, 7. SYR 4/2	84.0	99.0	1.0	59.0	40.0	0.010	3Ag	27.0			
silty clay, 7. SYR 4/2, (CH)	85.0	99.0	1.0	39.0	60.0	0.002	3Ag	32.0	51.0	27.0	0.3
silty clay, 7. SYR 4/2	86.5	98.0	2.0	48.0	50.0	0.004	3Ag	35.0			
	Mean:	27.4	72.6	24.8	2.6	0.089					
	St. Dev.	9.0	9.0	7.8	2.2	0.012					

Case number:	340
Earthquake:	2010 Jia Shan Earthquake
Magnitude:	6.3 (USGS)
Location:	Siinhua
References:	Chang et al 2011
Nature of Failure:	Sand boils from soil liquefaction were observed in Sinhua
GPS LAT	23.05055 coordinates are approximate
GPS LONG	120.290783
Liq. layer consist of:	silty sand (SM)
Geological Unit:	flood plains and terrace deposits
Site Response Anlaysis:	No
Comments:	SPT, SCPTu and MASW are available at the site. There exist 3 boreholes, one of them was performed after the earthquake on sand boil and it has FC, PI information etc. Hence that borehole is taken into consideration. Huang et al 2011 suggested PGA as 0.189 g (Mw=6.4). CHY021 is the closest station to Sinhua site and VS30 of the SMS is 212 m/s which is located on the same geological formation with the site. A site specific amplification factor is calculated and PGA of CHY021 is adjusted as 0.172 g which is in good correlation with the locally calibrated model.
Gravel Content (%):	0
CPT available:	Yes
Vs available:	Yes









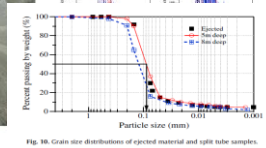


Table 1
Summary of seismic stations around the Sinhua site.

Station	Distance to epicenter (km)	Distance to Site (km)	MHA (gal) Vertical/NS/EW	Geologic formation
CHY063	37.6	6.4	71.2/ 174.7/ 385.2	Toukoushan formation
CHY021	44.1	3.2	57.4/ 136.1/ 110.9	Quaternary alluvium
CHY023	43.3	9.5	37.0/ 85.0/ 121.5	Quaternary alluvium
CHY078	48.1	5.9	25.3/ 61.5/ 101.7	Quaternary alluvium

Note: The epicenter distance for the Sinhua site is 44 km.

Fig. 2. Sand boils at Sinhua site (2010/03/05).

Fig. 10. Grain size distributions of ejected material and split tube samples.

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{cr1c} range (m)	-	-	-	-	4.5 - 9.5
d_{cr1} (m)	-	-	-	-	7.0
GWT (m)	-	-	-	-	1.2 ± 0.2
γ_{moist} (kN/m^3)	-	-	-	-	20.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	19.7 ± 0.8
σ_v (kPa)	-	-	-	-	139.2 ± 17.0
σ_v' (kPa)	-	-	-	-	82.6 ± 9.6
a_{max} (g)	-	-	-	-	0.172 ± 0.034
r_d	-	-	-	-	0.56 ± 0.093
CSR	-	-	-	-	0.105 ± 0.028
M_w	-	-	-	-	6.30
D_{50}	-	-	-	-	0.090 ± 0.050
% Fines	-	-	-	-	29.2 ± 10.3
% PI	-	-	-	-	0
N	-	-	-	-	6.8 ± 3.5
C_R	-	-	-	-	0.95
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.15
C_N	-	-	-	-	1.11
$(N_1)_{60}$	-	-	-	-	8.2 ± 4.2
V_{s30m} (m/s)	-	-	-	-	NA
V_{s12m} (m/s)	-	-	-	-	112.8

EVENT PARAMETERS

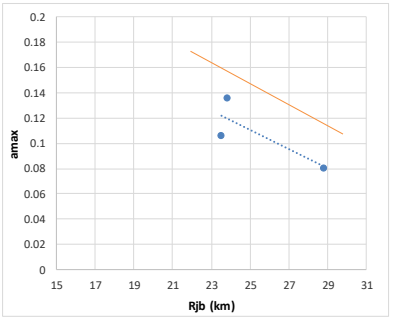
2010 Jia Shan Earthquake — hanging wall site

Magnitude: 6.30 — approximate measurement

Fault Type: southwestward — Z_{tor} (km): 10 — R_{rup} (km): 26.3

Dip: 41 — Width (km): 13 — R_{jb} (km): 21.1

ACCELERATION TIME HISTORY



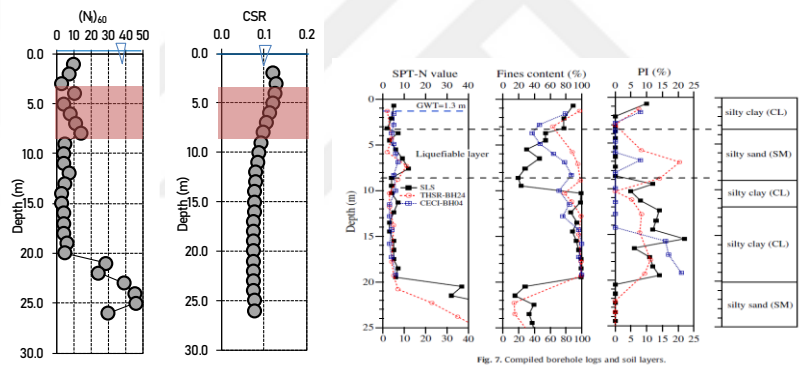


Fig. 7. Compiled borehole logs and soil layers.

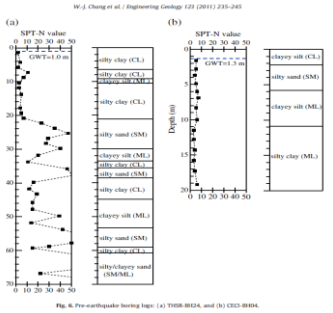


Fig. 6. Pre-earthquake boring logs: (a) THSR-BH24, and (b) CECI-BH04.

pre-earthquake soil strata
THSR-BH24 located 100 m away from the closest sand boil spot.
CECI-BH04 borehole located only 30 m away from the closest sand boil spot.

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	Soil Description	Sand	Silt	Clay	FC	USCS	PI	γ(t/m3)	Borehole
silty clay (CL)	1	3.3	NA	5	2.00	0.84	9.6	yellow silty clay 1.3 m	11	45	44	89	CL	10	1.97	SLS
silty clay (CL)	2	6.6	0.12	4	1.75	0.87	7.0	yellow silty fine sand 2.9 m	23	52	24	76	ML	NP	1.78	SLS
silty clay (CL)	3	9.8	0.13	2	1.54	0.89	3.2		23	57	20	77	ML	NP	1.85	SLS
silty sand (SM)	4	13.1	0.13	7	1.39	0.91	10.2	grey silty clay 3.4 m	46	40	14	54	ML	NP	2	SLS
silty sand (SM)	***5***	***16.4***	***0.12***	***3***	***1.27***	***0.93***	***4.1***	***grey silty fine sand with***	***70***	***27***	***3***	***30***	***SM***	***NP***	***1.83***	SLS
silty sand (SM)	***6***	***19.7***	***0.11***	***6***	***1.18***	***0.94***	***7.7***	***silt seams 8.1 m***	***54***	***43***	***3***	***46***	***SM***	***NP***	***1.98***	SLS
silty sand (SM)	***7***	***23.0***	***0.11***	***9***	***1.11***	***0.95***	***10.9***		***72***	***23***	***5***	***28***	***SM***	***NP***	***1.87***	SLS
silty sand (SM)	***8***	***26.2***	***0.10***	***12***	***1.05***	***0.96***	***13.9***		***81***	***15***	***4***	***19***	***SM***	***NP***	***1.91***	SLS
silty sand (SM)	***9***	***29.5***	***0.09***	***4***	***1.00***	***0.97***	***4.4***	***grey silty fine sand 9.0 m***	***77***	***19***	***4***	***23***	***SM***	***NP***	***1.79***	SLS
silty clay (CL)	10	32.8	0.09	4	0.95	0.97	4.3	grey silty clay with silt	2	54	44	98	CL	12	1.78	SLS
silty clay (CL)	11	36.1	0.08	4	0.91	0.98	4.1	seams 10.7 m	1	54	45	99	CL-ML	5	1.89	SLS
silty clay (CL)	12	39.4	0.08	7	0.88	0.98	7.0	grey silty clay 11.9 m	2	54	44	98	CL	8	1.87	SLS
silty clay (CL)	13	42.7	0.08	5	0.85	0.99	4.8	grey silty clay with silt	14	46	40	86	CL	14	2.05	SLS
silty clay (CL)	14	45.9	0.08	3	0.82	0.99	2.8	seams 20.0 m	6	54	40	94	CL	13	1.83	SLS
silty clay (CL)	15	49.2	0.08	3	0.79	0.99	2.7		12	53	35	88	CL	12	1.82	SLS
silty clay (CL)	16	52.5	0.08	5	0.77	0.99	4.4		7	50	43	93	CL	22	1.78	SLS
silty clay (CL)	17	55.8	0.08	5	0.75	0.99	4.3		4	58	38	96	CL-ML	5	1.97	SLS
silty clay (CL)	18	59.1	0.08	5	0.73	1.00	4.2		1	48	51	99	CL	11	1.9	SLS
silty clay (CL)	19	62.3	0.08	7	0.71	1.00	5.7		1	51	48	99	CL	12	2.04	SLS
silty sand (SM)	20	65.6	0.08	6	0.69	1.00	4.8	grey silty fine sand ~30.0 m	1	51	48	99	CL	14	1.97	SLS
silty sand (SM)	21	68.9	0.08	37	0.68	1.00	28.8		72	23	5	28	SM	-	1.91	SLS
silty sand (SM)	22	72.2	0.08	32	0.66	1.00	24.4		85	10	5	15	SM	-	1.87	SLS
silty sand (SM)	23	75.5	0.08	53	0.65	1.00	39.6		61	34	5	39	SM	-	1.89	SLS
silty sand (SM)	24	78.7	0.08	62	0.64	1.00	45.4		67	28	5	33	SM	-	2.01	SLS
silty sand (SM)	25	82.0	0.08	64	0.62	1.00	46.0		63	32	5	37	SM	-	2.02	SLS
silty sand (SM)	26	85.3	0.08	42	0.61	1.00	29.6		60	35	5	40	SM	-	1.96	SLS
						Mean:	8.2		70.8	25.4	3.8	29.2		**γ(t/m3)**	2.0	
						St. Dev.	4.2		10.3	10.8	0.8	10.3		**γ(t/m3)**	1.9	
															0.1	

Note: 1. Ground water table at 1.4 m below surface.
2. Silt defined as grain size between 5 and 75 μm.
3. Clay defined as grain size smaller than 5 μm.

Case number:	212
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	20 Corhampton Street (VSVP 57194)
References:	McLaughlin (2017), NZGD
Nature of Failure:	Moderate
GPS LAT:	-43.511608
GPS LONG:	172.711428
Liq. layer consist of:	Sand
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	SPT data is retrieved from New Zealand Geotechnical database. The site initially studied by McLaughlin (2017). CPT and Vs are available at the site. amax is reported as 0.48 g by McLaughlin (2017) after 2011 Christchurch Earthquake based on the conditional distributions described by Green et al. (2014) and Bradley (2014). amax=0.359 g is calculated by site response analysis. rd=0.87 is used based on site response analysis. rd=0.94 based on Cetin and Seed (2004). Vs,12m is calculated based on the mesaured Vs values. Vs30m could not be calculated since there were not direct measurements until depth of 30 m. Vs data that has been used in site reponse analysis was attained from a nearby measurement considering the stratigraphy. Vs30m used in the 1D site reponse analysis is 249.7 m/s. GWT is retrieved from SPT. The standard deviation of GWT is calculated based on Vs and SPT data. FC and PI are assigned based on the SP classification from USCS. Hammer energy is assigned as 82% for PQDT/Auto SPT.



After McLaughlin (2017)

Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	2.5 - 7.0
d_{crt} (m)	-	-	-	-	4.7
GWT (m)	-	-	-	-	1.9 ± 0.5
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	88.2 ± 15.9
σ_v' (kPa)	-	-	-	-	60.4 ± 8.8
a_{max} (g)	-	-	-	-	0.480 ± 0.072
r_d	-	-	-	-	0.87 ± 0.033
CSR	-	-	-	-	0.397 ± 0.070
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	10.9 ± 4.2
C_R	-	-	-	-	0.92
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.30
$(N_1)_{60}$	-	-	-	-	17.8 ± 6.8
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	189.8

EVENT PARAMETERS

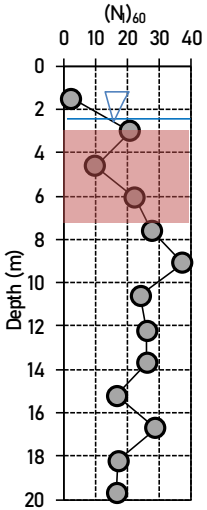
2011 Christchurch Earthquake

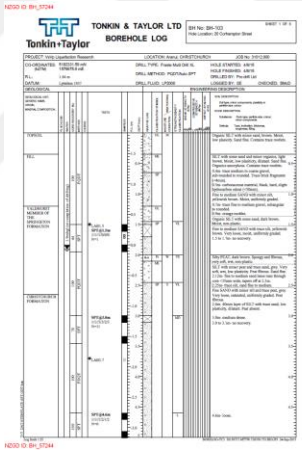
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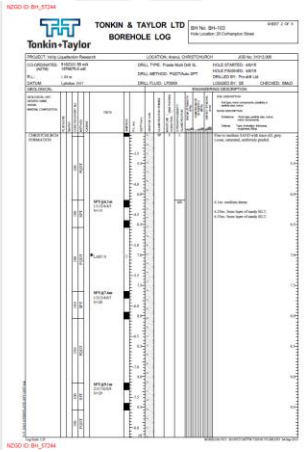
Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 2.5

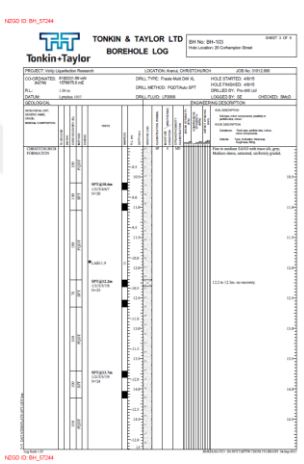
Dip: 64 | Width (km): 6.5 | R_{jb} (km): 2.5

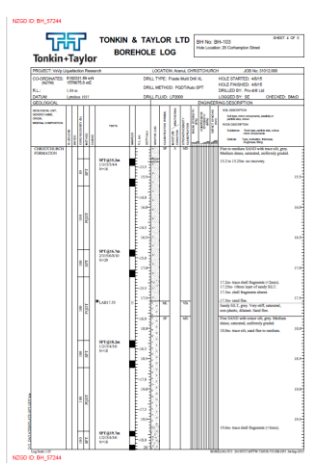
ACCELERATION TIME HISTORY











	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
SP	1.5	4.9		1	2.00	0.85	2.3	above GWT - outlier
SP	***3***	***9.8***		***11***	***1.56***	***0.89***	***20.9***	
SP	***4.6***	***15.1***		***6***	***1.31***	***0.92***	***9.9***	
SP	***6.1***	***20.0***		***15***	***1.16***	***0.94***	***22.5***	
SP	*7.6*	*24.9*	Site Response is performed	*20*	*1.05*	*0.96*	*27.6*	
SP	*9.1*	*29.9*		*29*	*0.97*	*0.97*	*37.3*	
SP	*10.6*	*34.8*		*20*	*0.91*	*0.98*	*24.2*	
SP	*12.2*	*40.0*		*23*	*0.85*	*0.98*	*26.2*	
SP	*13.7*	*44.9*		*24*	*0.80*	*0.99*	*26.0*	
SP	*15.2*	*49.9*		*16*	*0.76*	*0.99*	*16.6*	
SP	*16.7*	*54.8*		*29*	*0.73*	*0.99*	*28.8*	
SP	*18.2*	*59.7*		*18*	*0.70*	*1.00*	*17.2*	
SP	*19.7*	*64.6*		*18*	*0.68*	*1.00*	*16.6*	
						Mean:	17.8	
						St. Dev.	6.8	

GWT (m)	
by Vs	2.79
by Vs	2.86
SPT	1.90

Case number:	213
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	EQC-4 - Avondale
References:	Beyzaei et al. (2020), Beyzaei et al. (2018 a, b), and Bradley, B.A. and Hughes, M. (2012a and b),
Nature of Failure:	Moderate-to-severe liquefaction manifestations, including lateral spread and ejecta, were observed at EQC-4 following both the Darfield and Christchurch earthquakes.
GPS LAT:	-43.5014
GPS LONG:	172.6857
Liq. layer consist of:	Fine SAND with minor silt, grey, loose. (SP)
Geological Unit:	Alluvium
Site Response Anlaysis:	No
Comments:	The site is located approximately 80 m from the Avon River. There is a silty sand layer extending from 0-3 m, followed by cleaner sands. amax is calculated as 0.36 g based on the conditional distribution of PGA (Bradley and Hughes, 2012a and b). Vs12m is calculated based on the correlation between SPTN and Vs. The regional groundwater maps were updated over time by cross-correlating water level records from piezometers installed before and after the Canterbury earthquake sequence. As more post-event data (including seasonal fluctuations) were obtained, the groundwater models were refined. A backward extrapolation was done to estimate the groundwater levels immediately prior to the earthquake events (groundwater maps developed/updated by Tonkin + Taylor). GWT is taken as 1.88 m based on personel communication with Dr. Beyzaei.
Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Beyzaei 2017, NZGD, NGL, Original reference

EQC-4 (Silty Soils Project and Ground Improvement Trials).



Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.0 - 8.0
d_{crt} (m)	-	-	-	-	5.0
GWT (m)	-	-	-	-	1.9 ± 0.3
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	94.0 ± 20.7
σ_v' (kPa)	-	-	-	-	63.3 ± 11.0
a_{max} (g)	-	-	-	-	0.360 ± 0.072
r_d	-	-	-	-	0.97 ± 0.070
CSR	-	-	-	-	0.336 ± 0.074
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	0.200 ± 0.050
% Fines	-	-	-	-	7.1 ± 6.9
% PI	-	-	-	-	0
N	-	-	-	-	12.1 ± 1.6
C_R	-	-	-	-	0.93
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.27
$(N_1)_{60}$	-	-	-	-	19.4 ± 2.5
$V_{s,30m}$ (m/s)	-	-	-	-	NA
$V_{s,12m}$ (m/s)	-	-	-	-	213.4

EVENT PARAMETERS

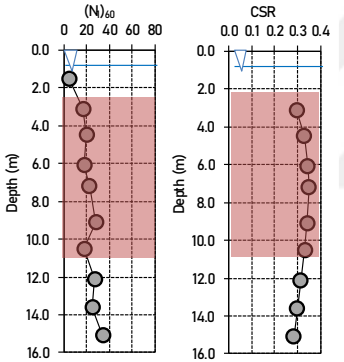
2011 Christchurch Earthquake

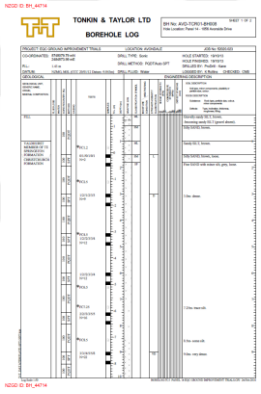
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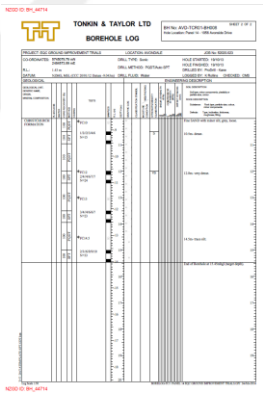
Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 4.6

Dip: 64 | Width (km): 6.5 | R_{jb} (km): 4.6

ACCELERATION TIME HISTORY







	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	NZGD ID: BH_44714 PQDT/Auto SPT	
ML	1.50	4.92	NA	2	2.00	0.85	4.7	Sandy SILT, brown.	
SP	***3.10***	***10.17***	***0.30***	***9***	***1.54***	***0.89***	***16.9***	***Fine SAND with minor silt, grey, loose***	
SP	***4.50***	***14.76***	***0.33***	***12***	***1.32***	***0.92***	***20.0***	***Fine SAND with minor silt, grey, loose.***	
SP	***6.10***	***20.01***	***0.35***	***12***	***1.16***	***0.94***	***18.0***	***Fine SAND with minor silt, grey, loose.***	
SP	***7.20***	***23.62***	***0.35***	***16***	***1.08***	***0.95***	***22.5***	***Fine SAND with minor silt, grey, loose.***	
SP	9.10	29.86	0.34	22	0.97	0.97	28.3	**Fine SAND with minor silt, grey, loose.**	outlier
SP	10.50	34.45	0.33	15	0.91	0.98	18.2	**Fine SAND with minor silt, grey, loose.**	
SP	12.10	39.70	0.31	24	0.85	0.98	27.5	**Fine SAND with minor silt, grey, loose.**	
SP	13.60	44.62	0.30	23	0.81	0.99	25.0	**Fine SAND with minor silt, grey, loose.**	
SP	15.10	49.54	0.28	33	0.77	0.99	34.3	**Fine SAND with minor silt, grey, loose.**	
						Mean:	19.4		
						St. Dev.	2.5		

	Depth (m)	FC	LL	PL	PI
NZGD ID: BH_44714	1.8-2.1	84.72	26.00	22.00	4.00
NZGD ID: BH_44714	2.3-2.4	30.00			
NZGD ID: BH_44714	3.2-3.3	7.82			
NZGD ID: BH_44714	3.7-3.8	8.41			
NZGD ID: BH_44714	**Mean:**	-			
NZGD ID: BH_44714	**St. Dev.**	-			
NZGD ID: BH_44714					
NZGD ID: BH_44714					
NZGD ID: BH_44714					
NZGD ID: BH_44714					

BH21495 is located at the same location with CPT which is detailly studied by Beyzaei et al. and it indicates to organic material in the upper silty layer. That borehole NZGD ID: BH_44714 did not have SPT measurements.
BH_34456 indicates some organic material in the upper silt layers. Although 34456 is closer to CPT location, a few meters away, there is BH 44714 which is taken into account as that borehole did not indicate organic material (similar with CPT)

Case number:	214
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Site 14-Barrington
References:	Bayzei et al. (2020), Bayzei et al. (2018 a, b), Beyzaei 2017, NZGD, NGL, Bradley, B.A. and Hughes, M. (2012)
Nature of Failure:	Ejecta observed and documented in aerial photographs from the New Zealand Geotechnical Database. original reference "Site 14" (Silty Soils Project)
GPS LAT:	-43.554
GPS LONG:	172.61773
Liq. layer consist of:	Sand (SP-SW)
Geological Unit:	Alluvium
Site Response Anlaysis:	No
Comments:	amax is calculated as 0.42 g based on conditional distribution of PGA by Bradley, B.A. and Hughes, M. (2012a and b). Vs12m is caluclated based the correlation VS-SPTN.The regional groundwater maps were updated over time by cross-correlating water level records from piezometers installed before and after the Canterbury earthquake sequence. As more post-event data (including seasonal fluctuations) were obtained, the groundwater models were refined. A backward extrapolation was done to estimate the groundwater levels immediately prior to the earthquake events (groundwater maps developed/updated by Tonkin + Taylor). GWT is taken as 0.10 m based on personel communication with Dr. Beyzaei. Hammer energy is given as 87%.



Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.5 - 5.5
d_{crt} (m)	-	-	-	-	4.0
GWT (m)	-	-	-	-	0.1 ± 0.2
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	75.4 ± 9.6
σ_v' (kPa)	-	-	-	-	37.1 ± 5.1
a_{max} (g)	-	-	-	-	0.420 ± 0.084
r_d	-	-	-	-	0.99 ± 0.058
CSR	-	-	-	-	0.552 ± 0.118
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	0.100 ± 0.050
% Fines	-	-	-	-	30.0 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	8.2 ± 2.0
C_R	-	-	-	-	0.91
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.45
C_N	-	-	-	-	1.65
$(N_1)_{60}$	-	-	-	-	17.8 ± 4.3
$V_{s,30m}$ (m/s)	-	-	-	-	NA
$V_{s,12m}$ (m/s)	-	-	-	-	253.0

EVENT PARAMETERS

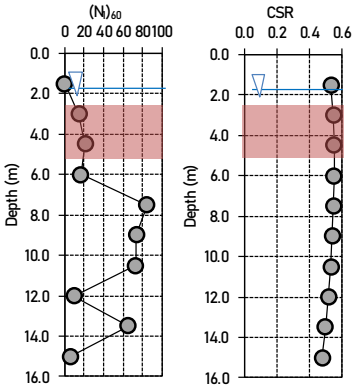
2011 Christchurch Earthquake

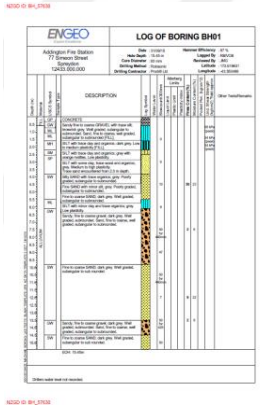
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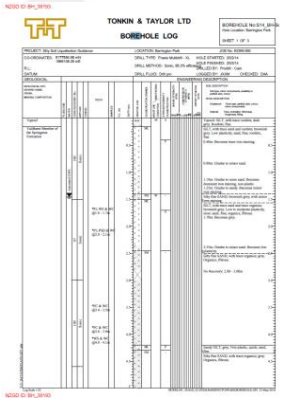
Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 2.5

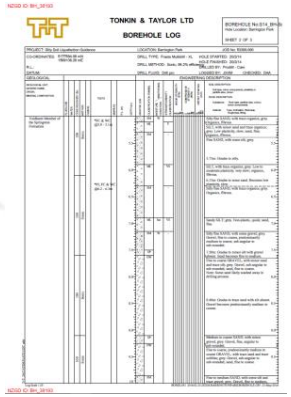
Dip: 64 | Width (km): 6.5 | R_{jb} (km): 2.4

ACCELERATION TIME HISTORY









Personel coomunication with Dr. Beyzaei

	Event Specific GWT (m)	
	Sept. 2010	Feb. 2011
Gainsborough	0.57	1.36
Barrington	0.10	0.10
Caulfield	0.10	0.10
Riccarton	0.59	0.59
Clarence	0.7	0.7
Cashmere	0.76	0.90
EQC-3	1.92	1.85
EQC-4	1.88	1.88
EQC-5	1.58	1.53

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
ML	1.50	4.92	0.53	0	2.00	0.85	0.0		SILT with trace clay and organics; dark grey. Low to medium plasticity [FILL].
SP	***3.00***	***9.84***	***0.55***	***6***	***1.90***	***0.89***	***14.8***		***Fine SAND with minor silt; grey. Poorly graded, subangular to subrounded.Trace sand encountered from 2.0 m depth.***
SW	***4.50***	***14.76***	***0.55***	***10***	***1.56***	***0.92***	***20.8***	***30.0***	***Fine to coarse SAND; dark grey. Well graded, subangular to subrounded***
ML	6.00	19.69	0.55	9	1.36	0.94	16.7		SILT with minor clay and trace organics; grey. Low plasticity
GW	7.50	24.61	0.55	50	1.21	0.96	84.3	2.0	Sandy, fine to coarse gravel; dark grey. Well graded, subrounded. Sand, fine to coarse, well graded, subangular to subrounded.
GW	9.00	29.53	0.54	47	1.11	0.97	73.3		Sandy, fine to coarse gravel; dark grey. Well graded, subrounded. Sand, fine to coarse, well graded, subangular to subrounded.
SW	10.50	34.45	0.53	50	1.03	0.98	72.8		Fine to coarse SAND; dark grey. Well graded, subangular to sub rounded.
SW	12.00	39.37	0.52	7	0.96	0.98	9.6	9.0	Fine to coarse SAND; dark grey. Well graded, subangular to sub rounded.
GW	13.50	44.29	0.50	50	0.91	0.99	65.0	2.0	Sandy, fine to coarse gravel; dark grey. Well graded, subrounded. Sand, fine to coarse, well graded, subangular to subrounded.
SW	15.00	49.21	0.48	5	0.86	0.99	6.2		Fine to coarse SAND; dark grey. Well graded, subangular to sub rounded.
						Mean:	17.8	30.0	
						St. Dev.	4.3	8.6	assigned

**the given hammer efficiency is considered as the mean of the asymptotic values at depths >10 m hence short rod correction was applied. If energy measurement were provided at depths no short rod correction would be applied.*

Case number:	217
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Normans Road/Papanui Road (VsVp57200)
References:	McLaughlin (2017), NZGD
Nature of Failure:	Moderate Liquefaction
GPS LAT	-43.506153
GPS LONG	172.615603
Liq. layer consist of:	Sand (SP)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. Acceleration value of 0.30 g is calculated based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Hammer energy is assigned as 82% for PQDT/Auto SPT. Vs values were available up to 6 m. Vs12m is calculated based on SPT-N values. GWT is 3.2 m by SPT data. FC and PI are assigned based on the SP and GW classification from USCS. Sand in the gravel matrix liquefiable Site response analysis are performed for one of the horizantal component.





After McLaughlin (2017)

Gravel Content:	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	4.4 - 8.0
d_{crt} (m)	-	-	-	-	6.2
GWT (m)	-	-	-	-	2.7 ± 0.4
γ_{moist} (kN/m^3)	-	-	-	-	18.9
γ_{sat} (kN/m^3)	-	-	-	-	20.6
σ_v (kPa)	-	-	-	-	123.3 ± 12.6
σ_v' (kPa)	-	-	-	-	88.7 ± 7.7
a_{max} (g)	-	-	-	-	0.300 ± 0.045
r_d	-	-	-	-	0.74 ± 0.042
CSR	-	-	-	-	0.200 ± 0.034
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	8.6 ± 0.2
C_R	-	-	-	-	0.94
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.07
$(N_1)_{60}$	-	-	-	-	11.8 ± 0.3
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	198.1

EVENT PARAMETERS

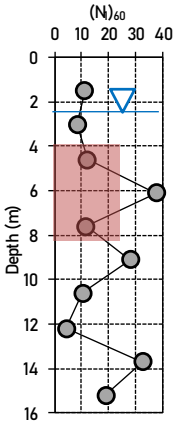
2011 Christchurch Earthquake

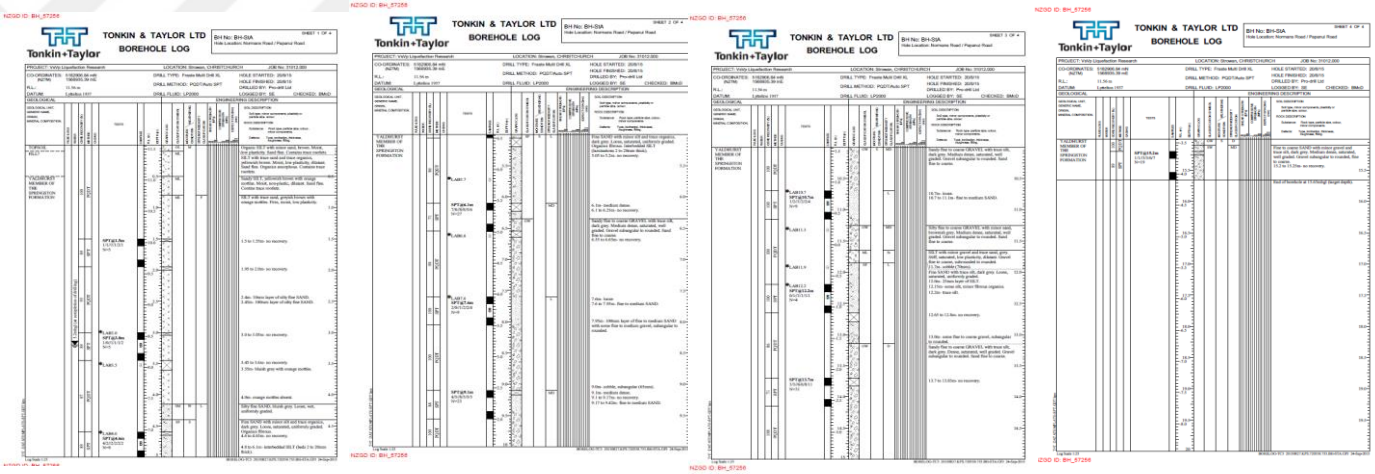
Magnitude: 6.20

Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 9

Dip: 64 | Width (km): 6.5 | R_{jb} (km): 9

ACCELERATION TIME HISTORY





	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$			
ML	1.5	4.9		5	1.89	0.85	11.0	CPT suggests plastic material	Vs	2.81 m
ML	3	9.8		5	1.37	0.89	8.4	CPT suggests plastic material	Vs	2.86 m
SP (organic trace_interbedded SILT ?)	***4.6***	***15.1***		***8***	***1.19***	***0.92***	***12.0***	CPT did not confirm organic traces	SPT	3.2 m
SP	6.1	20.0		27	1.08	0.94	37.5	immeadiately before Gravel excluded	CPT	2 m
GW?	***7.6***	***24.9***	Site	***9***	***0.99***	***0.96***	***11.7***	fine to medium sand	Mean:	2.68 m
GW	9.1	29.9	Response	23	0.92	0.97	28.0	excluded		
Sand band	10.6	34.8		9	0.86	0.98	10.4	fine to medium sand	CPT indicates plastic material	
SP	12.2	40.0		4	0.81	0.98	4.4	some silt	CPT indicates plastic material	
GW	13.7	44.9		31	0.77	0.99	32.4			
SW	15.2	49.9		19	0.74	0.99	19.0			
						Mean:	11.8			
						St. Dev.	0.3			

GWT

Case number:	218
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Avondale Park (VSVP 57187)
References:	McLaughlin (2017), NZGD
Nature of Failure:	Moderate
GPS LAT	-43.505578
GPS LONG	172.690892
Liq. layer consist of:	Sand-Silt (SP-ML)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.37 g by McLaughlin (2017) after 2011 Christchurch Earthquake based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD. Hammer energy is assigned as 82% for PQDT/Auto SPT. Vs,12m is calculated based on the mesaured Vs values. GWT is estimated based on Vs measurement FC is assigned based on the SP classification from USCS. Lab data is asked to Tonkin and Taylor.



After McLaughlin (2017)

Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

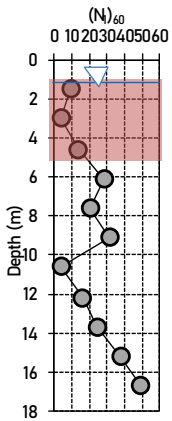
Summary of Input Data

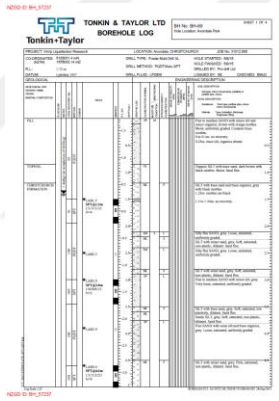
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	1.4 - 5.0
d_{crt} (m)	-	-	-	-	3.2
GWT (m)	-	-	-	-	1.4 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	58.3 ± 11.4
σ_v' (kPa)	-	-	-	-	40.6 ± 5.7
a_{max} (g)	-	-	-	-	0.370 ± 0.056
r_d	-	-	-	-	0.94 ± 0.024
CSR	-	-	-	-	0.325 ± 0.054
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	30-70 ± 10.0
% PI	-	-	-	-	0-7
N	-	-	-	-	4.7 ± 2.6
C_R	-	-	-	-	0.90
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.58
$(N_1)_{60}$	-	-	-	-	9.1 ± 5.0
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	162.9

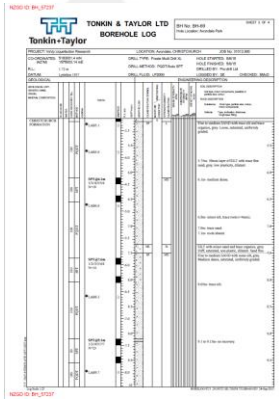
EVENT PARAMETERS

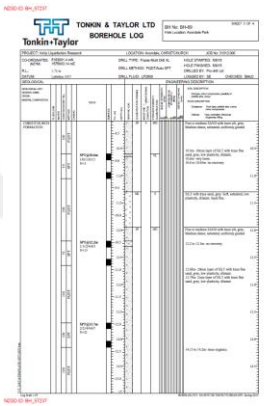
2011 Christchurch Earthquake
Magnitude: 6.20
Fault Type: Reverse Fault — Z_{tor} (km): 0.5 — R_{rup} (km): 3.9
Dip: 64 — Width (km): 6.5 — R_{jb} (km): 3.9

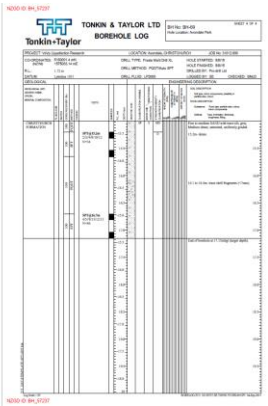
ACCELERATION TIME HISTORY











	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
ML	***1.5***	***4.9***		***4***	***2.00***	***0.85***	***9.3***	non plastic
SP	***3***	***9.8***		***2***	***1.62***	***0.89***	***3.9***	non plastic
ML	***4.6***	***15.1***		***8***	***1.38***	***0.92***	***13.9***	non plastic
SP	6.1	20.0		18	1.23	0.94	28.6	
SP	7.6	24.9	site	14	1.12	0.96	20.6	
SP	9.1	29.9	response	23	1.04	0.97	31.7	
SP	10.6	34.8		3	0.97	0.98	3.9	plastic from CPT
SP	12.2	40.0		13	0.91	0.98	15.9	
SP	13.7	44.9		21	0.86	0.99	24.5	
SP	15.2	49.9		34	0.82	0.99	38.0	
SP	16.7	54.8		46	0.79	0.99	49.3	
						Mean:	9.1	
						St. Dev.	5.0	

GWT

by Vs	1.6 m
by Vs	1.68 m

One sand layer 5.1-7.35 — Fine to medium SAND with trace silt and trace organics, grey. Loose, saturated, uniformly graded

the second layer undeneath 7.5-17.15 with a silt layer in it 11.30-11.95 m — SILT with trace sand, grey. Soft, saturated, low plasticity, dilatant. Sand fine.

Case number:	219
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Avondale Playground
References:	McLaughlin (2017), NZGD
Nature of Failure:	Moderate-Severe. Sand boils were observed
GPS LAT	-43.508503
GPS LONG	172.686906
Liq. layer consist of:	Sand (SP)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.40 g by McLaughlin (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD.
	Hammer energy is assigned as 82% for PQDT/Auto SPT.
	Vs,12m is calculated based on the mesaured Vs values.
	GWT is estimated based on SPT
	FC is assigned based on the SP classification from USCS.



After McLaughlin (2017)

Gravel Content (%)	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.4 - 6.0
d_{crt} (m)	-	-	-	-	4.2
GWT (m)	-	-	-	-	0.9 ± 0.7
γ_{moist} (kN/m^3)	-	-	-	-	15.7
γ_{sat} (kN/m^3)	-	-	-	-	18.9
σ_v (kPa)	-	-	-	-	76.1 ± 11.8
σ_v' (kPa)	-	-	-	-	43.9 ± 7.4
a_{max} (g)	-	-	-	-	0.400 ± 0.020
r_d	-	-	-	-	0.83 ± 0.030
CSR	-	-	-	-	0.374 ± 0.056
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	7.2 ± 2.2
C_R	-	-	-	-	0.92
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.52
$(N_1)_{60}$	-	-	-	-	13.6 ± 4.2
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	158.7

EVENT PARAMETERS

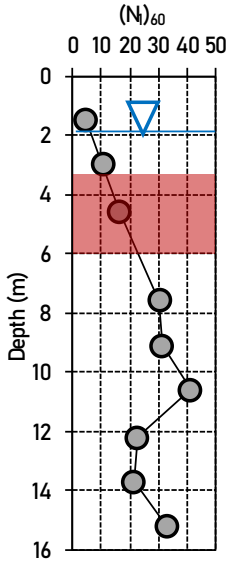
2011 Christchurch Earthquake

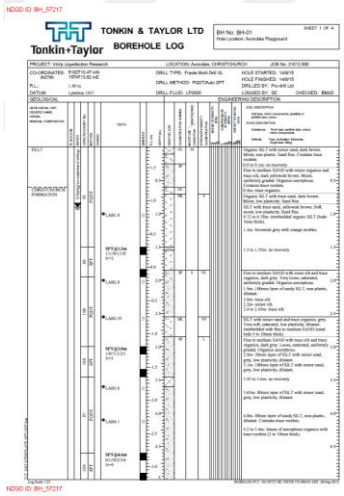
Magnitude: 6.20

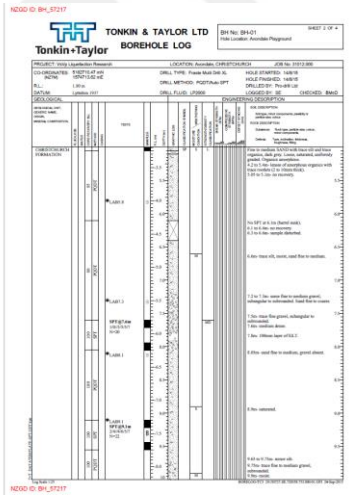
Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 3.83

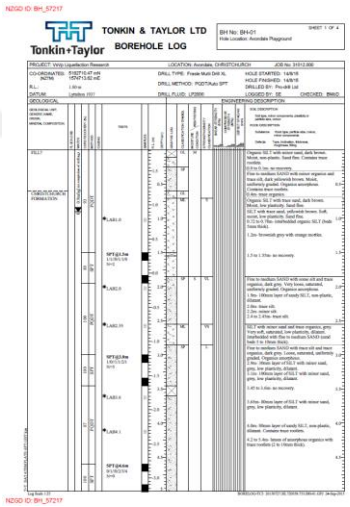
Dip: 64 | Width (km): 6.5 | R_{jb} (km): 3.80

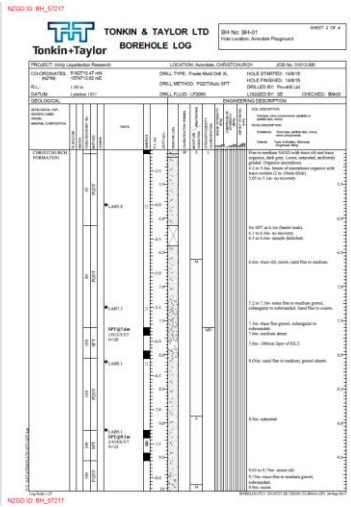
ACCELERATION TIME HISTORY











	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
ML	1.5	4.9		2	2.00	0.85	4.7
SP	***3***	***9.8***		***5***	***1.75***	***0.89***	***10.7***
SP	***4.6***	***15.1***		***9***	***1.46***	***0.92***	***16.5***
SP	7.6	24.9	Site	20	1.16	0.96	30.5
SP	9.1	29.9	Response	22	1.07	0.97	31.2
SP	10.6	34.8	Analysis	31	1.00	0.98	41.3
SP	12.2	40.0		18	0.93	0.98	22.6
SP	13.7	44.9		18	0.88	0.99	21.5
SP	15.2	49.9		29	0.84	0.99	33.0
						Mean:	13.6
						St. Dev.	4.2

GWT	
by Vs	2.05 m
by Vs	2.14 m
SPT	0.9 m

Case number:	220
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	EQC-6 - Bexley NGL, Original reference EQC-4 (Silty Soils Project and Ground Improvement Trials).
References:	Beyzaei et al. (2020), Beyzaei et al. (2018 a, b), and Bradley, B.A. and Hughes, M. (2012a and b), Beyzaei 2017, NZGD,
Nature of Failure:	Minor-to-moderate liquefaction manifestations.
GPS LAT	-43.5102
GPS LONG	172.7215
Liq. layer consist of:	Sand and silt
Geological Unit:	Alluvium
Site Response Anlaysis:	No
Comments:	amax is calculated as 0.53 g based on conditional distribution of PGA from Bradley, B.A. and Hughes, M. (2012a and b).The regional groundwater maps were updated over time by cross-correlating water level records from piezometers installed before and after the Canterbury earthquake sequence. As more post-event data (including seasonal fluctuations) were obtained, the groundwater models were refined. A backward extrapolation was done to estimate the groundwater levels immediately prior to the earthquake events (groundwater maps developed/updated by Tonkin + Taylor). GWT is taken as 1.53 m based on personel communication with Dr. Beyzaei. PI is assigned as 0-7 considering sand and silt layers based on USCS. Estimated hammer energy is given as 85%. Since there is no direct energy measurements available CR is applied



Free field



Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.1 - 5.0
d_{crt} (m)	-	-	-	-	3.6
GWT (m)	-	-	-	-	1.5 ± 0.3
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	67.1 ± 9.2
σ_v' (kPa)	-	-	-	-	47.2 ± 5.4
a_{max} (g)	-	-	-	-	0.530 ± 0.106
r_d	-	-	-	-	0.98 ± 0.052
CSR	-	-	-	-	0.482 ± 0.106
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	13.0 ± 8.7
% PI	-	-	-	-	0-7
N	-	-	-	-	5.2 ± 4.7
C_R	-	-	-	-	0.90
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.42
C_N	-	-	-	-	1.47
$(N_1)_{60}$	-	-	-	-	9.8 ± 8.8
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	219.5

EVENT PARAMETERS

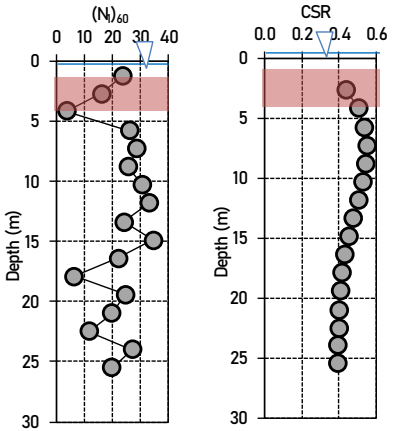
2011 Christchurch Earthquake

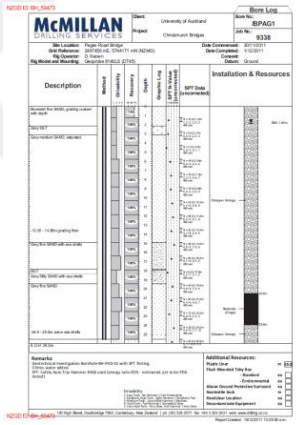
Magnitude: 6.20

Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 2.2

Dip: 64 | Width (km): 6.5 | R_{jb} (km): 2.1

ACCELERATION TIME HISTORY





Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	NZGD ID: BH_59473
1.2	3.9	NA	10	2.00	0.84	23.9	Brownish fine SAND, grading coarser with depth
2.7	***8.9***	***0.440***	***8***	***1.60***	***0.88***	***16.1***	***Grey SILT-Grey medium SAND; saturated***
4.2	***13.8***	***0.504***	***2***	***1.38***	***0.92***	***3.6***	***Grey medium SAND; saturated***
5.8	19.0	0.537	16	1.23	0.94	26.1	Grey medium SAND; saturated
7.3	24.0	0.548	19	1.12	0.96	28.8	Grey medium SAND; saturated
8.8	28.9	0.544	18	1.03	0.97	25.5	Grey medium SAND; saturated
10.3	33.8	0.529	23	0.97	0.98	30.8	Grey medium SAND; saturated
11.8	38.7	0.505	26	0.91	0.98	33.0	Grey medium SAND; saturated
13.4	44.0	0.476	20	0.86	0.99	24.1	Grey medium SAND; saturated
14.9	48.9	0.451	30	0.82	0.99	34.6	Grey medium SAND; saturated
16.4	53.8	0.431	20	0.79	0.99	22.2	Grey fine SAND with sea shells
17.9	58.7	0.417	6	0.76	0.99	6.4	Grey fine SAND with sea shells
19.4	63.6	0.407	24	0.73	1.00	24.7	Grey fine SAND
21	68.9	0.401	20	0.70	1.00	19.9	Grey fine SAND
22.5	73.8	0.399	12	0.68	1.00	11.6	Grey fine SAND
24	78.7	0.397	29	0.66	1.00	27.1	Grey fine SAND
25.5	83.7	0.397	22	0.64	1.00	20.0	Grey fine SAND
					Mean:	9.8	
					St. Dev.	8.8	

**the given hammer efficiency is estimated as 85% for automatic trip hammer no direct measurements was available hence short rod correction was applied. If energy measurement were provided at depths no short rod correction would be applied.*

Case number:	221
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Carisbroke Playground (57193)
References:	McLaughlin (2017), NZGD
Nature of Failure:	Moderate
GPS LAT	-43.511014
GPS LONG	172.709708
Liq. layer consist of:	Sand (SP)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.46 g by McLaughlin (2017) after 2011 Christchurch Earthquake. Test results are retrieved from NZGD. Hammer energy is assigned as 82% for PQDT/Auto SPT. Vs,12m and Vs,30 m are calculated based on the measured Vs values. GWT is estimated based on SPT. Acceleration value based on the conditional distributions described by Green et al. (2014) and Bradley (2014). FC is assigned based on the SP classification from USCS. PI is assigned as 0 for the SP.



After McLaughlin (2017)

Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data					
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	3.0 - 5.0
d_{crt} (m)	-	-	-	-	4.0
GWT (m)	-	-	-	-	1.8 ± 0.6
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	76.6 ± 7.3
σ_v' (kPa)	-	-	-	-	54.9 ± 5.6
a_{max} (g)	-	-	-	-	0.460 ± 0.069
r_d	-	-	-	-	0.92 ± 0.029
CSR	-	-	-	-	0.383 ± 0.071
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	15.4 ± 1.4
C_R	-	-	-	-	0.91
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.36
$(N_1)_{60}$	-	-	-	-	26.0 ± 2.4
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	218.2

EVENT PARAMETERS

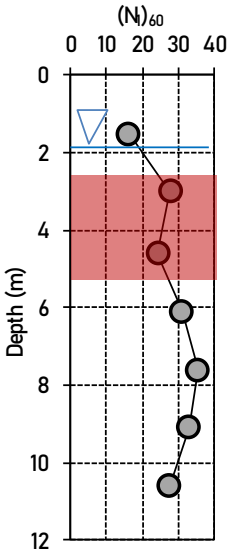
2011 Christchurch Earthquake

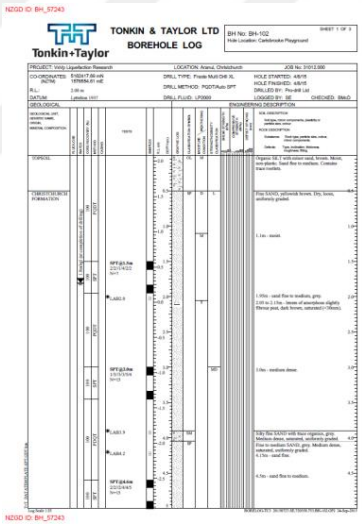
Magnitude: 6.20

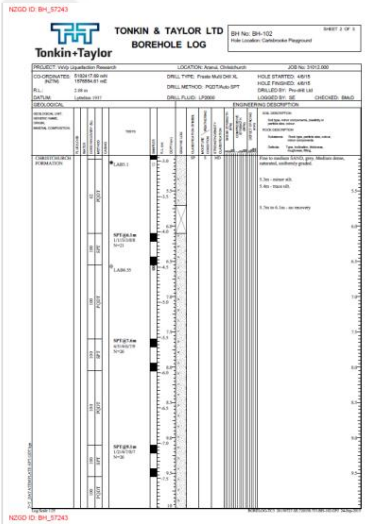
Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 2.6

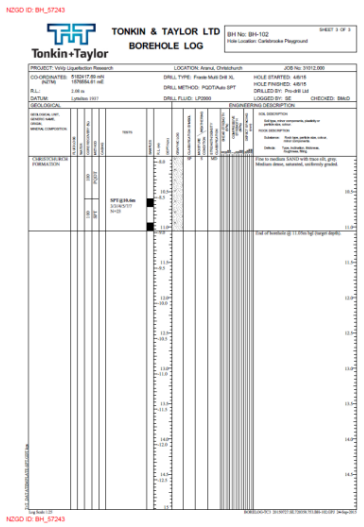
Dip: 64 | Width (km): 6.5 | R_{jb} (km): 2.6

ACCELERATION TIME HISTORY









	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
SP	1.5	4.9		7	1.98	0.85	16.1	surficial layer excluded
SP	***3***	***9.8***		***15***	***1.52***	***0.89***	***27.73***	
SP	***4.6***	***15.1***		***15***	***1.29***	***0.92***	***24.31***	
SP	6.1	20.0	Site Response	21	1.14	0.94	31.0	
SP	7.6	24.9		26	1.04	0.96	35.4	
SP	9.1	29.9		26	0.96	0.97	33.1	
SP	10.6	34.8		23	0.90	0.98	27.6	
						Mean:	26.0	
						St. Dev.	2.4	

GWT	
by Vs	2.91 m
by Vs	2.87 m
SPT	1.8 m

0.5-3.9 Fine SAND, yellowish brown. Dry, loose, uniformly graded.

4.05-11.05 Fine to medium SAND, grey. Medium dense, saturated, uniformly graded.

Case number:	222
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	29 Charles Street (VSVP 57196)
References:	McLaughlin (2017), NZGD
Nature of Failure:	Moderate
GPS LAT	-43.5432
GPS LONG	172.657544
Liq. layer consist of:	Sand (SP)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	No
Comments:	CPT and Vs are available at the site. amax is reported as 0.52 g by McLaughlin (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD.
	Hammer energy is assigned as 82% for PQDT/Auto SPT.
	Vs,12m is calculated based on the mesaured Vs values.
	GWT is estimated based on SPT measurement
	FC is assigned based on the SP classification from USCS.
	PI is assigned as 0 for the SP layer.



After McLaughlin (2017)

Gravel Content	0
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	3.0 - 10.0
d_{crt} (m)	-	-	-	-	6.5
GWT (m)	-	-	-	-	1.4 ± 0.5
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	127.4 ± 24.3
σ_v' (kPa)	-	-	-	-	77.0 ± 13.0
a_{max} (g)	-	-	-	-	0.520 ± 0.104
r_d	-	-	-	-	0.74 ± 0.087
CSR	-	-	-	-	0.412 ± 0.098
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	14.2 ± 3.0
C_R	-	-	-	-	0.95
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.15
$(N_1)_{60}$	-	-	-	-	21.1 ± 4.4
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	152.4

EVENT PARAMETERS

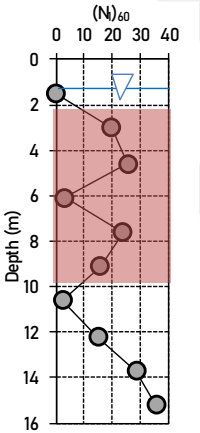
2011 Christchurch Earthquake

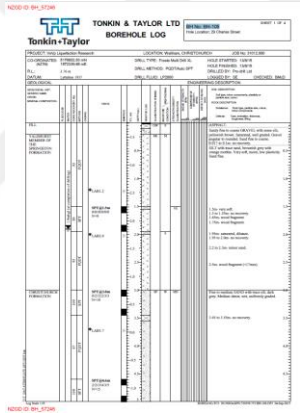
Magnitude: 6.20

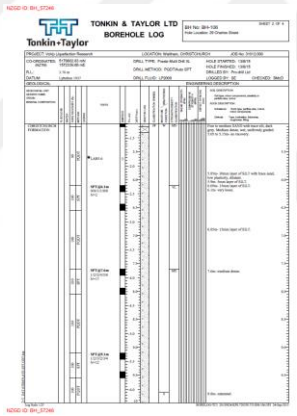
Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 1.7

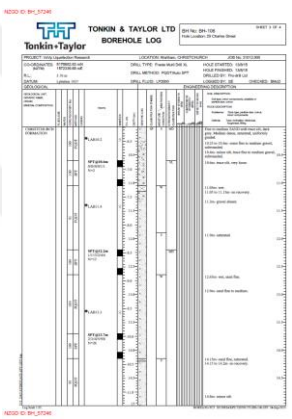
Dip: 64 | Width (km): 6.5 | R_{jb} (km): 1.6

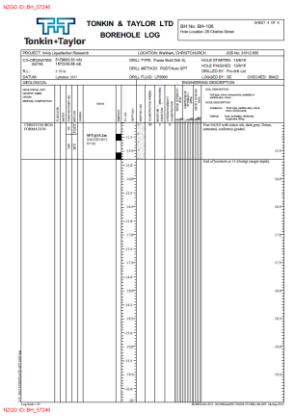
ACCELERATION TIME HISTORY











860

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
ML	1.5	4.9		0	2.00	0.85	0.0	very shallow CN>2, not saturated, above GWT
SP	***3***	***9.8***		***10***	***1.61***	***0.89***	***19.6***	
SP	***4.6***	***15.1***		***15***	***1.34***	***0.92***	***25.3***	
SP	6.1	20.0		2	1.18	0.94	3.0	very thin layer of silt layer (35 cm) SPTN 0/0/1/1/0/0 qt = 7 - 8 MPa
SP	***7.6***	***24.9***	site	***17***	***1.07***	***0.96***	***23.8***	
SP	***9.1***	***29.9***	response	***12***	***0.98***	***0.97***	***15.6***	
SP	10.6	34.8		2	0.92	0.98	2.4	trace silt very thin within sand layer SPTN 0/0/1/1/0/0 qt = 2 - 3 MPa very thin layer like 4 cm according to CPT
SP	12.2	40.0		13	0.86	0.98	15.0	
SP	13.7	44.9		26	0.81	0.99	28.4	outlier
SP	15.2	49.9		34	0.77	0.99	35.5	outlier within the layer very dense
						Mean:	21.1	
						St. Dev.	4.4	

GWT (m)		
by Vs	1.22	
by Vs	1.03	
SPT	1.9	

Case number:	223
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Harrington Park (VSVP 57141)
References:	McLaughlin (2017), NZGD
Nature of Failure:	None to minor
GPS LAT	-43.5345
GPS LONG	172.590233
Liq. layer consist of:	Sand (SP)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.34 g by McLaughlin (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD. Hammer energy is assigned as 82% for PQDT/Auto SPT by Tonkin and Taylor. Critical layer is selected from the CPT as 3.5-5 m and the SPT blowcount at 4.6m is assigned to that critical layer. Vs,12m and Vs30m are calculated based on the mesaured Vs values. GWT is estimated based on Vs measurement FC is assigned based on the SP classification from USCS.



After McLaughlin (2017)

Gravel Content (%)	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

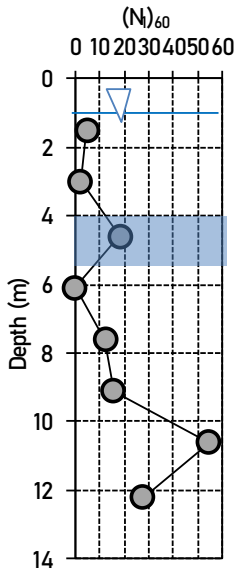
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crlc} range (m)	-	-	-	-	4.4 - 6.1
d_{cr1} (m)	-	-	-	-	5.2
GWT (m)	-	-	-	-	1.0 ± 0.4
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	95.1 ± 5.9
σ_v' (kPa)	-	-	-	-	53.8 ± 4.4
a_{max} (g)	-	-	-	-	0.340 ± 0.051
r_d	-	-	-	-	0.73 ± 0.036
CSR	-	-	-	-	0.284 ± 0.049
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	10.5 ± 1.1
C_R	-	-	-	-	0.93
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.37
$(N_1)_{60}$	-	-	-	-	18.3 ± 2.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	170.21

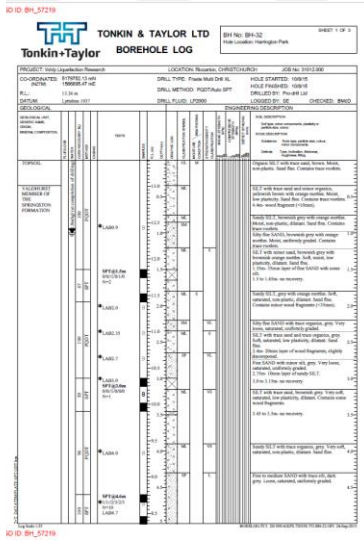
EVENT PARAMETERS

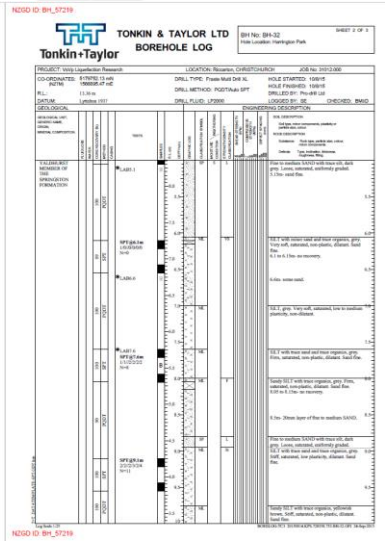
2011 Christchurch Earthquake

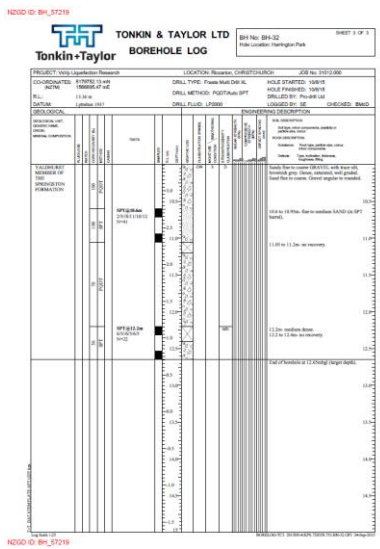
Magnitude:	6.20				
Fault Type:	Reverse Fault	Z_{tor} (km):	0.5	R_{rup} (km):	5.2
Dip:	64	Width (km):	6.5	R_{jb} (km):	5.2

ACCELERATION TIME HISTORY





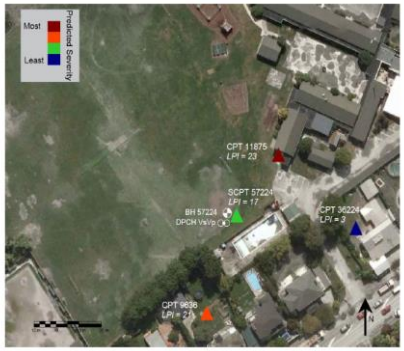




	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
ML	1.5	4.9		2	2.00	0.85	4.7	organic content
SP or ML	3	9.8		1	1.73	0.89	2.1	organic content
SP	***4.6***	***15.1***		***10***	***1.45***	***0.92***	***18.3***	single SPT suspicious but confirmed, consistent with CPT
ML	6.1	20.0	Site	0	1.28	0.94	0.0	based on CPT RF=4% plastic?
ML	7.6	24.9	Response	8	1.16	0.96	12.1	
ML	9.1	29.9		11	1.07	0.97	15.5	
GW	10.6	34.8		41	0.99	0.98	54.4	
GW	12.2	40.0		22	0.93	0.98	27.5	
						Mean:	18.3	
						St. Dev.	2.0	

GWT	
by Vs	1.74 m
by Vs	1.78 m
SPT	1 m

Case number:	224
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Heaton Normal Intermediate School (57181)
References:	McLaughlin (2017), NZGD
Nature of Failure:	Moderate
GPS LAT	-43.510556
GPS LONG	172.614753
Liq. layer consist of:	Sand and Silt (SP-ML)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.32 g by McLaughlin (2017) after 2011 Christchurch Earthquake based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NZGD. Hammer energy is assigned as 82% for PQDT/Auto SPT. Vs,12m is calculated based on the mesaured Vs values. GWT is estimated based on SPT measurement FC is assigned 50-60 % based on the SP and ML classification from USCS. Based upon available CPT logs following conclusions were made at 0-3 m clayey soil, 3-6 m sand silt mixtures (nonplastic) hence on the SPT borelog sand and silt interlayering were chosen as the suspect layer



After McLaughlin (2017)

Gravel Content (%)	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	6.0 - 8.0
d_{crt} (m)	-	-	-	-	7.0
GWT (m)	-	-	-	-	1.2 ± 0.2
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	128.5 ± 6.9
σ_v' (kPa)	-	-	-	-	71.5 ± 4.4
a_{max} (g)	-	-	-	-	0.320 ± 0.048
r_d	-	-	-	-	0.60 ± 0.047
CSR	-	-	-	-	0.224 ± 0.039
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	25-55 ± 7.0
% PI	-	-	-	-	0-7
N	-	-	-	-	7.1 ± 1.8
C_R	-	-	-	-	0.95
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.19
$(N_1)_{60}$	-	-	-	-	11.0 ± 2.8
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	143.0

EVENT PARAMETERS

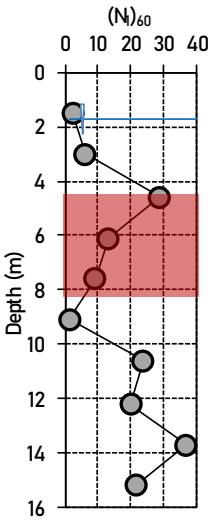
2011 Christchurch Earthquake

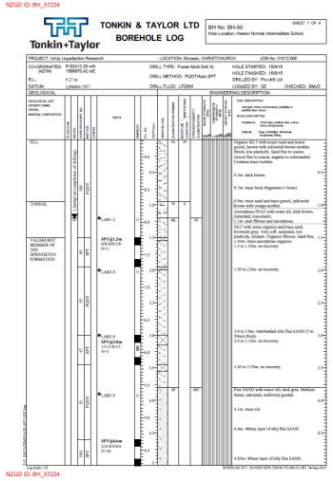
Magnitude: 6.20

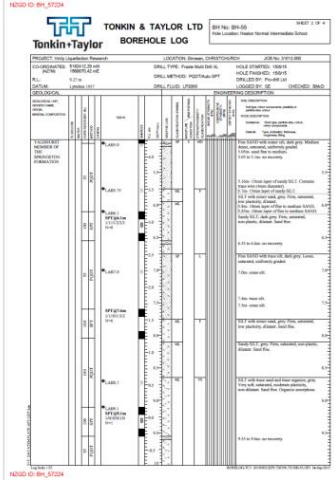
Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 6.5

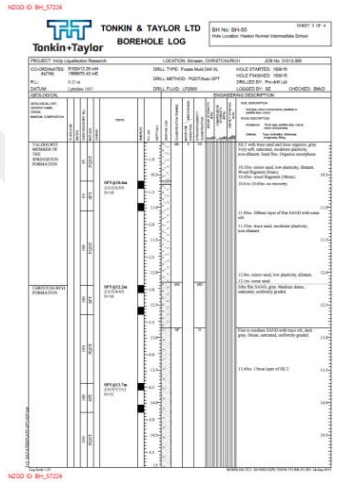
Dip: 64 | Width (km): 6.5 | R_{jb} (km): 6.5

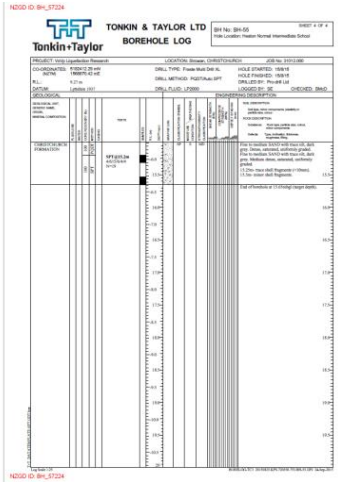
ACCELERATION TIME HISTORY











	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
ML	1.5	4.9	0.23	1	2.00	0.85	2.3	trace organic content
ML	3.0	9.8	0.28	3	1.70	0.89	6.2	within same layer with the above one
SP	4.6	15.1	0.28	16	1.43	0.92	28.8	
ML	***6.1***	***20.0***	***0.27***	***8***	***1.27***	***0.94***	***13.1***	non plastic
SP	***7.6***	***24.9***	***0.24***	***6***	***1.15***	***0.96***	***9.0***	
ML	9.1	29.9	0.22	1	1.06	0.97	1.4	trace organic content
ML	10.6	34.8	0.20	18	0.99	0.98	23.7	trace organic content
SM	12.2	40.0	0.19	16	0.93	0.98	19.9	
SP	13.7	44.9	0.18	31	0.88	0.99	36.7	
SP	15.2	49.9	0.17	19	0.83	0.99	21.5	
						Mean:	11.0	
						St. Dev.	2.8	

GWT	
by Vs	1.42 m
by Vs	1.63 m
SPT	1.2 m

Case number:	225
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Hillmerton Highschool (57201)
References:	McLaughlin (2017), NZGD
Nature of Failure:	Moderate
GPS LAT	-43.556233
GPS LONG	172.593325
Liq. layer consist of:	Silt (ML)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.39 g by McLaughlin (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NZGD.
	Hammer energy is assigned as 82% for PQDT/Auto SPT.
	Vs,12m is calculated based on the mesaured Vs values.
	GWT is estimated based on SPT measurement
	PI is assigned as 0-7. Silt is nonplastic mostly according to borehole description.
	FC is assigned based on the SM classification from USCS.



After McLaughlin (2017)

Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	3.5 - 8.5
d_{crt} (m)	-	-	-	-	6.0
GWT (m)	-	-	-	-	1.9 ± 0.5
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	17.3 ± 0.5
σ_v (kPa)	-	-	-	-	100.9 ± 14.6
σ_v' (kPa)	-	-	-	-	60.7 ± 7.7
a_{max} (g)	-	-	-	-	0.390 ± 0.059
r_d	-	-	-	-	0.75 ± 0.041
CSR	-	-	-	-	0.316 ± 0.057
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	>50 ± 12.5
% PI	-	-	-	-	0-7
N	-	-	-	-	2.0 ± 0.1
C_R	-	-	-	-	0.94
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.29
$(N_1)_{60}$	-	-	-	-	3.3 ± 0.2
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	143.7

EVENT PARAMETERS

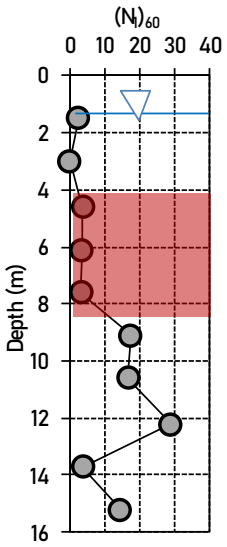
2011 Christchurch Earthquake

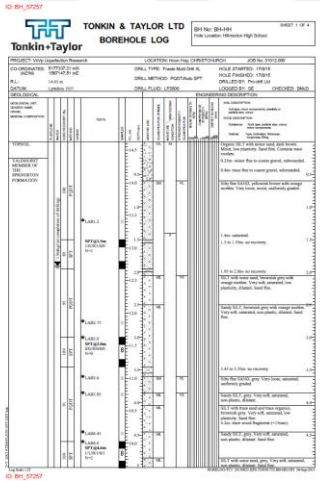
Magnitude: 6.20

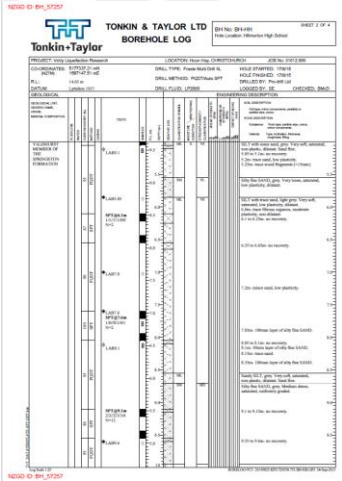
Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 3.2

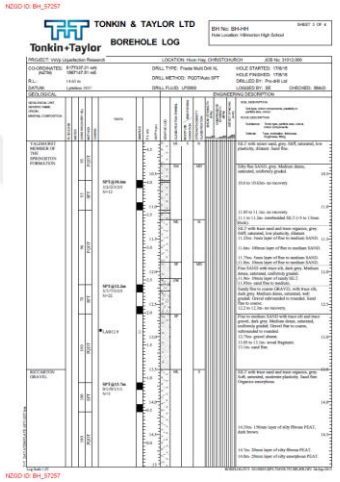
Dip: 64 | Width (km): 6.5 | R_{jb} (km): 3.2

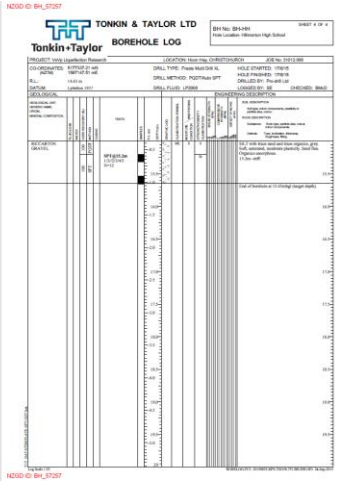
ACCELERATION TIME HISTORY











	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
SM	1.50	4.92	NA	1	2.00	0.85	2.33	above GWT
ML	3.00	9.84	0.29	0	1.63	0.89	0.00	excluded
ML	***4.60***	***15.09***	***0.32***	***2***	***1.42***	***0.92***	***3.59***	
ML	***6.10***	***20.01***	***0.31***	***2***	***1.29***	***0.94***	***3.31***	
ML	***7.60***	***24.93***	***0.29***	***2***	***1.18***	***0.96***	***3.10***	
SM	*9.10*	*29.86*	*0.27*	*12*	*1.10*	*0.97*	*17.49*	
SM	*10.60*	*34.78*	*0.24*	*12*	*1.03*	*0.98*	*16.56*	
GW	12.20	40.03	0.23	22	0.97	0.98	28.80	
ML	13.70	44.95	0.22	3	0.93	0.99	3.75	
ML	15.20	49.87	0.21	12	0.89	0.99	14.39	
						Mean:	3.3	
						St. Dev.	0.2	

	GWT
by VS	2.78 m
by VS	2.64 m
spt	1.9 m

Case number:	272
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Hillsborough Park (VSVP 57202)
References:	McLaughlin (2017), NZGD
Nature of Failure:	None to minor
GPS LAT	-43.560664
GPS LONG	172.673108
Liq. layer consist of:	Sand (SP)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	No
Comments:	CPT and Vs are available at the site. amax is reported as 0.63 g by McLaughlin (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD. Hammer energy is assigned as 82% for PQDT/Auto SPT. Vs,12m is calculated based on the mesaured Vs values. GWT is estimated based on Vs measurement PI is assigned as 0. Silt is nonplastic mostly according to borehole description. FC is assigned based on the SP classification from USCS.



NZGD

After McLaughlin (2017)

Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	3.9 - 5.0
d_{crt} (m)	-	-	-	-	4.5
GWT (m)	-	-	-	-	0.9 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	19.6 ± 0.5
σ_v (kPa)	-	-	-	-	85.5 ± 4.0
σ_v' (kPa)	-	-	-	-	50.4 ± 2.6
a_{max} (g)	-	-	-	-	0.630 ± 0.126
r_d	-	-	-	-	0.91 ± 0.063
CSR	-	-	-	-	0.632 ± 0.135
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	15.0 ± 1.1
C_R	-	-	-	-	0.92
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.42
$(N_1)_{60}$	-	-	-	-	26.7 ± 2.0
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	174.5

EVENT PARAMETERS

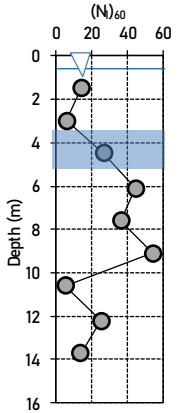
2011 Christchurch Earthquake

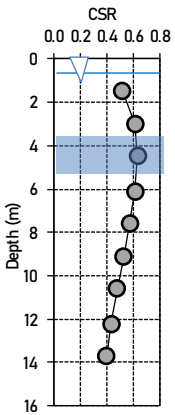
Magnitude: 6.20 — Hanging wall site

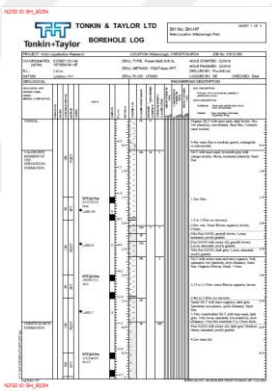
Fault Type: Reverse Fault — Z_{tor} (km): 0.5 — R_{rup} (km): 0.9

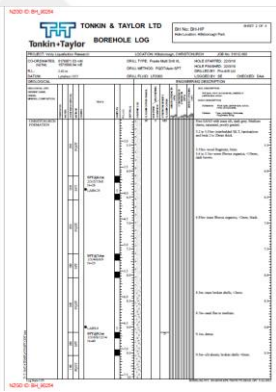
Dip: 64 — Width (km): 6.5 — R_{jb} (km): 0.8

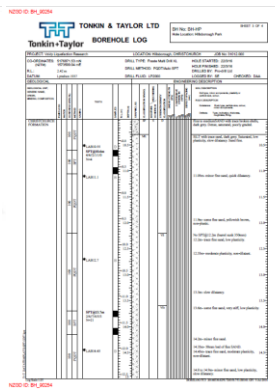
ACCELERATION TIME HISTORY

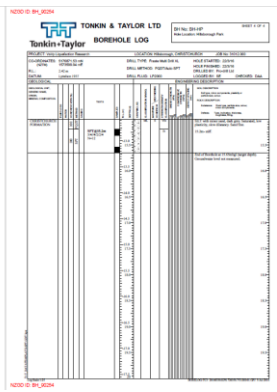








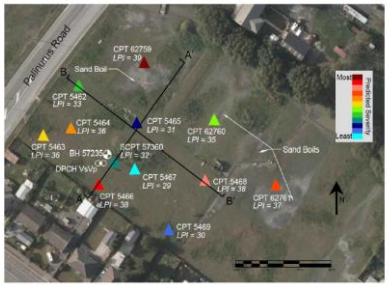




			GWT	
by Vs	0.89	m		
by Vs	0.86	m		
SPT	NA	m		

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
OL	1.5	4.9	0.517	6	2.00	0.85	14.0	SILT with trace sand,
ML	3	9.8	0.615	3	1.68	0.89	6.1	SILT with minor sand and trace organics
SP	***4.5***	***14.8***	***0.632***	***15***	***1.41***	***0.92***	***26.7***	***Fine SAND with minor silt, dark grey. Medium dense, saturated, poorly graded.***
SP	6.1	20.0	0.613	28	1.23	0.94	44.5	Fine SAND with trace silt, dark grey. Medium dense, saturated, poorly graded. some fibrous organics
SP	7.6	24.9	0.575	25	1.12	0.96	36.6	Fine SAND with trace silt, dark grey. Medium dense, saturated, poorly graded. some fibrous organics
SP	9.1	29.9	0.526	40	1.03	0.97	54.4	Fine SAND with trace silt, dark grey. Medium dense, saturated, poorly graded. some fibrous organics
SP	***10.6***	***34.8***	***0.476***	***4***	***0.96***	***0.98***	***5.1***	***SILT with trace sand, dark grey. Saturated, low plasticity, slow dilatancy. Sand fine CPT indicates plastic material RF=4%***
SP	12.2	40.0	0.431	21	0.90	0.98	25.3	SILT with trace sand, dark grey. Saturated, low plasticity, slow dilatancy. Sand fine.
SP	13.7	44.9	0.399	12	0.85	0.99	13.7	SILT with minor sand, dark grey. Saturated, low plasticity, slow dilatancy. Sand fine.
						Mean:	26.7	
						St. Dev.	2.0	assigned

Case number:	227
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Palinurus Road (VSVP 57185)
References:	McLaughlin (2017), NZGD
GPS LAT	-43.551286
GPS LONG	172.688208
Liq. layer consist of:	SP
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Nature of Failure:	Sand boils were observed approximately 40 m away to the north and 80 m to the east
Comments:	CPT and Vs are available at the site. amax is reported as 0.68 g by McLaughlin (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD.
	Vs,12m is calculated based on the mesaured Vs values.
	GWT is estimated based on SPT measurement PI is assigned as 0 for SP. FC is assigned based on the SP classification from USCS. Hammer energy is assigned as 82% for PQDT/Auto SPT.



After McLaughlin (2017)

Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	1.2 - 5.0
d_{crt} (m)	-	-	-	-	3.1
GWT (m)	-	-	-	-	1.2 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	58.1 ± 13.1
σ_v' (kPa)	-	-	-	-	39.4 ± 6.9
a_{max} (g)	-	-	-	-	0.680 ± 0.102
r_d	-	-	-	-	1.00 ± 0.023
CSR	-	-	-	-	0.649 ± 0.105
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	15
N	-	-	-	-	11.2 ± 0.1
C_R	-	-	-	-	0.89
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.61
$(N_1)_{60}$	-	-	-	-	22.0 ± 0.2
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	162.8

EVENT PARAMETERS

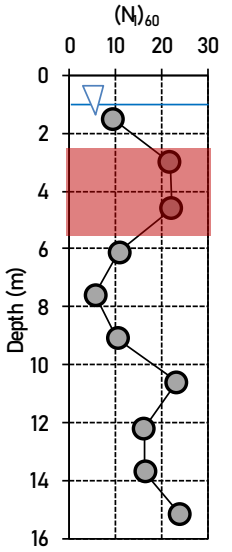
2011 Christchurch Earthquake

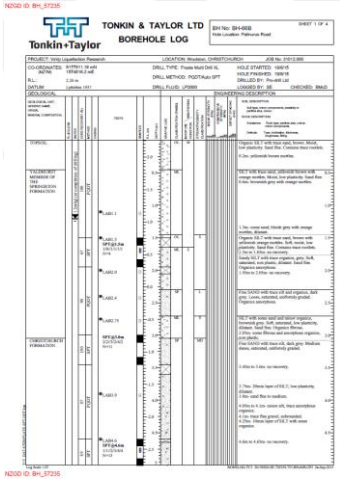
Magnitude: 6.20

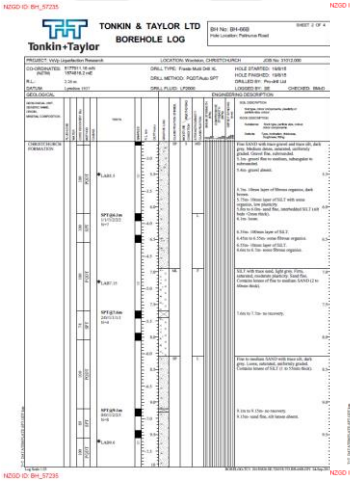
Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 0.7

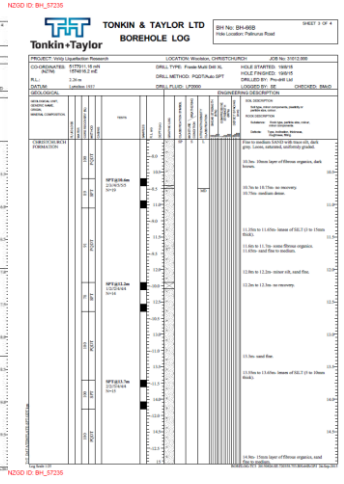
Dip: 64 | Width (km): 6.5 | R_{jb} (km): 0.5

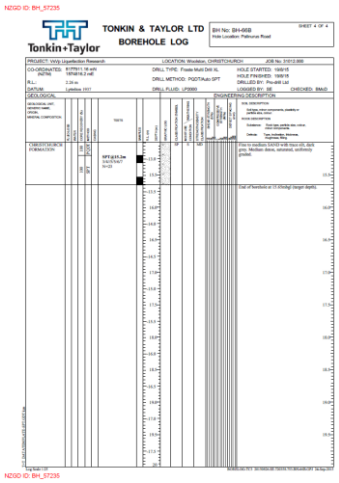
ACCELERATION TIME HISTORY











	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		
-	1.5	4.9		4	2.00	0.85	9.3	organic silt up to 3 m depth	
SP	3	9.8		11	1.63	0.89	21.8		
SP	4.6	15.1		13	1.35	0.92	22.1		
SP	6.1	20.0	Site Response Analysis	7	1.19	***0.94***	10.7	interbedded silt	possibly high plastic according to CPT RF>3%
ML	7.6	24.9		4	1.07	***0.96***	5.6	moderate plasticity	possibly high plastic according to CPT RF>3%
SP	9.1	29.9		8	0.99	***0.97***	10.5	contains lenses of silt	possibly high plastic according to CPT RF>3%
SP	10.6	34.8		19	0.92	0.98	23.3		
SP	12.2	40.0		14	0.86	0.98	16.2		
SP	13.7	44.9		15	0.81	0.99	16.5		
SP	15.2	49.9		23	0.77	0.99	24.1		
						Mean:	22.0		
						St. Dev.	0.2		

GWT	
by Vs	1.34 m
by Vs	1.23 m
SPT	1.2 m

Case number:	228
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Rawhiti Domain (VSVP 57188)
References:	McLaughlin (2017), NZGD
Nature of Failure:	None to Minor
GPS LAT	-43.506536
GPS LONG	172.720961
Liq. layer consist of:	Sand (SP)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.52 g by McLaughlin (2017) after 2011 Christchurch Earthquake based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD. Hammer energy is assigned as 82% for PQDT/Auto SPT. Vs,12m is calculated based on the mesaured Vs values. GWT is estimated based on SPT measurement FC is assigned based on the SP classification from USCS.



After McLaughlin (2017)

Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	A
d_{vnr} range (m)	-	-	-	-	2.5 - 11.1
d_{cr1} (m)	-	-	-	-	6.8
GWT (m)	-	-	-	-	1.5 ± 0.6
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	137.2 ± 29.5
σ_v' (kPa)	-	-	-	-	85.4 ± 16.4
a_{max} (g)	-	-	-	-	0.520 ± 0.078
r_d	-	-	-	-	0.82 ± 0.045
CSR	-	-	-	-	0.445 ± 0.078
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	20.3 ± 3.5
C_R	-	-	-	-	0.95
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.09
$(N_1)_{60}$	-	-	-	-	28.7 ± 5.0
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	197.6

EVENT PARAMETERS

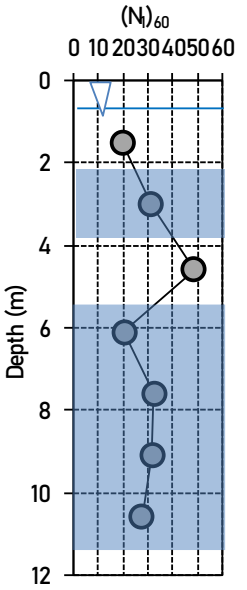
2011 Christchurch Earthquake

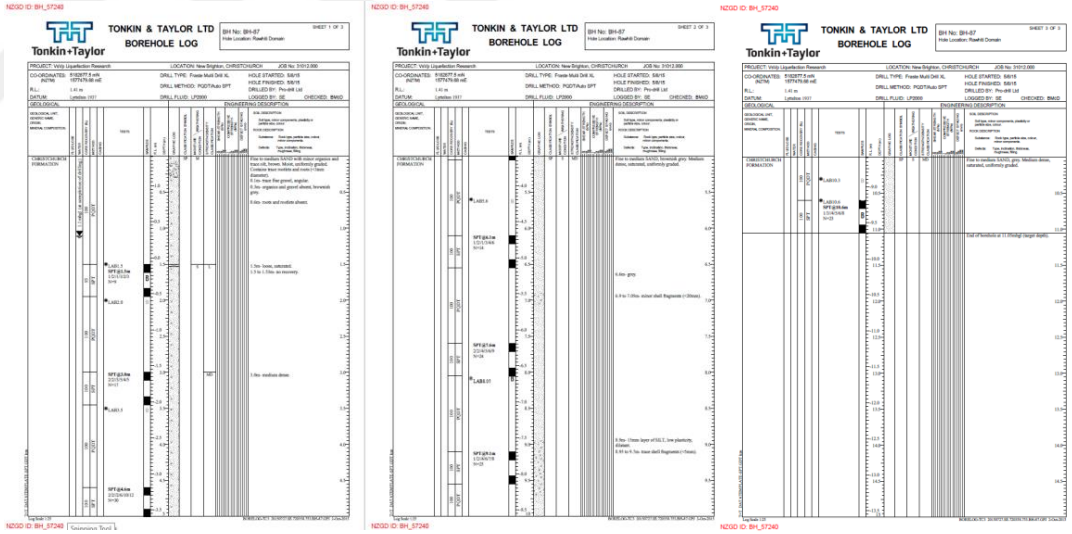
Magnitude: 6.20

Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 2.6

Dip: 64 | Width (km): 6.5 | R_{jb} (km): 2.6

ACCELERATION TIME HISTORY





	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
SP	1.5	4.9		9	1.89	0.85	19.8
SP	***3***	***9.8***		***17***	***1.51***	***0.89***	***31.3***
SP	4.6	15.1	***site***	30	1.28	0.92	48.4
SP	***6.1***	***20.0***	***response***	***14***	***1.14***	***0.94***	***20.6***
SP	***7.6***	***24.9***	***analysis***	***24***	***1.04***	***0.96***	***32.6***
SP	***9.1***	***29.9***		***25***	***0.96***	***0.97***	***31.8***
SP	***10.6***	***34.8***		***23***	***0.90***	***0.98***	***27.5***
						Mean:	28.7
						St. Dev.	5.0

surfacial CN>2.0

saturated below 2.5 m according to VP/VS data

outlier SPT-N values

GWT	
by Vs	1.23 m
by Vs	1.22 m
SPT	1.1 m
CPT	2.2 m
Mean:	1.51 m

Case number:	228
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Rydal Reserve (VSVP 57190)
References:	McLaughlin (2017), NZGD
Nature of Failure:	None to Minor
GPS LAT	-43.565975
GPS LONG	172.608153
Liq. layer consist of:	Sand-Silt-Gravel (ML-SP-GW)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	No
Comments:	CPT and Vs are available at the site. amax is reported as 0.44 g by McLaughlin (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD. Hammer energy is assigned as 82% for PQDT/Auto SPT. Vs,12m is calculated based on SPT-N values. Vs values were available up to 6 m. GWT is estimated based on SPT measurement FC is assigned based on the SP classification from USCS.



After McLaughlin (2017)

Gravel Conetnt (%):	12.0-60.0
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.0 - 9.5
d_{crt} (m)	-	-	-	-	5.8
GWT (m)	-	-	-	-	1.6 ± 0.2
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	113.3 ± 25.9
σ_v' (kPa)	-	-	-	-	72.5 ± 13.7
a_{max} (g)	-	-	-	-	0.440 ± 0.088
r_d	-	-	-	-	0.97 ± 0.079
CSR	-	-	-	-	0.435 ± 0.096
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	6.0-16.0 ± 2.5
% PI	-	-	-	-	0-4
N	-	-	-	-	12.4 ± 3.3
C_R	-	-	-	-	0.94
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.18
$(N_1)_{60}$	-	-	-	-	18.8 ± 5.0
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	228.60

EVENT PARAMETERS

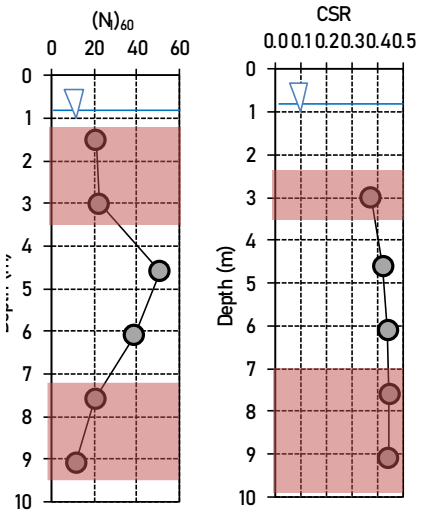
2011 Christchurch Earthquake

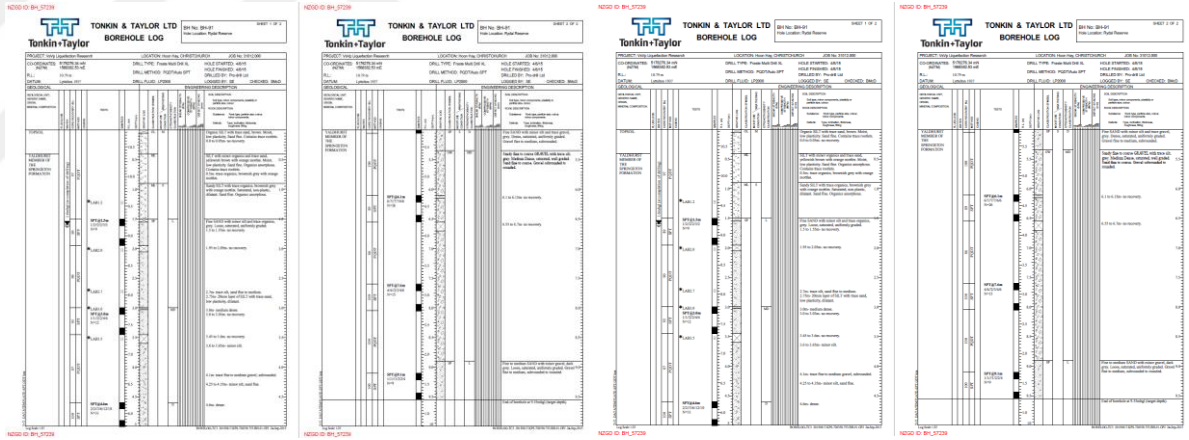
Magnitude: 6.20

Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 1.6

Dip: 64 | Width (km): 6.5 | R_{jb} (km): 1.5

ACCELERATION TIME HISTORY





	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
ML-SP band	***1.5***	***4.9***	***NA***	***9***	***1.98***	***0.85***	***20.7***	saturated below 2 m according to Vp/Vs
SP	***3***	***9.8***	***0.37***	***12***	***1.54***	***0.89***	***22.5***	
SP	4.6	15.1	0.419	31	1.30	0.92	50.8	outlier
GW	6.1	20.0	0.438	26	1.15	0.94	38.7	outier
GW	***7.6***	***24.9***	***0.44***	***15***	***1.05***	***0.96***	***20.6***	
SP	***9.1***	***29.9***	***0.442***	***9***	***0.97***	***0.97***	***11.5***	
						Mean:	18.8	
						St. Dev.	5.0	

GWT	
by Vs	1.72 m
by Vs	1.32 m
SPT	1.6 m

Case number:	230
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Sabina Playground (VSVP 57192)
References:	McLaughlin (2017), NZGD
Nature of Failure:	Moderate
GPS LAT	-43.504394
GPS LONG	172.660661
Liq. layer consist of:	Sand-Gravel (SP-GW)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.34 g by McLaughlin (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD.
	Vs,12m is calculated based on the mesaured Vs values.
	GWT is estimated based on SPT measurement
	Gravel Content is assigned according to USCS
	FC is assigned based on the SP classification from USCS.



After McLaughlin (2017)

Gravel Content (%):	25-75
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	7.0 - 9.5
d_{crt} (m)	-	-	-	-	8.3
GWT (m)	-	-	-	-	1.6 ± 0.3
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	167.4 ± 9.2
σ_v' (kPa)	-	-	-	-	102.1 ± 5.9
a_{max} (g)	-	-	-	-	0.340 ± 0.051
r_d	-	-	-	-	0.70 ± 0.054
CSR	-	-	-	-	0.256 ± 0.044
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	15.8 ± 3.5
C_R	-	-	-	-	0.96
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.00
$(N_1)_{60}$	-	-	-	-	20.8 ± 4.6
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	184.1

EVENT PARAMETERS

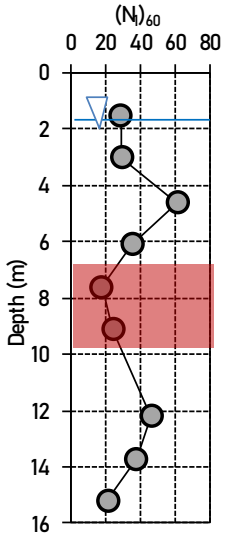
2011 Christchurch Earthquake

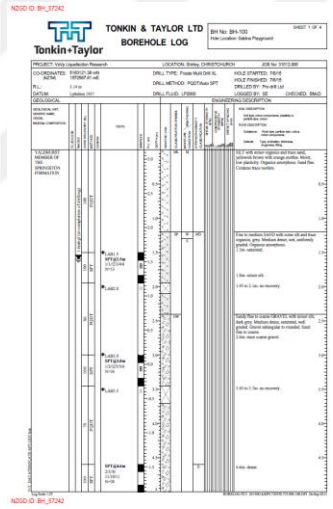
Magnitude: 6.20

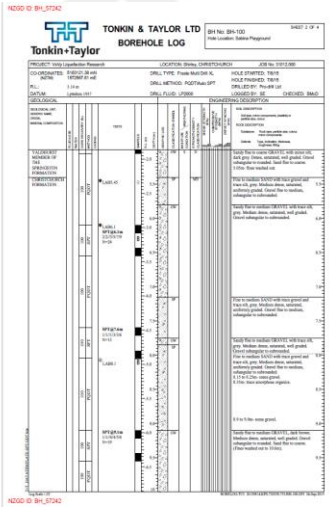
Fault Type: Reverse Fault — Z_{tor} (km): 0.5 — R_{rup} (km): 5.2

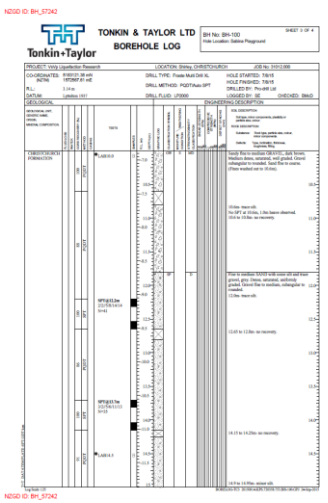
Dip: 64 — Width (km): 6.5 — R_{jb} (km): 5.2

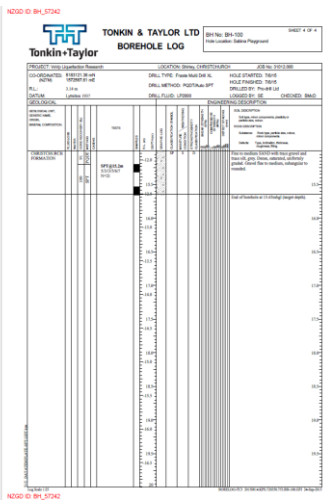
ACCELERATION TIME HISTORY











	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
SP	***1.5***	***4.9***		***13***	***1.89***	***0.85***	***28.7***	
GW	***3***	***9.8***		***16***	***1.50***	***0.89***	***29.2***	
GW	4.6	15.1		38	1.27	0.92	61.0	outlier
GW	6.1	20.0	***site***	24	1.14	0.94	35.1	outlier
SP	***7.6***	***24.9***	***response***	***13***	***1.03***	***0.96***	***17.6***	more critical when
GW	***9.1***	***29.9***	***analysis***	***19***	***0.96***	***0.97***	***24.0***	compared to upper
SP	12.2	40.0		41	0.84	0.98	46.2	outlier
SP	13.7	44.9		35	0.79	0.99	37.5	outlier
SP	15.2	49.9		21	0.76	0.99	21.5	
						Mean:	20.8	
						St. Dev.	4.6	

GWT	
by Vs	1.08 m
by Vs	1.25 m
SPT	1.6 m

SP - GW matrix

Case number:	231
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Shirley Intermediate School (VSVP 57203)
References:	McLaughlin (2017), NZGD
Nature of Failure:	Major to Very Severe
GPS LAT	-43.510356
GPS LONG	172.661992
Liq. layer consist of:	Sand (SP)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.38 g by McLaughlin (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD. Hammer energy is assigned as 82% for PQDT/Auto SPT. Vs,12m is calculated based on the mesaured Vs values. GWT is estimated based onVs and CPT measurement Top silt has organic content. Sand is suspectible to liquefaction. FC is assigned based on the SP classification from USCS.



After McLaughlin (2017)

Gravel Content (%)	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	4.0 - 9.4
d_{crt} (m)	-	-	-	-	6.7
GWT (m)	-	-	-	-	2.4 ± 0.4
γ_{moist} (kN/m^3)	-	-	-	-	17.4 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	130.6 ± 18.8
σ_v' (kPa)	-	-	-	-	88.6 ± 10.3
a_{max} (g)	-	-	-	-	0.380 ± 0.057
r_d	-	-	-	-	0.76 ± 0.045
CSR	-	-	-	-	0.276 ± 0.047
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	13.5 ± 2.8
C_R	-	-	-	-	0.95
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.07
$(N_1)_{60}$	-	-	-	-	18.8 ± 3.9
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	175.9

EVENT PARAMETERS

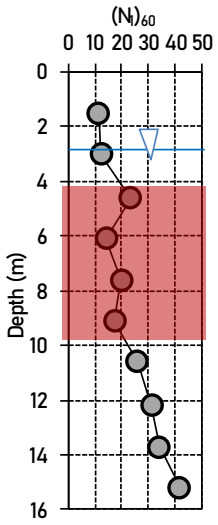
2011 Christchurch Earthquake

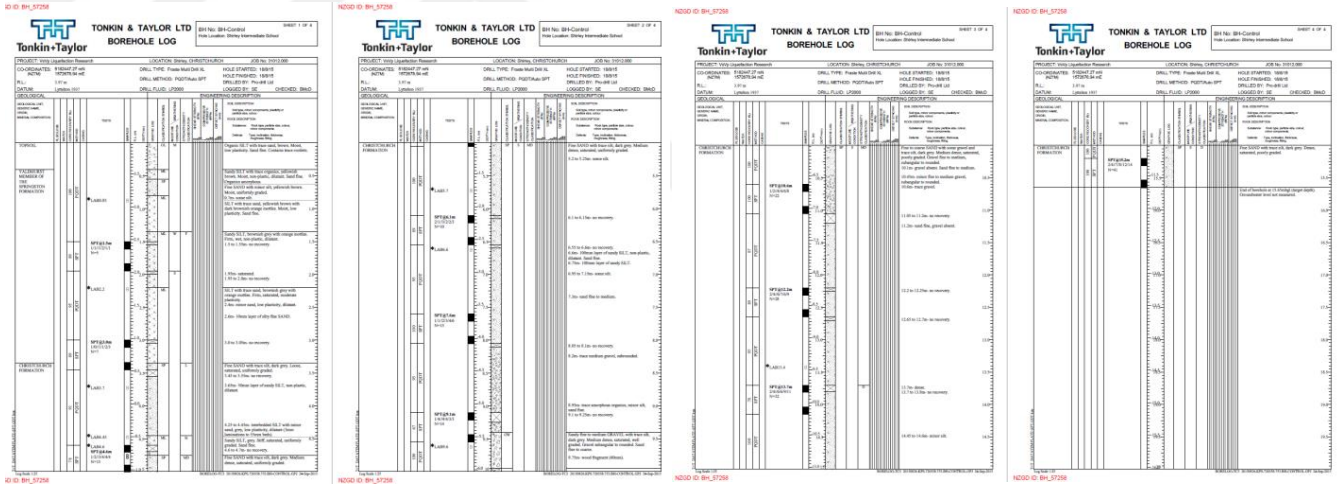
Magnitude: 6.20

Fault Type: Reverse Fault — Z_{tor} (km): 0.5 — R_{rup} (km): 4.6

Dip: 64 — Width (km): 6.5 — R_{jb} (km): 4.6

ACCELERATION TIME HISTORY





	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
ML	1.5	4.9		5	1.97	0.85	11.5	not fully saturated
ML	3	9.8		7	1.45	0.89	12.3	moderate plasticity
ML-SP BAND	***4.6***	***15.1***		***15***	***1.24***	***0.92***	***23.5***	sandy silt
SP	***6.1***	***20.0***	site	***10***	***1.11***	***0.94***	***14.3***	
SP	***7.6***	***24.9***	response	***15***	***1.02***	***0.96***	***20.0***	
SP	***9.1***	***29.9***	analysis	***14***	***0.94***	***0.97***	***17.5***	
SP	10.6	34.8		22	0.88	0.98	25.9	
SP	12.2	40.0		28	0.83	0.98	31.2	
SP	13.7	44.9		32	0.79	0.99	34.0	
SP	15.2	49.9		41	0.75	0.99	41.7	
						Mean:	18.8	
						St. Dev.	3.9	

CPT FR>2% plastic

GWT	
by Vs	2.8 m
by Vs	2.7 m
CPT	2 m
CPT	2.2 m

Case number:	232
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	St. Albans Catholic School (VSVP 57180)
References:	McLaughlin (2017), NZGD
Nature of Failure:	Moderate
GPS LAT	-43.507189
GPS LONG	172.629139
Liq. layer consist of:	Sand- Silt (SP-SM-ML)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.34 g by McLaughlin (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD.
	Hammer energy is assigned as 82% for PQDT/Auto SPT.
	Vs,12m is calculated based on the mesaured Vs values.
	GWT is estimated based on SPT measurement
	FC is assigned based on the SP-SM-ML classification from USCS. A large unceratinty is assigned.
	SP <5
	SM >12
	ML >50



After McLaughlin (2017)

Gravel Content:	NAV
CPT available:	Yes
Vs available:	Yes

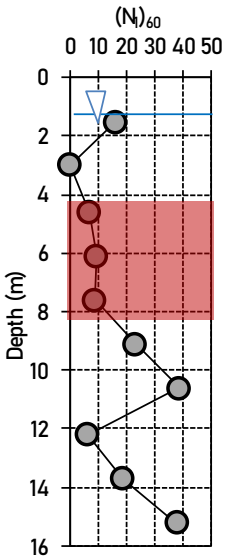
Summary of Input Data

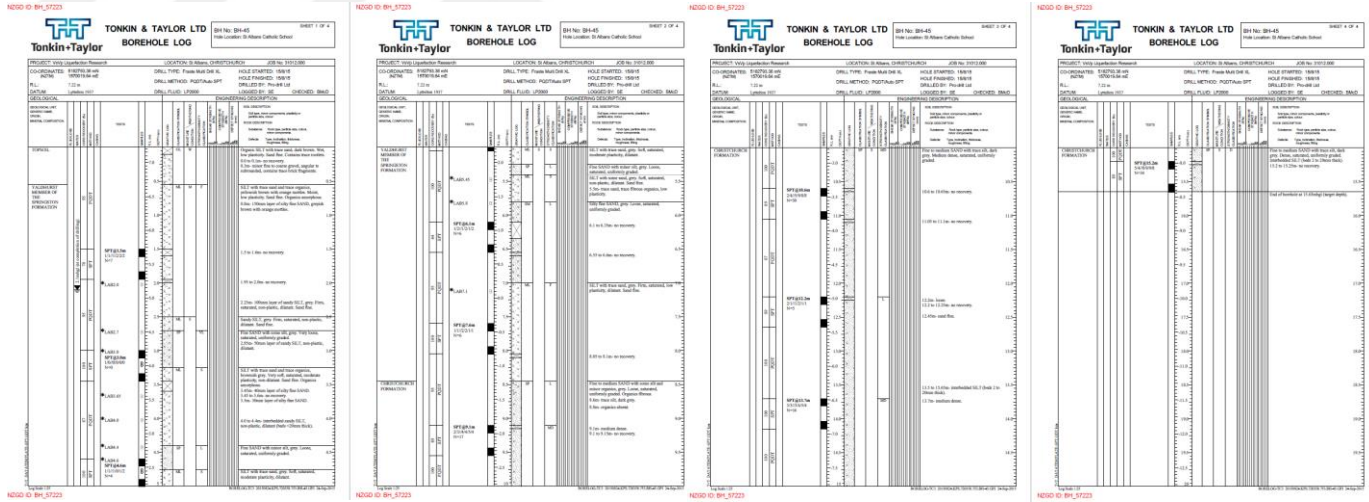
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	4.4 - 8.5
d_{crt} (m)	-	-	-	-	6.4
GWT (m)	-	-	-	-	1.7 ± 0.4
γ_{moist} (kN/m^3)	-	-	-	-	17.4 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	119.1 ± 13.0
σ_v' (kPa)	-	-	-	-	72.3 ± 7.3
a_{max} (g)	-	-	-	-	0.340 ± 0.051
r_d	-	-	-	-	0.81 ± 0.043
CSR	-	-	-	-	0.296 ± 0.050
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	20.0-50.0 ± 7.5
% PI	-	-	-	-	0-7
N	-	-	-	-	5.4 ± 0.8
C_R	-	-	-	-	0.95
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.19
$(N_1)_{60}$	-	-	-	-	8.3 ± 1.3
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	159.1

EVENT PARAMETERS

2011 Christchurch Earthquake			Hanging wall site
Magnitude: 6.20			
Fault Type: Reverse Fault	Z_{tor} (km): 0.5		R_{rup} (km): 6.2
Dip: 64	Width (km): 6.5		R_{jb} (km): 6.2

ACCELERATION TIME HISTORY





	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
ML	1.5	4.9		7	1.97	0.85	16.1	above GWT
SP	3	9.8		0	1.57	0.89	0.0	outlier
SP	***4.6***	***15.1***		***4***	***1.35***	***0.92***	***6.8***	
SM	***6.1***	***20.0***		***6***	***1.21***	***0.94***	***9.4***	
ML	***7.6***	***24.9***	site response analysis	***6***	***1.11***	***0.96***	***8.7***	low plasticity
SP	9.1	29.9		17	1.03	0.97	23.1	
SP	10.6	34.8		30	0.96	0.98	38.5	
SP	12.2	40.0		5	0.90	0.98	6.1	outlier
SP	13.7	44.9		16	0.86	0.99	18.5	
SP	15.2	49.9		34	0.82	0.99	37.7	
						Mean:	8.3	
						St. Dev.	1.3	

just below there is an organic ML layer

GWT		
by Vs	1.3	m
by Vs	1.27	m
SPT	2.1	m

Case number:	233
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	St. Teresa's School (VSVP 57191)
References:	McLaughlin (2017), NZGD
GPS LAT	-43.529833
GPS LONG	172.59205
Liq. layer consist of:	Silt (ML)-Sand
Geological Unit:	Natural Deposit
Site Response Anlaysis:	No
Nature of Failure:	No observations of surficial liquefaction manifestation.
Comments:	CPT and Vs are available at the site. amax is reported as 0.34 g by McLaughlin (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Hammer energy is taken as 80% and 95.6 % for the two borehole respectively. Vs,12m is calculated based on the mesaured Vs values. GWT is estimated based on two SPT measurements Test results are retrieved from NGZD. FC is assigned based on the SM-ML classification from USCS. A large uncertainty is assigned There exist 2 borehole at the site. Same soil layering in both borehole. For one of the borheole ER is given as 95.6%. N60 values are calculated for the two borehole. Hence CE is used as 60%.
Gravel Content	NAV
CPT available:	Yes
Vs available:	Yes



After McLaughlin (2017)

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	C
d_{crtc} range (m)	-	-	-	-	2.0 - 4.5
d_{crt} (m)	-	-	-	-	3.3
GWT (m)	-	-	-	-	2.0 ± 1.6
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	19.0 ± 0.5
σ_v (kPa)	-	-	-	-	55.4 ± 9.6
σ_v' (kPa)	-	-	-	-	43.2 ± 11.3
a_{max} (g)	-	-	-	-	0.340 ± 0.068
r_d	-	-	-	-	0.89 ± 0.049
CSR	-	-	-	-	0.253 ± 0.102
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	12.5-62.5 ± 7.5
% PI	-	-	-	-	0-4
N	-	-	-	-	6.0 ± 1.8
C_R	-	-	-	-	0.90
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.00
C_N	-	-	-	-	1.53
$(N_1)_{60}$	-	-	-	-	8.3 ± 2.5
V_{s30m} (m/s)	-	-	-	-	NA
V_{s12m} (m/s)	-	-	-	-	146.4

EVENT PARAMETERS

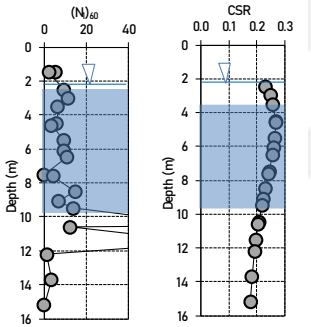
2011 Christchurch Earthquake — Hanging wall site

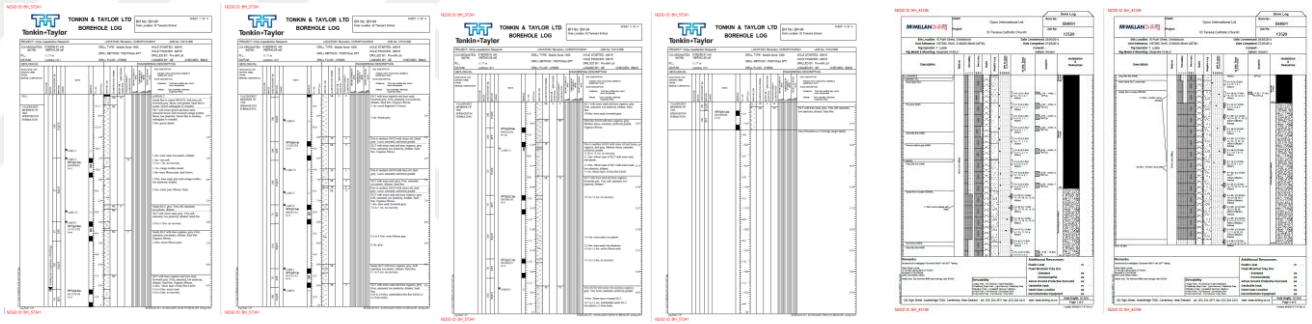
Magnitude: 6.20

Fault Type: Reverse Fault — Z_{tor} (km): 0.5 — R_{rup} (km): 5.7

Dip: 64 — Width (km): 6.5 — R_{jb} (km): 5.7

ACCELERATION TIME HISTORY



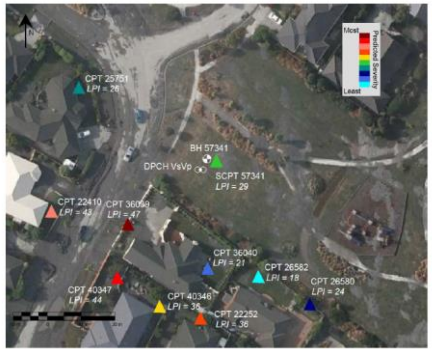


	Depth (m)	Depth (ft)	CSR	N_{60}	C_N	C_R	$(N1)_{60}$	Borehole Name	
Grey Sandy SILT	1.5	4.9	NA	3	2.00	0.85	5.4	45186	above GWT
ML	1.5	4.9	NA	1	2.00	0.85	2.3	57241	above GWT
Fine grey SAND	***2.5***	***8.2***	***0.231***	***6***	***1.67***	***0.88***	***9.4***	45186	
ML	***3***	***9.8***	***0.247***	***8***	***1.58***	***0.89***	***11.3***	57241	
Fine grey SAND	***3.5***	***11.5***	***0.258***	***5***	***1.50***	***0.90***	***6.4***	45186	
Fine grey SAND	***4.5***	***14.8***	***0.267***	***5***	***1.36***	***0.92***	***6.0***	45186	
ML	4.6	15.1	0.267	3	1.35	0.92	3.3	57241	organics
Grey Silty fine SAND	***5.5***	***18.0***	***0.265***	***8***	***1.26***	***0.94***	***9.4***	**45186**	*CPT indicates plastic*
SP	***6.1***	***20.0***	***0.260***	***8***	***1.21***	***0.94***	***9.1***	**57241**	*material RF>3-4% hence*
Fine to medium grey SAND	***6.5***	***21.3***	***0.256***	***10***	***1.18***	***0.95***	***10.7***	**45186**	*upper layer is selected*
Grey Silty fine SAND	7.5	24.6	0.244	0	1.11	0.96	0.0	45186	outlier
ML	7.6	24.9	0.243	4	1.10	0.96	4.2	57241	organics
Grey Silty fine SAND	8.5	27.9	0.231	14	1.05	0.97	14.6	45186	
ML	9.1	29.9	0.223	7	1.02	0.97	6.6	57241	organics
Grey Silty fine SAND	9.5	31.2	0.218	14	1.00	0.97	14.0	45186	
Sandy fine to coarse GRAVEL	10.5	34.4	0.206	88	0.96	0.98	82.3	45186	
SM	10.6	34.8	0.205	13	0.96	0.98	12.5	57241	
Sandy fine to coarse GRAVEL	11.5	37.7	0.197	86	0.92	0.98	77.9	45186	
ML	12.2	40.0	0.191	1	0.90	0.98	1.2	57241	
ML	13.7	44.9	0.183	4	0.85	0.99	3.4	57241	*trace organics*
ML	15.2	49.9	0.177	0	0.81	0.99	0.0	57241	
						Mean:	8.3		
						St. Dev.	2.5		

	Depth (m)	N	Borehole Name	ER	CE	N60		
Grey Sandy SILT	*1.5*	*2*	45186	0.956	1.59	3	GWT	3.1
Fine grey SAND	*2.5*	*4*	45186	0.956	1.59	6	(m)	
Fine grey SAND	*3.5*	*3*	45186	0.956	1.59	5		
Fine grey SAND	*4.5*	*3*	45186	0.956	1.59	5		
Grey Silty fine SAND	*5.5*	*5*	45186	0.956	1.59	8		
Fine to medium grey SAND	*6.5*	*6*	45186	0.956	1.59	10		
Grey Silty fine SAND	*7.5*	*0*	45186	0.956	1.59	0		
Grey Silty fine SAND	*8.5*	*9*	45186	0.956	1.59	14		
Grey Silty fine SAND	*9.5*	*9*	45186	0.956	1.59	14		
Sandy fine to coarse GRAVEL	10.5	55	45186	0.956	1.59	88		
Sandy fine to coarse GRAVEL	11.5	54	45186	0.956	1.59	86		
ML	*1.5*	*1*	57241	0.8	1.33	1	GWT	4.6
ML	*3*	*6*	57241	0.8	1.33	8	(m)	
ML	*4.6*	*2*	57241	0.8	1.33	3		
SP	*6.1*	*6*	57241	0.8	1.33	8		
ML	*7.6*	*3*	57241	0.8	1.33	4		
ML	*9.1*	*5*	57241	0.8	1.33	7		
SM	10.6	10	57241	0.8	1.33	13		
ML	12.2	1	57241	0.8	1.33	1		
ML	13.7	3	57241	0.8	1.33	4		
ML	15.2	0	57241	0.8	1.33	0		

**N60 values were calculated*

Case number:	234
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Ti Rakau Reserve (VSVP 57186)
References:	McLaughlin (2017), NZGD
Nature of Failure:	Moderate
GPS LAT	-43.548878
GPS LONG	172.695286
Liq. layer consist of:	Sand (SP) and minor silt
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.68 g by McLaughlin (2017)based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD. Hammer energy is assigned as 82% for PQDT/Auto SPT. Vs,12m is calculated based on the mesaured Vs values. GWT is estimated based on SPT measurement FC is assigned based on the SP classification from USCS.



After McLaughlin (2017)

Gravel Content	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

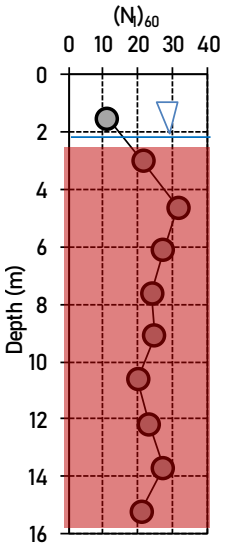
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	3.3 - 15.7
d_{crt} (m)	-	-	-	-	9.5
GWT (m)	-	-	-	-	1.9 ± 1.7
γ_{moist} (kN/m^3)	-	-	-	-	17.4 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	189.0 ± 43.1
σ_v' (kPa)	-	-	-	-	114.6 ± 25.3
a_{max} (g)	-	-	-	-	0.680 ± 0.102
r_d	-	-	-	-	0.83 ± 0.060
CSR	-	-	-	-	0.608 ± 0.129
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	20.3 ± 3.0
C_R	-	-	-	-	0.97
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.33
C_N	-	-	-	-	0.94
$(N_1)_{60}$	-	-	-	-	24.8 ± 3.7
$V_{s,30m}$ (m/s)	-	-	-	-	NA
$V_{s,12m}$ (m/s)	-	-	-	-	155.8

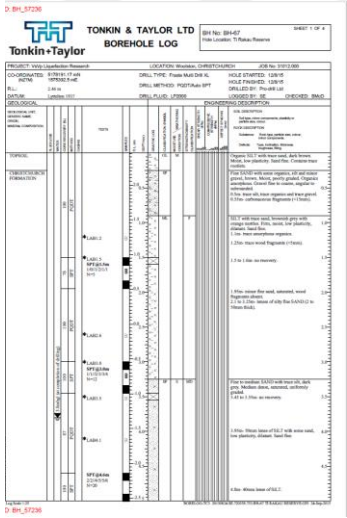
EVENT PARAMETERS

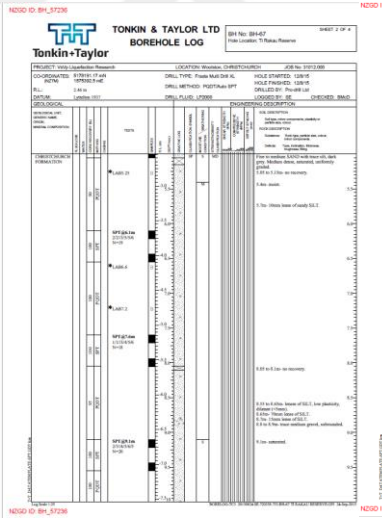
2011 Christchurch Earthquake

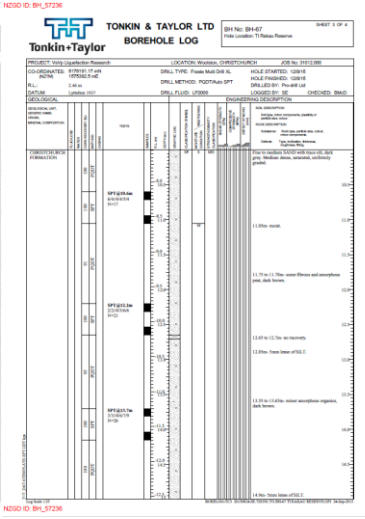
Magnitude: 6.20			
Fault Type: Reverse Fault	Z_{tor} (km): 0.5	R_{rup} (km): 0.7	
Dip: 64	Width (km): 6.5	R_{jb} (km): 0.5	

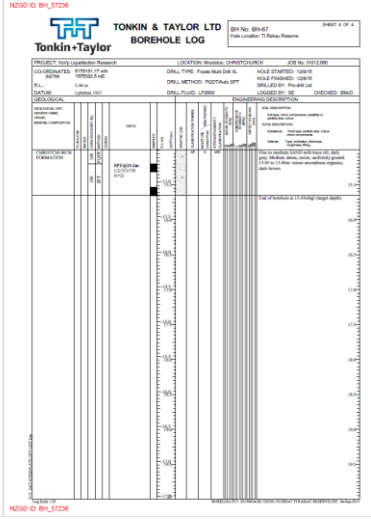
ACCELERATION TIME HISTORY











	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
ML	1.5	4.9		5	1.97	0.85	11.2	above GWT
ML	*3*	*9.8*		*12*	*1.5*	0.89	*21.5*	trace wood and organics
SP	***4.6***	***15.1***		***20***	***1.28***	***0.92***	***31.4***	
SP	***6.1***	***20.0***		***19***	***1.14***	***0.94***	***27.2***	
SP	***7.6***	***24.9***	site response analysis	***18***	***1.04***	***0.96***	***23.8***	
SP	***9.1***	***29.9***		***20***	***0.96***	***0.97***	***24.7***	
SP	***10.6***	***34.8***		***17***	***0.89***	***0.98***	***19.8***	
SP	***12.2***	***40.0***		***21***	***0.84***	***0.98***	***23.1***	
SP	***13.7***	***44.9***		***26***	***0.80***	***0.99***	***27.2***	
SP	***15.2***	***49.9***		***21***	***0.76***	***0.99***	***21.0***	
						Mean:	24.8	
						St. Dev.	3.7	

GWT	
by Vs	0.59 m
by Vs	0.67 m
SPT	3.8 m
CPT	1.2 m
Mean	1.88 m

Case number:	235
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Wharenui School (VSVP 57165)
References:	McLaughlin (2017), NZGD
Nature of Failure:	None to minor
GPS LAT	-43.53611
GPS LONG	172.597625
Liq. layer consist of:	Sand - Silt (SM-ML)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	No
Comments:	CPT and Vs are available at the site. amax is reported as 0.36 g by McLaughlin (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014).Test results are retrieved from NGZD. Hammer energy is assigned as 82% for PQDT/Auto SPT. Vs,12m is calculated based on the mesaured Vs values. GWT is estimated based on SPT measurement FC is assigned based on the GW classification from USCS.



After McLaughlin (2017)

Gravel Content	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
$d_{crit.}$ range (m)	-	-	-	-	4.5 - 6.7
$d_{crt.}$ (m)	-	-	-	-	5.6
GWT (m)	-	-	-	-	1.6 ± 0.4
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	19.0 ± 0.5
σ_v (kPa)	-	-	-	-	100.9 ± 7.3
σ_v' (kPa)	-	-	-	-	61.9 ± 4.8
a_{max} (g)	-	-	-	-	0.360 ± 0.072
r_d	-	-	-	-	0.75 ± 0.077
CSR	-	-	-	-	0.288 ± 0.067
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	12.0-50.0 ± 10.0
% PI	-	-	-	-	0-7
N	-	-	-	-	7.8 ± 5.6
C_R	-	-	-	-	0.94
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.28
$(N_1)_{60}$	-	-	-	-	12.8 ± 9.1
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	141.9

EVENT PARAMETERS

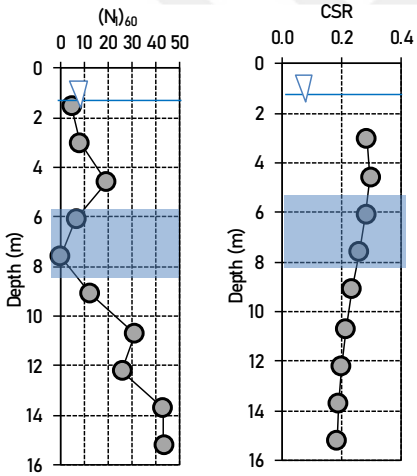
2011 Christchurch Earthquake

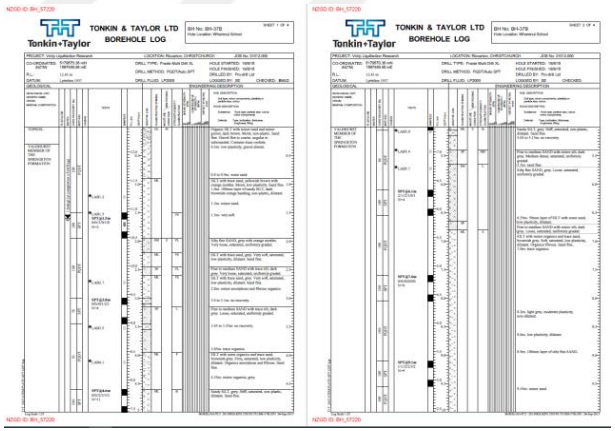
Magnitude: 6.20

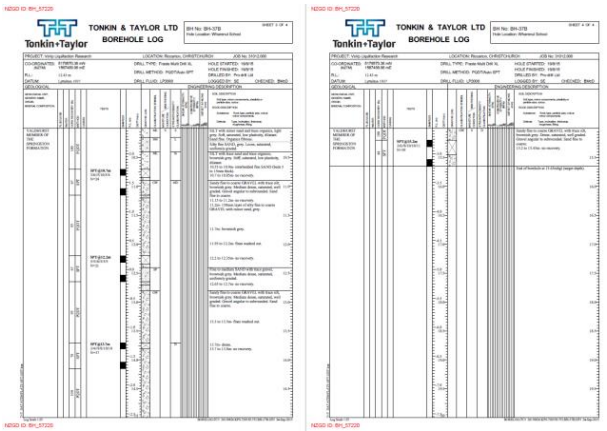
Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 4.9

Dip: 64 | Width (km): 6.5 | R_{jb} (km): 4.9

ACCELERATION TIME HISTORY







	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
ML	1.50	4.92	NA	2	2.00	0.85	5	nonplastic-above GWT
ML	3.00	9.84	0.28	4	1.63	0.89	8	minor organics
ML	***4.60***	***15.09***	***0.30***	***11***	***1.39***	***0.92***	***19***	nonplastic CPT suggest to combine these two sublayers
SM	***6.10***	***20.01***	***0.28***	***4***	***1.23***	***0.94***	***6***	
ML	7.60	24.93	0.26	0	1.12	0.96	0	organics
ML	9.10	29.86	0.23	9	1.04	0.97	12	minor organics
-	10.70	35.10	0.21	24	0.96	0.98	31	
GW	12.20	40.03	0.20	21	0.91	0.98	26	
GW	13.70	44.95	0.19	37	0.86	0.99	43	
GW	15.20	49.87	0.18	39	0.82	0.99	43	
						Mean:	12.8	
						St. Dev.	9.1	

GWT		
by Vs	2.32	m
by Vs	2.35	m
SPT	1.6	m

Case number:	237
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	SW KAN 09
References:	Wood et al (2017), NZGD
Nature of Failure:	None. No surficial evidence of liquefaction.
GPS LAT	-43.3813667
GPS LONG	172.6614833
Liq. layer consist of:	SP-SM-SW
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.186 g by Wood et al (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD. Gravel layer is sandy. There exist interlayering of sand and gravel layer hence gravel and sand layers are com Hammer energy is assigned as 82% for PQDT/Auto SPT. FC information is available.



NZGD



After Wood et al (2017)

Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{nrtc} range (m)	-	-	-	-	1.5 - 3.5
d_{crt} (m)	-	-	-	-	2.5
GWT (m)	-	-	-	-	1.5 ± 0.3
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	49.1 ± 7.0
σ_v' (kPa)	-	-	-	-	38.7 ± 4.5
a_{max} (g)	-	-	-	-	0.186 ± 0.028
r_d	-	-	-	-	0.95 ± 0.019
CSR	-	-	-	-	0.145 ± 0.026
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	25.3 ± 9.7
% PI	-	-	-	-	0
N	-	-	-	-	7.6 ± 1.4
C_R	-	-	-	-	0.88
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.62
$(N_1)_{60}$	-	-	-	-	14.7 ± 2.8
$V_{s,30m}$ (m/s)	-	-	-	-	245.9
$V_{s,12m}$ (m/s)	-	-	-	-	163.8

EVENT PARAMETERS

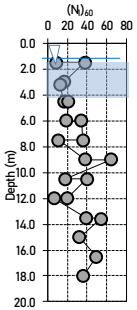
2011 Christchurch Earthquake

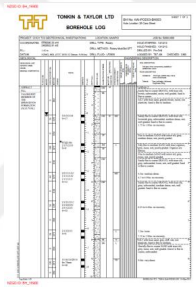
Magnitude: 6.20

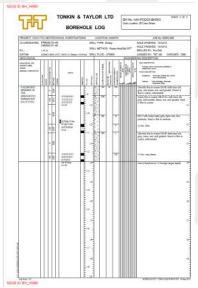
Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 16.9

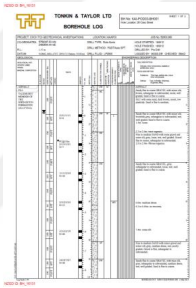
Dip: 64 | Width (km): 6.5 | R_{jb} (km): 16.9

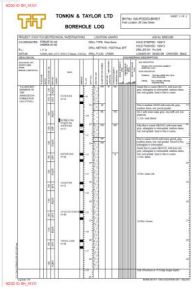
ACCELERATION TIME HISTORY

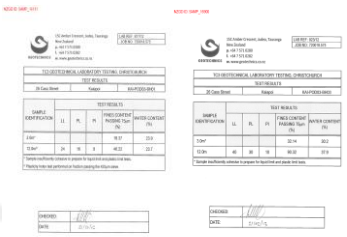




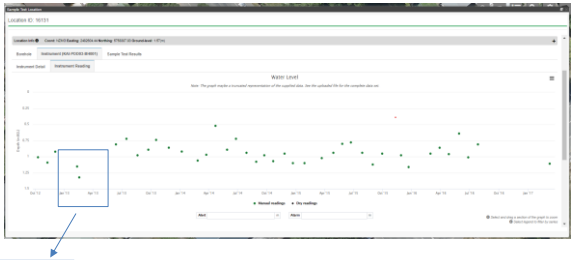








	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	Borehole	N	FC	LL	PL	PI	
GW	1.5	4.92		4	1.91	0.85	8.9	16131						
GW	1.5	4.92		17	1.91	0.85	37.8	16900						
SP-SM	***3.0***	***9.84***		***9***	***1.52***	***0.89***	***16.6***	***16900***		***32.14***	***outlier FC***			SP 0-5 % inconsistent FC info
SW	***3.2***	***10.50***		***7***	***1.48***	***0.90***	***12.7***	***16131***		***18.37***	***for average this FC was include***			SW 0-5 % inconsistent FC info
GW	4.5	14.76		10	1.30	0.92	16.3	16131		0.00				
GW	4.5	14.76		13	1.30	0.92	21.2	16900		0.00				
GW	6.0	19.69		13	1.15	0.94	19.3	16131		0.00				
GW	6.0	19.69		23	1.15	0.94	34.1	16900						outlier gravel influence
GW	7.5	24.61		26	1.05	0.96	35.6	16131						
GW	7.5	24.61	site	8	1.05	0.96	11.0	16900						outlier gravel?
SP-GW	9.0	29.53	response	30	0.97	0.97	38.3	16131						
SW	9.0	29.53	analysis	50	0.97	0.97	63.9	16900	>50					
GW	10.5	34.45		15	0.90	0.98	18.0	16131						
GW	10.5	34.45		33	0.90	0.98	39.7	16900						
ML-GW	12.0	39.37		17	0.85	0.98	19.4	16131		46.22	24.00	16.00	8.00	
ML	12.0	39.37		6	0.85	0.98	6.8	16900		90.32	40.00	30.00	10.00	multile suspect but PI=10
GW	13.5	44.29		36	0.80	0.99	39.0	16131						hence the upper layer is claimed
SW	13.6	44.62		50	0.80	0.99	54.0	16900	>50					to be more critical
GW	15.0	49.21		31	0.76	0.99	32.1	16131						
GW	16.5	54.13		50	0.73	0.99	49.6	16131						
GW	18.0	59.06		38	0.70	1.00	36.3	16131						
						Mean:	14.7			25.3				
						St. Dev.	2.8			9.7				



2011 EQ occured in February

GWT	
16131	1.4 m
16900	1.5 m

Case number:	238
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	SW KAN 19
References:	Wood et al (2017), NZGD
Nature of Failure:	No surficial evidence of liquefaction
GPS LAT	-43.380567
GPS LONG	172.668707
Liq. layer consist of:	SP-SM
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.187 g by Wood et al (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD. Rrup= 16.91 km. Vs,12m is calculated based on the mesaured Vs values. Hammer energy is assigned as 82% for PQDT/Auto SPT. FC information is available.



Figure ESA-9a. Site plots of KAN 19 (Post-Christchurch EQ) showing the location of the surface wave array and CPT sounding.

After Wood et al (2017)



NZGD

Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	A
$d_{crit.}$ range (m)	-	-	-	-	2.0 - 10.5
d_{crt} (m)	-	-	-	-	6.3
GWT (m)	-	-	-	-	1.2 ± 0.3
γ_{moist} (kN/m^3)	-	-	-	-	17.4 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	125.2 ± 29.3
σ_v' (kPa)	-	-	-	-	75.5 ± 15.6
a_{max} (g)	-	-	-	-	0.187 ± 0.028
r_d	-	-	-	-	0.79 ± 0.042
CSR	-	-	-	-	0.159 ± 0.026
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	5.5 ± 2.7
% PI	-	-	-	-	0
N	-	-	-	-	13.8 ± 5.1
C_R	-	-	-	-	0.94
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.16
$(N_1)_{60}$	-	-	-	-	20.6 ± 7.6
$V_{s,30m}$ (m/s)	-	-	-	-	202.3
$V_{s,12m}$ (m/s)	-	-	-	-	142.69

EVENT PARAMETERS

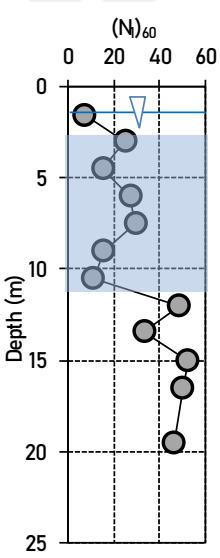
2011 Christchurch Earthquake

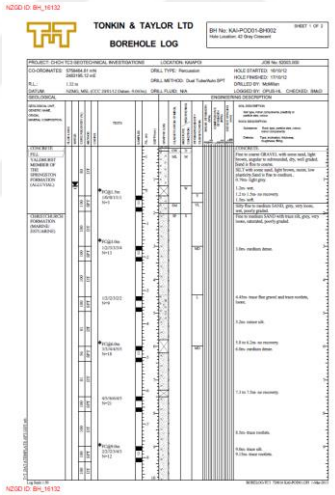
Magnitude: 6.20

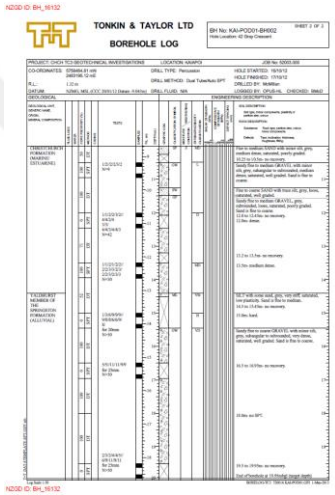
Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 16.7

Dip: 64 | Width (km): 6.5 | R_{jb} (km): 16.7

ACCELERATION TIME HISTORY

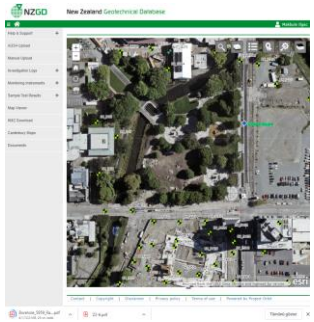






16132	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		FC
ML	1.5	4.9		3	2.00	0.85	7.0		54.5
SP	***3***	***9.8***		***13***	***1.59***	***0.89***	***25.1***		***3.6***
SP	***4.5***	***14.8***		***9***	***1.34***	***0.92***	***15.2***		***4.5***
SP-SM	***6***	***19.7***		***18***	***1.18***	***0.94***	***27.4***		***9.5***
SP	***7.5***	***24.6***	site response analysis	***21***	***1.07***	***0.96***	***29.3***		
SP	***9***	***29.5***		***12***	***0.98***	***0.97***	***15.6***		***4.5***
SP-GW	***10.5***	***34.4***		***9***	***0.91***	***0.98***	***11.0***		
GP	12	39.4		42	0.86	0.98	48.5		
GP	13.4	44.0		30	0.82	0.99	33.0		
??	15	49.2		50	0.77	0.99	52.3	N>50	
GW	16.5	54.1		50	0.74	0.99	50.1	N>50	
GW	19.5	64.0		50	0.68	1.00	46.4	N>50	
						Mean:	20.6		5.5
						St. Dev.	7.6		2.7

Case number:	240
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	SW Z2-4 (the Borehole is located closer to Z2-2)
References:	Wood et al (2017), NZGD
Nature of Failure:	Lateral spread cracking in road. Nearby building showed significant distress due to lateral spreading.
GPS LAT	-43.5283333
GPS LONG	172.6353167
Liq. layer consist of:	Sand-Gravel
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.477 g by Wood et al (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Energy Ratio is calculated as 0.9425 based on energy measurements of 97-92-93-95 Vs,12m is calculated based on the mesaured Vs values. Site response analysis amax 0.16 g and 0.164 g geometric mean of which is 0.162 g. Test results are retrieved from NGZD.



NZGD



Figure ESA-20a. Site photo of Z2-4 (Post-Christchurch EQ) showing the location of the surface wave array and CPT soundings.

After Wood et al (2017)

Gravel Content (%):	>11
CPT available:	Yes (Z2-11 Can (2021))
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	6.0 - 15.5
d_{crt} (m)	-	-	-	-	10.8
GWT (m)	-	-	-	-	1.0 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	220.0 ± 33.0
σ_v' (kPa)	-	-	-	-	124.2 ± 17.7
a_{max} (g)	-	-	-	-	0.477 ± 0.072
r_d	-	-	-	-	0.64 ± 0.067
CSR	-	-	-	-	0.354 ± 0.065
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	16.1 ± 2.8
C_R	-	-	-	-	0.97
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.57
C_N	-	-	-	-	0.90
$(N_1)_{60}$	-	-	-	-	22.2 ± 3.9
$V_{s,30m}$ (m/s)	-	-	-	-	201.7
$V_{s,12m}$ (m/s)	-	-	-	-	163.74

EVENT PARAMETERS

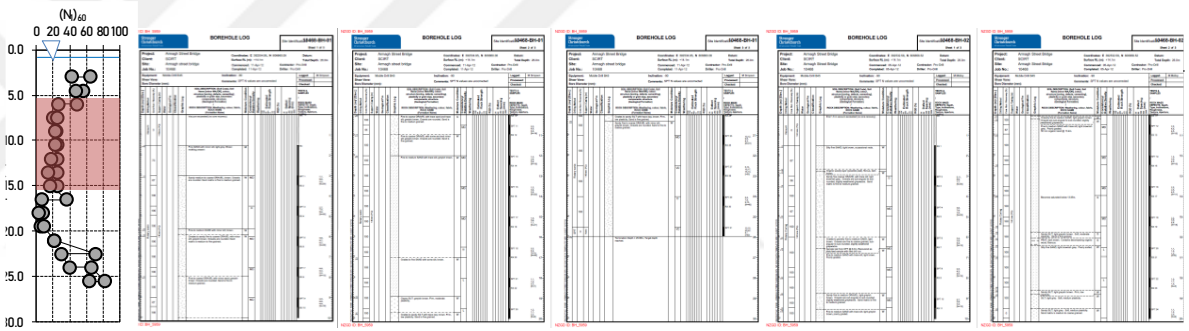
2011 Christchurch Earthquake

Magnitude: 6.20

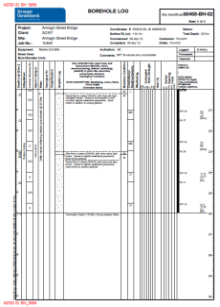
Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 3.6

Dip: 64 | Width (km): 6.5 | R_{jb} (km): 3.6

ACCELERATION TIME HISTORY



	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		
bh-1	3.0	9.8		20	1.58	0.86	42.9	Sandy medium to coarse GRAVEL	
bh-2	3.0	9.8		30	1.58	0.86	64.3	Sandy fine-coarse GRAVEL	
bh-1	4.5	14.8		30	1.34	0.90	56.7	Sandy medium to coarse GRAVEL	
bh-2	4.5	14.8		25	1.34	0.90	47.2	Sandy fine-coarse GRAVEL	
bh-1	6.0	19.7		28	1.18	0.93	48.0	Fine to medium SAND	
bh-2	***6.0***	***19.7***		***15***	***1.18***	***0.93***	***25.7***	***Grades to gravelly fine to medium SAND***	
bh-1	***7.5***	***24.6***		***13***	***1.07***	***0.95***	***20.6***	***Fine to medium SAND***	
bh-2	***7.5***	***24.6***		***16***	***1.07***	***0.95***	***25.4***	***Fine to medium SAND***	
bh-1	***9.0***	***29.5***		***16***	***0.98***	***0.96***	***23.7***	***Fine to coarse GRAVEL***	
bh-2	***9.0***	***29.5***		***15***	***0.98***	***0.96***	***22.2***	***Sandy fine to medium GRAVEL***	
bh-1	***10.5***	***34.4***		***18***	***0.91***	***0.97***	***25.1***	***Fine to coarse GRAVEL***	
bh-2	***10.5***	***34.4***		***16***	***0.91***	***0.97***	***22.3***	***Fine to medium SAND***	
bh-1	***12.0***	***39.4***		***19***	***0.86***	***0.98***	***25.1***	***Fine to medium SAND***	
bh-2	***12.0***	***39.4***		***13***	***0.86***	***0.98***	***17.2***	***Fine to medium SAND***	
bh-1	***13.5***	***44.3***	site	***20***	***0.81***	***0.98***	***25.1***	***Fine to medium SAND***	
bh-2	***13.5***	***44.3***	response	***11***	***0.81***	***0.98***	***13.8***	***Fine to medium SAND***	
bh-1	***15.0***	***49.2***	analysis	***21***	***0.77***	***0.99***	***25.2***	***Fine to medium SAND***	
bh-2	***15.0***	***49.2***		***14***	***0.77***	***0.99***	***16.8***	***Fine to medium SAND***	
bh-1	16.5	54.1		32	0.74	0.99	36.8	Fine to medium SAND	Outlier
bh-2	16.5	54.1		6	0.74	0.99	6.9	Silty fine SAND	
bh-1	18.0	59.1		7	0.71	0.99	**7.7**	**Grades to fine SAND**	
bh-2	18.0	59.1		3	0.71	0.99	**3.3**	**Silty fine SAND**	
bh-1	19.5	64.0		5	0.68	1.00	**5.3**	**Clayey SILT-Grades to sandy SILT**	
bh-2	19.5	64.0		8	0.68	1.00	**8.5**	**Sandy SILT**	
bh-1	21.0	68.9		21	0.66	1.00	21.6	Sandy fine to coarse GRAVEL	
bh-2	21.0	68.9		21	0.66	1.00	21.6	Sandy fine to coarse GRAVEL	
bh-1	22.5	73.8		71	0.64	1.00	70.8	Sandy fine to coarse GRAVEL	*
bh-2	22.5	73.8		30	0.64	1.00	29.9	Sandy fine to coarse GRAVEL	
bh-1	24.0	78.7		41	0.62	1.00	39.6	Sandy fine to coarse GRAVEL	
bh-2	24.0	78.7		68	0.62	1.00	65.7	Sandy fine to coarse GRAVEL	*
bh-1	25.5	83.7		88	0.60	1.00	82.6	Sandy fine to coarse GRAVEL	*
bh-2	25.5	83.7		67	0.60	1.00	62.9	Sandy fine to coarse GRAVEL	*
						Mean:	22.2		
						St. Dev.	3.9		



* N>50 - Extrapolated N value

** Hammer efficiency values were measured and provided around 10 m depth, the hammer efficiency is considered as the average of these values hence short rod correction was applied.*
** It was stated on the borehole that 1 ft should be added for total rod length.*
BH-1 is the closest borehole.

Case number:	241
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	SW Z4-4
References:	Wood et al (2017), NZGD
GPS LAT	-43.52867
GPS LONG	172.64241
Liq. layer consist of:	silty fine sand
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Nature of Failure:	Moderate amounts of liquefaction ejecta. Significant settlement of nearby buildings. Severe surficial liquefaction manifestation in form of liquefaction ejecta.
Comments:	CPT and Vs are available at the site. amax is reported as 0.450 g by Wood et al (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD. The efficiency of the SPT hammer is given as 99 % for BH 49057. The drilling method is same for the other borehole hence assuming same equipemts were used, ER is taken as 99 % for both borehole. Vs,12m is calculated based on the mesaured Vs values. FC is assigned for SM-ML layers accordingly with USCS. A large unceratinty is also assigned.
Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes



NZGD



Figure ESA-22a. Site photo of Z4-4-1 and Z4-4-2, (Post-Christchurch EQ) showing the location of the surface wave array and CPT soundings.

After Wood et al (2017)

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
$d_{crtc.}$ range (m)	-	-	-	-	2.0 - 3.3
d_{crt} (m)	-	-	-	-	2.6
GWT (m)	-	-	-	-	2.0 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.4 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	19.0 ± 0.5
σ_v (kPa)	-	-	-	-	46.9 ± 4.1
σ_v' (kPa)	-	-	-	-	40.7 ± 2.3
a_{max} (g)	-	-	-	-	0.450 ± 0.068
r_d	-	-	-	-	1.03 ± 0.020
CSR	-	-	-	-	0.346 ± 0.055
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	12.0-50.0 ± 10.0
% PI	-	-	-	-	0-7
N	-	-	-	-	7.7 ± 0.9
C_R	-	-	-	-	0.88
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.65
C_N	-	-	-	-	1.58
$(N_1)_{60}$	-	-	-	-	17.7 ± 2.0
$V_{s,30m}$ (m/s)	-	-	-	-	208.9
$V_{s,12m}$ (m/s)	-	-	-	-	178.5

EVENT PARAMETERS

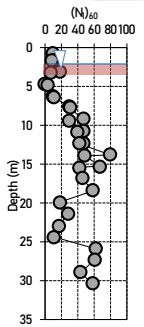
2011 Christchurch Earthquake

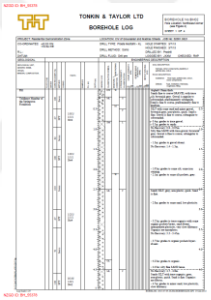
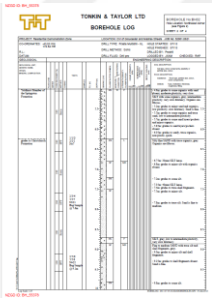
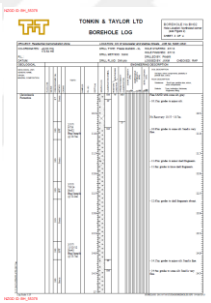
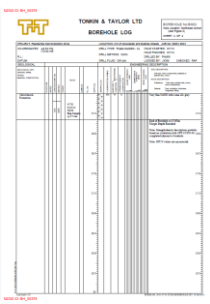
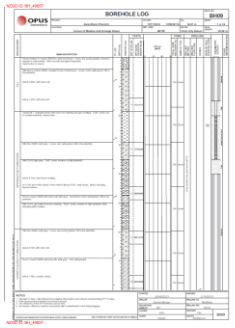
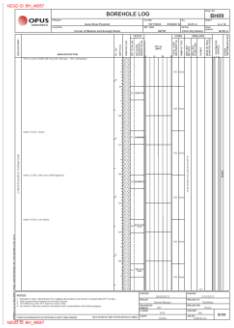
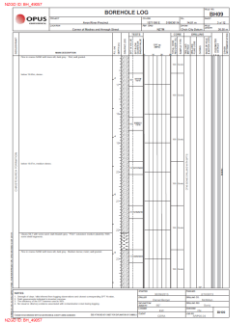
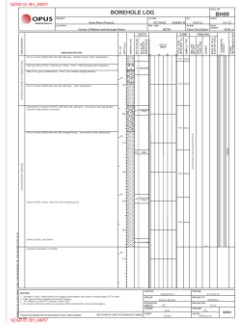
Magnitude: 6.20

Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 3.6

Dip: 64 | Width (km): 6.5 | R_{jb} (km): 3.6

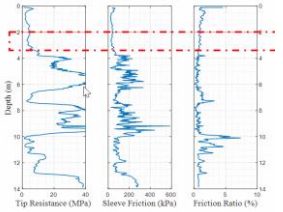
ACCELERATION TIME HISTORY



	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	C_E	$(N1)_{60}$		
55378	***0.7***	***2.3***	***NA***	***4***	***2.00***	***0.83***	***1.37***	***9.0***	***ML***	
49057	***1.6***	***5.2***	***NA***	***4***	***1.91***	***0.86***	***1.65***	***10.8***	***Silty fine to coarse sand***	
55378	***1.7***	***5.6***	***NA***	***4***	***1.85***	***0.86***	***1.37***	***8.7***	***SM***	
49057	***3.1***	***10.2***	***0.347***	***8***	***1.50***	***0.89***	***1.65***	***17.7***	***silty fine sand***	*CPT data confirm this selection*
55378	*3.25*	*10.7*	*0.353*	*4*	*1.48*	*0.90*	*1.37*	*7.2*	ML	trace organics
49057	*4.7*	*15.4*	*0.387*	*0*	*1.30*	*0.92*	*1.65*	*0.0*	clay	
55378	*4.85*	*15.9*	*0.389*	*2*	*1.29*	*0.93*	*1.37*	*3.3*	ML	trace organics
49057	*6.2*	*20.3*	*0.394*	*5*	*1.17*	*0.94*	*1.65*	*9.1*	silty fine sand	trace organics??
55378	6.35	20.8	0.394	7	1.16	0.95	1.37	10.5	SM	trace organics
55378	*7.6*	*24.9*	*0.385*	*21*	*1.08*	0.96	1.37	29.8	SP	
49057	7.7	25.3	0.38	18	1.08	0.96	1.65	30.7	fine to coarse sand	
49057	9.2	30.2	0.363	29	1.00	0.97	1.65	46.4	fine to coarse sand	
55378	9.35	30.7	0.36	22	0.99	0.97	1.37	29.0	SP	
49057	10.7	35.1	0.338	31	0.94	0.98	1.65	47.0	fine to coarse sand	
55378	10.9	35.8	0.33	32	0.93	0.98	1.37	39.9	SM	
49057	12.3	40.4	0.313	33	0.88	0.98	1.65	47.4	fine to coarse sand	
55378	12.35	40.5	0.31	35	0.88	0.98	1.37	41.5	SM	
49057	13.8	45.3	0.295	58	0.84	0.99	1.65	79.5	fine to coarse sand	
55378	13.9	45.6	0.29	43	0.84	0.99	1.37	48.7	SM	
49057	15.3	50.2	0.283	51	0.80	0.99	1.65	67.0	fine to coarse sand	
55378	15.4	50.5	0.28	39	0.80	0.99	1.37	42.3	SM	
49057	16.8	55.1	0.275	36	0.77	0.99	1.65	45.4	fine to coarse sand	
49057	18.4	60.4	0.27	48	0.74	1.00	1.65	58.2	fine to coarse sand	
49057	19.9	65.3	0.268	16	0.71	1.00	1.65	18.7	fine to coarse sand	
49057	21.4	70.2	0.27	25	0.69	1.00	1.65	28.4	fine to coarse sand	
49057	22.9	75.1	0.267	15	0.67	1.00	1.65	16.5	fine to coarse sand	
49057	24.4	80.1	0.27	10	0.65	1.00	1.65	10.7	peat	
49057	25.9	85.0	0.267	60	0.63	1.00	1.65	62.4	gravel	60+
49057	27.3	89.6	0.27	60	0.62	1.00	1.65	60.9	fine to coarse sand	60+
49057	28.9	94.8	0.269	44	0.60	1.00	1.65	43.5	fine to coarse sand	
49057	30.4	99.7	0.27	60	0.58	1.00	1.65	57.9	fine to coarse sand	60+
						Mean:	1.65	17.7		
						St. Dev.		2.0	assigned	

Can (2022)



The given hammer efficiency is considered as the mean of the asymptotic values at depths >10 m hence short rod correction was applied.
If energy measurement were provided at depths no short rod correction would be applied.

Case number:	243
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	SW Z2-6
References:	Wood et al (2017), NZGD
Nature of Failure:	Lateral Spreading
GPS LAT	-43.5276333
GPS LONG	172.6369667
Liq. layer consist of:	Sand (SW)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Comments:	CPT and Vs are available at the site. amax is reported as 0.451 g by Wood et al (2017) based on the conditional distributions described by Green et al. (2014) and Bradley (2014). Test results are retrieved from NGZD. Hammer energy is assigned as 99% for Sonic based on energy mesaurement by a previous borehole by Tonkin and Taylor. BH49047 ER=99% GWT is estimated based on Vs and CPT data. FC is assigned accordingly with USCS, SP <5, Silty fine sand >12, SW <5, ML >50. A large unceratinty is assigned. Vs,12m is calculated based on the mesaured Vs values.



NZGD



Figure ESA-21a. Site photo of Z2-6(Post-Christmech EQ) showing the location of the surface wave array and CPT soundings.

After Wood et al (2017)

Gravel Conetnt (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.0 - 4.6
d_{crt} (m)	-	-	-	-	3.3
GWT (m)	-	-	-	-	1.3 ± 0.7
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	60.3 ± 8.3
σ_v' (kPa)	-	-	-	-	41.0 ± 7.2
a_{max} (g)	-	-	-	-	0.451 ± 0.068
r_d	-	-	-	-	0.92 ± 0.025
CSR	-	-	-	-	0.396 ± 0.090
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	4.9 ± 0.4
C_R	-	-	-	-	0.90
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.57
$(N_1)_{60}$	-	-	-	-	9.4 ± 0.8
$V_{s,30m}$ (m/s)	-	-	-	-	207.0
$V_{s,12m}$ (m/s)	-	-	-	-	162.61

EVENT PARAMETERS

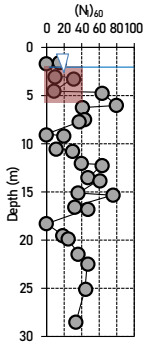
2011 Christchurch Earthquake

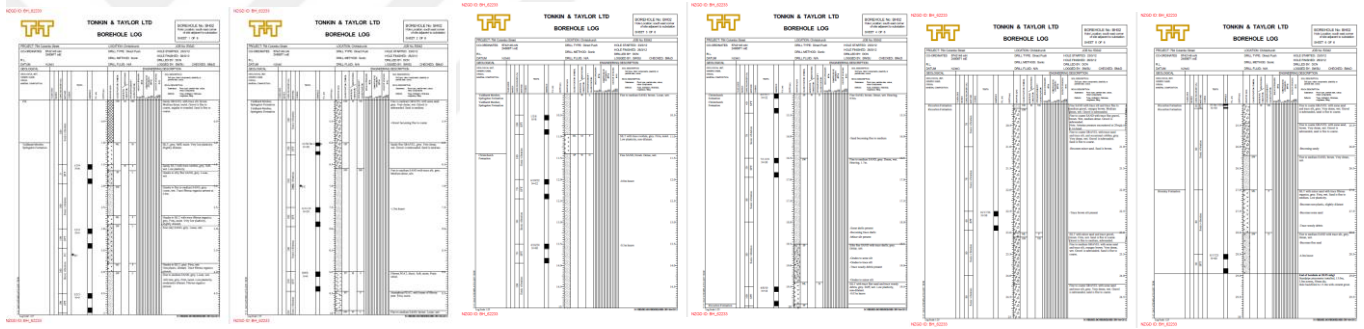
Magnitude: 6.20

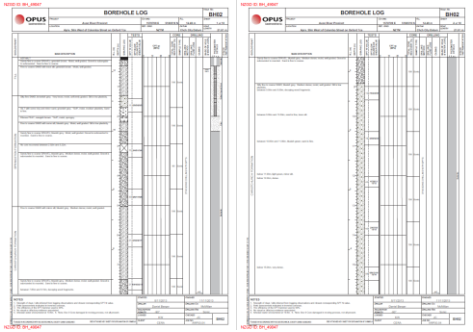
Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 3.9

Dip: 64 | Width (km): 6.5 | R_{jb} (km): 3.9

ACCELERATION TIME HISTORY







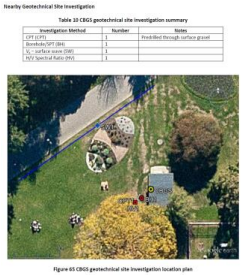
	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	C_E	$(N1)_{60}$		
SP-ML	1.5	4.9		6	2.00	0.85	1.37	14.0	62233 CN>2 excluded	above GWT
Silty fine sand	***1.6***	***5.2***		***0***	***1.99***	0.86	1.65	0.0	49047 outlier	above GWT
SW	***3***	***9.8***		***5***	***1.63***	***0.89***	***1.37***	***9.9***	***62233***	
no core recovery	***3.2***	***10.5***		***13***	***1.59***	0.90	1.65	30.6	49047 outlier	
SW	***4.5***	***14.8***		***5***	***1.40***	***0.92***	***1.37***	***8.8***	***62233***	
sandy fine to coarse gravel	4.7	15.4		30	1.38	0.92	1.65	62.9	49047	
GP	6	19.7		50	1.25	0.94	1.37	80.2	62233 >50	
Fine to coarse sand	6.2	20.3		21	1.23	0.94	1.65	40.2	49047	
SW	7.5	24.6		29	1.13	0.96	1.37	43.0	62233	
sandy fine to coarse gravel	7.7	25.3		21	1.12	0.96	1.65	37.2	49047	
PT	9	29.5		0	1.05	0.97	1.37	0.0	62233	
silty fine to coarse sand	9.2	30.2		12	1.04	0.97	1.65	19.9	49047	
SW	10.5	34.4		8	0.98	0.98	1.37	10.4	62233	
silty fine to coarse sand	10.7	35.1	site	19	0.97	0.98	1.65	29.7	49047	
SP-ML	12	39.4	response	32	0.92	0.98	1.37	39.6	62233	
silty fine to coarse sand	12.2	40.0	analysis	43	0.91	0.98	1.65	63.8	49047	
SP-ML	13.5	44.3		40	0.87	0.99	1.37	47.1	62233	
silty fine to coarse sand	13.8	45.3		43	0.86	0.99	1.65	60.6	49047	
SP-ML	15.1	49.5		32	0.83	0.99	1.37	35.9	62233	
silty fine to coarse sand	15.3	50.2		56	0.82	0.99	1.65	75.4	49047	
SW-SP LIMIT	16.5	54.1		30	0.80	0.99	1.37	32.4	62233	
silty fine to coarse sand	16.8	55.1		36	0.79	0.99	1.65	46.5	49047	
clayey silt	18.3	60.0		0	0.76	1.00	1.65	0.0	49047	
ML	19.5	64.0		18	0.74	1.00	1.37	18.0	62233	
silty fine to coarse sand	19.9	65.3		20	0.73	1.00	1.65	24.0	49047	
silty fine to coarse sand	21.4	70.2		31	0.70	1.00	1.65	35.9	49047	
GW	22.5	73.8		50	0.69	1.00	1.37	46.9	62233 >50	
GW	25.1	82.3		50	0.65	1.00	1.37	44.5	62233 >50	
SW	28.5	93.5		40	0.61	1.00	1.37	33.5	62233	
						Mean:	1.37	9.4		
						St. Dev.	0.00	0.8		

GWT		
by Vs	2	m
CPT	1.4	ext to far bh 3
CPT	1.5	m
CPT	1.2	m
CPT	1.2	m
CPT	0.7	m
CPT	0.1	m
CPT	2.6	m
CPT	1.8	m
CPT	1.7	m
CPT	0.5	m
avrg	**1.34**	**m**

**The given hammer efficiency for BH 49047 (99%) is considered as the mean of the asymptotic values at depths >10 m hence short rod correction was applied.*
Hammer efficiency is assigned as 82% for BH62233.

Case number:	244
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Christchurch Botanical Garden (CBGS) - SMS
References:	Wotherspoon et al. (2014), Network NSMN, GeoNet, NZGD
GPS LAT	-43.52933938
GPS LONG	172.6198776
Liq. layer consist of:	Sand (SP)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Nature of Failure:	No clear manifestation of liquefaction. Ground motion recordings indicate liquefaction. "A few hundred metres to the north of the SMS, significant volumes of ejecta were evident at the ground surface in North Hagley Park following the Christchurch earthquake. This indicates that liquefaction likely occurred during the Christchurch earthquake. However, the thick gravel layer near the surface simply prevented surface manifestation of liquefaction near the SMS." Wotherspoon et al. (2014)
Comments:	CPT and Vs are available at the site. amax is reported as 0.32 g by Wotherspoon et al (2014). However, based on the acceleration record data dowloaded from Geonet (2013) 0.53 g and 0.43 g is determined for two component geometric mean of which is 0.477 g which is used in the analysis. Additionally the figure presented by Wotherspoon et al (2014) aslo suggests amax= 0.48 g but the table in the same study suggests amax=0.32 g. SPT values are given as N60 so ER is taken as 60%. GWT is determined from the figure provided by Wotherspoon et al (2014), probably interpreted from CPT. FC is assigned accordingly with USCS, SP <5. Vs,12m, Vs,30 m are calculated based on the mesaured Vs values.
Gravel Content (%)	NAV
CPT available:	Yes
Vs available:	Yes





After Wotherspoon et al. (2014)

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No or Yes
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	8.9 - 12.5
d_{crt} (m)	-	-	-	-	10.7
GWT (m)	-	-	-	-	3.2 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	19.6 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	21.2 ± 0.5
σ_v (kPa)	-	-	-	-	222.3 ± 13.4
σ_v' (kPa)	-	-	-	-	148.7 ± 7.9
a_{max} (g)	-	-	-	-	0.477 ± 0.024
r_d	-	-	-	-	0.58 ± 0.067
CSR	-	-	-	-	0.267 ± 0.034
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	3.2 ± 2.1
% PI	-	-	-	-	0
N	-	-	-	-	16.9 ± 2.5
C_R	-	-	-	-	0.98
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.00
C_N	-	-	-	-	0.83
$(N_1)_{60}$	-	-	-	-	13.7 ± 2.0
$V_{s,30m}$ (m/s)	-	-	-	-	196.8
$V_{s,12m}$ (m/s)	-	-	-	-	161.6

EVENT PARAMETERS

2011 Christchurch Earthquake

Magnitude: 6.20

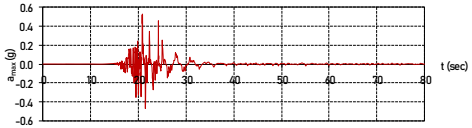
Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 4.6

Dip: 64 | Width (km): 6.5 | R_{jb} (km): 4.6

ACCELERATION TIME HISTORY

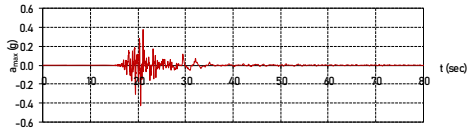
Full Record

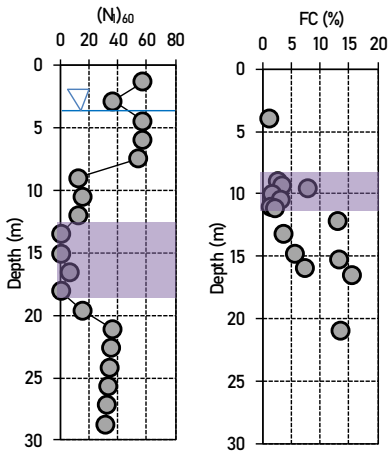
N_{H1}	7.5
N_{H2}	5.7
N_{gm}	6.5
PGA_{H1}	0.529
PGA_{H2}	0.431
PGA	0.477
M_w	6.2
$M_{w,cycle}$	4.1

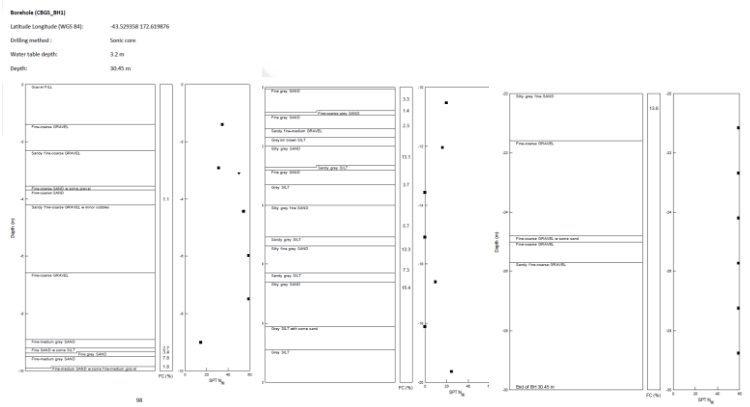


Untill Liquefaction

$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-



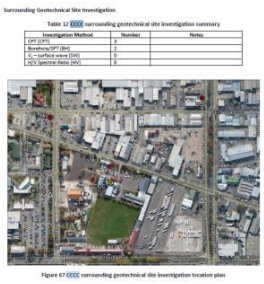




	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
Gravel Fill	1.33	4.4		34	1.97	0.85	57.6	Gravel fill
GW	2.88	9.4		31	1.34	0.89	36.8	Sandy fine coarse gravel
GW	4.46	14.6		54	1.15	0.92	57.3	Sandy fine coarse gravel w minor cobbles
GW	5.96	19.6		59	1.04	0.94	57.5	Sandy fine coarse gravel w minor cobbles
GW	7.51	24.6		59	0.95	0.96	53.9	Fine coarse gravel
SP	***9.03***	***29.6***		***15***	***0.89***	***0.97***	***12.5***	***Fine medium grey sand***
SP	***10.53***	***34.5***		***20***	***0.83***	***0.98***	***16.0***	***Fine grey sand***
ML	***12.02***	***39.4***		***16***	***0.79***	***0.98***	***12.5***	***Silty grey sand***
ML	*13.55*	*44.5*	Site	1	0.75	*0.99*	0.8	Grey silt
SM-ML	*15.07*	*49.4*	Response	1	0.71	*0.99*	0.7	Sandy grey fine sand
SM-ML	*16.62*	*54.5*	Analysis	10	0.69	*0.99*	6.5	Sandy grey silt
SM-ML	*18.06*	*59.3*		1	0.66	*1.00*	0.7	Silty grey sand
ML	19.61	64.3		24	0.64	1.00	15.5	Grey silt
SM	21.11	69.3		59	0.62	1.00	36.2	Silty grey fine sand
GW	22.66	74.3		59	0.60	1.00	35.2	Fine coarse gravel
GW	24.18	79.3		59	0.58	1.00	34.1	Fine coarse gravel
GW	25.71	84.4		59	0.56	1.00	33.3	Sandy fine coarse gravel
GW	27.2	89.2		59	0.55	1.00	32.4	Sandy fine coarse gravel
GW	28.73	94.3		59	0.54	1.00	31.5	Sandy fine coarse gravel
						Mean:	13.7	
						St. Dev.	2.0	

Depth (m)	FC
4	1.1
9	***2.7***
9.3	***3.4***
9.6	***7.8***
10	***1.8***
10.5	***3.3***
11	***1.4***
11.2	***2.3***
12.2	13.1
13.2	3.7
14.8	5.7
15.3	13.3
16	7.3
16.5	15.4
21	13.6
Mean:	3.2
St. Dev.	2.1

Case number:	245
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Christchurch Cathedral College (CCCC)
References:	Wotherspoon et al. (2014), Cannet
GPS LAT	-43.538085
GPS LONG	172.647427
Liq. layer consist of:	Sand with some silt
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Nature of Failure:	Minor volumes of ejecta and a few sand boils. Recorded ground motions indicate liquefaction.
Comments:	CPT and Vs are available at the site. amax is reported as 0.35 g by Wotherspoon et al (2014). Based on the acceleration recording data downloaded from Geonet (2013), 0.4839 g and 0.367 g is determined for two component, geometric mean of which is 0.421 g which is used in the analysis. Wotherspoon et al. (2014) provided SPT boreholes BH1 and BH2 which are 240 and 320 m away from the station. However closer two borehole (76451 and 76452) data were retrieved from NZGD located 30 m away. ER=85% is measured for these two borehole. They have been used to represent the site for this SMS. BH1 and BH2 were also processed where the average SPT value for the sand layer is lower when compared to 76451 and 76452. CPT data and the close borehole inditaces that surficial layers consist of clayey material underlying by a potenatially liquefiable sand layer having silt content. Hammer energy is taken as 60% since N values are given as N60 for BH1 and BH2. GWT is determined from the figure provided by Wotherspoon et al (2014). Vs,12m is calculated based on the mesaured Vs values. Rrup 15.9 km , Rjb=16.2 km Bradley 2012
Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes



After Wotherspoon et al. (2014)



NZGD

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	A
$d_{crit.}$ range (m)	-	-	-	-	6.2 - 14.0
d_{crt} (m)	-	-	-	-	10.1
GWT (m)	-	-	-	-	1.2 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	19.6 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	21.2 ± 0.5
σ_v (kPa)	-	-	-	-	212.8 ± 28.0
σ_v' (kPa)	-	-	-	-	125.4 ± 15.5
a_{max} (g)	-	-	-	-	0.421 ± 0.021
r_d	-	-	-	-	0.64 ± 0.064
CSR	-	-	-	-	0.298 ± 0.034
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	3.9 ± 2.2
% PI	-	-	-	-	0
N	-	-	-	-	17.5 ± 6.5
C_R	-	-	-	-	0.97
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.42
C_N	-	-	-	-	0.90
$(N_1)_{60}$	-	-	-	-	21.7 ± 8.1
$V_{s,30m}$ (m/s)	-	-	-	-	186.6
$V_{s,12m}$ (m/s)	-	-	-	-	137.8

EVENT PARAMETERS

2011 Christchurch Earthquake

Magnitude: 6.20

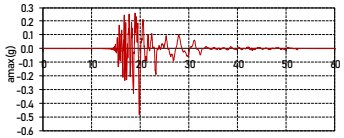
Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 2.6

Dip: 64 | Width (km): 6.5 | R_{jb} (km): 2.6

ACCELERATION TIME HISTORY

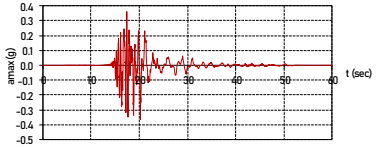
Full Record

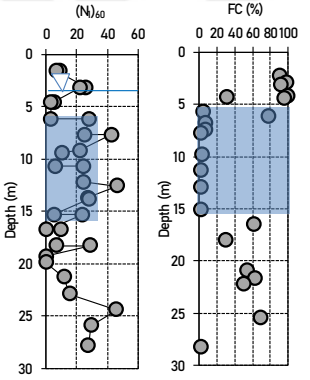
N_{H1}	4.9
N_{H2}	11.0
N_{gm}	7.3
PGA_{H1}	0.483
PGA_{H2}	0.367
PGA	0.421
M_w	6.2
$M_{w,cycle}$	5.2

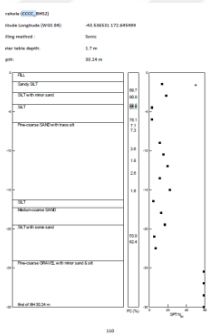


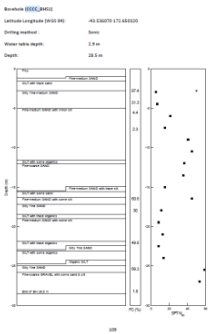
Untill Liquefaction

$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-







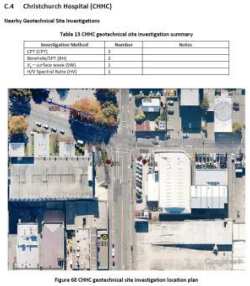


GWT		
BHS1	2.9	m
BHS2	1.7	m
76451	1.20	m
76452	1.20	m
avrg.	2.3	m

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		
Clay	1.6	5.2	0.29	4	1.90	0.86	9	76451	
CLAY with minor silt	1.6	5.2	0.29	3	1.90	0.86	7	76452	
Silty fine to medium SAND	3.2	10.5	0.339	14	1.48	0.90	26	76451	
SILT with some clay; grey	3.2	10.5	0.339	12	1.48	0.90	23	76452	
Silty Clay	4.6	15.1	0.332	3	1.27	0.92	5	76451	
Silty CLAY;	4.6	15.1	0.332	2	1.27	0.92	3	76452	
Fine to medium SAND	6.2	20.3	0.305	2	1.12	0.94	3	76451	outlier
Fine SAND with trace silt	**6.2**	**20.3**	**0.305**	**19**	**1.12**	**0.94**	**28**	**76452**	
Fine to medium SAND	**7.7**	**25.3**	**0.273**	**18**	**1.02**	**0.96**	**25**	**76451**	
Fine SAND with trace silt	7.7	25.3	0.273	31	1.02	0.96	43	76452	outlier
Fine to medium SAND	**9.2**	**30.2**	**0.244**	**17**	**0.94**	**0.97**	**22**	**76451**	
Fine SAND with trace silt	**9.4**	**30.8**	**0.241**	**8**	**0.93**	**0.97**	**10**	**76452**	
Fine to medium SAND	**10.7**	**35.1**	**0.222**	**5**	**0.88**	**0.98**	**6**	**76451**	
Fine SAND with trace silt	**10.7**	**35.1**	**0.222**	**20**	**0.88**	**0.98**	**24**	**76452**	
Fine to medium SAND	**12.2**	**40.0**	**0.206**	**21**	**0.82**	**0.98**	**24**	**76451**	
Fine SAND with trace silt	12.6	41.3	0.202	41	0.81	0.99	46	76452	outlier
Fine SAND with trace silt	**13.7**	**44.9**	**0.195**	**25**	**0.78**	**0.99**	**27**	**76452**	
Fine to medium SAND	**13.8**	**45.3**	**0.194**	**26**	**0.78**	**0.99**	**28**	**76451**	
Silty fine sand	**15.3**	**50.2**	**0.188**	**5**	**0.74**	**0.99**	**5**	**76451**	very thin layer
Fine SAND with trace silt	15.3	50.2	0.188	23	0.74	0.99	24	76452	
Silt	16.8	55.1	0.184	0	0.71	0.99	0	76451	
Fine to coarse SAND;	16.8	55.1	0.184	10	0.71	0.99	10	76452	0/ sunk under weight of hammer.
Sand	18.3	60.0	0.182	7	0.68	1.00	7	76451	
Fine to coarse SAND;	18.3	60.0	0.182	30	0.68	1.00	29	76452	
Sandy Silt	19.3	63.3	0.181	0	0.66	1.00	0	76451	
SILT, moderate plasticity	19.9	65.3	0.181	0	0.65	1.00	0	76452	
Becomes CLAY with minor silt	21.3	69.9	0.181	13	0.63	1.00	12	76452	
Medium to coarse SAND	22.9	75.1	0.180	18	0.61	1.00	16	76452	
Fine to coarse SAND	24.4	80.1	0.181	55	0.59	1.00	46	76452	
Sandy fine to coarse GRAVEL	25.9	85.0	0.181	36	0.58	1.00	29	76452	
Becomes gravelly fine to coarse SAND	27.8	91.2	0.181	35	0.56	1.00	27.6	76452	
						Mean:	21.7		
						St. Dev.	8.1		

Depth (m)	FC	
2.18	89.70	BHS2
2.86	97.40	BHS1
3.11	90.90	BHS2
4.12	98.80	BHS2
4.26	31.30	BHS1
4.41	95.00	BHS2
5.67	***4.40***	***BHS1***
6.06	78.10	BHS2
6.75	***7.10***	***BHS2***
7.36	***7.30***	***BHS2***
7.69	***2.30***	***BHS1***
9.74	***3.60***	***BHS2***
11.24	1.80	BHS2
12.86	2.60	BHS2
15.08	1.80	BHS2
16.47	60.60	BHS1
17.92	30.00	BHS1
20.90	53.90	BHS2
21.63	62.40	BHS2
22.14	49.80	BHS1
25.34	69.30	BHS1
28.24	1.80	BHS1
Mean:	3.9	
St. Dev.	2.2	

Case number:	246
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Christchurch Hospital (CHHC)
References:	Wotherspoon et al. (2014), cannet, Bradley and Cubrinovski (2011)
GPS LAT	-43.53592591
GPS LONG	172.6275195
Liq. layer consist of:	Gravel (GW)-Sand (SM)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Nature of Failure:	Minor to moderate volumes of ejecta. Ground motions recording indicate the occurence of liquefaction.
Comments:	CPT and Vs are available at the site. amax is reported as 0.37 g by Wotherspoon et al (2014). However, based on the acceleration record data dowloaded from Geonet (2013) 0.34 g and 0.36 g is determined for two component geometric mean of which is 0.348 g which is used in the analysis. Hammer energy is taken as 60% since Wotherspoon et al (2014) presents N60 values. GWT is determined from the figure provided by Wotherspoon et al (2014), probably interpreted from CPT. FC is assigned accordingly with USCS, GW <5. Vs,12m is calculated based on the mesaured Vs values. Rrup 3.8 km , Rjb=3.7 km Bradley and Cubrinovski (2011).


C.4 Christchurch Hospital (CHHC)

Nearby Geotechnical Site Investigations

Table 13 CHHC geotechnical site investigation summary

Investigation Method	Number	Notes
CPT (CPT)	2	
Borehole/SPT (BH)	2	
V_s – surface wave (SW)	1	
H/V Spectral Ratio (HV)	1	

Figure 68 CHHC geotechnical site investigation location plan

After Wotherspoon et al. (2014)

Gravel Content (%):	50.0-100.0
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{cr1c} range (m)	-	-	-	-	5.5 - 7.0
d_{cr1} (m)	-	-	-	-	6.3
GWT (m)	-	-	-	-	3.1 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	21.5 ± 0.5
σ_v (kPa)	-	-	-	-	126.8 ± 5.8
σ_v' (kPa)	-	-	-	-	95.3 ± 3.7
a_{max} (g)	-	-	-	-	0.348 ± 0.017
r_d	-	-	-	-	0.81 ± 0.042
CSR	-	-	-	-	0.243 ± 0.018
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	5.0 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	22.0 ± 3.3
C_R	-	-	-	-	0.94
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.00
C_N	-	-	-	-	1.03
$(N_1)_{60}$	-	-	-	-	21.5 ± 3.2
$V_{s,30m}$ (m/s)	-	-	-	-	193.4
$V_{s,12m}$ (m/s)	-	-	-	-	163.9

EVENT PARAMETERS

2011 Christchurch Earthquake

Magnitude: 6.20

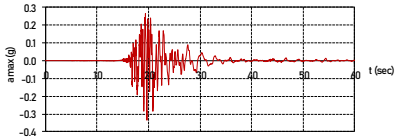
Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 3.7

Dip: 64 | Width (km): 6.5 | R_{jb} (km): 3.7

ACCELERATION TIME HISTORY

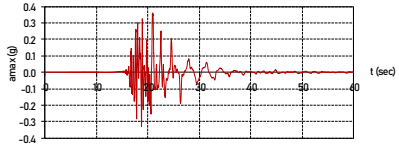
Full Record

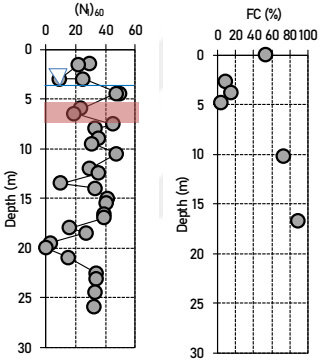
N_{H1}	9.0
N_{H2}	10.7
N_{gm}	9.8
PGA_{H1}	0.336
PGA_{H2}	0.361
PGA	0.348
M_w	6.2
$M_{w,cycle}$	5.8

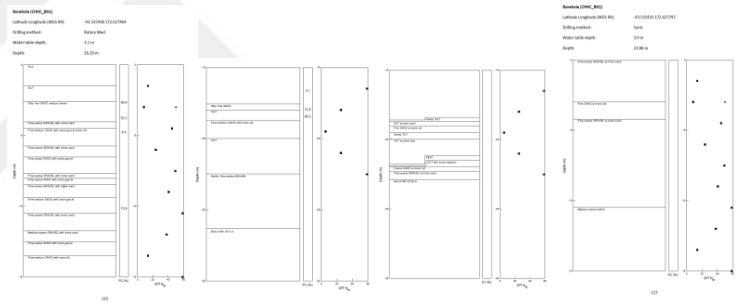


Untill Liquefaction

$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-







0-4 m Silts with organics

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N_1)_{60}$		
BH-2	1.44	4.7	NA	18	1.93	0.85	29.6	GW	not saturated
BH-1	1.55	5.1	NA	14	1.86	0.85	22.3	ML	organics
BH-1	2.99	9.8	NA	8	1.34	0.89	9.6	SM	not saturated
BH-2	2.99	9.8	NA	21	1.34	0.89	25.1	SP-GW	not saturated
BH-2	4.44	14.6	0.24	46	1.17	0.92	49.6	GW	
BH-1	4.47	14.7	0.239	44	1.17	0.92	47.3	GW	
BH-1	***5.95***	***19.5***	***0.246***	***24***	***1.05***	***0.94***	***23.8***	***GW***	
BH-2	***6.48***	***21.3***	***0.244***	***20***	***1.02***	***0.95***	***19.3***	***GW***	
BH-1	7.54	24.7	0.238	49	0.96	0.96	45.0	SW	
BH-2	7.99	26.2	0.234	37	0.94	0.96	33.3	GW	
BH-1	9.01	29.6	0.224	41	0.89	0.97	35.4	GW	
BH-2	9.51	31.2	0.218	37	0.87	0.97	31.4	GW	
BH-1	10.49	34.4	0.208	58	0.84	0.98	47.4	GW	
BH-1	12.01	39.4	0.195	38	0.79	0.98	29.5	GW	
BH-2	***12.46***	40.9	0.191	***46***	0.78	***0.98***	35.2	***SP***	
BH-1	***13.49***	44.3	0.185	***14***	0.75	***0.99***	10.4	***SP***	***N1,60,average=35 the***
BH-2	***13.98***	45.9	0.183	***46***	0.74	***0.99***	33.6	***SP***	***upper layer is more***
BH-1	***15.04***	49.3	0.178	***58***	0.72	***0.99***	41.1	***SP***	***critic***
BH-2	***15.46***	50.7	0.177	***58***	0.71	***0.99***	40.6	***SP***	
BH-1	***16.55***	54.3	0.174	***58***	0.69	***0.99***	39.5	***SP***	
BH-2	***16.97***	55.7	0.174	***58***	0.68	***0.99***	39.1	***SP***	
BH-1	17.99	59.0	0.173	25	0.66	1.00	16.4	SM-ML	
BH-2	18.45	60.5	0.172	42	0.65	1.00	27.3	SP	
BH-1	19.47	63.9	0.172	5	0.64	1.00	3.2	SP	
BH-2	20	65.6	0.172	1	0.63	1.00	0.6	SM-ML-OL-PT	
BH-1	20.95	68.7	0.171	25	0.62	1.00	15.4	ML	
BH-1	22.5	73.8	0.172	57	0.60	1.00	33.9	GW	
BH-2	23.06	75.7	0.172	58	0.59	1.00	34.1		
BH-2	24.44	80.2	0.172	58	0.57	1.00	33.2		
BH-2	25.88	84.9	0.173	58	0.56	1.00	32.4		
						Mean:	21.5		
						St. Dev.	3.2		

Depth (m)	FC	
2.7	58.5	BH-1
3.8	52.2	BH-1
4.8	8.5	BH-1
10.2	13.9	BH-1
16.7	3.1	BH-1
18.0	72.5	BH-1
18.6	88.3	BH-1
	-	
	-	

Case number:	247
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Cashmere High School (CMHS)
References:	Wotherspoon et al. (2014), network: NSMN, Geonet (2013)
GPS LAT	-43.56561744
GPS LONG	172.6241694
Liq. layer consist of:	Sand-Silt (SM-ML)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Nature of Failure:	No surface evidence of liquefaction in the vicinity of SMS. Ground motion recordings indicate liquefaction. The gravel layer in the upper layers prevented surface manifestation.
Comments:	CPT and Vs are available at the site. amax is reported as 0.37 g by Wotherspoon et al (2014). Based on the acceleration recording data dowloaded from Geonet (2013), 0.355g and 0.397 g is determined for two component, geometric mean of which is 0.375 g which is used in the analysis.
	Hammer energy is taken as 60% since N values are given as N60 by Wotherspoon et al. (2014). GWT is determined from the figure provided by Wotherspoon et al (2014), probably interpreted from CPT.
	FC is assigned accordingly with USCS, SP <5.
	Vs,12m is calculated based on the mesaured Vs values.
	Rrup 1.4 km , Rjb=1.0 km Bradley and Cubrinovski (2011).



After Wotherspoon et al. (2014)

Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No or Yes
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	7.0 - 11.0
d_{crs} (m)	-	-	-	-	9.0
GWT (m)	-	-	-	-	2.0 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	20.0 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	21.5 ± 0.5
σ_v (kPa)	-	-	-	-	191.0 ± 14.8
σ_v' (kPa)	-	-	-	-	122.2 ± 8.6
a_{max} (g)	-	-	-	-	0.375 ± 0.019
r_d	-	-	-	-	0.68 ± 0.058
CSR	-	-	-	-	0.257 ± 0.026
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	23.0 ± 5.6
% PI	-	-	-	-	0-7
N	-	-	-	-	13.4 ± 6.3
C_R	-	-	-	-	0.97
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.00
C_N	-	-	-	-	0.91
$(N_1)_{60}$	-	-	-	-	11.8 ± 5.6
$V_{s,30m}$ (m/s)	-	-	-	-	199.4
$V_{s,12m}$ (m/s)	-	-	-	-	152.5

EVENT PARAMETERS

2011 Christchurch Earthquake

Magnitude: 6.20

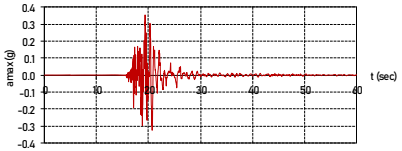
Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 1.1

Dip: 64 | Width (km): 6.5 | R_{jb} (km): 1.0

ACCELERATION TIME HISTORY

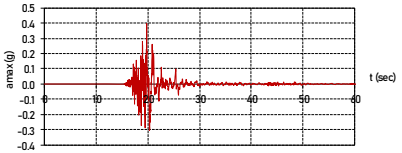
Full Record

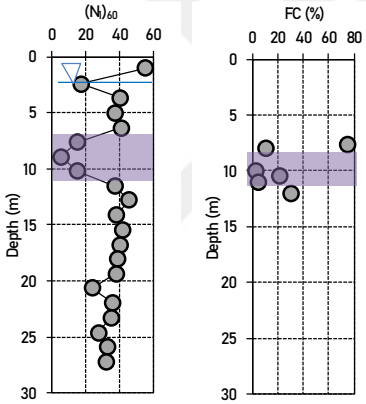
N_{H1}	9.2
N_{H2}	7.1
N_{gm}	8.0
PGA_{H1}	0.355
PGA_{H2}	0.397
PGA	0.375
M_w	6.2
$M_{w,cycle}$	6.3

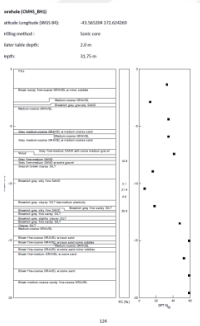


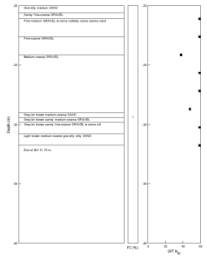
Untill Liquefaction

$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-









	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
	1.01	3.3	NA	33	2.00	0.84	55.2	Fill
GW	***2.39***	***7.8***	***0.249***	***13***	***1.51***	***0.88***	***17.2***	Medium coarse gravel lower layer is more critical
GW	3.67	12.0	0.277	34	1.31	0.91	40.2	Medium coarse gravel
GW	5.05	16.6	0.281	35	1.16	0.93	37.6	Medium coarse gravel
SP	6.33	20.8	0.271	41	1.06	0.95	41.0	Grey fine-medium sand with some medium gravel
ML	**7.61**	**25.0**	**0.255**	**16**	**0.98**	**0.96**	**15.0**	**Greyish fine-medium sand**
SM	**8.90**	**29.2**	**0.237**	**6**	**0.92**	**0.97**	**5.3**	**Brownish grey silty fine sand**
SM-ML	**10.23**	**33.6**	**0.219**	**18**	**0.86**	**0.98**	**15.1**	**Brownish grey fine sandy silt**
SM-ML	11.56	37.9	0.204	47	0.82	0.98	37.7	Brownish grey fine sandy silt
GW-GP	12.80	42.0	0.194	59	0.78	0.99	45.4	Brown fine-coarse gravel w trace sand
GW-GP	14.13	46.4	0.186	52	0.75	0.99	38.4	Brown fine-medium gravel with some sand
GW-GP	15.46	50.7	0.181	59	0.72	0.99	41.9	Brown fine-medium gravel with some sand
GW-GP	16.79	55.1	0.178	59	0.69	0.99	40.4	Brown medium-coarse sandy fine-coarse gravel
GW-GP	18.07	59.3	0.176	59	0.67	1.00	39.1	fine-medium gravel with some cobbles some coarse sand
GW-GP	19.36	63.5	0.175	59	0.65	1.00	37.9	fine-medium gravel with some cobbles some coarse sand
GW-GP	20.64	67.7	0.175	38	0.63	1.00	23.7	Medium coarse gravel
GW-GP	21.93	71.9	0.175	59	0.61	1.00	35.8	Medium coarse gravel
GW-GP	23.26	76.3	0.175	59	0.59	1.00	34.9	Medium coarse gravel
GW-GP	24.63	80.8	0.175	48	0.58	1.00	27.6	Medium coarse gravel
GW-GP	25.92	85.0	0.176	59	0.56	1.00	33.2	Greyish brown sandy fine-coarse
GW-GP	27.25	89.4	0.176	59	0.55	1.00	32.4	Light brown medium-coarse gravelly silty sand
						Mean:	11.8	
						St. Dev.	5.6	

Depth (m)	FC	
7.60	***75.0***	***ML*** ***guesstimated***
8.00	***10.8***	***Grey fine-medium sand with some medium gravel***
10.00	***3.1***	***Brownish grey silty fine sand***
10.50	***21.4***	***Brownish grey silty fine sand***
11.00	***4.8***	***Brownish grey silty fine sand***
12.00	30.9	Brownish grey silty fine sand
Mean:	23.0	
St. Dev.	29.9	

Case number:	248
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Hulverone Drive Pumping Station (HPSC)
References:	Wotherspoon et al. (2014), Network: cannet, Bradley & Cubrinovski (2011)
GPS LAT	-43.50157144
GPS LONG	172.7021909
Liq. layer consist of:	Sand (SM-SP-SW)
Geological Unit:	Natural Deposit
Site Response Antaysis:	Yes
Nature of Failure:	Surface manifestation of liquefaction was observed. The acceleration recordings indicate liquefaction (Bradley & Cubrinovski 2011).
Comments:	CPT and Vs are available at the site. amax is reported as 0.22 g by Wotherspoon et al (2014). However, based on the acceleration recording data dowloaded from Geonet (2013), 0.149 g and 0.237 g is determined for two component geometric mean of which is 0.188 g. The PGA is recorded as 0.188 g and the site is liquefied. Based on the protocol, it is necessary to use PGApredicted that had not liquefied. Based on the recordings, it became apparent that the site has liquefied 28th second. Site reponse analysis result gives amax as 0.323 g which is used in the analysis.
	Hammer energy is taken as 60 % since N values are given as N60 by Wotherspoon et al. (2014).
	GWT is determined from the figure provided by Wotherspoon et al (2014), probably interpreted from CPT.
	FC is assigned accordingly with USCS, SP <5.
	Vs,12m is calculated based on the mesaured Vs values.
	Rrup 3.9 km , Rjb=3.8 km Bradley and Cubrinovski (2011).



Free field



After Wotherspoon et al. (2014)

Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

N_{H1}	13.3
N_{H2}	15.0
N_{gm}	14.1
PGA_{H1}	0.149
PGA_{H2}	0.237
PGA	0.188
M_w	6.2
$M_{w,cycle}$	6.9
Untill Liquefaction	
$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	1.5 - 11.0
d_{rr} (m)	-	-	-	-	6.3
GWT (m)	-	-	-	-	1.5 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	126.3 ± 32.7
σ_v' (kPa)	-	-	-	-	79.7 ± 17.3
a_{max} (g)	-	-	-	-	0.323 ± 0.016
r_d	-	-	-	-	0.68 ± 0.042
CSR	-	-	-	-	0.225 ± 0.021
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	7.0 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	8.4 ± 3.6
C_R	-	-	-	-	0.94
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.00
C_N	-	-	-	-	1.13
$(N_1)_{60}$	-	-	-	-	9.0 ± 3.8
$V_{s,30m}$ (m/s)	-	-	-	-	207.0
V_{s12m} (m/s)	-	-	-	-	128.0

EVENT PARAMETERS

2011 Christchurch Earthquake

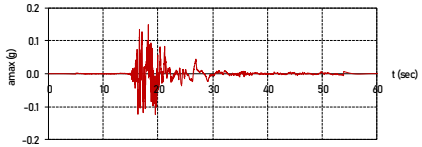
Magnitude: 6.20

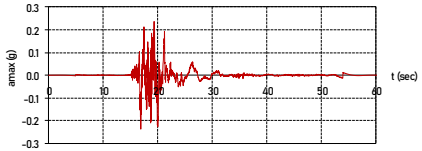
Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 3.8

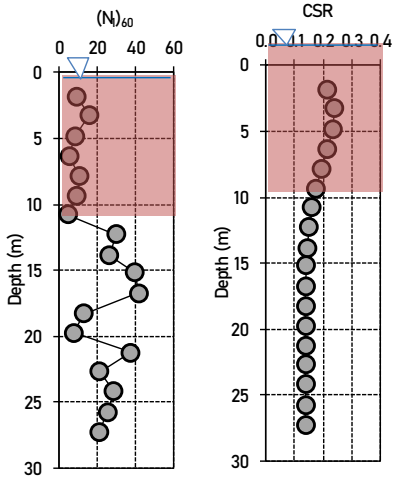
Dip: 64 | Width (km): 6.5 | R_{jb} (km): 3.8

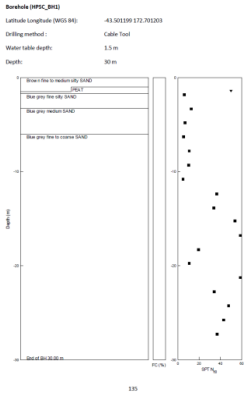
ACCELERATION TIME HISTORY

Full Record









FC is assigned according to USCS

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
SM	***1.82***	***6.0***	***0.213***	***6***	***1.79***	***0.86***	***9.2***	***>12***	Blue grey fien silty sand
SM	***3.28***	***10.8***	***0.24***	***12***	***1.46***	***0.90***	***15.7***	***>12***	blue grey medium sand
SP	***4.86***	***15.9***	***0.234***	***7***	***1.25***	***0.93***	***8.1***	***0-5***	blue grey medium sand
SW	***6.36***	***20.9***	***0.215***	***5***	***1.12***	***0.95***	***5.3***	***0-5***	blue grey fine to coarse sand
SW	***7.86***	***25.8***	***0.19***	***11***	***1.02***	***0.96***	***10.8***	***0-5***	blue grey fine to coarse sand
SW	***9.31***	***30.5***	***0.175***	***10***	***0.95***	***0.97***	***9.2***	***0-5***	blue grey fine to coarse sand
SW	***10.76***	***35.3***	***0.161***	***5***	***0.89***	***0.98***	***4.4***	***0-5***	blue grey fine to coarse sand
SW	12.3	40.4	0.151	36	0.84	0.98	29.7		blue grey fine to coarse sand
SW	13.89	45.6	0.145	34	0.79	0.99	26.6		blue grey fine to coarse sand
SW	15.17	49.8	0.142	53	0.76	0.99	39.9		blue grey fine to coarse sand
SW	16.75	55.0	0.140	58	0.73	0.99	41.8		blue grey fine to coarse sand
SW	18.29	60.0	0.138	19	0.70	1.00	13.2		blue grey fine to coarse sand
SW	19.7	64.6	0.138	11	0.67	1.00	7.4		blue grey fine to coarse sand
SW	21.24	69.7	0.138	58	0.65	1.00	37.5		blue grey fine to coarse sand
SW	22.69	74.4	0.138	34	0.63	1.00	21.3		blue grey fine to coarse sand
SW	24.19	79.4	0.138	47	0.61	1.00	28.6		blue grey fine to coarse sand
SW	25.78	84.6	0.138	43	0.59	1.00	25.4		blue grey fine to coarse sand
SW	27.27	89.5	0.139	36	0.58	1.00	20.7		blue grey fine to coarse sand
						Mean:	9.0		
						St. Dev.	3.8		

Case number:	249
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Kaiapoi North School
References:	Wotherspoon et al. (2014), CANNET, Geonet (2013), Bradley and Cubrinovski (2011)
GPS LAT	-43.37646016
GPS LONG	172.6637603
Liq. layer consist of:	Gravel (GW)-Sand (SW)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Deconvolution Analysis
Nature of Failure:	Ground motion indicates no liquefaction. No clear manifestation of liquefaction.
Comments:	Vs is available at the site. amax was not reported by Wotherspoon et al (2014). However, based on the acceleration record data dowloaded from Geonet (2013) 0.212 g and 0.190 g is determined for two component geometric mean of which is 0.201 g which is used in the analysis.
	Hammer energy is assigned as 60% since SPTN values are given as N60.
	GWT is determined from the figure provided by Wotherspoon et al (2014), interpreted from SPT.
	FC is assigned accordingly with USCS, GW <5.
	Vs,12m is calculated based on the mesaured Vs values.
	Rrup 17.4 km , Rjb=17.3 km Bradley and Cubrinovski (2011)

C.8 Kaiapoi North School (KPOC)

Nearby Geotechnical Site Investigation

Table 17 KPOC geotechnical site investigation summary

Investigation Method	Number	Notes
CPT (CPT)	6	Gravelly site
Borehole/SPT (Bh)	1	
SL - surface wave (SW)	1	
H/V (HV)	1	



Figure 72 KPOC geotechnical site investigation location plan

After Wotherspoon et al. (2014)

Gravel Content (%):	50.0-100.0
CPT available:	No
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	A
$d_{crit.}$ range (m)	-	-	-	-	2.5 - 30.0
d_{crit} (m)	-	-	-	-	16.3
GWT (m)	-	-	-	-	1.2 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	21.5 ± 0.5
σ_v (kPa)	-	-	-	-	345.5 ± 99.1
σ_v' (kPa)	-	-	-	-	197.6 ± 54.3
a_{max} (g)	-	-	-	-	0.201 ± 0.010
r_d	-	-	-	-	0.52 ± 0.075
CSR	-	-	-	-	0.118 ± 0.018
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	5.0 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	57.3 ± 8.6
C_R	-	-	-	-	0.99
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.00
C_N	-	-	-	-	0.72
$(N_1)_{60}$	-	-	-	-	40.8 ± 6.1
$V_{s,30m}$ (m/s)	-	-	-	-	257.0
$V_{s,12m}$ (m/s)	-	-	-	-	164.4

EVENT PARAMETERS

2011 Christchurch Earthquake

Magnitude: 6.20

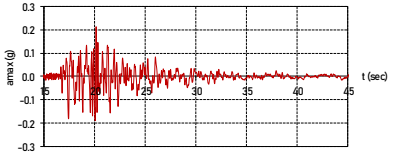
Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 17.3

Dip: 64 | Width (km): 6.5 | R_{jb} (km): 17.3

ACCELERATION TIME HISTORY

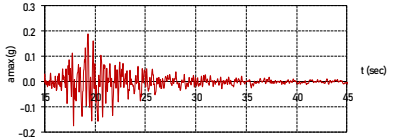
Full Record

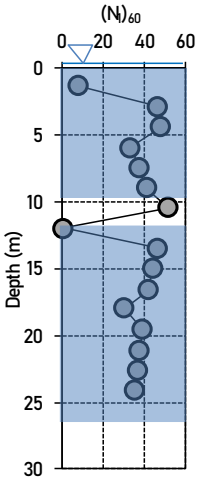
N_{H1}	17.1
N_{H2}	17.2
N_{gm}	17.1
PGA_{H1}	0.212
PGA_{H2}	0.190
PGA	0.201
M_w	6.2
$M_{w,cycle}$	6.7

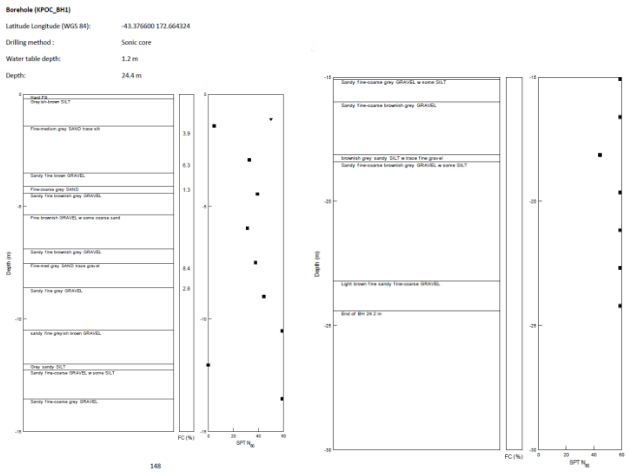


Untill Liquefaction

$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-





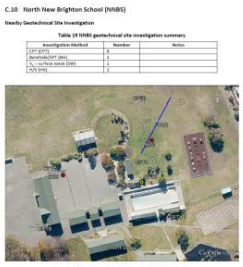


	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N_1)_{60}$	
SP	1.3	4.4		5	2.00	0.85	8.4	shallow CN<2.0 very 10 cm below GWT
SP	***2.9***	***9.4***		***33***	***1.59***	***0.89***	***46.4***	
GW	***4.4***	***14.5***		***40***	***1.32***	***0.92***	***48.1***	
GW	***5.9***	***19.5***		***31***	***1.15***	***0.94***	***33.5***	
GW	***7.5***	***24.5***		***38***	***1.04***	***0.96***	***37.8***	
GW	***9.0***	***29.5***	site	***45***	***0.95***	***0.97***	***41.1***	
GW	***10.5***	***34.3***	response	***60***	***0.89***	***0.98***	***51.9***	
ML	12.0	39.3	analysis	1	0.83	0.98	0.9	very thin ML layer about 10 cm
GW	***13.5***	***44.2***	were	***60***	***0.78***	***0.99***	***46.5***	
GW	***15.0***	***49.3***	performed	***60***	***0.74***	***0.99***	***44.3***	
GW	***16.6***	***54.4***	.	***60***	***0.71***	***0.99***	***42.3***	
GW	***18.0***	***59.0***		***45***	***0.68***	***1.00***	***30.3***	
GW	***19.5***	***64.1***		***60***	***0.66***	***1.00***	***39.2***	
GW	***21.1***	***69.2***		***60***	***0.63***	***1.00***	***37.8***	
GW	***22.6***	***74.1***		***60***	***0.61***	***1.00***	***36.6***	
GW	***24.1***	***79.1***		***60***	***0.59***	***1.00***	***35.5***	
						Mean:	40.8	
						St. Dev.	6.1	

Case number:	250
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	North New Brighton School (NNBS)
References:	Wotherspoon et al. (2014), NSMN, Bradley and Cubrinovski (2011), GeoNet (2013), NZGD
GPS LAT	-43.49541878
GPS LONG	172.7179969
Liq. layer consist of:	Sand (SP)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Nature of Failure:	No liquefaction manifestation. Ground motion recording indicate liquefaction.
Comments:	CPT and Vs are available at the site. amax is reported as 0.32 g by Wotherspoon et al (2014). The acceleration record data could not be dowloaded from Geonet (2013). Bradley and Cubrinovski (2011) suggest amax=0.67 g. Additionally the figure by Wotherspoon et al (2014) suggests amax 0.78 g but the table in the same study suggest amax=0.32 g. Site response analysis is performed and amax is calculated as 0.539 g which is used in this study.
	GWT is determined based on SPT soundings.
	FC is assigned accordingly with USCS, SP <5.
	Vs,12m is calculated based on the mesaured Vs values.
	Probably BH1 and BH 30210 are identical where ER is measured as 85%. Based on the detailed description of the site by Wotherspoon et al 2014, the SMS located in the elevated portion where no manifestation occured due to liquefation. However, ground motions recording presented by Wotherspoon et al. (2014) indicates liquefaction after Christchurch event. The deep sand layer which has relatively lower SPT-N values are claimed to caused that behavior hence it was selected as the critical layer.



Free field



after Wotherspoon et al. (2014)

CPT available:	Yes
Vs available:	Yes
Gravel Content:	NAV

Summary of Input Data					
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No or Yes
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	14.5 - 18.5
d_{crt} (m)	-	-	-	-	16.5
GWT (m)	-	-	-	-	2.3 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	336.4 ± 15.3
σ_v' (kPa)	-	-	-	-	196.9 ± 10.0
a_{max} (g)	-	-	-	-	0.539 ± 0.027
r_d	-	-	-	-	0.54 ± 0.075
CSR	-	-	-	-	0.322 ± 0.048
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	4.5 ± 2.8
% PI	-	-	-	-	0
N	-	-	-	-	14.4 ± 4.3
C_R	-	-	-	-	0.99
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.42
C_N	-	-	-	-	0.72
$(N_1)_{60}$	-	-	-	-	14.6 ± 4.3
V_{s30m} (m/s)	-	-	-	-	211.7
V_{s12m} (m/s)	-	-	-	-	144.7

EVENT PARAMETERS

2011 Christchurch Earthquake

Magnitude: 6.20

Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 3.7

Dip: 64 | Width (km): 6.5 | R_{jb} (km): 3.7

ACCELERATION TIME HISTORY

Full Record

N_{H1} -

N_{H2} -

N_{gm} -

PGA_{H1} -

PGA_{H2} -

PGA -

M_w -

$M_{w,cycle}$ -

Untill Liquefaction

$N_{H1,L}$ -

$N_{H2,L}$ -

$N_{gm,L}$ -

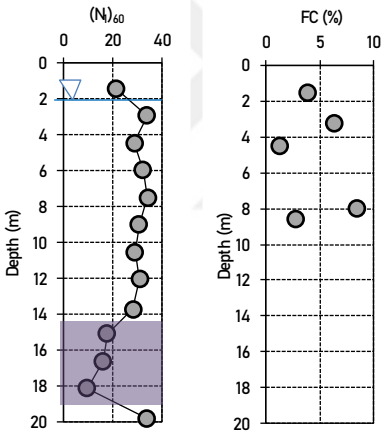
PGA_{H1} -

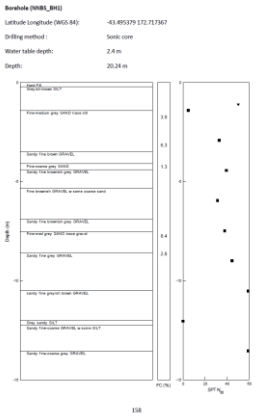
PGA_{H2} -

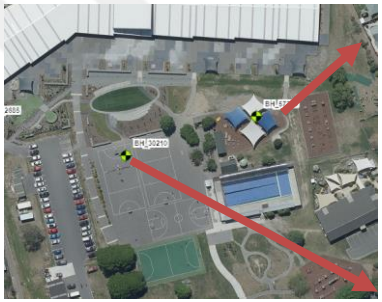
PGA_L -

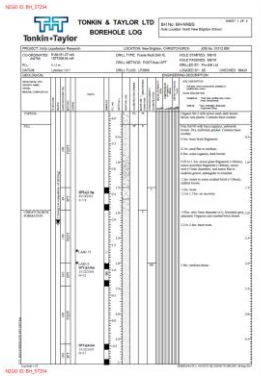
$M_{w,eq}$ -

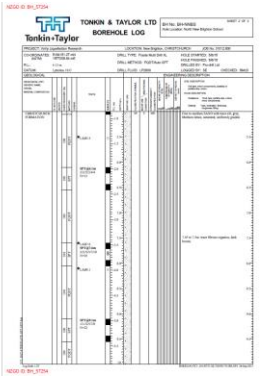
t_L -

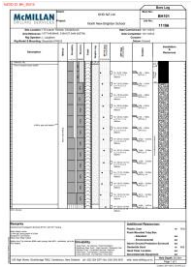












based on borehole retrieved from NZGD

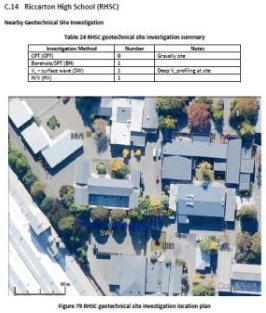
	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N_1)_{60}$
SP	1.4	4.6	NA	9	1.96	0.85	21.2
SP	2.9	9.6	0.353	19	1.42	0.89	34.1
SP	4.4	14.6	0.378	18	1.24	0.92	29.0
SP	6.0	19.6	0.367	22	1.11	0.94	32.5
SP	7.5	24.5	0.338	25	1.01	0.96	34.3
SP	9.0	29.5	0.306	24	0.94	0.97	30.8
SP	10.5	34.5	0.278	24	0.88	0.98	29.1
SP	12.0	39.5	0.257	27	0.83	0.98	31.1
SP	13.7	45.0	0.242	26	0.78	0.99	28.4
SP	***15.1***	***49.5***	***0.234***	***17***	***0.75***	***0.99***	***17.9***
SP	***16.6***	***54.5***	***0.229***	***16***	***0.72***	***0.99***	***16.1***
SP	***18.1***	***59.4***	***0.227***	***10***	***0.69***	***1.00***	***9.7***
SP	19.8	64.9	0.225	36	0.66	1.00	33.6
						Mean:	14.6
						St. Dev.	4.3

FC
0-5
0-5
0-5
0-5
0-5
0-5
0-5
0-5
0-5
0-5
0-5
0-5
0-5

Depth (m)	FC
1.5	3.9
3.2	6.3
4.5	1.3
8.0	8.4
8.6	2.8
Mean:	4.5
St. Dev.	2.8

Same layer consistent info this FC is used

Case number:	254
Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Riccarton High School (RHSC)
References:	Wotherspoon et al. (2014), cannet
GPS LAT	-43.536172
GPS LONG	172.564404
Liq. layer consist of:	Gravel (GW)
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Deconvolution Analysis
Nature of Failure:	No clear manifestation of liquefaction. Ground motion do not indicate the occurence of liquefaction.
Comments:	Vs is available at the site. amax was not reported by Wotherspoon et al (2014). However, based on the acceleration record data dowloaded from Geonet (2013) 0.293 g and 0.250 g is determined for two component geometric mean of which is 0.271 g which is used in the analysis. 0.28 g is suggested by Bradley and Cubrinovski (2011).
	GWT is determined from the figure provided by Wotherspoon et al (2014), interpreted from SPT.
	FC is assigned accordingly with USCS, GW <5.
	Vs,12m is calculated based on the mesaured Vs values.
	Rrup 6.5 km , Rjb=6.5 km Bradley and Cubrinovski 2011.



After Wotherspoon et al. (2014)

Gravel Content (%):	50.0-100.0
CPT available:	No
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	10.0 - 17.0
d_{crt} (m)	-	-	-	-	13.5
GWT (m)	-	-	-	-	6.4 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	21.5 ± 0.5
σ_v (kPa)	-	-	-	-	274.1 ± 25.6
σ_v' (kPa)	-	-	-	-	204.4 ± 14.4
a_{max} (g)	-	-	-	-	0.271 ± 0.014
r_d	-	-	-	-	0.64 ± 0.075
CSR	-	-	-	-	0.150 ± 0.020
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	0.0 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	44.4 ± 9.3
C_R	-	-	-	-	0.99
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.00
C_N	-	-	-	-	0.71
$(N_1)_{60}$	-	-	-	-	30.9 ± 6.5
$V_{s,30m}$ (m/s)	-	-	-	-	285.3
$V_{s,12m}$ (m/s)	-	-	-	-	205.0

EVENT PARAMETERS

2011 Christchurch Earthquake

Magnitude: 6.20

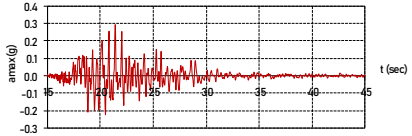
Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 6.5

Dip: 64 | Width (km): 6.5 | R_{jb} (km): 6.5

ACCELERATION TIME HISTORY

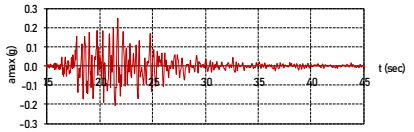
Full Record

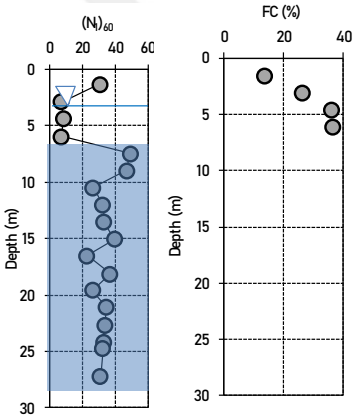
N_{H1}	13.7
N_{H2}	18.4
N_{gm}	15.9
PGA_{H1}	0.293
PGA_{H2}	0.250
PGA	0.271
M_w	6.2
$M_{w,cycle}$	7.1

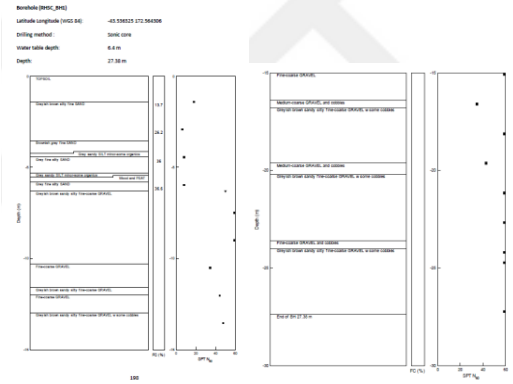


Untill Liquefaction

$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-



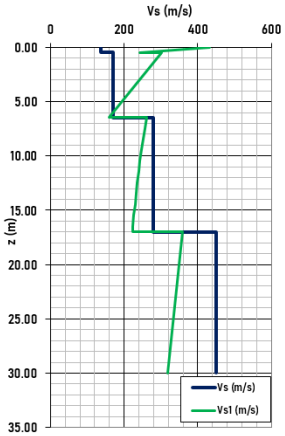




	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
top soil	1.33	4.4	NA	18	2.00	0.85	30.5	SM
grayish brow n silty fine sand	2.86	9.4	NA	6	1.37	0.89	7.3	SM
grey sandy silt minor some organics	4.39	14.4	NA	8	1.11	0.92	8.1	CL
ghrey fine silty sand	5.93	19.5	NA	8	0.95	0.94	7.2	SM
grayish brown sandy silt fine-coarse gravel	7.46	24.48	0.17	59	0.87	0.96	49.3	GW
grayish brown sandy silt fine-coarse gravel	8.99	29.49	0.18	59	0.82	0.97	46.8	GW
fine-coarse gravel	**10.48**	**34.4**	**0.18**	**35**	**0.78**	**0.98**	**26.5**	**GW**
fine-coarse gravel	**12.02**	**39.4**	**0.17**	**45**	**0.74**	**0.98**	**32.6**	**GW**
grayish brown sandy silt fine-coarse gravel with some cobbles	**13.55**	**44.5**	**0.17**	**48**	**0.70**	**0.99**	**33.4**	**GW**
fine-coarse gravel	**15.04**	**49.3**	**0.16**	**59**	**0.68**	**0.99**	**39.5**	**GW**
medium-coarse gravel and cobbles	**16.53**	**54.2**	**0.16**	**35**	**0.65**	**0.99**	**22.6**	**GW**
greyish brow n sandy silty fine-coarse gravel w some cobbles	18.11	59.4	0.16	59	0.63	1.00	36.8	GW
greyish brow n sandy silty fine-coarse gravel w some cobbles	19.60	64.3	0.16	43	0.61	1.00	26.0	GW
greyish brow n sandy silty fine-coarse gravel w some cobbles	21.09	69.2	0.16	59	0.59	1.00	34.6	GW
greyish brow n sandy silty fine-coarse gravel w some cobbles	22.67	74.4	0.16	59	0.57	1.00	33.6	GW
greyish brow n sandy silty fine-coarse GRAVEL w some cobblesEnd	24.16	79.3	0.16	59	0.56	1.00	32.7	GW
greyish brow n sandy silty fine-coarse GRAVEL w some cobblesEnd	24.74	81.2	0.16	59	0.55	1.00	32.4	GW
greyish brow n sandy silty fine-coarse GRAVEL w some cobblesEnd	27.22	89.3	0.16	59	0.53	1.00	31.1	GW
						Mean:	30.9	
						St. Dev.	6.5	

Vs profile indicates a sub layer in gravel

This layer has sligthly higher N1,60



Depth (m)	FC
1.55	13.7
3.08	26.2
4.65	36.0
6.15	36.6
Mean:	
St. Dev.	

Earthquake:	2011 Christchurch Earthquake
Magnitude:	6.2
Location:	Styx Mill Transfer Station (SMTC)
References:	Wotherspoon et al. (2014), cannet, Geonet (2013)
GPS LAT	-43.4675293
GPS LONG	172.6138611
Liq. layer consist of:	fine-coarse gravel w minor cobbles
Geological Unit:	Natural Deposit
Site Response Anlaysis:	Yes
Nature of Failure:	No clear manifestation of liquefaction. Ground motion recordings do not indicate liquefaction.
Comments:	Vs is available at the site. amax was not reported by Wotherspoon et al (2014). However, based on the acceleration recording data dowloaded from Geonet (2013), 0.180 g and 0.143 g is determined for two component, geometric mean of which is 0.160 g which is used in the analysis. 0.16 g is suggested by Bradley and Cubrinovski (2011). GWT is determined from the figure provided by Wotherspoon et al (2014), interpreted from SPT. Vs,12m is calculated based on the mesaured Vs values. Rrup 10.7 km , Rjb=10.8 km Bradley and Cubrinovski 2011.

C.16 Styx Mill Transfer Station (SMTC)

Nearby Geotechnical Site Investigation

Table 26 SMTC geotechnical site investigation summary

Investigation Method	Number	Notes
CPT (CPT)	0	Gravelly site
Borehole/SPT (BH)	1	
V_s – surface wave (SW)	1	
H/V (HV)	1	



Figure 81 SMTC geotechnical site investigation location plan

After Wotherspoon et al. (2014)

Gravel Content (%):	>50
CPT available:	No
Vs available:	Yes

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	A
d_{crc} range (m)	-	-	-	-	7.0 - 11.0
d_{crt} (m)	-	-	-	-	9.0
GWT (m)	-	-	-	-	1.0 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	20.0 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	21.5 ± 0.5
σ_v (kPa)	-	-	-	-	192.6 ± 14.9
σ_v' (kPa)	-	-	-	-	114.0 ± 8.8
a_{max} (g)	-	-	-	-	0.160 ± 0.024
r_d	-	-	-	-	0.81 ± 0.058
CSR	-	-	-	-	0.143 ± 0.024
M_w	-	-	-	-	6.20
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	5.9 ± 5.8
% PI	-	-	-	-	0
N	-	-	-	-	47.2 ± 6.2
C_R	-	-	-	-	0.97
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.00
C_N	-	-	-	-	0.94
$(N_1)_{60}$	-	-	-	-	43.2 ± 5.7
$V_{s,30m}$ (m/s)	-	-	-	-	221.4
$V_{s,12m}$ (m/s)	-	-	-	-	183.2

EVENT PARAMETERS

2011 Christchurch Earthquake

Magnitude: 6.20

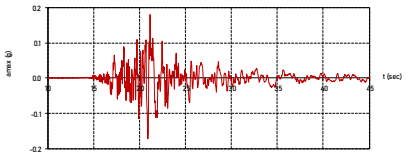
Fault Type: Reverse Fault | Z_{tor} (km): 0.5 | R_{rup} (km): 10.7

Dip: 64 | Width (km): 6.5 | R_{jb} (km): 10.7

ACCELERATION TIME HISTORY

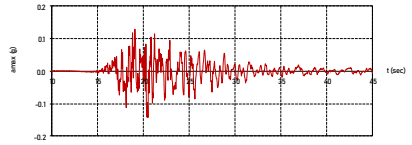
Full Record

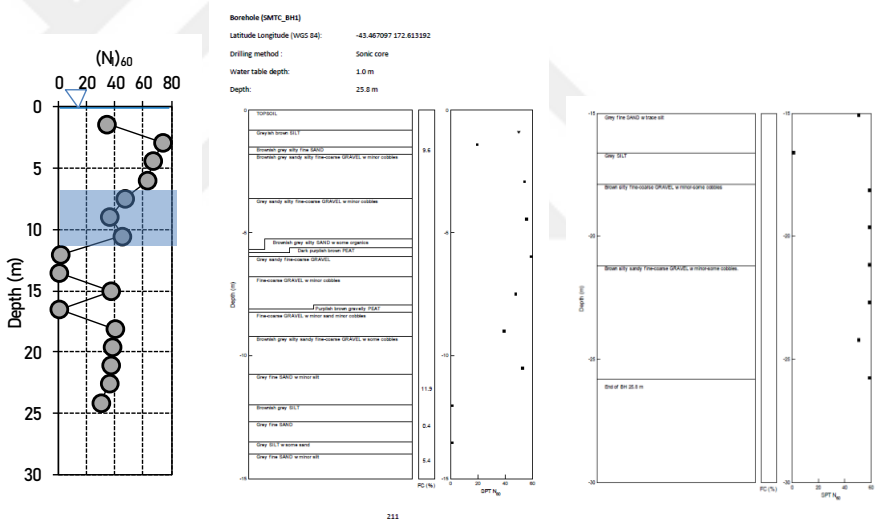
N_{H1}	10.5
N_{H2}	16.8
N_{gm}	13.3
PGA_{H1}	0.180
PGA_{H2}	0.143
PGA	0.160
M_w	6.2
$M_{w,cycle}$	6.0



Untill Liquefaction

$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-



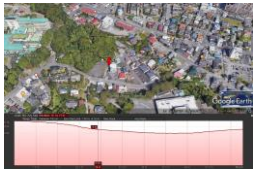


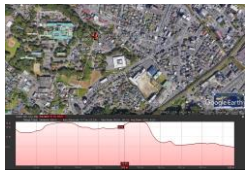
		Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
ML	greyish brown silt	1.4	4.4	0.118	20	2.00	0.85	33.9	CN>2 exclude
GW	***brownish grey sandy fine-coarse gravel w cobbles***	***2.9***	***9.5***	***0.146***	***54***	***1.55***	***0.89***	***74.4***	
GW	***grey sandy silt fine-coarse gravel w minor cobbles***	***4.4***	***14.5***	***0.153***	***56***	***1.30***	***0.92***	***66.9***	
GW	***grey sandy fine-coarse gravel***	***6.0***	***19.6***	***0.152***	***59***	***1.14***	***0.94***	***63.2***	
GW	***fine-coarse gravel w minor cobbles***	***7.4***	***24.3***	***0.147***	***48***	***1.03***	***0.96***	***47.4***	
GW	***fine-coarse gravel w minor cobbles***	***9.0***	***29.4***	***0.139***	***40***	***0.95***	***0.97***	***36.6***	
GW	***brownish grey silty sandy fine-coarse gravel w some cobbles***	***10.5***	***34.4***	***0.129***	***53***	***0.88***	***0.98***	***45.5***	
ML-GP	brownish grey silt	12.0	39.5	0.121	1	0.82	0.98	0.8	PLASTIC
ML-GP	grey silt w some sand	13.5	44.4	0.114	1	0.78	0.99	0.8	PLASTIC
GW	***grey fine sand w minor silt***	***15.0***	***49.3***	***0.109***	***51***	***0.74***	***0.99***	***37.5***	
ML	grey silt	16.5	54.2	0.105	1	0.71	0.99	0.7	PLASTIC
GW	***brown silty fine-coarse gravel w minor some cobbles***	***18.12***	***59.4***	***0.103***	***59***	***0.68***	***1.00***	***39.8***	
GW	***brown silty fine-coarse gravel w minor some cobbles***	***19.56***	***64.2***	***0.102***	***59***	***0.65***	***1.00***	***38.4***	
GW	***brown silty sandy fine-coarse gravel w minor some***	***21.09***	***69.2***	***0.101***	***59***	***0.63***	***1.00***	***37.1***	
GW	***brown silty sandy fine-coarse gravel w minor some***	***22.57***	***74.0***	***0.101***	***59***	***0.61***	***1.00***	***35.9***	low CSR
GW	***brown silty sandy fine-coarse gravel w minor some***	***24.13***	***79.2***	***0.101***	***51***	***0.59***	***1.00***	***30.1***	low CSR
GW	***brown silty sandy fine-coarse gravel w minor some***	***26***	***85.3***	***0.101***	***59***	***0.57***	***1.00***	***33.5***	low CSR
							Mean:	43.2	
							St. Dev.	5.7	

inconsisten FC info for ML

Depth (m)	FC
1.67	***9.6***
11.33	***11.9***
12.81	***0.4***
14.25	***5.4***
	5.9
	5.8

Case number:	377
Earthquake:	2011 Tohoku-oki (or Great East Japan) Earthquake
Magnitude:	9.1
Location:	IBR014 TSUCHIURA
References:	Greenfield (2017, 2018), NGL Porject, KNET, Cox et al. (2013)
Nature of Failure:	Ejecta and minor cracking in parking lot. Liquefaction modified recorded ground motions.
GPS LAT	36.0728
GPS LONG	140.1948
Liq. layer consist of:	Sand and sand (SW) with silt content
Geological Unit:	terraced cuts and fills
Site Response Anlaysis:	No
Comments:	The site is a KNET recording station. In 2015, site investigation were performed by Tokyo Soil Research and Greenfield. An automatic trip hammer with a cathead and rope was used. Hammer energy is estimated between 72 to 82%. Greenfield (2017) estimated time of liquefaction as TL=104 sec. amax is recorded as 0.509 g and 0.392 g, geometric mean of which is 0.447 g is used in the analysis. The site is free field. The silt layer located between 7-17 m exhibits moderate plasticity with a PI of about 20. The lower silt layer possibly exbitih the same character although there is not atterberg limit measurements. Hence sand layer between 17-28 is taken as potentially liquefaible layer excluding the silty layer within it.





Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crc} range (m)	-	-	-	-	17.1 - 28.0
d_{cr1} (m)	-	-	-	-	22.6
GWT (m)	-	-	-	-	1.3 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	13.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	17.0 ± 0.5
σ_v (kPa)	-	-	-	-	378.8 ± 32.5
σ_v' (kPa)	-	-	-	-	170.0 ± 16.5
a_{max} (g)	-	-	-	-	0.447 ± 0.022
r_d	-	-	-	-	0.65 ± 0.149
CSR	-	-	-	-	0.420 ± 0.100
M_w	-	-	-	-	9.10
D_{50}	-	-	-	-	NAV
% Fines	-	-	-	-	15.0 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	21.2 ± 9.2
C_R	-	-	-	-	1.00
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.27
C_N	-	-	-	-	0.77
$(N_1)_{60}$	-	-	-	-	20.8 ± 9.0
$V_{s,30m}$ (m/s)	-	-	-	-	230.0
V_{s12m} (m/s)	-	-	-	-	178.8

EVENT PARAMETERS

2011 Tohoku-oki (or Great East Japan) Earthquake

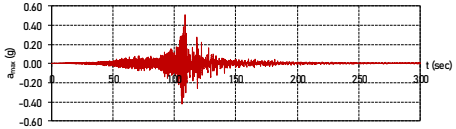
Magnitude: 9.10 USGS Depth :29 km

Fault Type: shallow thrust Z_{tor} (km): - R_{rup} (km): -

Dip: 9--81 Width (km): 150 R_{jb} (km): 71.0

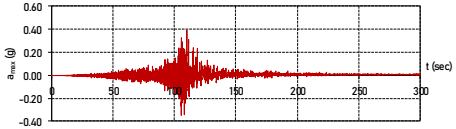
Full Record

N_{H1}	16.3
N_{H2}	21.2
N_{gm}	18.6
PGA_{H1}	0.509
PGA_{H2}	0.392
PGA	0.447
M_w	9.1
$M_{w,cycle}$	6.2



Untill Liquefaction

$N_{H1,L}$	22.1
$N_{H2,L}$	26.3
$N_{gm,L}$	24.1
PGA_{H1}	0.278
PGA_{H2}	0.237
PGA_L	0.257
$M_{w,eq}$	8.0
t_L	105.0



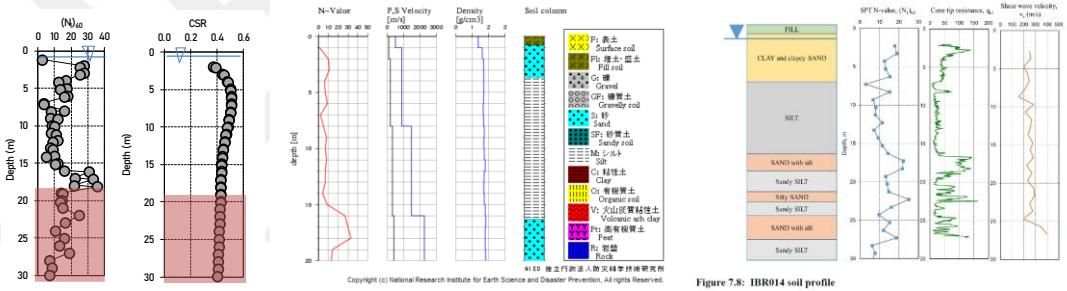


Figure 7.8: IBR014 soil profile

	Depth (m)	Depth (ft)	rd	CSR	N	C_N	C_R	$(N1)_{60}$	Energy	Rod Length		SPEC_ID	GRAG_ID	PLAS_LL	PLAS_PL	INDX_GS	INDX_WC	FC
Sand	1.15	3.8	0.992	NA	1	2.00	1.00	2.5			NIED							
SC	2	6.56	0.985	0.374	11	2.00	1.00	27.9		3.1	Mike Greenfield / Hiroshio Suzuki	2862	688				41.0	33.0
Sand	2.15	7.1	0.983	0.387	10	2.00	1.00	25.3			NIED							
SC	3	9.84	0.973	0.442	12	1.85	1.00	28.2	76.0	4.1	Mike Greenfield / Hiroshio Suzuki	2863						
Sand	3.15	10.3	0.971	0.449	11	1.82	1.00	25.4			NIED							
SC	4	13.12	0.958	0.479	8	1.66	1.00	16.8	72.0	5.1	Mike Greenfield / Hiroshio Suzuki	2864	689	44.0	17.0		44.0	39.0
Silt	4.15	13.6	0.955	0.483	6	1.64	1.00	12.5			NIED							
SC	5	16.40	0.939	0.498	9	1.52	1.00	17.3		6.1	Mike Greenfield / Hiroshio Suzuki	2865						
Silt	5.15	16.9	0.936	0.500	7	1.50	1.00	13.3			NIED							
SC	6	19.7	0.916	0.506	10	1.41	1.00	17.9	76.0	7.1	Mike Greenfield / Hiroshio Suzuki	2866	690	44.0	22.0			64.0
Silt	6.15	20.2	0.912	0.507	9	1.39	1.00	15.9			NIED							
CL	7	23.0	0.889	0.506	2	1.32	1.00	3.3	73.0	8.1	Mike Greenfield / Hiroshio Suzuki	2867						
Silt	7.15	23.5	0.885	0.506	2	1.31	1.00	3.3			NIED							
ML	8	26.2	0.860	0.500	10	1.25	1.00	15.8	82.0	9.1	Mike Greenfield / Hiroshio Suzuki	2868	691				57.0	
Silt	8.15	26.7	0.855	0.499	5	1.24	1.00	7.8			NIED							
ML	9	29.5	0.829	0.491	5	1.18	1.00	7.5	76.0	10.1	Mike Greenfield / Hiroshio Suzuki	2869		48.0	20.0		47.0	
Silt	9.15	30.0	0.824	0.489	8	1.17	1.00	11.9			NIED							
ML	10	32.8	0.798	0.480	6	1.13	1.00	8.6	77.0	11.1	Mike Greenfield / Hiroshio Suzuki	2870					***47.0***	
Silt	10.15	33.3	0.794	0.478	7	1.12	1.00	9.9			NIED							
ML	11	36.1	0.770	0.468	6	1.08	1.00	8.2		12.1	Mike Greenfield / Hiroshio Suzuki	2871						
Silt	11.15	36.6	0.765	0.466	8	1.07	1.00	10.9			NIED							
ML	12	39.4	0.744	0.457	9	1.04	1.00	11.8		13.1	Mike Greenfield / Hiroshio Suzuki	2872						
Silt	12.15	39.9	0.741	0.456	7	1.03	1.00	9.2			NIED							
ML	13	42.7	0.723	0.448	6	1.00	1.00	7.6		14.1	Mike Greenfield / Hiroshio Suzuki	2873	***692***					***77.0***
Silt	13.15	43.1	0.720	0.447	7	1.00	1.00	8.8			NIED			***no data but Greenfield (2018) "..The silt typically exhibited moderate plasticity with a PI of about 20..."***					
ML	14	45.9	0.706	0.440	8	0.97	1.00	9.8		15.1	Mike Greenfield / Hiroshio Suzuki	2874						
Silt	14.15	46.4	0.703	0.439	4	0.96	1.00	4.9			NIED							
ML	15	49.2	0.692	0.435	10	0.94	1.00	11.9		16.1	Mike Greenfield / Hiroshio Suzuki	2875	***693***					***78.0***
Silt	15.15	49.7	0.690	0.434	9	0.93	1.00	10.6			NIED							
ML	16	52.5	0.682	0.430	14	0.91	1.00	16.1		17.1	Mike Greenfield / Hiroshio Suzuki	2876						
Silt	16.15	53.0	0.680	0.430	27	0.90	1.00	31.0			NIED							
ML	17	55.8	0.674	0.428	20	0.88	1.00	22.4		18.1	Mike Greenfield / Hiroshio Suzuki	2877						
Sand	***17.15***	***56.3***	***0.673***	***0.427***	***30***	***0.88***	***1.00***	***33.4***			***NIED***							
SW	***18***	***59.1***	***0.668***	***0.426***	***20***	***0.86***	***1.00***	***21.8***		***19.1***	***Mike Greenfield / Hiroshio Suzuki***	***2878***						
Sand	***18.15***	***59.5***	***0.667***	***0.426***	***33***	***0.86***	***1.00***	***35.8***			***NIED***							
M	19	62.3	0.664	0.425	13	0.84	1.00	13.8		20.1	Mike Greenfield / Hiroshio Suzuki	2879	694				39.0	59.0
Sand	***19.15***	***62.8***	***0.663***	***0.425***	***14***	***0.84***	***1.00***	***14.8***			***NIED***							
ML	20	65.6	0.661	0.424	14	0.82	1.00	14.5		21.1	Mike Greenfield / Hiroshio Suzuki	2880						
Sand	***20.15***	***66.1***	***0.660***	***0.424***	***13***	***0.82***	***1.00***	***13.4***			***NIED***							
ML	21	68.9	0.656	0.423	15	0.80	1.00	15.2		22.1	Mike Greenfield / Hiroshio Suzuki	2881	695					68.0
ML	22	72.2	0.651	0.421	25	0.78	1.00	24.8		23.1	Mike Greenfield / Hiroshio Suzuki	2882				2.6	36.0	
ML	23	75.5	0.647	0.419	17	0.77	1.00	16.5		24.1	Mike Greenfield / Hiroshio Suzuki	2883						
ML	24	78.7	0.642	0.417	11	0.75	1.00	10.5		25.1	Mike Greenfield / Hiroshio Suzuki	2884						
SW	***25***	***82.0***	***0.638***	***0.415***	***17***	***0.74***	***1.00***	***15.8***		***26.1***	***Mike Greenfield / Hiroshio Suzuki***	***2885***						
SW	***26***	***85.3***	***0.633***	***0.413***	***14***	***0.72***	***1.00***	***12.8***		***27.1***	***Mike Greenfield / Hiroshio Suzuki***	***2886***						
SW	***27***	***88.6***	***0.628***	***0.411***	***21***	***0.71***	***1.00***	***18.9***		***28.1***	***Mike Greenfield / Hiroshio Suzuki***	***2887***						
SW-ML	28	91.9	0.624	0.408	8	0.70	1.00	7.1		29.1	Mike Greenfield / Hiroshio Suzuki	2888						
ML	29	95.1	0.619	0.406	10	0.69	1.00	8.7		30.1	Mike Greenfield / Hiroshio Suzuki	2889						
ML	30	98.4	0.615	0.404	8	0.67	1.00	6.8		31.1	Mike Greenfield / Hiroshio Suzuki	2890						
							Mean:	20.8	76.0				**Mean:**	-	-	-	-	-
							St. Dev.	9.0					**St. Dev.**	-	-	-	-	-

Case number:	378
Earthquake:	2011 Tohoku-oki (or Great East Japan) Earthquake
Magnitude:	9.1
Location:	CHB009 (SMS)
References:	Cox et al. (2013), KNET
Nature of Failure:	No ground failure
GPS LAT	35.607591
GPS LONG	140.10774
Liq. layer consist of:	Sand
Geological Unit:	Alluvial plain? Fill (1966-1975)
Site Response Anlaysis:	No
Comments:	The site is a KNET strong ground motion station. The two horizontal component is recorded as 0.143 g and 0.182 g, geometric mean of which is 0.161 g is used in the analysis after 2011 Tohoku event. Fines content information was not available however Cox et al (2013) estimated the fines content of the sandy soil to be 25% based on its visual description. Cox et al. (2013) suggests the sand layer is likely the suspicious layer. Because if the silty layer is considered as a nonplastic silt, the site will likely to have settlements after 2011 Tohoku event. Thus silt is probably plastic. As a result sand layer is taken as potentailly liquefaible soil. Atterberg limit data is not available. GWT is at 3 m hence fill layer is not saturated. Density measurements were provided by KNET. 950 m away from the site there is a SPT. At this location same fill, sand and silt layer exist hence FC is assigned from this borehole. NGL Webinar Series 07 presentation by Dongyoup Kwak is used to retrieve fines content information.



Gravel Content (%):	NAV
CPT available:	No
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	A
d_{crit} range (m)	-	-	-	-	3.5 - 9.5
d_{crt} (m)	-	-	-	-	6.5
GWT (m)	-	-	-	-	3.0 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.8 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	17.2 ± 0.5
σ_v (kPa)	-	-	-	-	113.6 ± 17.3
σ_v' (kPa)	-	-	-	-	79.2 ± 7.8
a_{max} (g)	-	-	-	-	0.161 ± 0.008
r_d	-	-	-	-	0.89 ± 0.087
CSR	-	-	-	-	0.134 ± 0.017
M_w	-	-	-	-	9.10
D_{50}	-	-	-	-	NAV
% Fines	-	-	-	-	9.8 ± 4.3
% PI	-	-	-	-	NAV
N	-	-	-	-	19.1 ± 1.7
C_R	-	-	-	-	0.95
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.13
$(N_1)_{60}$	-	-	-	-	28.1 ± 2.5
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	169.2

EVENT PARAMETERS

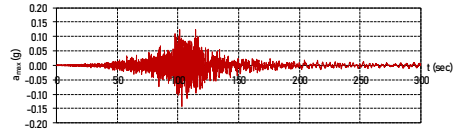
2011 Tohoku-oki (or Great East Japan) Earthquake

Magnitude: 9.10 USGS Depth: 29 km

Fault Type: shallow thrust Z_{tor} (km): - R_{rup} (km): -

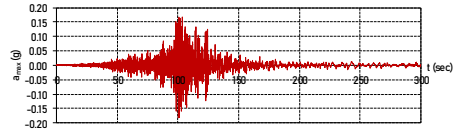
Dip: 9--81 Width (km): 150 R_{jb} (km): 90-100

Full Record	https://www.strongmotioncenter.org/
N_{H1}	28.5 https://www.kyoshin.bosai.go.jp/kyoshin/pubdata/knet/3comp/2011/03/20110311144600/CHB009
N_{H2}	45.8
N_{gm}	36.1
PGA_{H1}	0.143
PGA_{H2}	0.182
PGA	0.161
M_w	9.1
$M_{w,cycle}$	8.7

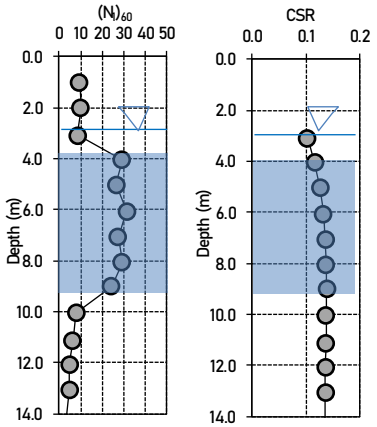


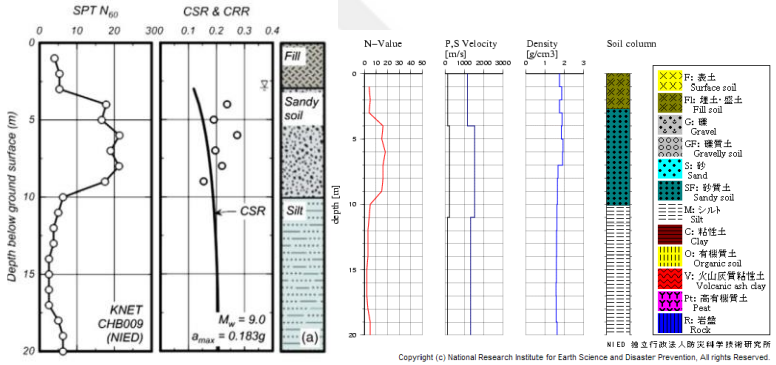
Untill Liquefaction

$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-



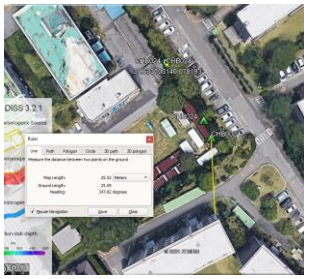
Hypocentral dist: 362.0 km





Density (g/cm^3)	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$			Depth (m)	FC (%)	PI	
1.75	1.0	3.3	NA	4	2.00	0.86	9.4	Fill	above GWT	1.3	17.2	NP	SM
1.87	2.0	6.6	NA	5	1.69	0.88	10.2	Fill	above GWT	2.3	39.1	21.8	SC
1.75	3.1	10.0	0.103	5	1.37	0.91	8.5	Sand	SPT=5 at 3.1 m probably belongs to fill layer. GWT is at 3 m hence fill layer is not saturated	3.3	37.5	22.7	SC
1.88	***4.0***	***13.3***	***0.117***	***18***	***1.29***	***0.92***	***29.3***	***Sand***		***4.3***	***6.3***	***NP***	SP-SM
1.85	***5.0***	***16.4***	***0.126***	***17***	***1.22***	***0.94***	***26.6***	***Sand***		***5.3***	***10.0***	***NP***	SP-SM
1.93	***6.1***	***19.9***	***0.132***	***21***	***1.16***	***0.95***	***31.5***	***Sand***		***6.3***	***7.0***	***NP***	SP-SM
1.91	***7.1***	***23.2***	***0.136***	***19***	***1.10***	***0.96***	***27.5***	***Sand***		***7.3***	***7.1***	***NP***	SP-SM
1.67	***8.1***	***26.4***	***0.138***	***21***	***1.06***	***0.97***	***29.3***	***Sand***		***8.3***	***10.4***	***NP***	SP-SM
1.64	***9.0***	***29.5***	***0.138***	***18***	***1.02***	***0.97***	***24.4***	***Sand***		***9.3***	***17.8***	***NP***	SM
1.64	10.0	32.9	0.138	6	0.98	0.98	7.9	Sand	SPT=6 probably belongs to the silt layer.	10.3	12.8	NP	SM
1.61	11.1	36.5	0.137	5	0.95	0.98	6.4	Silt		11.3	48.3	40.5	SC
1.62	12.0	39.5	0.136	4	0.92	0.99	5.0	Silt		12.3	78.0	59.9	CH
1.59	13.1	42.8	0.136	4	0.89	0.99	4.8	Silt	Cox et al 2013 suggests the sand layer is likely the suspicious layer. Because if the silty layer is considered as a nonplastic silt, the site will likely to have settlements after 2011 Tohoku event. Thus silt is probably plastic. As a result sand layer is taken as potentailly liquefaible soil. atterberg data is not available.				
1.59	14.0	46.1	0.136	3	0.87	0.99	3.5	Silt					
1.58	15.1	49.4	0.136	2	0.84	0.99	2.3	Silt					
1.58	16.1	52.8	0.136	2	0.82	0.99	2.2	Silt					
1.56	17.1	56.1	0.136	2	0.80	0.99	2.2	Silt					
1.57	18.1	59.3	0.137	5	0.79	1.00	5.3	Silt					
1.57	19.1	62.6	0.138	6	0.77	1.00	6.3	Silt					
1.63	20.1	65.9	0.139	6	0.75	1.00	6.2	Silt					
						Mean:	28.1		*SPT profile near Chiba G indicates high plastic material*	**Mean:**	9.8		
						St. Dev.	2.5			**St. Dev.**	4.3		

Case number:	379
Earthquake:	2011 Tohoku-Oki Earthquake
Magnitude:	9.1
Location:	CHB024 (SMS) Mihama, Chiba Inage
References:	Cox et al. (2013), Greenfield (2017), KNET
Nature of Failure:	extensive sand boils and moderate ground deformations.
GPS LAT	35.633703
GPS LONG	140.078193
Liq. layer consist of:	Sand
Geological Unit:	Fill
Site Response Anlaysis:	No
Comments:	The site is a KNET strong ground motion station. The ground motions indicate liquefaction. Greenfield (2017) performed analysis and estimated time of liquefaction as 120 sec.The two horizontal component are recorded as 0.239g and 0.206 g, geometric mean of which is 0.222 g. Liquefaction occured at late stages hence did not affect PGA levels so 0.222 g which is used in the analysis. The fines content of the sand is not available, however Cox et al. (2013) estimated fines content to be 5% based on its visual description. Greenfield 2017 determined time of liquefaction as 120 sec and critical depth as 20.3 m. Rrup as 52 km, Vs30 as 298 m/s. Density data is provided by KNET.



Gravel Content (%):	NAV
CPT available:	No
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	18.5 - 20.5
d_{crt} (m)	-	-	-	-	19.5
GWT (m)	-	-	-	-	3.0 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	14.4 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.2 ± 0.5
σ_v (kPa)	-	-	-	-	345.1 ± 10.0
σ_v' (kPa)	-	-	-	-	182.9 ± 8.4
a_{max} (g)	-	-	-	-	0.222 ± 0.011
r_d	-	-	-	-	0.76 ± 0.149
CSR	-	-	-	-	0.206 ± 0.042
M_w	-	-	-	-	9.10
D_{50}	-	-	-	-	0.126 ± 0.050
% Fines	-	-	-	-	5.0 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	5.0 ± 0.1
C_R	-	-	-	-	1.00
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	0.75
$(N_1)_{60}$	-	-	-	-	5.1 ± 0.1
$V_{s,30m}$ (m/s)	-	-	-	-	298.0
$V_{s,12m}$ (m/s)	-	-	-	-	196.4

EVENT PARAMETERS

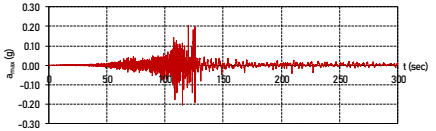
2011 Tohoku-Oki Earthquake

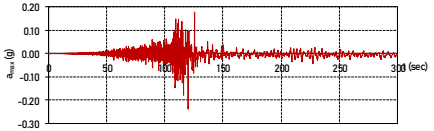
Magnitude: 9.10 USGS Depth :29 km

Fault Type: shallow thrust Z_{tor} (km): - R_{rup} (km): -

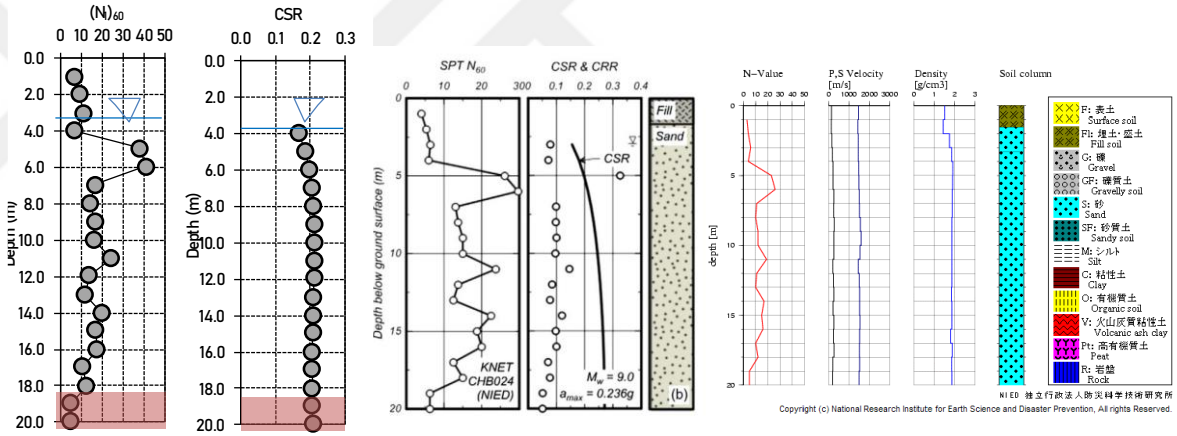
Dip: 9--81 Width (km): 150 R_{jb} (km): 52.0

Full Record	https://www.strongmotioncenter.org/vdc/scripts/plot.plx?stn=3650&evt=1206
N_{H1}	11.2 https://www.kyoshin.bosai.go.jp/kyoshin/pubdata/knet/3comp/2011/03/20110311144600/CHB024
N_{H2}	21.2
N_{gm}	15.4
PGA_{H1}	0.239
PGA_{H2}	0.206
PGA	0.222
M_w	9.1
$M_{w,cyclic}$	5.5
	Untill Liquefaction
$N_{H1,L}$	3.4
$N_{H2,L}$	3.0
$N_{gm,L}$	3.2
PGA_{H1}	0.179
PGA_{H2}	0.206
PGA_L	0.192
$M_{w,eq}$	1.14
t_L	120.0





Hypocentral Distance: 360.0 km



Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		
1.0	3.3	NA	3	2.00	0.86	7.0	Fill	
2.0	6.4	NA	4	1.89	0.88	9.1	Sand	
3.0	9.8	0.143	6	1.53	0.90	11.4	Sand	saturated??
4.0	***13.1***	***0.168***	***4***	***1.40***	***0.92***	***7.1***	***Sand***	*below layer is more critical* *one single SPT*
5.0	16.3	0.185	23	1.30	0.94	38.3	Sand	
6.0	19.5	0.197	26	1.22	0.95	41.1	Sand	
7.0	22.8	0.205	11	1.15	0.96	16.6	Sand	
8.0	26.1	0.210	10	1.09	0.97	14.4	Sand	
9.0	29.5	0.212	12	1.04	0.97	16.6	Sand	
10.0	32.6	0.213	12	1.00	0.98	16.0	Sand	
11.0	36.0	0.212	19	0.96	0.98	24.4	Sand	
11.9	39.2	0.210	11	0.92	0.98	13.7	Sand	
13.0	42.7	0.209	10	0.89	0.99	12.0	Sand	
14.0	45.9	0.208	17	0.86	0.99	19.9	Sand	
14.9	49.0	0.206	15	0.84	0.99	17.1	Sand	
16.0	52.5	0.206	16	0.81	0.99	17.7	Sand	
16.9	55.6	0.205	10	0.79	0.99	10.8	Sand	
18.0	59.2	0.206	12	0.77	1.00	12.6	Sand	
19.0	***62.2***	***0.206***	***5***	***0.75***	***1.00***	***5.1***	***Sand***	CSR is higher
20.0	***65.5***	***0.206***	***5***	***0.74***	***1.00***	***5.0***	***Sand***	sublayer within sand layer
					Mean:	5.1		Both Cox et al. (2013) and Greenfield (2017)
					St. Dev.	0.1		suggested that FC is 5% for sand layer

Case number:	380
Earthquake:	2011 Tohoku-oki Earthquake
Magnitude:	9
Location:	MYG010
References:	Greenfield (2017), Cox et al. (2013), KNET
Nature of Failure:	Liquefaction modified ground motions.
GPS LAT	38.428
GPS LONG	141.281
Liq. layer consist of:	sand (SW and SM)
Geological Unit:	Late Pleistocene to Holocene marine and non-marine sediments or Late Pleistocene to Holocene sand dune deposits
Site Response Anlaysis:	No
Comments:	The site is a KNET strong ground motion station. The two horizantal component are recorded as 0.384 g and 0.467 g, geometric mean of which is 0.424 g is used in the analysis. Greenfield (2018) "The bay and surrounding areas of Ishinomaki were heavily damaged by the tsunami caused by the main shock of the Tohoku earthquake on March 11, 2011. Extensive liquefaction was reported around Ishinomaki, although much of the liquefaction damage was obscured by the tsunami (Cox et al. 2013)." A new strong motion recording is installed since the original one is damaged after 2011 Tohoku event. Greenfield (2017) estimated time of liquefaction as 46 sec. The below silt layer has relatively lower SPT values however sand boils observed on the surface after the aftershock of 2011 Tohoku event. There is no information about PI of silt layer. Grain size distribution curve for sand layer is available up to a depth of 6m. There is a sublayer within the sand layer which is more likely to liquefy. That layer is selected as the critical layer. Greenfield (2017) "The thick, saturated layers of medium dense to dense sand between depths of about 2.5 and 15 m likely liquefied during the Tohoku earthquake, although direct surficial evidence of liquefaction was obscured by the tsunami."Gradation curve data exist. Vs measurements are available.



Figure is taken from Greenfield (2018)



Gravel Content (%):	NAV
CPT available:	No
Vs available:	Yes Downhole test

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes*
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	7.5 - 15.5
d_{crt} (m)	-	-	-	-	11.5
GWT (m)	-	-	-	-	2.1 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	15.4 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	19.8 ± 0.5
σ_v (kPa)	-	-	-	-	219.1 ± 26.9
σ_v' (kPa)	-	-	-	-	126.7 ± 14.1
a_{max} (g)	-	-	-	-	0.424 ± 0.021
r_d	-	-	-	-	0.65 ± 0.142
CSR	-	-	-	-	0.309 ± 0.070
M_w	-	-	-	-	9.10
D_{50}	-	-	-	-	0.200 ± 0.050
% Fines	-	-	-	-	5.0 ± 8.6
% PI	-	-	-	-	NAV
N	-	-	-	-	15.0 ± 3.5
C_R	-	-	-	-	0.98
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	0.90
$(N_1)_{60}$	-	-	-	-	18.1 ± 4.2
V_{s30m} (m/s)	-	-	-	-	160.0
V_{s12m} (m/s)	-	-	-	-	149.6

EVENT PARAMETERS

2011 Tohoku-oki Earthquake

Magnitude: 9.10 USGS Depth :29 km

Fault Type: shallow thrust Z_{tor} (km): - R_{rup} (km): -

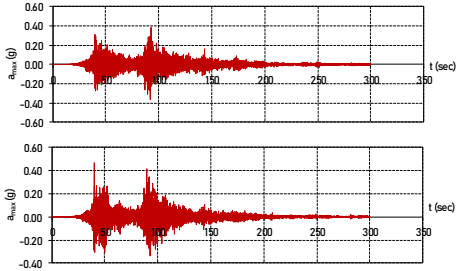
Dip: 9--81 Width (km): 150 R_{jb} (km): 45.0

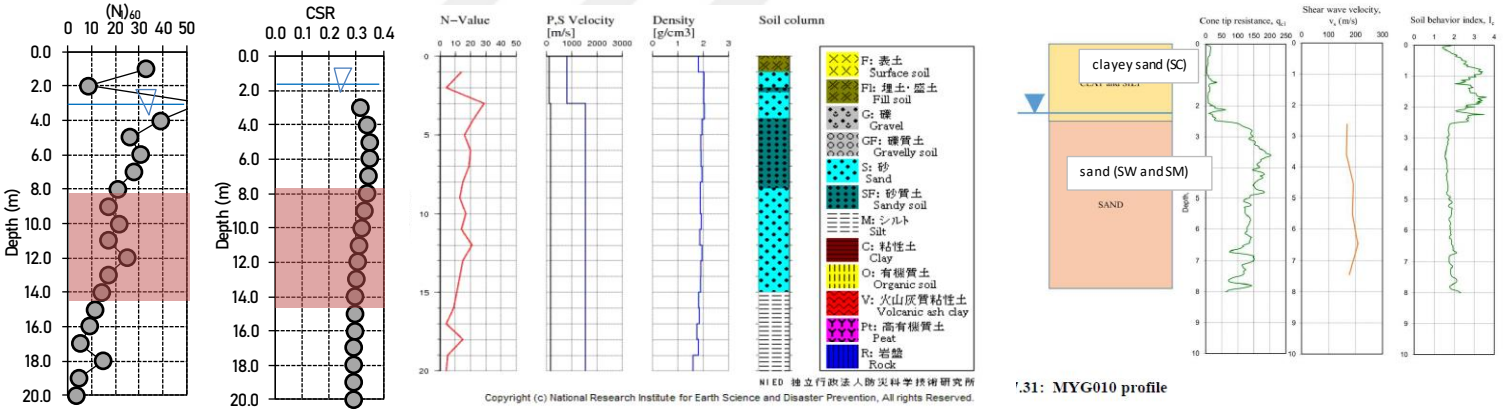
Full Record

N_{H1}	48.9
N_{H2}	31.1
N_{gm}	39.0
PGA_{H1}	0.384
PGA_{H2}	0.467
PGA	0.424
M_w	9.1
$M_{w,cycle}$	9.1

Untill Liquefaction

$N_{H1,L}$	18.5
$N_{H2,L}$	7.5
$N_{gm,L}$	11.8
PGA_{H1}	0.310
PGA_{H2}	0.467
PGA_L	0.381
$M_{w,eq}$	2.7
t_L	46.0





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'.31: MYG010 profile

Greenfield (2017)	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	KNET	Depth (m)	FC
clayey sand (SC)	1.0	3.3	NA	14	2.00	0.86	32.7	Fl		
clayey sand (SC)	2.0	6.6	NA	4	1.81	0.88	8.8	Fl - SF	2-2.6	23.3
sand (SW and SM)	3.0	9.8	0.313	29	1.57	0.90	56.1	S		
sand (SW and SM)	4.0	13.1	0.340	22	1.40	0.92	38.9	S	4-4.6	8
sand (SW and SM)	5.0	16.4	0.351	16	1.29	0.94	26.3	S		
sand (SW and SM)	6.0	19.7	0.352	20	1.19	0.95	30.9	S	6-6.6	18.8
sand (SW and SM)	7.0	23.0	0.346	19	1.12	0.96	27.8	S		
sand	***8.0***	***26.2***	***0.338***	***15***	***1.05***	***0.97***	***20.9***	***S***	*Greenfield (2017)*	
sand	***9.0***	***29.5***	***0.329***	***13***	***1.00***	***0.97***	***17.3***	***S***	*9.3 m dense sand liquefied*	
sand	***10.0***	***32.8***	***0.320***	***17***	***0.95***	***0.98***	***21.7***	***S***	*sublayer*	
sand	***11.0***	***36.1***	***0.312***	***14***	***0.91***	***0.98***	***17.2***	***S***		
sand	***12.0***	***39.4***	***0.306***	***21***	***0.88***	***0.99***	***24.8***	***S***	*sand boils observed in*	
sand	***13.0***	***42.7***	***0.301***	***15***	***0.85***	***0.99***	***17.1***	***S***	*the areial photos after*	
sand	***14.0***	***45.9***	***0.298***	***13***	***0.82***	***0.99***	***14.4***	***S***	*afterschok M=7.1. No*	
sand	***15.0***	***49.2***	***0.295***	***11***	***0.79***	***0.99***	***11.8***	***S***	*information on PI for the*	
	16.0	***52.5***	***0.294***	***9***	***0.77***	***0.99***	***9.4***	***M***	*below silt layer.*	
	17.0	***55.8***	***0.293***	***5***	***0.75***	***0.99***	***5.1***	***M***		
	18.0	***59.1***	***0.293***	***15***	***0.73***	***1.00***	***14.8***	***M***		
	19.0	***62.3***	***0.293***	***5***	***0.71***	***1.00***	***4.8***	***M***		
	20.0	***65.6***	***0.293***	***4***	***0.69***	***1.00***	***3.8***	***M***		
						Mean:	18.1			
						St. Dev.	4.2			

Case number:	382
Earthquake:	2011 Tohoku-oki Earthquake
Magnitude:	9.1
Location:	Onahama
References:	Greenfield (2017, 2018), PARI, KNET, Iai et al (1989), Kramer et al (2016), Rotten et al. (2013), NGL Project
Nature of Failure:	Liquefaction modified ground motions. No surface manifestation is observed.
GPS LAT	36.945
GPS LONG	140.912
Liq. layer consist of:	Sand
Geological Unit:	Recent (Holocene) alluvium.
Site Response Anlaysis:	No
Comments:	The site is a vertical array, a downhole seismometer at a depth of about 11.05 m is located in the ground. The two horizontal component on the ground surface are recorded as 0.765 g and 0.624 g, geometric men of which is 0.691 g is used in the analysis. Kramer et al (2016) described the damage in the port as follows "Onahama Port suffered damage in the form of settlement that displaced crane rails and other port facilities. While the port was affected by tsunami, sand boils were observed from aftershocks." Borehole information is provided by PARI. The shear wave velocity measurements are available. Yamazaki and Gotoh indicate the groundwater table is at a depth of 1.3 m below the ground surface. Time of liquefaction is determined as 79 s by Greenfeld and Kramer. No information regarding surface manifestation. However the thin layer of sand is probably liquefied. No surface manifestaion occured. The layer is very thin possibly hence it is probably the reason of no surface manifestation.



Gravel Content (%):	0
CPT available:	No
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes*
Data Class	-	-	-	-	B
$d_{crit.}$ range (m)	-	-	-	-	1.3 - 3.0
d_{GT} (m)	-	-	-	-	2.2
GWT (m)	-	-	-	-	1.3 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	42.1 ± 5.9
σ_v' (kPa)	-	-	-	-	33.7 ± 3.2
a_{max} (g)	-	-	-	-	0.691 ± 0.035
r_d	-	-	-	-	1.00 ± 0.034
CSR	-	-	-	-	0.560 ± 0.046
M_w	-	-	-	-	9.10
D_{50}	-	-	-	-	NAV
% Fines	-	-	-	-	5.5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	8.0 ± 1.0
C_R	-	-	-	-	0.89
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.73
$(N_1)_{60}$	-	-	-	-	16.8 ± 2.0
$V_{s,30m}$ (m/s)	-	-	-	-	390-540
$V_{s,12m}$ (m/s)	-	-	-	-	496.1

EVENT PARAMETERS

2011 Tohoku-oki Earthquake

Magnitude: 9.10 USGS Depth :29 km

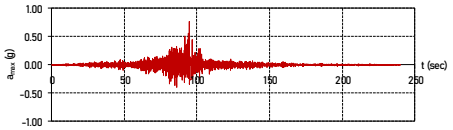
Fault Type: shallow thrust Z_{tor} (km): - R_{rup} (km): -

Dip: 9--81 Width (km): 150 R_{jb} (km): 55.0

ACCELERATION TIME HISTORY

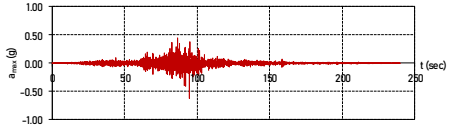
Full Record

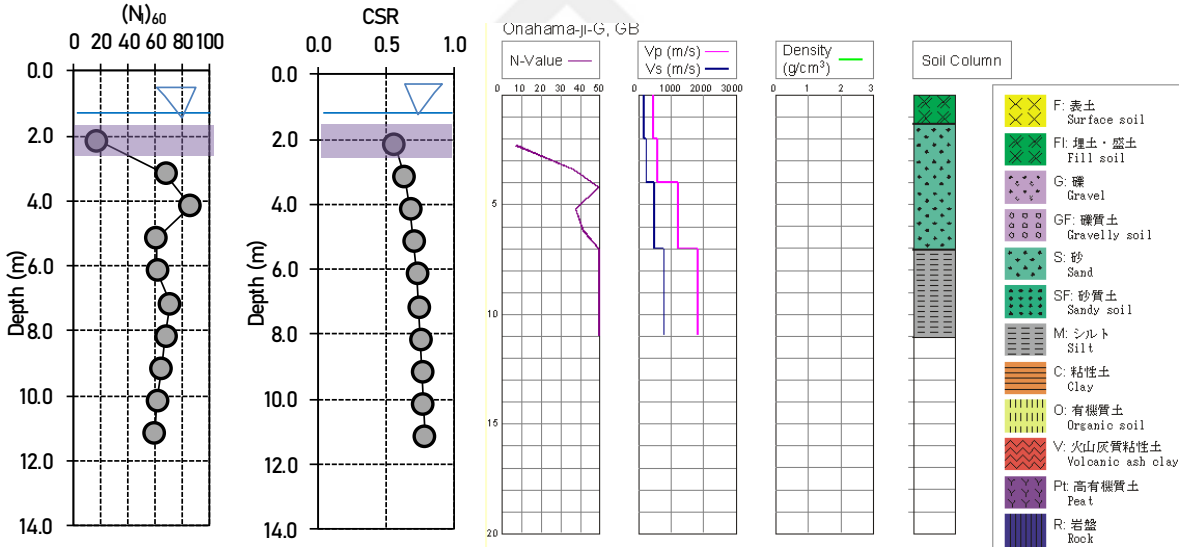
N_{H1}	12.8
N_{H2}	14.9
N_{gm}	13.8
PGA_{H1}	0.765
PGA_{H2}	0.624
PGA	0.691
M_w	9
$M_{w,cycle}$	5.4



Untill Liquefaction

$N_{H1,L}$	41.0
$N_{H2,L}$	40.9
$N_{gm,L}$	40.9
PGA_{H1}	0.198
PGA_{H2}	0.199
PGA_L	0.199
$M_{w,eq}$	15.9
t_L	79.0





	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
Sand	***2.2***	***7.1***	***0.560***	***8***	***1.73***	***0.89***	***16.8***
Sand	3.2	10.3	0.632	36	1.51	0.91	67.4
Sand	4.15	13.6	0.676	50	1.35	0.92	85.6
Sand	5.2	16.9	0.706	38	1.24	0.94	60.4
Sand	6.15	20.2	0.727	41	1.15	0.95	61.2
Silt	7.2	23.5	0.743	50	1.08	0.96	70.5
Silt	8.15	26.7	0.756	50	1.02	0.97	67.1
Silt	9.2	30.0	0.766	50	0.96	0.97	64.1
Silt	10.15	33.3	0.774	50	0.92	0.98	61.5
Silt	11.2	36.6	0.781	50	0.88	0.98	59.1
						Mean:	16.8
						St. Dev.	2.0
							assigned

Depth (m)	FC
3.15	***5.5***
4.15	10.6
5.15	7.5
6.15	30.4
7.15	15.3
	5.50
	8.60

Case number:	391
Earthquake:	2011 Tohoku Earthquake
Magnitude:	9
Location:	Chiba-G, GB (Chuoko, Chiba (KNET), Kashima, Ibaraki (Cox et al 2013))
References:	Cox et al. (2013), PARI
Nature of Failure:	No ground failure
GPS LAT	35.60171
GPS LONG	140.10272
Liq. layer consist of:	Sand
Geological Unit:	Fill
Site Response Anlaysis:	No
Comments:	The site is a KNET strong ground motion station. The two horizontal component are recorded as 0.112 g and 0.127 g, geometric mean of which is 0.119 g is used in the analysis. 100 m away from the site there is another SPT. At this location same fill, sand and silt-clay layers exist hence FC is assigned from there. This information is retrieved from NGL Webinar Series 07 presentation by Dongyoup Kwak. Vs measurements are available at the site. The site is located on man-made fill.





Gravel Content (%):	NAV
CPT available:	Nearby not on the site
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	7.5 - 10.5
d_{crt} (m)	-	-	-	-	9.0
GWT (m)	-	-	-	-	3.5 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	17.0 ± 0.5
σ_v (kPa)	-	-	-	-	155.5 ± 9.0
σ_v' (kPa)	-	-	-	-	101.5 ± 4.8
a_{max} (g)	-	-	-	-	0.119 ± 0.006
r_d	-	-	-	-	0.82 ± 0.115
CSR	-	-	-	-	0.097 ± 0.015
M_w	-	-	-	-	9.10
D_{50}	-	-	-	-	NAV
% Fines	-	-	-	-	13.7 ± 3.8
% PI	-	-	-	-	0
N	-	-	-	-	6.7 ± 2.7
C_R	-	-	-	-	0.97
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.00
$(N_1)_{60}$	-	-	-	-	8.9 ± 3.6
$V_{s,30m}$ (m/s)	-	-	-	-	185.0
$V_{s,12m}$ (m/s)	-	-	-	-	167.8

EVENT PARAMETERS

2011 Tohoku Earthquake

Magnitude: 9.10 USGS Depth: 29 km

Fault Type: shallow thrust Z_{tor} (km): - R_{rup} (km): -

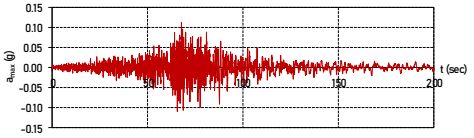
Dip: 9--81 Width (km): 150 R_{jb} (km): 101.0

ACCELERATION TIME HISTORY

Full Record https://www.strongmotioncenter.org/

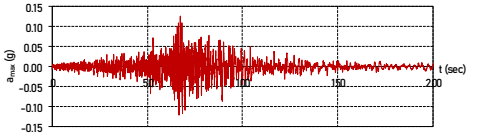
https://www.kyoshin.bosai.go.jp

N_{H1}	38.9
N_{H2}	29.7
N_{gm}	34.0
PGA_{H1}	0.112
PGA_{H2}	0.127
PGA	0.119
M_w	9.1
$M_{w,cycle}$	8.4

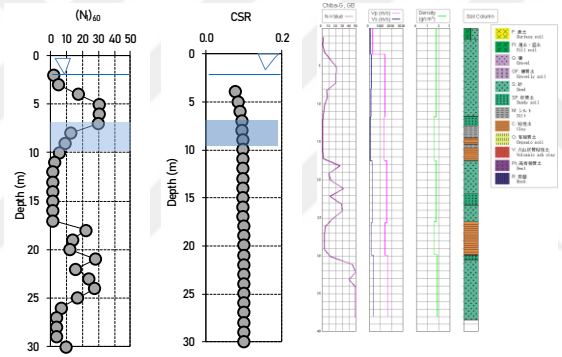


Untill Liquefaction

$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-



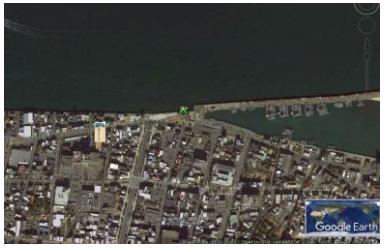
Epicentral distance: 370.4 Km



	Depth (m)	Depth (ft)	rd	CSR	N	C_N	C_R	$(N1)_{60}$	Density (g/cm^3)
Fill soil, Sand	1.0	3.3	0.99	NA	3	2.00	0.86	7.0	1.80
Sand	2.0	6.6	0.98	NA	1	1.69	0.88	2.0	1.80
Sand	3.0	9.8	0.97	NA	3	1.38	0.90	5.1	1.80
Sand	***4.0***	***13.1***	***0.95***	***0.079***	***11***	***1.24***	***0.92***	***17.3***	***1.80***
Sand	***5.0***	***16.4***	***0.93***	***0.086***	***20***	***1.18***	***0.94***	***30.3***	***1.80***
Sand	***6.0***	***19.7***	***0.91***	***0.091***	***21***	***1.13***	***0.95***	***30.7***	***1.80***
Sand	***7.0***	***23.0***	***0.88***	***0.095***	***21***	***1.08***	***0.96***	***29.7***	***1.80***
Sand	***8.0***	***26.2***	***0.85***	***0.096***	***9***	***1.04***	***0.97***	***12.3***	***1.80***
Sand	***9.0***	***29.5***	***0.82***	***0.097***	***7***	***1.00***	***0.97***	***9.3***	***1.80***
Sand	***10.0***	***32.8***	***0.79***	***0.097***	***4***	***0.97***	***0.98***	***5.2***	***1.80***
Sand	11.0	36.1	0.77	0.097	2	0.94	0.98	2.5	1.80
Sandy soil	*12.0*	*39.4*	*0.75*	*0.097*	***1***	*0.91*	*0.99*	*1.2*	*1.60*
Sandy soil	*13.0*	*42.7*	*0.73*	*0.097*	***1***	*0.88*	*0.99*	*1.2*	*1.60*
Silt	*14.0*	*45.9*	*0.72*	*0.097*	***1***	*0.86*	*0.99*	*1.2*	*1.60*
Clay	*15.0*	*49.2*	*0.71*	*0.098*	***1***	*0.84*	*0.99*	*1.1*	*1.60*
Silt	*16.0*	*52.5*	*0.70*	*0.098*	***1***	*0.82*	*0.99*	*1.1*	*1.60*
Clay	*17.0*	*55.8*	*0.69*	*0.099*	***1***	*0.80*	*0.99*	*1.1*	*1.60*
Sand	18.0	59.1	0.69	0.099	21	0.78	1.00	22.3	1.80
Sand	19.0	62.3	0.69	0.100	13	0.77	1.00	13.6	1.80
Sand	20.0	65.6	0.69	0.101	12	0.75	1.00	12.3	1.80
Sand	21.0	68.9	0.68	0.101	28	0.74	1.00	28.1	1.80
Sand	22.0	72.2	0.68	0.101	16	0.72	1.00	15.8	1.80
Sandy soil	23.0	75.5	0.67	0.101	25	0.71	1.00	24.2	1.80
Sand	24.0	78.7	0.67	0.101	29	0.70	1.00	27.6	1.80
Sand	25.0	82.0	0.66	0.101	18	0.69	1.00	16.8	1.80
Clay	26.0	85.3	0.66	0.101	7	0.67	1.00	6.4	1.60
Clay	27.0	88.6	0.65	0.101	4	0.66	1.00	3.6	1.60
Clay	28.0	91.9	0.65	0.101	4	0.65	1.00	3.6	1.60
Clay	29.0	95.1	0.64	0.101	4	0.64	1.00	3.5	1.60
Clay	30.0	98.4	0.64	0.100	11	0.63	1.00	9.5	1.90
Sand	31.0	101.7	0.63	0.100	38	0.63	1.00	32.5	1.90
Sand	32.0	105.0	0.63	0.100	48	0.62	1.00	40.5	1.90
Sand	33.0	108.3	0.63	0.100	42	0.61	1.00	34.9	1.90
Sand	34.0	111.5	0.62	0.099	47	0.60	1.00	38.6	1.90
Sand	35.0	114.8	0.62	0.099	50	0.59	1.00	40.6	1.90
Sand	36.0	118.1	0.61	0.098	50	0.59	1.00	40.1	1.90
Sand	37.0	121.4	0.61	0.098	50	0.58	1.00	39.6	1.90
Sand	38.0	124.7	0.60	0.098	50	0.57	1.00	39.1	1.90
							Mean:	8.9	
							St. Dev.	3.6	

	Depth (m)	FC (%)	PI	
	1.3	17.2	NP	SM
	2.3	39.1	21.8	SC
	3.3	37.5	22.7	SC
	4.3	6.3	NP	SP-SM
	5.3	10.0	NP	SP-SM
sublayer	6.3	7.0	NP	SP-SM
within sand	7.3	7.1	NP	SP-SM
layer	***8.3***	***10.4***	***NP***	***SP-SM***
transition	***9.3***	***17.8***	***NP***	***SM***
	10.3	***12.8***	***NP***	***SM***
	11.3	48.3	40.5	SC
clayey soils	12.3	78.0	59.9	CH
	Mean:	13.7		
	St. Dev.	3.8		

Case number:	393
Earthquake:	2011 Tohoku Earthquake
Magnitude:	9.1
Location:	CHB005 (Choshi-C, Chiba)
References:	Cox et al. (2013), KNET, KIKNET
Nature of Failure:	No ground failure
GPS LAT	35.735802
GPS LONG	140.830002
	"The station is located in the west where CPT is performed." Personal communication with Prof. Rob Kayen
Liq. layer consist of:	Sand and Sandy soils (SM)
Geological Unit:	Fill
Site Response Anlaysis:	No
Comments:	The site is a KNET strong ground motion station. The two horizontal component are recorded as 0.178 g and 0.179 g, geometric mean of which is 0.179 g is used in the analysis. CHB005 station is listed in Cox et al (2013). The acceleration is reported as 0.179 g by Cox et al (2013). The site is located on sand dune rigth next to a fill. SPT data were provided by Kiknet. No ground water table information is available. Borehole at CHBH14 shows 1.33 m GWT which is also adopted herein. No FC information regarding to sandy soil is available. FC is assumed as 25 % for sandy soil by Cox et al. (2013). In the NGL Webinar Series 07 presentation by Dongyoup Kwak, another SPT data is presented which is 20 m away from the site and FC information is retrieved from this borehole as 12.9%. Personal coomunication with Prof. Dr. Robert Kayen "SPT was located west side of the street where liqufaction was not observed but Vs measurement was performed on the east side where liquefaction was observed in the newer fill (post 1969)." Vs and density measurement are available.





Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.1 - 2.7
d_{crt} (m)	-	-	-	-	2.4
GWT (m)	-	-	-	-	1.3 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	16.2 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	17.6 ± 0.5
σ_v (kPa)	-	-	-	-	40.0 ± 1.8
σ_v' (kPa)	-	-	-	-	29.7 ± 1.3
a_{max} (g)	-	-	-	-	0.179 ± 0.009
r_d	-	-	-	-	1.00 ± 0.037
CSR	-	-	-	-	0.156 ± 0.011
M_w	-	-	-	-	9.10
D_{50}	-	-	-	-	NAV ± NAV
% Fines	-	-	-	-	12.9 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	6.3 ± 0.9
C_R	-	-	-	-	0.89
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.85
$(N_1)_{60}$	-	-	-	-	14.1 ± 2.0
$V_{s,30m}$ (m/s)	-	-	-	-	NAV ± NAV
$V_{s,12m}$ (m/s)	-	-	-	-	369.9

EVENT PARAMETERS

2011 Tohoku Earthquake

Magnitude: 9.10 USGS Depth :29 km

Fault Type: shallow thrust | Z_{tor} (km): - | R_{rup} (km): -

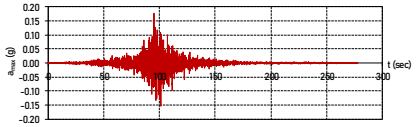
Dip: 9--81 | Width (km): 150 | R_{jb} (km): 30-40

ACCELERATION TIME HISTORY

Full Record https://www.strongmotioncenter.org/

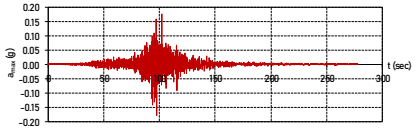
https://www.kyoshin.bosai.go.jp

N_{H1}	15.7
N_{H2}	16.6
N_{gm}	16.2
PGA_{H1}	0.178
PGA_{H2}	0.179
PGA	0.179
M_w	9.1
$M_{w,cycle}$	5.8

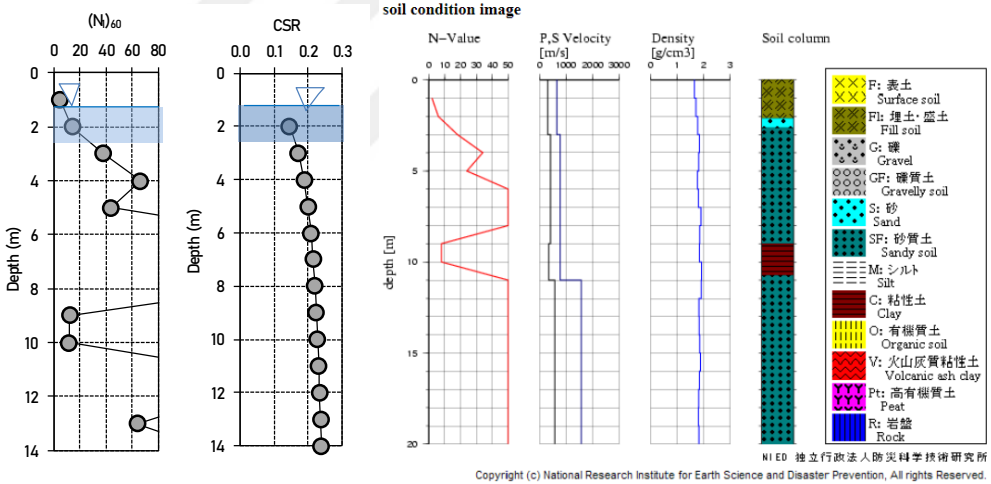


Untill Liquefaction

$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-



Hypocentral Distance: 317.0 km



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	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	Density (g/cm^3)
Fl	1.00	3.28	NA	2	2.00	0.86	4.7	1.65
S	***2.00***	***6.56***	***0.14***	***6***	***1.95***	***0.88***	***14.1***	***1.71***
SF	3.00	9.84	0.17	18	1.71	0.90	38.1	1.77
SF	4.00	13.12	0.19	34	1.55	0.92	66.4	1.85
SF	5.00	16.40	0.20	24	1.42	0.94	43.7	1.81
SF	6.00	19.69	0.21	99	1.32	0.95	170.0	1.76
SF	7.00	22.97	0.21	99	1.24	0.96	161.2	1.80
SF	8.00	26.25	0.22	99	1.18	0.97	153.7	1.90
SF	9.00	29.53	0.22	8	1.12	0.97	11.9	1.86
C	10.00	32.81	0.23	8	1.07	0.98	11.4	1.84
SF	11.00	36.09	0.23	99	1.02	0.98	136.1	1.92
SF	12.00	39.37	0.23	99	0.99	0.99	131.4	1.91
SF	13.00	42.65	0.24	50	0.95	0.99	64.2	1.82
SF	14.00	45.93	0.24	99	0.92	0.99	123.2	1.83
SF	15.00	49.21	0.24	99	0.89	0.99	119.6	1.86
SF	16.00	52.49	0.24	99	0.87	0.99	116.3	1.88
SF	17.00	55.77	0.25	99	0.84	0.99	113.2	1.85
SF	18.00	59.06	0.25	99	0.82	1.00	110.4	1.81
SF	19.00	62.34	0.25	99	0.80	1.00	107.8	1.80
SF	20.00	65.62	0.26	99	0.78	1.00	105.3	1.82
						Mean:	14.1	
						St. Dev.	2.0	assigned

	Depth (m)	FC	PI	
clayey??	1.8	24.5	3.8	SM
	2.3	***12.9***	***NP***	***SM***
	3.3	3.5	NP	SP
	4.3	4.8	NP	SP
	5.3	15.6	NP	SM
	6.3	-	-	
	7.3	55.4	20.8	CL
	8.3	74.8	23.1	MH
	9.3	57.0	21.9	CL
	10.3	48.6	NP	SM
	11.3	35?	NP	SM
	12.3	52.4	NP	SM
	Mean:	12.9		
	St. Dev.	8.6	assigned	

Case number: 401
Earthquake: 2011 Tohoku-oki (or Great East Japan) Earthquake

Magnitude: 9.1
Location: Irifune -3
References: Ishihara et al. (2011), Cox et al. (2013), Tokimatsu et al. (2012)
Nature of Failure: clear manifestation of liquefaction in the reclaimed area
GPS LAT: 35.643219
GPS LONG: 139.914583
approximate locations
Liq. layer consist of: Sand with fines
Geological Unit: Fill
Site Response Anlaysis: No
Comments: As described by Ishihara et al. (2011) "There was a sharp contrast between the areas of liquefaction or no liquefaction which are divided by the old shore-line before the reclamation started each in 1960's.... After filling hydraulically, dry sand was transported onland and spread by bulldozers to a thickness of 1~2m. No means was taken further to compact the soils." The peak gound acceleration of 0.20 g is selected based on the available nearby recording stations (IRF, TKK, JAL)





Free field



Figure 15 Places of the serious damage to private houses in Urayasu

Gravel Content (%): NAV
CPT available: No
Vs available: No

Summary of Input Data

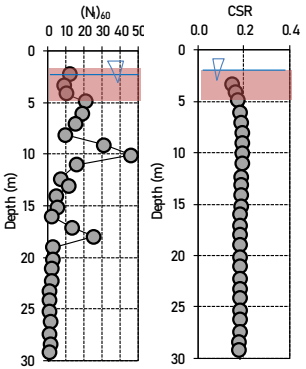
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.4 - 5.0
d_{crt} (m)	-	-	-	-	3.7
GWT (m)	-	-	-	-	2.4 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	19.6 ± 0.5
σ_v (kPa)	-	-	-	-	66.8 ± 8.8
σ_v' (kPa)	-	-	-	-	53.8 ± 4.6
a_{max} (g)	-	-	-	-	0.200 ± 0.040
r_d	-	-	-	-	0.99 ± 0.054
CSR	-	-	-	-	0.160 ± 0.034
M_w	-	-	-	-	9.10
D_{50}	-	-	-	-	NAV
% Fines	-	-	-	-	10.0-50.0 ± 14.0
% PI	-	-	-	-	0
N	-	-	-	-	6.0 ± 0.9
C_R	-	-	-	-	0.92
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.37
$(N_1)_{60}$	-	-	-	-	10.3 ± 1.5
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	207.3

EVENT PARAMETERS

2011 Tohoku-oki (or Great East Japan) Earthquake
Magnitude: 9.10 USGS Depth :29 km
Fault Type: shallow thrust Z_{tor} (km): - R_{rup} (km): -
Dip: 9--81 Width (km): 150-200 R_{jb} (km): 110-120

	Depth (m)	Depth (ft)	rd	CSR	N	C_N	C_R	$(N1)_{60}$	FC	
fills, fine sand	***2.2***	***7.2***	***0.995***	***NA***	***6***	***1.63***	***0.89***	***11.9***	10--50	
alluvial sand	***3.3***	***10.83***	***0.990***	***0.153***	***5***	***1.42***	***0.91***	***8.9***	10--50	reclaimed layer
alluvial sand	***4.1***	***13.5***	***0.986***	***0.166***	***6***	***1.32***	***0.92***	***10.0***	10--50	
alluvial sand	4.9	16.08	0.981	0.176	13	1.24	0.94	20.6		
alluvial sand	6.1	20.0	0.970	0.186	13	1.14	0.95	19.3		
fine sand	7.1	23.29	0.959	0.191	11	1.08	0.96	15.5		
fine sand	8.1	26.6	0.945	0.194	7	1.02	0.97	9.4		
fine sand	9.1	29.86	0.929	0.196	24	0.97	0.97	31.1		
fine sand	10.1	33.1	0.912	0.196	37	0.93	0.98	46.1		
silty fine sand	***11***	***36.1***	***0.895***	***0.195***	***13***	***0.90***	***0.98***	***15.7***		
silty with sand	***12.4***	***40.7***	***0.869***	***0.193***	***6***	***0.85***	***0.99***	***6.9***		
silty with sand	***13.1***	***43.0***	***0.856***	***0.192***	***10***	***0.83***	***0.99***	***11.2***		
silt	***14.1***	***46.3***	***0.841***	***0.190***	***4***	***0.81***	***0.99***	***4.4***		
silt	***15.2***	***49.9***	***0.826***	***0.188***	***5***	***0.78***	***0.99***	***5.3***		
silt	***16***	***52.5***	***0.818***	***0.188***	***2***	***0.76***	***0.99***	***2.1***		
sandy silt	17.1	56.1	0.808	0.187	13	0.74	0.99	13.1		
sandy silt	18	59.1	0.802	0.186	26	0.72	1.00	25.5		
silt	19	62.3	0.797	0.186	3	0.70	1.00	2.9		soft clayey silt
silt	20.2	66.3	0.792	0.186	3	0.68	1.00	2.8		soft clayey silt
silt	21.1	69.2	0.788	0.186	2	0.67	1.00	1.8		soft clayey silt
silt	22.3	73.2	0.782	0.186	2	0.65	1.00	1.8		soft clayey silt
silt	23.3	76.4	0.778	0.185	1	0.64	1.00	0.9		soft clayey silt
silt	24.1	79.1	0.774	0.185	1	0.63	1.00	0.9		soft clayey silt
silt	25.3	83.0	0.769	0.184	1	0.62	1.00	0.8		soft clayey silt
silt	26.2	86.0	0.764	0.184	2	0.61	1.00	1.7		soft clayey silt
silt	27.4	89.9	0.759	0.183	1	0.59	1.00	0.8		soft clayey silt
silt	28.4	93.2	0.754	0.182	2	0.58	1.00	1.6		soft clayey silt
silt	29.2	95.8	0.751	0.182	1	0.58	1.00	0.8		soft clayey silt
silt	30.5	100.1	0.745	0.181	1	0.56	1.00	0.8		soft clayey silt
silt	31.4	103.0	0.741	0.180	1	0.56	1.00	0.8		soft clayey silt
silt	32.5	106.6	0.736	0.179	1	0.55	1.00	0.7		soft clayey silt
silt	33.5	109.9	0.731	0.179	1	0.54	1.00	0.7		soft clayey silt
silt	34.3	112.5	0.727	0.178	1	0.53	1.00	0.7		soft clayey silt
silt	35.5	116.5	0.722	0.177	1	0.53	1.00	0.7		soft clayey silt
silt	36.3	119.1	0.718	0.176	1	0.52	1.00	0.7		soft clayey silt
silt	37.4	122.7	0.713	0.175	3	0.51	1.00	2.1		soft clayey silt
silt	38.3	125.7	0.709	0.175	4	0.51	1.00	2.8		soft clayey silt
silt	39.4	129.3	0.704	0.174	5	0.50	1.00	3.4		soft clayey silt
silt	40.5	132.9	0.699	0.173	7	0.49	1.00	4.7		soft clayey silt
silt	41.3	135.5	0.695	0.172	5	0.49	1.00	3.3		soft clayey silt
silt	42.4	139.1	0.690	0.171	6	0.48	1.00	4.0		soft clayey silt
silt	43.4	142.4	0.685	0.170	7	0.48	1.00	4.6		soft clayey silt
silt	44.6	146.3	0.680	0.169	6	0.47	1.00	3.9		soft clayey silt
silt	45.3	148.6	0.677	0.168	10	0.47	1.00	6.4		soft clayey silt
sandy silt	46.2	151.6	0.673	0.167	39	0.46	1.00	24.7		
fine sand (alluvium)	47.3	155.2	0.668	0.166	41	0.46	1.00	25.7		
fine sand (alluvium)	48.1	157.8	0.664	0.165	50	0.45	1.00	31.1		
fine sand (alluvium)	49.1	161.1	0.659	0.164	50	0.45	1.00	30.8		
fine sand (alluvium)	49.9	163.7	0.656	0.163	50	0.45	1.00	30.5		
fine sand (alluvium)	50.7	166.3	0.652	0.163	50	0.44	1.00	30.3		
fine sand (alluvium)	51.6	169.3	0.648	0.162	50	0.44	1.00	30.0		
fine sand (alluvium)	52.4	171.9	0.644	0.161	50	0.44	1.00	29.8		
							Mean:	10.3		
							St. Dev.	1.5		

Tokimatsu et al 2012 "Underlying below are deep silt and cohesive soil layers, with N-values of mostly 0 to 3."



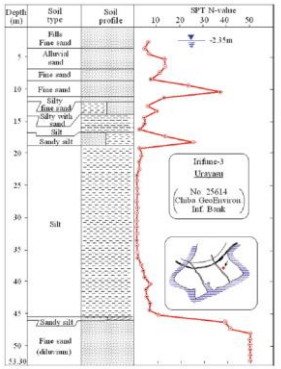


Fig. 4.19 Soil profile at Irifune 3-chome

Case number: 405
Earthquake: 2011 Tohoku Earthquake

Magnitude: 9.1
Location: Nekozane 2
References: Ishihara et al. (2011)
Nature of Failure: no visible sign of liquefaction was observed at the time of the 2011 earthquak
GPS LAT 35.660364 approximate location
GPS LONG 139.896417 approximate location
Liq. layer consist of: Fine sand
Geological Unit: Fill
Site Response Anlaysis: No
Comments: The location of the site is roughly estimated by the map provided by Ishihara et al. (2011). The site is located in the old city of Urayasu where no liquefaction was observed. The site is located in a neighbourhood where the buildings are 1-2 storey hence the site is accepted in the database. The site is approximately 500 m away from the strong ground motion station HOS where no liquefaction was occured (Cox et al 2013). Hence the PGA which is reported as 0.180 g is assigned to the site. FC and PI information was not available however a general information regarding with the soil descriptions in Japan is used to assign FC as 30 %.

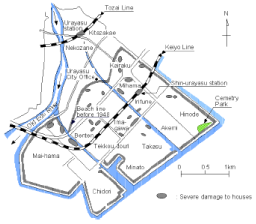


Figure 15 Places of the serious damage to private houses in Urayasu



Gravel Content (%): NAV
CPT available: No
Vs available: No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.2 - 6.4
d_{crt} (m)	-	-	-	-	4.3
GWT (m)	-	-	-	-	2.2 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	77.6 ± 13.2
σ_v' (kPa)	-	-	-	-	57.1 ± 6.5
a_{max} (g)	-	-	-	-	0.180 ± 0.036
r_d	-	-	-	-	0.91 ± 0.061
CSR	-	-	-	-	0.145 ± 0.032
M_w	-	-	-	-	9.10
D_{50}	-	-	-	-	NAV
% Fines	-	-	-	-	30.0 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	6.6 ± 2.2
C_R	-	-	-	-	0.93
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.33
$(N_1)_{60}$	-	-	-	-	11.2 ± 3.8
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	152.4

EVENT PARAMETERS

2011 Tohoku Earthquake
Magnitude: 9.10 USGS Depth :29 km
Fault Type: shallow thrust Z_{tor} (km): - R_{rup} (km): -
Dip: 9---81 Width (km): 150 R_{jb} (km): 110-120

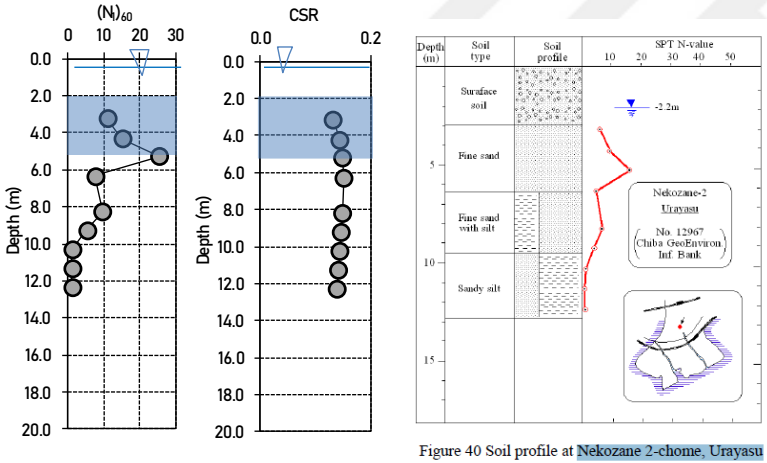


Figure 40 Soil profile at Nekozane 2-chome, Urayasu

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$			FC
Fine sand	***3.2***	***10.6***	***0.134***	***6***	***1.46***	***0.91***	***10.9***		3-6.5 m is nonplastic according to CPT. There is elevation difference however SPT log and CPT is similar.	***30.0***
Fine sand	***4.3***	***14.11***	***0.145***	***9***	***1.33***	***0.93***	***15.2***			***30.0***
Fine sand	***5.3***	***17.3***	***0.150***	***16***	***1.24***	***0.94***	***25.5***	outlier		***30.0***
Fine sand	***6.3***	***20.73***	***0.152***	***5***	***1.16***	***0.95***	***7.5***			***30.0***
fine sand with silt	8.3	27.1	0.150	7	1.04	0.97	9.7		7-10 m is plastic according to CPT. There is elevation difference however SPT log and CPT is similar.	>30
fine sand with silt	9.2	30.31	0.147	4	1.00	0.97	5.3			>30
Sandy silt	10.3	33.8	0.144	1	0.95	0.98	1.3			65.0
Sandy silt	11.3	37.07	0.142	1	0.92	0.98	1.2		10-13 m is plastic according to CPT. There is elevation difference however SPT log and CPT is similar.	65.0
Sandy silt	12.4	40.6	0.140	1	0.88	0.99	1.2			65.0
						Mean:	11.2			30.0
						St. Dev.	3.8			8.6 assigned

Case number:	407
Earthquake:	2011 Tohoku Earthquake
Magnitude:	9.1
Location:	Isobe-8, Mihama-ku, Chiba
References:	Maugeri and Soccodato (2014), Ishihara et al. (2012)
Nature of Failure:	Settlement occured
GPS LAT	35.631156 approximate location
GPS LONG	140.04995 approximate location
Liq. layer consist of:	fill silty fine sand, fill fine sand
Geological Unit:	Fill
Site Response Anlaysis:	No
Comments:	Maugeri and Soccodato (2014) described the damage as follows "...serious damage due to liquefaction occurred to private houses..." The soil profile consist of silty sand or sandy silt deposits. At this site, observed settlement was as 60–80 cm. CHB024 SMS is located 2.5 km away from the site. CHB024 and ISobe 8-2 are both liquefied sites. CHB024 measured PGA of 0.222 g (geometric mean of the two components 0.239 g and 0.206 g) is used in the analysis. Fines content data is not available hence it is assigned based on a general information regarding the soil descriptions in Japan as 46.7%.



Figure 29 Makuhari-Isobe districts, Mihama-ku, Chiba





Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	1.2 - 11.0
d_{crt} (m)	-	-	-	-	6.1
GWT (m)	-	-	-	-	1.2 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	113.4 ± 31.0
σ_v' (kPa)	-	-	-	-	65.2 ± 15.0
a_{max} (g)	-	-	-	-	0.222 ± 0.044
r_d	-	-	-	-	0.76 ± 0.083
CSR	-	-	-	-	0.190 ± 0.044
M_w	-	-	-	-	9.10
D_{50}	-	-	-	-	NAV
% Fines	-	-	-	-	46.7 ± 18.5
% PI	-	-	-	-	NAV
N	-	-	-	-	3.1 ± 1.7
C_R	-	-	-	-	0.95
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.25
C_N	-	-	-	-	1.25
$(N_1)_{60}$	-	-	-	-	4.6 ± 2.6
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	125.0

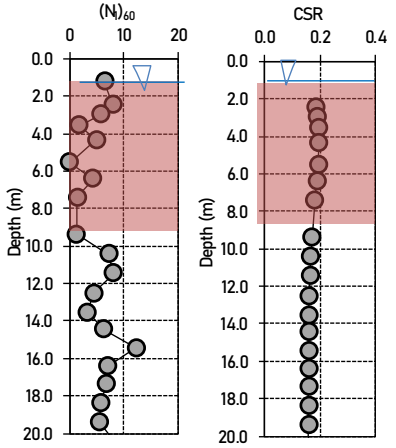
EVENT PARAMETERS

2011 Tohoku Earthquake

Magnitude: 9.10 USGS Depth :29 km

Fault Type: shallow thrust Z_{tor} (km): - R_{rup} (km): -

Dip: 9--81 Width (km): 150 R_{jb} (km): 100-110



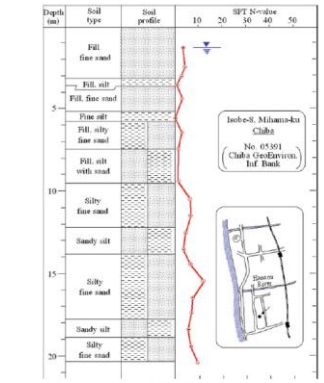


Fig. 4.50 Soil profile at Isobe-8, Mihama-ku, Chiba

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$		FC assigned
fill fine sand	***1.2***	***4.0***	***0.141***	***3***	***2.00***	***0.86***	***6***		***30***
fill fine sand	***2.5***	***8.0***	***0.183***	***4***	***1.78***	***0.89***	***8***		***30***
fill fine sand	***3.0***	***9.8***	***0.191***	***3***	***1.66***	***0.90***	***6***		***30***
fill silt	***3.6***	***11.7***	***0.195***	***1***	***1.55***	***0.91***	***2***		***75***
fill fine sand	***4.4***	***14.3***	***0.196***	***3***	***1.43***	***0.93***	***5***		***30***
fine silt	5.5	18.2	0.193	0	1.30	0.94	0	outlier	
fill silty fine sand	***6.4***	***21.0***	***0.188***	***3***	***1.22***	***0.95***	***4***		***50***
fill silty fine sand	***7.4***	***24.3***	***0.182***	***1***	***1.15***	***0.96***	***1***		***50***
fill silt with sand	***9.4***	***30.8***	***0.171***	***1***	***1.03***	***0.97***	***1***		***75***
silty fine sand	***10.5***	***34.3***	***0.167***	***6***	***0.99***	***0.98***	***7***		***50***
silty fine sand	11.5	37.6	0.164	7	0.94	0.98	8		
sandy silt	12.5	41.0	0.162	4	0.91	0.99	4		
sandy silt	13.5	44.4	0.160	3	0.87	0.99	3		
silty fine sand	14.5	47.4	0.159	6	0.85	0.99	6		
silty fine sand	15.4	50.6	0.159	12	0.82	0.99	12		
silty fine sand	16.4	53.9	0.158	7	0.80	0.99	7		
silty fine sand	17.4	57.0	0.158	7	0.78	1.00	7		
sandy silt	18.4	60.3	0.158	6	0.76	1.00	6		
silty fine sand	19.4	63.7	0.158	6	0.74	1.00	6		
silty fine sand	20.4	67.0	0.159	9	0.72	1.00	8		
						Mean:	4.6		46.7
						St. Dev.	2.6		18.5

Case number:	409
Earthquake:	2011 Tohoku Earthquake
Magnitude:	9.1
Location:	Takasu 4-2
References:	Maugeri and Soccodato (2014), Cox et al. (2013), Tokimatsu et al. (2012)
Nature of Failure:	signs of liquefaction such as sand boiling and settlements
GPS LAT	35.636964 approximate location
GPS LONG	139.914561 approximate location
Liq. layer consist of:	Sand and silt
Geological Unit:	Fill
Site Response Anlaysis:	No
Comments:	Maugeri and Soccodato (2014) described the occurence of liquefaction at the site as follows "...signs of liquefaction such as sand boiling and settlements were observed at the time of the earthquake...." The location of the site is approximately determined from the map that is provided by Maugeri and Soccodato (2014). The thickness of the fill layer was not reported, however the thickest fill in Urayasu has 10 m depth as reported by Tokimatsu et al. (2012). Hence the upper 5 m in the soil profile is claimed as a sublayer with a relatively lower SPTN values within the 10 m thickness. Hence this sub-layer is selected as the liquefied layer. The site is 100-200 m away from the strong ground motion station TKK where liquefaction was reported by Cox et al (2013) and the PGA level is reported as 0.213 g. This PGA is assigned to site Takasu 4-2. Ishihara et al (2011) estimated fines content of the fill layer as 10-50 %. FC values recommended for Japan in general suggests FC=55% for the sand and silt layers which is selected as the critical layer.



Gravel Content (%):	NAV
CPT available:	No
Vs available:	No

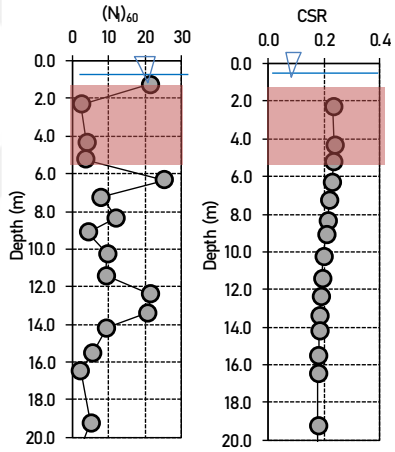
Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	1.0 - 5.7
d_{crt} (m)	-	-	-	-	3.4
GWT (m)	-	-	-	-	0.5 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	62.6 ± 14.9
σ_v' (kPa)	-	-	-	-	34.2 ± 7.3
a_{max} (g)	-	-	-	-	0.213 ± 0.043
r_d	-	-	-	-	0.94 ± 0.050
CSR	-	-	-	-	0.238 ± 0.050
M_w	-	-	-	-	9.10
D_{50}	-	-	-	-	NAV
% Fines	-	-	-	-	55.0 ± 10.0
% PI	-	-	-	-	NAV
N	-	-	-	-	1.6 ± 0.4
C_R	-	-	-	-	0.91
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.72
$(N_1)_{60}$	-	-	-	-	3.3 ± 0.8
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	153.0

EVENT PARAMETERS

2011 Tohoku Earthquake

Magnitude: 9.10	USGS Depth :29 km	
Fault Type: shallow thrust	Z_{tor} (km): -	R_{rup} (km): -
Dip: 9--81	Width (km): 150	R_{jb} (km): 110-120



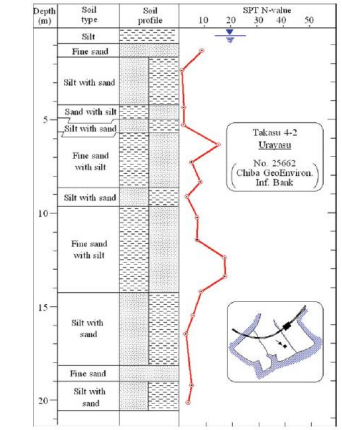
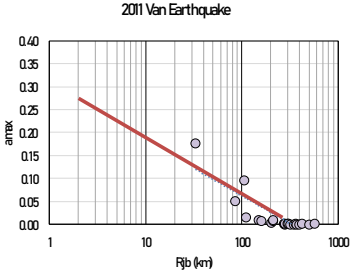


Fig. 4.46 Soil profile at Takasu 4-2, Urayasu

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC values recommended for Japan in general FC	
fine sand	1.3	4.1	0.2	9	2.00	0.86	21.2	30.0	
silt w sand	**2.3**	**7.6**	**0.232**	**1**	**2.00**	**0.89**	**2.4**	**<75**	reclaimed fill?
sand w silt	**4.3**	**14.2**	**0.238**	**2**	**1.54**	**0.93**	**3.9**	**>30**	reclaimed fill?
silt w sand	**5.3**	**17.2**	**0.234**	**2**	**1.41**	**0.94**	**3.6**	**<75**	reclaimed fill?
sine sand w silt	6.3	20.7	0.228	15	1.29	0.95	25.2		
sine sand w silt	7.3	23.8	0.221	5	1.21	0.96	7.9		
sine sand w silt	8.3	27.3	0.212	8	1.13	0.97	12.0		
silt w sand	9.1	29.9	0.206	3	1.08	0.97	4.3		
fine sand w silt	10.2	33.6	0.199	7	1.03	0.98	9.6		
fine sand w silt	11.4	37.5	0.192	7	0.97	0.98	9.1		
fine sand w silt	12.4	40.6	0.188	17	0.94	0.99	21.4		
fine sand w silt	13.4	43.9	0.185	17	0.90	0.99	20.7		Interpreted from Irifune-3
silt w sand	14.2	46.6	0.183	8	0.88	0.99	9.5		**soft clayey silt**
silt w sand	15.5	50.9	0.180	5	0.84	0.99	5.7		**soft clayey silt**
silt w sand	16.5	54.0	0.179	2	0.81	0.99	2.2		**soft clayey silt**
silt w sand	19.2	63.1	0.177	5	0.76	1.00	5.1		**soft clayey silt**
silt w sand	20.2	66.2	0.177	3	0.74	1.00	3.0		**soft clayey silt**
						Mean:	3.3		
						St. Dev.	0.8		

Case number:	342
Earthquake:	2011 Van Earthquake
Magnitude:	7.1 (USGS) 7.2 (KOERI)
Location:	Karasu River LHB-1
References:	Akin et al. (2013), Cetin et al. (2011), Aydan et al. (2014)
Nature of Failure:	Sand boil were observed
GPS LAT	38.598928 approximate location
GPS LONG	43.243953
Liq. layer consist of:	Sand (SP)
Geological Unit:	loose alluvial deposits (Late Pleistocene lacustrine)
Site Response Anlaysis:	No
Comments:	2011 Van earthquake occured on October 23, 2011. The epicenter of the earthquake is located at 38.71, 43.45 on a thrust fault.The area of Karasu is located on alluvium consists of clay, silt, poorly graded sand and fine gravel. No significant surface rupture was observed. The PGA values recorded at the Muradiye strong ground motion station, which is the closest station to the epicenter (42 km) as 178.5 cm/sn2 and 168.5 cm/sn2. Site response analyses were performed by Akın et al. (2013) using ProSHAKE software.The estimated PGA is 0.235 g based on site response analysis. Locally calibrated ground motion model is constructed and amax=0.235 g is concluded to be reasonable value for the site. A donut hammer is used for the SPT. Literature data for hammer efficiency values of donut hammers suggest ER as 49% which is implemented in this study. Fines content data and Vs measurements were available for the site.





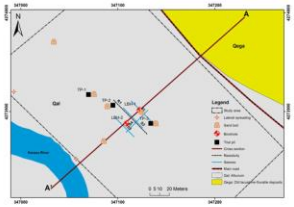


Fig. 10 Distribution of trial pits, boreholes, seismic and resistivity survey locations in the study area

Gravel Content (%):	NAV
CPT available:	No
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.4 - 6.4
d_{crt} (m)	-	-	-	-	4.4
GWT (m)	-	-	-	-	0.4 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	90.1 ± 14.1
σ_v' (kPa)	-	-	-	-	50.8 ± 7.6
a_{max} (g)	-	-	-	-	0.235 ± 0.047
r_d	-	-	-	-	0.90 ± 0.063
CSR	-	-	-	-	0.243 ± 0.052
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	0.100 ± 0.050
% Fines	-	-	-	-	4.2 ± 3.1
% PI	-	-	-	-	0
N	-	-	-	-	19.1 ± 3.0
C_R	-	-	-	-	0.92
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	0.82
C_N	-	-	-	-	1.41
$(N_1)_{60}$	-	-	-	-	20.3 ± 3.2
V_{s30m} (m/s)	-	-	-	-	333.3
V_{s12m} (m/s)	-	-	-	-	159.5

EVENT PARAMETERS

2011 Van Earthquake

Magnitude: 7.10		hanging wall side approximate
Fault Type: thrust fault	Z_{tor} (km): 0	R_{rup} (km): 3.9
Dip: 40-60	Width (km): 20	R_{jb} (km): 3.9

ACCELERATION TIME HISTORY

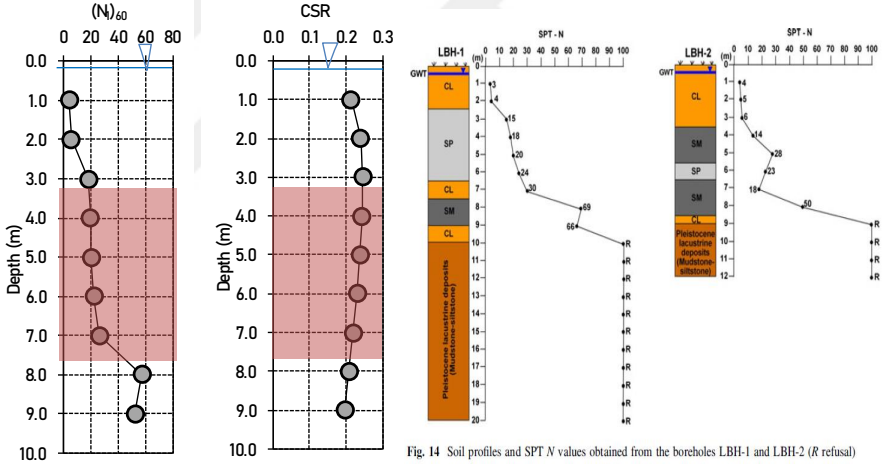
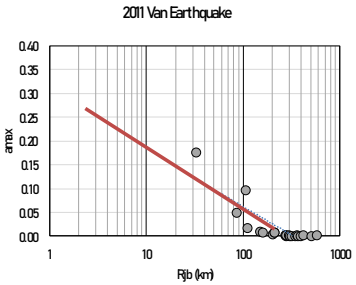


Fig. 14 Soil profiles and SPT *N* values obtained from the boreholes LBH-1 and LBH-2 (*R* refusal)

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	Depth (m)		
CL	1.00	3.28	0.21	3	2.00	0.84	4	55	1	LBH-1	CL
CL	2.00	6.56	0.24	4	2.00	0.87	6	81	2	LBH-1	CL
SP	***3.00***	***9.84***	***0.25***	***15***	***1.69***	***0.89***	***18***	***8***	***3***	***LBH-1***	***SP***
SP	***4.00***	***13.12***	***0.25***	***18***	***1.48***	***0.91***	***20***	***5***	***4***	***LBH-1***	***SP***
SP	***5.00***	***16.40***	***0.24***	***20***	***1.33***	***0.93***	***20***	***2***	***5***	***LBH-1***	***SP***
SP	***6.00***	***19.69***	***0.23***	***24***	***1.22***	***0.94***	***23***	***2***	***6***	***LBH-1***	***SP***
CL	7.00	22.97	0.22	30	1.13	0.95	26	65	7	LBH-1	CL
SM	8.00	26.25	0.21	69	1.06	0.96	58	32	8	LBH-1	SM
CL	9.00	29.53	0.20	66	1.01	0.97	52	100	9	LBH-1	CL
						Mean:	**20.3**	99	10	LBH-1	Mudstone-Sandstone
						St. Dev.	**3.2**	100	11	LBH-1	Mudstone-Sandstone
								92	12	LBH-1	Mudstone-Sandstone
								86	13	LBH-1	Mudstone-Sandstone
								35	16	LBH-1	Mudstone-Sandstone
								44	17	LBH-1	Mudstone-Sandstone
							Mean:	**4.2**			
							St. Dev.	**3.1**			

Case number:	343
Earthquake:	2011 Van Earthquake
Magnitude:	7.1 (USGS)
Location:	Karasu River LHB-2
References:	Akin et al. (2013), Cetin et al. (2011), Aydan et al. (2014)
Nature of Failure:	No surface manifestation was observed
GPS LAT	38.598928 approximate location
GPS LONG	43.243953
Liq. layer consist of:	Sand (SM-SP)
Geological Unit:	loose alluvial deposits (Late Pleistocene lacustrine)
Site Response Anlaysis:	No
Comments:	2011 Van earthquake occured on October 23, 2011. The epicenter of the earthquake is located at 38.71, 43.45 on a thrust fault.The area of Karasu is located on alluvium consists of clay, silt, poorly graded sand and fine gravel. No significant surface rupture was observed. The PGA values recorded at the Muradiye strong ground motion station, which is the closest station to the epicenter (42 km) as 178.5 cm/sn2 and 168.5 cm/sn2. Site response analyses were performed by Akın et al. (2013) using ProSHAKE software.The estimated PGA is 0.235 g based on site response analysis. Locally calibrated ground motion model is constructed and amax=0.235 g is concluded to be reasonable value for the site. A donut hammer is used for the SPT. Literature data for hammer efficiency values of donut hammers suggest ER as 49% which is implemented in this study. Fines content data and Vs measurements were available for the site.





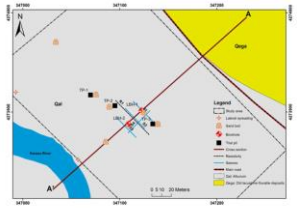


Fig. 10 Distribution of trial pits, boreholes, seismic and resistivity survey locations in the study area

Gravel Content (%):	NAV
CPT available:	No
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crit} range (m)	-	-	-	-	3.7 - 7.5
d_{crt} (m)	-	-	-	-	5.6
GWT (m)	-	-	-	-	0.4 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	114.8 ± 13.3
σ_v' (kPa)	-	-	-	-	63.7 ± 7.3
a_{max} (g)	-	-	-	-	0.235 ± 0.047
r_d	-	-	-	-	0.84 ± 0.077
CSR	-	-	-	-	0.230 ± 0.051
M_w	-	-	-	-	7.10
D_{50}	-	-	-	-	0.100 ± 0.050
% Fines	-	-	-	-	19.9 ± 16.3
% PI	-	-	-	-	0
N	-	-	-	-	21.0 ± 6.2
C_R	-	-	-	-	0.94
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	0.82
C_N	-	-	-	-	1.26
$(N_1)_{60}$	-	-	-	-	20.3 ± 6.0
V_{s30m} (m/s)	-	-	-	-	319.1
V_{s12m} (m/s)	-	-	-	-	155.0

EVENT PARAMETERS

2011 Van Earthquake

Magnitude: 7.10		hanging wall side approximate
Fault Type: thrust fault	Z_{tor} (km): 0	R_{rup} (km): 3.9
Dip: 40-60	Width (km): 20	R_{jb} (km): 3.9

ACCELERATION TIME HISTORY

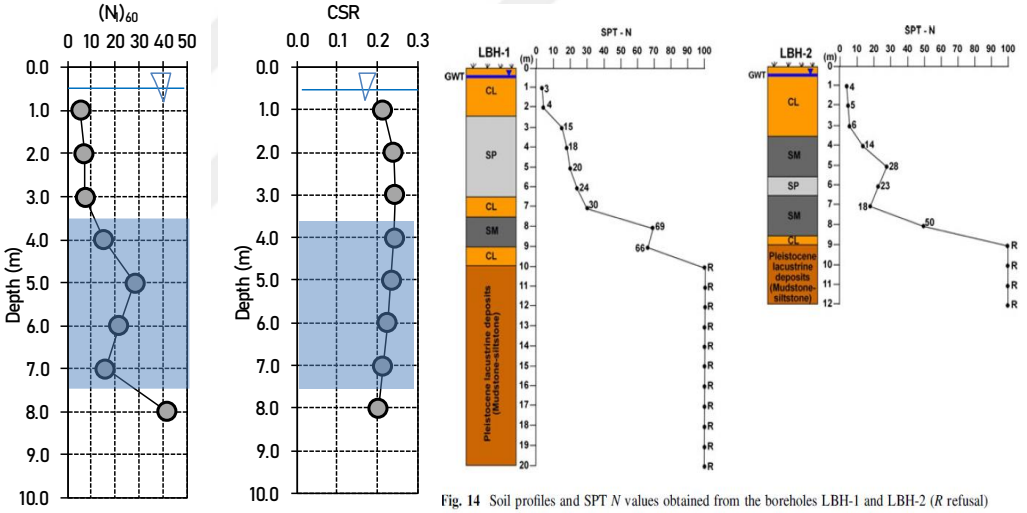
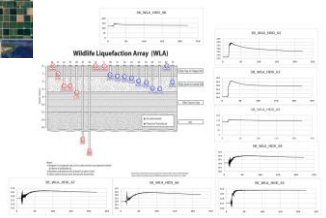


Fig. 14 Soil profiles and SPT *N* values obtained from the boreholes LBH-1 and LBH-2 (*R* refusal)

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC	Depth (m)		
CL	1.0	3.3	0.21	4	2.00	0.84	5	86	1	CL	LBH-2
CL	2.0	6.6	0.24	5	2.00	0.87	7	74	2	CL	LBH-2
CL	3.0	9.8	0.24	6	1.69	0.89	7	76	3	CL	LBH-2
SM	***4.0***	***13.1***	***0.24***	***14***	***1.48***	***0.91***	***15***	***43***	***4***	***SM***	***LBH-2***
SM	***5.0***	***16.4***	***0.24***	***28***	***1.33***	***0.93***	***28***	***20***	***5***	***SM***	***LBH-2***
SP	***6.0***	***19.7***	***0.23***	***23***	***1.22***	***0.94***	***22***	***5***	***6***	***SP***	***LBH-2***
SM	***7.0***	***23.0***	***0.21***	***18***	***1.13***	***0.95***	***16***	***12***	***7***	***SM***	***LBH-2***
SM	8.0	26.2	0.20	50	1.06	0.96	42	38	8	SM	LBH-2
						Mean:	**20.3**	80	9	CL	LBH-2
						St. Dev.	**6.0**	99	10	Mudstone-Sandstone	LBH-2
								100	11	Mudstone-Sandstone	LBH-2
								100	12	Mudstone-Sandstone	LBH-2
							Mean:	**19.9**			
							St. Dev.	**16.3**			

Case number:	415
Earthquake:	2012 Brawley Earthquake Swarm M=4.9
Magnitude:	4.9 http://www.nees.ucsb.edu/facilities/wla
Location:	Wildlife Array Greenfield (2018), El-Sekelly et al 2017, Mccrink et al 2011, USGS, NGL Project
References:	Bennett et al. (1984) and Fear et al. (1995), Youd and Wieczorek (1984),Bierschwale (1984),
Nature of Failure:	co-located piezometric recordings indicates no liquefaction ru,max~0.16-0.63
GPS LAT	33.0976
GPS LONG	-115.5306
Liq. layer consist of:	Silty Sand
Geological Unit:	Holocene floodplain
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much ad 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The site is very closely monitored. Strong ground motion seismometers were installed at the surface and at 6.7 m depth. Piezometers were installed almost at every meter along the potentially liquefiable layer of thickness 4 m. A: very loose and very soft interbedded micaceous sandy silt, silt and clayey silts (0-2.5 m) flood plain deposits B: very loose to loose moderately sorted sandy silt (2.5-6.8m); point bar deposits C: silty clay (medium to very stiff) and clayey silt (medium to stiff); lacustrine deposit. Vs1=145–155 m/s. Energy ratio ~68 %" The Brawley Seismic Zone is a northeast-striking transition zone between the Imperial and San Andreas faults. A field visit on 8/27/12 by a Caltech geologist found no evidence of surface rupture or liquefaction (by Martha Merriam of Caltrans) Upper silty clayey layer is very soft (SPT-N=1) hence it is difficult to estimate rd. As a result site response analysis is performed to estimate rd. https://earthquake.usgs.gov/earthquakes/eventpage/ci15202921/executive Mag: 4.9 Lat: 33.021 Lon: -115.519 Depth: 4.1km Starttime: 2012-08-27 04:41:26.6445
Gravel Content (%):	0
CPT available:	Yes
Vs available:	Yes





Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No*
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	2.7 - 7.0
d_{GT} (m)	-	-	-	-	4.9
GWT (m)	-	-	-	-	1.2 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	87.9 ± 13.7
σ_v' (kPa)	-	-	-	-	52.0 ± 6.8
a_{max} (g)	-	-	-	-	0.327 ± 0.016
r_d	-	-	-	-	0.49 ± 0.034
CSR	-	-	-	-	0.177 ± 0.016
M_w	-	-	-	-	4.90
D_{50}	-	-	-	-	0.089 ± 0.012
% Fines	-	-	-	-	27.4 ± 9.0
% PI	-	-	-	-	0
N	-	-	-	-	8.0 ± 3.5
C_R	-	-	-	-	0.92
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.13
C_N	-	-	-	-	1.40
$(N_1)_{60}$	-	-	-	-	11.6 ± 5.1
V_{s30m} (m/s)	-	-	-	-	179.0
V_{s12m} (m/s)	-	-	-	-	131.0

EVENT PARAMETERS

2012 Brawley Earthquake Swarm M=4.9 epicentral distanc

Magnitude: 4.90	USGS		8.8
Fault Type: northeast striki	Z_{tor} (km): NAV	R_{rup} (km): NAV	
Dip: 33-59	Width (km): NAV	R_{jb} (km): NAV	

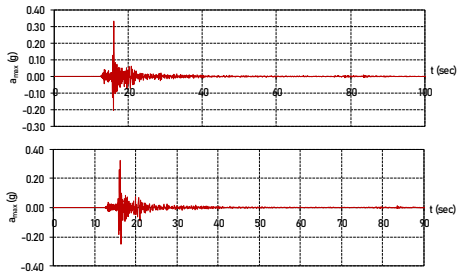
ACCELERATION TIME HISTORY

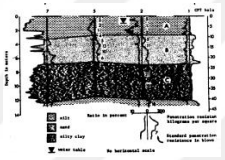
Full Record

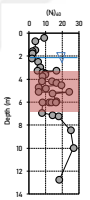
N_{H1}	4.6
N_{H2}	4.8
N_{gm}	4.7
PGA_{H1}	0.322
PGA_{H2}	0.331
PGA_L	0.327
M_w	4.9
$M_{w,cycle}$	no convergence

Untill Liquefaction

$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-



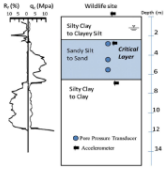


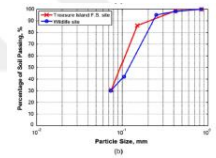


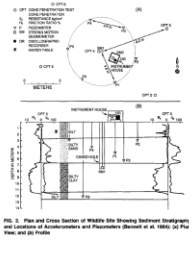




El-Sekelly et al 2017







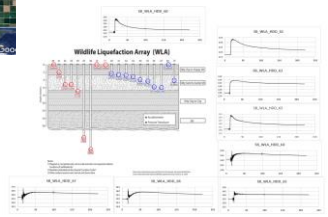
	Depth (m)	Depth (ft)	CSR	N	C_N	C_E	$(N1)_{60}$		
A	0.40	1.3		5	2.00	0.80	9.1	silt, ML	2Ng1
	0.69	2.3		2	2.00	0.81	3.7	silty to silty sand	5Ng
	1.45	4.8		2	2.00	0.84	3.8	clayey silt	5Ng
B	*1.58*	*5.2*		*1*	*2.00*	*0.85*	*1.9*	*silty clay, ML*	2Ng1
A	*1.75*	*5.8*		*1*	*2.00*	*0.85*	*1.9*	*silt*	1Ns
	1.75	*5.8*		*1*	*2.00*	*0.85*	*1.9*	*silt*	3Ns
	2.21	*7.3*		*1*	*1.90*	*0.86*	*1.9*	*silt*	5Ng
C	2.50	8.2		3	1.82	0.87	5.4	sandy silt, ML	2Ng1
	2.97	*9.8*		*4*	*1.70*	*0.88*	*6.8*	*sandy silt*	5Ng
B	*3.28*	*10.8*		*3*	*1.64*	*0.89*	*5.0*	*sand to silty sand*	1Ns
	3.28	*10.8*		*10*	*1.64*	*0.89*	*16.6*	*sand to silty sand*	3Ns
C	*3.41*	*11.2*		*5*	*1.61*	*0.89*	*8.2*	*sand, SM*	2Ng1
	3.48	*11.4*		*6*	*1.60*	*0.90*	*9.8*	*silty sand*	2Ng3
	3.58	*11.8*		*6*	*1.58*	*0.90*	*9.7*	*silty sand*	2Ng2
	3.73	*12.3*		*5*	*1.56*	*0.90*	*8.0*	*very fine sand*	5Ng
B	*4.19*	*13.8*		*5*	*1.49*	*0.91*	*7.7*	*sand to silty sand*	1Ns
	4.19	*13.8*		*9*	*1.49*	*0.91*	*13.8*	*sand to silty sand*	3Ns
	4.33	*14.2*		*11*	*1.47*	*0.91*	*16.7*	*sand, SM*	2Ng1
	4.50	*14.8*		*13*	*1.44*	*0.92*	*19.5*	*very fine sand*	5Ng
	4.70	*15.4*		*4*	*1.42*	*0.92*	*5.9*	*silty sand*	2Ng3
	4.80	*15.8*		*7*	*1.40*	*0.92*	*10.3*	*silty sand*	2Ng2
B	*5.11*	*16.8*		*4*	*1.37*	*0.93*	*5.7*	*sand to silty sand*	1Ns
	5.11	*16.8*		*17*	*1.37*	*0.93*	*24.4*	*sand to silty sand*	3Ns
	5.26	*17.3*		*10*	*1.35*	*0.93*	*14.2*	*very fine sand*	5Ng
	5.91	*19.4*		*12*	*1.28*	*0.94*	*16.4*	*silty sand*	2Ng3
B	*6.02*	*19.8*		*9*	*1.27*	*0.94*	*12.2*	*sand to silty sand*	1Ns
	6.02	*19.8*		*10*	*1.27*	*0.94*	*13.5*	*silty sand*	2Ng2
	6.02	*19.8*		*12*	*1.27*	*0.94*	*16.3*	*sand to silty sand*	3Ns
	6.02	*19.8*		*6*	*1.27*	*0.94*	*8.1*	*silty sand*	5Ng
	6.93	*22.8*		*6*	*1.20*	*0.95*	*7.7*	*sand, SM*	2Ng1
	7.12	23.4		11	1.18	0.95	14.0	clayey silt	2Ng3
	7.24	23.8		14	1.17	0.95	17.7	silty sand	2Ng2
	8.46	27.8		21	1.09	0.96	25.1	silty clay, CH	2Ng1
	9.98	32.8		24	1.02	0.97	26.9	clayey silt, MH	2Ng1
	12.73	41.8		18	0.91	0.98	18.2	silt, ML	2Ng1
						Mean:	11.6		
						St. Dev.	5.1		

	Depth (ft)	FC	Sand	Silt	Clay	D_{50}	
sandy silt, ML	0.6	82.0	18.0	72.0	10.0	0.046	2Ng1
silt ML	1.3	99.0	1.0	87.0	12.0	0.015	2Ng1
silt	4.3	98.0	2.0	76.0	22.0	0.011	2Ng1
silt ML	4.7	93.0	7.0	76.0	17.0	0.038	2Ng1
silty clay ML	5.2	99.0	1.0	41.0	58.0	0.003	2Ng1
silt ML	7.5	89.0	11.0	76.0	13.0	0.034	2Ng1
sandy silt ML	8.2	70.0	30.0	66.0	4.0	0.052	2Ng1
silty sand ML	*10.5*	*34.0*	*66.0*	*34.0*	*0.0*	*0.076*	*2Ng1*
sand SM	*11.2*	*17.0*	*83.0*	*17.0*	*0.0*	*0.096*	*2Ng1*
silty sand SM	*13.5*	*27.0*	*73.0*	*26.0*	*1.0*	*0.090*	*2Ng1*
sand SM	*14.2*	*20.0*	*80.0*	*20.0*	*0.0*	*0.100*	*2Ng1*
silty sand SM	*18.3*	*33.0*	*67.0*	*29.0*	*4.0*	*0.082*	*2Ng1*
sand SM	*20.8*	*18.0*	*82.0*	*17.0*	*1.0*	*0.102*	*2Ng1*
silty clay CH	27.8	100.0	0.0	34.0	66.0	0.002	2Ng1
clayey silt MH	32.8	100.0	0.0	57.0	43.0	0.005	2Ng1
silt ML	41.8	100.0	1.0	84.0	16.0	0.026	2Ng1
clayey silt, SYR 4/2, (CL-ML)	1.3	87.0	13.0	69.0	18.0	0.020	3Ag
clayey silt, 5Y 4.5/1	3.0	89.0	11.0	89.0	0.0		3Ag
silt, 5Y 4.5/1	3.5	97.0	3.0	75.0	22.0	0.016	3Ag
silt, SY 4.5/1, (CL-ML)	4.5	98.0	2.0	78.0	20.0	0.020	3Ag
sandy silt, 2.5Y 3/2, (ML)	5.8	56.0	44.0	44.0	12.0	0.056	3Ag
silt, 2.5Y 3/2, (CL)	7.3	96.0	4.0	78.0	18.0	0.025	3Ag
sandy silt, 10YR 4/2, ML	9.0	63.0	37.0	53.0	10.0	0.056	3Ag
sandy silt, 10YR 4/2, ML	9.5	56.0	44.0	46.0	10.0	0.057	3Ag
silty sand, 10YR 4/2, SM	*11.4*	*31.0*	*69.0*	*26.0*	*5.0*	*0.086*	*3Ag*
sand, 10YR 4/2, (SM)	*13.5*	*22.0*	*78.0*	*19.0*	*3.0*	*0.095*	*3Ag*
silty sand, 10YR 4/2, SM	*15.0*	*26.0*	*74.0*	*23.0*	*3.0*	*0.088*	*3Ag*
silty sand, 10YR 4/2, SM	*18.0*	*31.0*	*69.0*	*26.0*	*5.0*	*0.086*	*3Ag*
silty sand, 10YR 3/3,SM	*19.5*	*49.0*	*51.0*	*43.0*	*6.0*	*0.063*	*3Ag*
sand, 10YR 3/3, (SM)	*21.0*	*21.0*	*79.0*	*18.0*	*3.0*	*0.109*	*3Ag*
clayey silt, 10YR 4/2, CL	22.8	96.0	4.0	66.0	30.0	0.012	3Ag
clayey silt, 10YR 4/2	24.5	97.0	3.0	71.0	26.0	0.013	3Ag
silty clay, SYR 4/2	25.5	97.0	3.0	41.0	56.0	0.003	3Ag
silty clay, SYR 4/2	27.5	99.0	1.0	28.0	71.0	0.001	3Ag
clay, SYR 4/2, (CH)	30.0	98.0	2.0	23.0	75.0	0.001	3Ag
silty clay, SYR 4/2	33.0	98.0	2.0	29.0	69.0	0.002	3Ag
clay, SYR 4/2, (CH)	36.0	99.0	1.0	11.0	88.0	0.001	3Ag
silty clay, SYR 4/2	37.0	92.0	8.0	26.0	66.0	0.002	3Ag
silt, (ML)	40.0	88.0	12.0	75.0	13.0	0.046	3Ag
clayey silt	41.0	98.0	2.0	56.0	42.0	0.007	3Ag
silt, 5Y 4/2, (ML)	44.0	97.0	3.0	79.0	18.0	0.023	3Ag
silt, 5Y 4/2, (ML)	46.5	96.0	4.0	86.0	10.0	0.030	3Ag
clayey silt, 10YR 3.5/2	49.0	88.0	12.0	74.0	14.0	0.028	3Ag
silt, 10YR 3.5/2, (ML)	51.5	96.0	4.0	84.0	12.0	0.022	3Ag
silt, 10YR 3.5/2, (ML)	53.3	95.0	5.0	82.0	13.0	0.028	3Ag
sandy silt, 10YR 3.5/2,	56.0	85.0	15.0	71.0	14.0	0.034	3Ag
sandy silt, 10YR 3.5/2,	58.0	66.0	34.0	56.0	10.0	0.050	3Ag
silty clay, SYR 4/2	58.8	95.0	5.0	31.0	64.0	0.002	3Ag
silty sand, SYR 4/3, (SM)	59.5	49.0	51.0	39.0	10.0	0.063	3Ag
clayey silt, SYR 4/2.5	61.0	94.0	6.0	66.0	28.0	0.015	3Ag
clayey silt, SYR 4/2.5	62.5	97.0	3.0	73.0	24.0	0.018	3Ag
sand, (SM)	66.0	14.0	86.0	14.0		0.114	3Ag
silty sand, 7. SYR 4/2, (SM)	68.0	34.0	66.0	28.0	6.0	0.088	3Ag
silty sand, 7. SYR 4/2, (SM)	70.0	53.0	47.0	41.0	12.0	0.056	3Ag
silt, 7. SYR 4/2, (ML)	72.0	96.0	4.0	82.0	14.0	0.023	3Ag
clayey silt, 7. SYR 4/2	73.0	96.0	4.0	69.0	27.0	0.013	3Ag
clayey silt, SYR 4/2.5, (CL)	74.5	95.0	5.0	61.0	34.0	0.009	3Ag
clayey silt, SYR 4/2.5	76.5	90.0	10.0	61.0	29.0	0.013	3Ag
sandy silt, (ML)	78.0	80.0	20.0	66.0	14.0	0.041	3Ag
silty sand, (SM)	80.0	29.0	71.0	23.0	6.0	0.088	3Ag
clayey silt	82.0	85.0	15.0	65.0	20.0	0.036	3Ag
silty clay, 7. SYR 4/2	83.0	96.0	4.0	42.0	54.0	0.003	3Ag
clayey silt, 7. SYR 4/2	84.0	99.0	1.0	59.0	40.0	0.010	3Ag
silty clay, 7. SYR 4/2, (CH)	85.0	99.0	1.0	39.0	60.0	0.002	3Ag
silty clay, 7. SYR 4/2	86.5	98.0	2.0	48.0	50.0	0.004	3Ag
Mean:	27.4	72.6	24.8	2.6	0.089		
St. Dev.	9.0	9.0	7.8	2.2	0.012		

wn	wl	Pl	LI
32.0			
28.0			
31.0	30.0	5.0	1.6
33.0	38.0	11.0	0.4
26.0	64.0	26.0	-0.5
24.0	57.0	22.0	-0.5
24.0	30.0	4.0	-0.5
27.0	26.0	5.0	1.2
31.0			
43.0	28.0	6.0	3.5
28.0			
34.0	30.0	9.0	1.6
30.0	36.0	16.0	0.6
30.0			
28.0			
29.0			
27.0	68.0	41.0	0.0
28.0			
26.0	68.0	39.0	-0.1
31.0			
26.0			
25.0			
27.0	28.0	4.0	1.0
28.0			
30.0			
31.0			
29.0			
24.0			
28.0			
31.0			
31.0			
31.0	33.0	12.0	0.8
24.0			
25.0			
33.0			
27.0			
32.0	51.0	27.0	0.3
35.0			

Case number:	416
Earthquake:	2012 Brawley Earthquake Swarm M=4.61
Magnitude:	4.61 http://www.nees.ucsb.edu/facilities/wla
Location:	Wildlife Array Greenfield (2018), El-Sekelly et al 2017, Mccrink et al 2011, USGS, NGL Project
References:	Bennett et al. (1984) and Fear et al. (1995), Youd and Wieczorek (1984),Bierschwale (1984),
Nature of Failure:	co-located piezometric recordings indicates no liquefaction ru~0.17-0.47
GPS LAT	33.0976
GPS LONG	-115.5306
Liq. layer consist of:	Silty Sand
Geological Unit:	Holocene floodplain
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much ad 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The site is very closely monitored. Strong ground motion seismometers were installed at the surface and at 6.7 m depth. Piezometers were installed almost at every meter along the potentially liquefiable layer of thickness 4 m. A: very loose and very soft interbedded micaceous sandy silt, silt and clayey silts (0-2.5 m) flood plain deposits B: very loose to loose moderately sorted sandy silt (2.5-6.8m); point bar deposits C: silty clay (medium to very stiff) and clayey silt (medium to stiff); lacustrine deposit. Vs1=145–155 m/s. Energy ratio ~68 %." The Brawley Seismic Zone is a northeast-striking transition zone between the Imperial and San Andreas faults. A field visit on 8/27/12 by a Caltech geologist found no evidence of surface rupture or liquefaction (by Martha Merriam of Caltrans)
	Upper silty clayey layer is very soft (SPT-N=1) hence it is difficult to estimate rd. As a result site response analysis is performed to estimate rd.
	https://earthquake.usgs.gov/earthquakes/eventpage/ci15201537/executive
	Lat: 33.028 Lon: -115.531
	Depth: 7.4km
	SampleInterval: 0.0050s
	Starttime: 2012-08-26 23:33:14.9795
Gravel Content (%):	0
CPT available:	Yes
Vs available:	Yes





Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No*
Data Class	-	-	-	-	A
d_{crc} range (m)	-	-	-	-	2.7 - 7.0
d_{crt} (m)	-	-	-	-	4.9
GWT (m)	-	-	-	-	1.2 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	87.9 ± 13.7
σ_v' (kPa)	-	-	-	-	52.0 ± 6.8
a_{max} (g)	-	-	-	-	0.292 ± 0.015
r_d	-	-	-	-	0.48 ± 0.034
CSR	-	-	-	-	0.153 ± 0.014
M_w	-	-	-	-	4.61
D_{50}	-	-	-	-	0.089 ± 0.012
% Fines	-	-	-	-	27.4 ± 9.0
% PI	-	-	-	-	0
N	-	-	-	-	8.0 ± 3.5
C_R	-	-	-	-	0.92
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.13
C_N	-	-	-	-	1.40
$(N_1)_{60}$	-	-	-	-	11.6 ± 5.1
V_{s30m} (m/s)	-	-	-	-	179.0
V_{s12m} (m/s)	-	-	-	-	131.0

EVENT PARAMETERS

2012 Brawley Earthquake Swarm M=4.61 epicentral distanc

Magnitude: 4.61	USGS		7.7
Fault Type: northeast striki	Z_{tor} (km): NAV		R_{rup} (km): NAV
Dip: 23-69	Width (km): NAV		R_{jb} (km): NAV

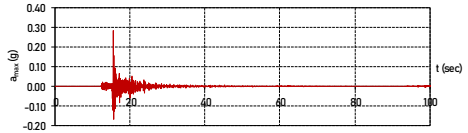
ACCELERATION TIME HISTORY

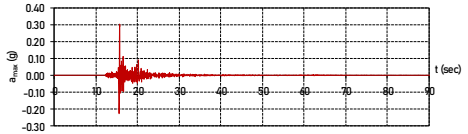
Full Record

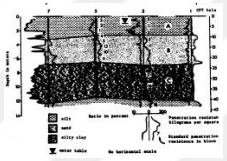
N_{H1}	3.1
N_{H2}	5.1
N_{gm}	4.0
PGA_{H1}	0.302
PGA_{H2}	0.282
PGA	0.292
M_w	4.61
$M_{w,cycle}$	no convergence

Untill Liquefaction

$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-



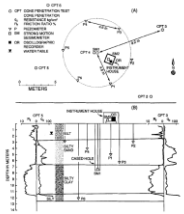


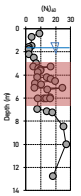


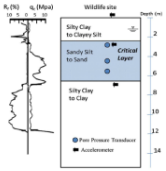


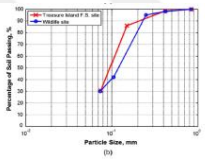


El-Sekelly et al 2017







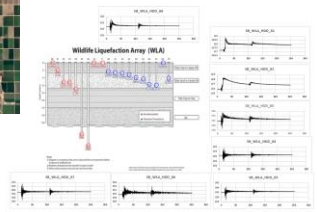


	Depth (m)	Depth (ft)	CSR	N	C_N	C_E	$(N_1)_{60}$		
A	0.40	1.3		5	2.00	0.80	9.1	silt, ML	2Ng1
	0.69	2.3		2	2.00	0.81	3.7	silty to silty sand	5Ng
	1.45	4.8		2	2.00	0.84	3.8	clayey silt	5Ng
B	*1.58*	*5.2*		*1*	*2.00*	*0.85*	*1.9*	*silty clay, ML*	2Ng1
A	*1.75*	*5.8*		*1*	*2.00*	*0.85*	*1.9*	*silt*	1Ns
	1.75	*5.8*		*1*	*2.00*	*0.85*	*1.9*	*silt*	3Ns
	2.21	*7.3*		*1*	*1.90*	*0.86*	*1.9*	*silt*	5Ng
C	2.50	8.2		3	1.82	0.87	5.4	sandy silt, ML	2Ng1
	2.97	***9.8***		***4***	***1.70***	***0.88***	***6.8***	***sandy silt***	5Ng
B	***3.28***	***10.8***		***3***	***1.64***	***0.89***	***5.0***	***sand to silty sand***	1Ns
	3.28	***10.8***		***10***	***1.64***	***0.89***	***16.6***	***sand to silty sand***	3Ns
C	*3.41*	*11.2*		*5*	*1.61*	*0.89*	*8.2*	*sand, SM*	2Ng1
	3.48	*11.4*		*6*	*1.60*	*0.90*	*9.8*	*silty sand*	2Ng3
	3.58	*11.8*		*6*	*1.58*	*0.90*	*9.7*	*silty sand*	2Ng2
	3.73	*12.3*		*5*	*1.56*	*0.90*	*8.0*	*very fine sand*	5Ng
B	*4.19*	*13.8*		*5*	*1.49*	*0.91*	*7.7*	*sand to silty sand*	1Ns
	4.19	*13.8*		*9*	*1.49*	*0.91*	*13.8*	*sand to silty sand*	3Ns
	4.33	*14.2*		*11*	*1.47*	*0.91*	*16.7*	*sand, SM*	2Ng1
	4.50	*14.8*		*13*	*1.44*	*0.92*	*19.5*	*very fine sand*	5Ng
	4.70	*15.4*		*4*	*1.42*	*0.92*	*5.9*	*silty sand*	2Ng3
	4.80	*15.8*		*7*	*1.40*	*0.92*	*10.3*	*silty sand*	2Ng2
B	*5.11*	*16.8*		*4*	*1.37*	*0.93*	*5.7*	*sand to silty sand*	1Ns
	5.11	*16.8*		*17*	*1.37*	*0.93*	*24.4*	*sand to silty sand*	3Ns
	5.26	*17.3*		*10*	*1.35*	*0.93*	*14.2*	*very fine sand*	5Ng
	5.93	*19.4*		*12*	*1.28*	*0.94*	*16.4*	*silty sand*	2Ng3
B	*6.02*	*19.8*		*9*	*1.27*	*0.94*	*12.2*	*sand to silty sand*	1Ns
	6.02	*19.8*		*10*	*1.27*	*0.94*	*13.5*	*silty sand*	2Ng2
	6.02	*19.8*		*12*	*1.27*	*0.94*	*16.3*	*sand to silty sand*	3Ns
	6.02	*19.8*		*6*	*1.27*	*0.94*	*8.1*	*silty sand*	5Ng
	6.89	*22.6*		*6*	*1.20*	*0.95*	*7.7*	*sand, SM*	2Ng1
	7.12	23.4		11	1.19	0.95	14.0	clayey silt	2Ng3
	7.24	23.8		14	1.17	0.95	17.7	silty sand	2Ng2
	8.46	27.8		21	1.09	0.96	25.1	silty clay, CH	2Ng1
	9.98	32.8		24	1.02	0.97	26.9	clayey silt, MH	2Ng1
	12.73	41.8		18	0.91	0.98	18.2	silt, ML	2Ng1
						Mean:	11.6		
						St. Dev.	5.1		

	Depth (ft)	FC	Sand	Silt	Clay	D_{50}		wn	wl	PI	LI
sandy silt, ML	0.6	82.0	18.0	72.0	10.0	0.046	2Ng1				
silt ML	1.3	99.0	1.0	87.0	12.0	0.015	2Ng1	32.0			
silt	4.3	98.0	2.0	76.0	22.0	0.011	2Ng1	28.0			
silt ML	4.7	93.0	7.0	76.0	17.0	0.038	2Ng1	31.0	30.0	5.0	1.6
silty clay ML	5.2	99.0	1.0	41.0	58.0	0.003	2Ng1	33.0	38.0	11.0	0.4
silt ML	7.5	89.0	11.0	76.0	13.0	0.034	2Ng1				
sandy silt ML	8.2	70.0	30.0	66.0	4.0	0.052	2Ng1				
silty sand ML	***10.5***	***34.0***	***66.0***	***34.0***	***0.0***	***0.076***	***2Ng1***				
sand SM	***11.2***	***17.0***	***83.0***	***17.0***	***0.0***	***0.096***	***2Ng1***				
silty sand SM	***13.5***	***27.0***	***73.0***	***26.0***	***1.0***	***0.090***	***2Ng1***				
sand SM	***14.2***	***20.0***	***80.0***	***20.0***	***0.0***	***0.100***	***2Ng1***				
silty sand SM	***18.3***	***33.0***	***67.0***	***29.0***	***4.0***	***0.082***	***2Ng1***				
sand SM	***22.8***	***18.0***	***82.0***	***17.0***	***1.0***	***0.102***	***2Ng1***				
silty clay CH	27.8	100.0	0.0	34.0	66.0	0.002	2Ng1	26.0	64.0	26.0	-0.5
clayey silt MH	32.8	100.0	0.0	57.0	43.0	0.005	2Ng1	24.0	57.0	22.0	-0.5
silt ML	41.8	100.0	1.0	84.0	16.0	0.026	2Ng1	24.0	30.0	4.0	-0.5
clayey silt, SYR 4/2, (CL-ML)	1.3	87.0	13.0	69.0	18.0	0.020	3Ag	27.0	26.0	5.0	1.2
clayey silt, 5Y 4.5/1	3.0	89.0	11.0	89.0	0.0		3Ag	31.0			
silt, 5Y 4.5/1	3.5	97.0	3.0	75.0	22.0	0.016	3Ag				
silt, 5Y 4.5/1, (CL-ML)	4.5	98.0	2.0	78.0	20.0	0.020	3Ag	43.0	28.0	6.0	3.5
sandy silt, 2.5Y 3/2, (ML)	5.8	56.0	44.0	44.0	12.0	0.056	3Ag	28.0			
silt, 2.5Y 3/2, (CL)	7.3	96.0	4.0	78.0	18.0	0.025	3Ag	34.0	30.0	9.0	1.6
sandy silt, 10YR 4/2, ML	9.0	63.0	37.0	53.0	10.0	0.056	3Ag				
sandy silt, 10YR 4/2, ML	9.5	56.0	44.0	46.0	10.0	0.057	3Ag				
silty sand, 10YR 4/2, SM	***11.4***	***21.0***	***69.0***	***26.0***	***5.0***	***0.086***	***3Ag***				
sand, 10YR 4/2, (SM)	***13.5***	***22.0***	***78.0***	***19.0***	***3.0***	***0.095***	***3Ag***				
silty sand, 10YR 4/2, SM	***15.0***	***26.0***	***74.0***	***23.0***	***3.0***	***0.088***	***3Ag***				
silty sand, 10YR 4/2, SM	***18.0***	***31.0***	***69.0***	***26.0***	***5.0***	***0.086***	***3Ag***				
silty sand, 10YR 3/3,SM	***19.5***	***49.0***	***51.0***	***43.0***	***6.0***	***0.063***	***3Ag***				
sand, 10YR 3/3, (SM)	***21.0***	***21.0***	***79.0***	***18.0***	***3.0***	***0.109***	***3Ag***				
clayey silt, 10YR 4/2, CL	22.9	96.0	4.0	56.0	40.0	0.012	3Ag	30.0	36.0	16.0	0.6
clayey silt, 10YR 4/2	24.5	97.0	3.0	71.0	26.0	0.013	3Ag	30.0			
silty clay, SYR 4/2	25.5	97.0	3.0	41.0	56.0	0.003	3Ag	28.0			
silty clay, SYR 4/2	27.5	99.0	1.0	28.0	71.0	0.001	3Ag	29.0			
clay, SYR 4/2, (CH)	30.0	98.0	2.0	23.0	75.0	0.001	3Ag	27.0	68.0	41.0	0.0
silty clay, SYR 4/2	33.0	98.0	2.0	29.0	69.0	0.002	3Ag	28.0			
clay, SYR 4/2, (CH)	36.0	99.0	1.0	11.0	88.0	0.001	3Ag	26.0	68.0	39.0	-0.1
silty clay, SYR 4/2	37.0	92.0	8.0	26.0	66.0	0.002	3Ag	31.0			
silt, (ML)	40.0	88.0	12.0	75.0	13.0	0.046	3Ag	26.0			
clayey silt	41.0	98.0	2.0	56.0	42.0	0.007	3Ag	25.0			
silt, 5Y 4/2, (ML)	44.0	97.0	3.0	79.0	18.0	0.023	3Ag	27.0	28.0	4.0	1.0
silt, 5Y 4/2, (ML)	46.5	96.0	4.0	86.0	10.0	0.030	3Ag	28.0			
clayey silt, 10YR 3.5/2	49.0	88.0	12.0	74.0	14.0	0.028	3Ag	30.0			
silt, 10YR 3.5/2, (ML)	51.5	96.0	4.0	84.0	12.0	0.022	3Ag	31.0			
silt, 10YR 3.5/2, (ML)	53.3	95.0	5.0	82.0	13.0	0.028	3Ag	29.0			
sandy silt, 10YR 3.5/2,	56.0	85.0	15.0	71.0	14.0	0.034	3Ag				
sandy silt, 10YR 3.5/2,	58.0	66.0	34.0	56.0	10.0	0.050	3Ag				
silty clay, SYR 4/2	58.8	95.0	5.0	31.0	64.0	0.002	3Ag				
silty sand, SYR 4/3, (SM)	59.5	49.0	51.0	39.0	10.0	0.063	3Ag				
clayey silt, SYR 4/2.5	61.0	94.0	6.0	66.0	28.0	0.015	3Ag	24.0			
clayey silt, SYR 4/2.5	62.5	97.0	3.0	73.0	24.0	0.018	3Ag	28.0			
sand, (SM)	66.0	14.0	86.0	14.0		0.114	3Ag				
silty sand, 7. SYR 4/2, (SM)	68.0	34.0	66.0	28.0	6.0	0.088	3Ag				
silty sand, 7. SYR 4/2, (SM)	70.0	53.0	47.0	41.0	12.0	0.056	3Ag				
silt, 7. SYR 4/2, (ML)	72.0	96.0	4.0	82.0	14.0	0.023	3Ag	31.0			
clayey silt, 7. SYR 4/2	73.0	96.0	4.0	69.0	27.0	0.013	3Ag	31.0			
clayey silt, SYR 4/2.5, (CL)	74.5	95.0	5.0	61.0	34.0	0.009	3Ag	31.0	33.0	12.0	0.8
clayey silt, SYR 4/2.5	76.5	90.0	10.0	61.0	29.0	0.013	3Ag				
sandy silt, (ML)	78.0	80.0	20.0	66.0	14.0	0.041	3Ag	24.0			
silty sand, (SM)	80.0	29.0	71.0	23.0	6.0	0.088	3Ag				
clayey silt	82.0	85.0	15.0	65.0	20.0	0.036	3Ag	25.0			
silty clay, 7. SYR 4/2	83.0	96.0	4.0	42.0	54.0	0.003	3Ag	33.0			
clayey silt, 7. SYR 4/2	84.0	99.0	1.0	59.0	40.0	0.010	3Ag	27.0			
silty clay, 7. SYR 4/2, (CH)	85.0	99.0	1.0	39.0	60.0	0.002	3Ag	32.0	51.0	27.0	0.3
silty clay, 7. SYR 4/2	86.5	98.0	2.0	48.0	50.0	0.004	3Ag	35.0			
Mean:		27.4	72.6	24.8	2.6	0.089					
St. Dev.		9.0	9.0	7.8	2.2	0.012					

Case number:	417
Earthquake:	2012 Brawley Earthquake Swarm M=5.32
Magnitude:	5.32 http://www.nees.ucsb.edu/facilities/wla
Location:	Wildlife Array Greenfield (2018), El-Sekelly et al 2017, Mccrink et al 2011, USGS, NGL Project
References:	Bennett et al. (1984) and Fear et al. (1995), Youd and Wieczorek (1984),Bierschwale (1984),
Nature of Failure:	co-located piezometric recordings indicates no liquefaction ru~0.07-0.19
GPS LAT	33.0976
GPS LONG	-115.5306
Liq. layer consist of:	Silty Sand
Geological Unit:	Holocene floodplain
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much ad 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The site is very closely monitored. Strong ground motion seismometers were installed at the surface and at 6.7 m depth. Piezometers were installed almost at every meter along the potentially liquefiable layer of thickness 4 m. A: very loose and very soft interbedded micaceous sandy silt, silt and clayey silts (0-2.5 m) flood plain deposits B: very loose to loose moderately sorted sandy silt (2.5-6.8m); point bar deposits C: silty clay (medium to very stiff) and clayey silt (medium to stiff); lacustrine deposit. Vs1=145–155 m/s. Energy ratio ~68 %." The Brawley Seismic Zone is a northeast-striking transition zone between the Imperial and San Andreas faults. A field visit on 8/27/12 by a Caltech geologist found no evidence of surface rupture or liquefaction (by Martha Merriam of Caltrans)
	Upper silty clayey layer is very soft (SPT-N=1) hence it is difficult to estimate rd. As a result site response analysis is performed to estimate rd.
	https://earthquake.usgs.gov/earthquakes/eventpage/ci15199681/executive
	Mag: 5.32
	Lat: 33.017 Lon: -115.554
	Depth: 8.3km
	SampleInterval: 0.0050s
	Starttime: 2012-08-26 19:31:13.1844
Gravel Content (%):	0
CPT available:	Yes
Vs available:	Yes





N_{H1}	20.4
N_{H2}	13.5
N_{gm}	16.6
PGA_{H1}	0.165
PGA_{H2}	0.196
PGA	0.180
M_w	5.32
$M_{w,cycle}$	6.9
$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No*
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	2.7 - 7.0
d_{GT} (m)	-	-	-	-	4.9
GWT (m)	-	-	-	-	1.2 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	87.9 ± 13.7
σ_v' (kPa)	-	-	-	-	52.0 ± 6.8
a_{max} (g)	-	-	-	-	0.180 ± 0.009
r_d	-	-	-	-	0.58 ± 0.034
CSR	-	-	-	-	0.114 ± 0.010
M_w	-	-	-	-	5.32
D_{50}	-	-	-	-	0.089 ± 0.012
% Fines	-	-	-	-	27.4 ± 9.0
% PI	-	-	-	-	0
N	-	-	-	-	8.0 ± 3.5
C_R	-	-	-	-	0.92
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.13
C_N	-	-	-	-	1.40
$(N_1)_{60}$	-	-	-	-	11.6 ± 5.1
$V_{s,30m}$ (m/s)	-	-	-	-	179.0
V_{s12m} (m/s)	-	-	-	-	131.0

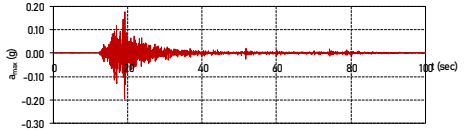
EVENT PARAMETERS

2012 Brawley Earthquake Swarm M=5.32 epicentral distanc

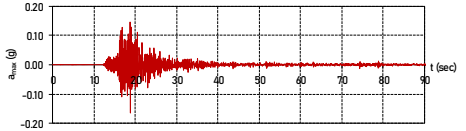
Magnitude: 5.32	USGS	9.3
Fault Type: northeast striki	Z_{tor} (km): NAV	R_{rup} (km): NAV
Dip: 67-79	Width (km): NAV	R_{jb} (km): NAV

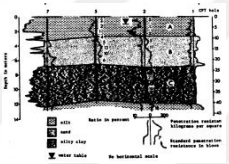
ACCELERATION TIME HISTORY

Full Record



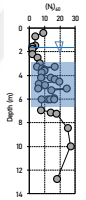
Untill Liquefaction



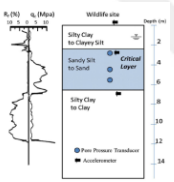


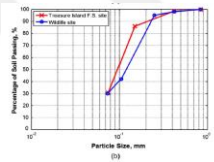


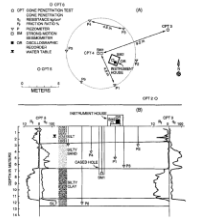




El-Sekelly et al 2017





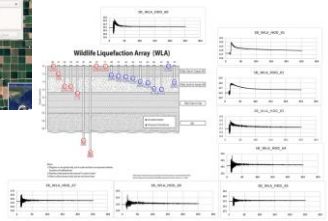


	Depth (m)	Depth (ft)	CSR	N	C_N	C_E	$(N1)_{60}$		
A	0.40	1.3		5	2.00	0.80	9.1	silt, ML	2Ng1
	0.69	2.3		2	2.00	0.81	3.7	silty to silty sand	5Ng
	1.45	4.8		2	2.00	0.84	3.8	clayey silt	5Ng
B	*1.58*	*5.2*		*1*	*2.00*	*0.85*	*1.9*	*silty clay, ML*	2Ng1
A	*1.75*	*5.8*		*1*	*2.00*	*0.85*	*1.9*	*silt*	1Ns
	1.75	*5.8*		*1*	*2.00*	*0.85*	*1.9*	*silt*	3Ns
	2.21	*7.3*		*1*	*1.90*	*0.86*	*1.9*	*silt*	5Ng
C	2.50	8.2		3	1.82	0.87	5.4	sandy silt, ML	2Ng1
	2.97	***9.8***		***4***	***1.78***	***0.88***	***6.8***	***sandy silt***	5Ng
B	***3.28***	***10.8***		***3***	***1.64***	***0.89***	***5.0***	***sand to silty sand***	1Ns
	3.28	***10.8***		***10***	***1.64***	***0.89***	***16.6***	***sand to silty sand***	3Ns
C	***3.41***	***11.2***		***5***	***1.61***	***0.89***	***8.2***	***sand, SM***	2Ng1
	3.48	***11.4***		***6***	***1.60***	***0.90***	***9.8***	***silty sand***	2Ng3
	3.58	***11.8***		***6***	***1.58***	***0.90***	***9.7***	***silty sand***	2Ng2
	3.73	***12.3***		***5***	***1.56***	***0.90***	***8.0***	***very fine sand***	5Ng
B	***4.19***	***13.8***		***5***	***1.49***	***0.91***	***7.7***	***sand to silty sand***	1Ns
	4.19	***13.8***		***9***	***1.49***	***0.91***	***13.8***	***sand to silty sand***	3Ns
	4.33	***14.2***		***11***	***1.47***	***0.91***	***16.7***	***sand, SM***	2Ng1
	4.50	***14.8***		***13***	***1.44***	***0.92***	***19.5***	***very fine sand***	5Ng
	4.70	***15.4***		***4***	***1.42***	***0.92***	***5.9***	***silty sand***	2Ng3
	4.80	***15.8***		***7***	***1.40***	***0.92***	***10.3***	***silty sand***	2Ng2
B	***5.11***	***16.8***		***4***	***1.37***	***0.93***	***5.7***	***sand to silty sand***	1Ns
	5.11	***16.8***		***17***	***1.37***	***0.93***	***24.4***	***sand to silty sand***	3Ns
	5.26	***17.3***		***10***	***1.35***	***0.93***	***14.2***	***very fine sand***	5Ng
	5.91	***19.4***		***12***	***1.28***	***0.94***	***16.4***	***silty sand***	2Ng3
B	***6.02***	***19.8***		***9***	***1.27***	***0.94***	***12.2***	***sand to silty sand***	1Ns
	6.02	***19.8***		***10***	***1.27***	***0.94***	***13.5***	***silty sand***	2Ng2
	6.02	***19.8***		***12***	***1.27***	***0.94***	***16.3***	***sand to silty sand***	3Ns
	6.02	***19.8***		***6***	***1.27***	***0.94***	***8.1***	***silty sand***	5Ng
	6.93	***22.8***		***6***	***1.20***	***0.95***	***7.7***	***sand, SM***	2Ng1
	7.12	23.4		11	1.18	0.95	14.0	clayey silt	2Ng3
	7.24	23.8		14	1.17	0.95	17.7	silty sand	2Ng2
	8.46	27.8		21	1.09	0.96	25.1	silty clay, CH	2Ng1
	9.98	32.8		24	1.02	0.97	26.9	clayey silt, MH	2Ng1
	12.73	41.8		18	0.91	0.98	18.2	silt, ML	2Ng1
						Mean:	11.6		
						St. Dev.	5.1		

	Depth (ft)	FC	Sand	Silt	Clay	D_{50}		wn	wl	PI	LI
sandy silt, ML	0.6	82.0	18.0	72.0	10.0	0.046	2Ng1				
silt ML	1.3	99.0	1.0	87.0	12.0	0.015	2Ng1	32.0			
silt	4.3	98.0	2.0	76.0	22.0	0.011	2Ng1	28.0			
silt ML	4.7	93.0	7.0	76.0	17.0	0.038	2Ng1	31.0	30.0	5.0	1.6
silty clay ML	5.2	99.0	1.0	41.0	58.0	0.003	2Ng1	33.0	38.0	11.0	0.4
silt ML	7.5	89.0	11.0	76.0	13.0	0.034	2Ng1				
sandy silt ML	8.2	70.0	30.0	66.0	4.0	0.052	2Ng1				
silty sand ML	***10.5***	***34.0***	***66.0***	***34.0***	***0.0***	***0.076***	***2Ng1***				
sand SM	***11.2***	***17.0***	***83.0***	***17.0***	***0.0***	***0.096***	***2Ng1***				
silty sand SM	***13.5***	***27.0***	***73.0***	***26.0***	***1.0***	***0.090***	***2Ng1***				
sand SM	***14.2***	***20.0***	***80.0***	***20.0***	***0.0***	***0.100***	***2Ng1***				
silty sand SM	***18.3***	***33.0***	***67.0***	***29.0***	***4.0***	***0.082***	***2Ng1***				
sand SM	***22.8***	***18.0***	***82.0***	***17.0***	***1.0***	***0.102***	***2Ng1***				
silty clay CH	27.8	100.0	0.0	34.0	66.0	0.002	2Ng1	26.0	64.0	26.0	-0.5
clayey silt MH	32.8	100.0	0.0	57.0	43.0	0.005	2Ng1	24.0	57.0	22.0	-0.5
silt ML	41.8	100.0	1.0	84.0	16.0	0.026	2Ng1	24.0	30.0	4.0	-0.5
clayey silt, SYR 4/2, (CL-ML)	1.3	87.0	13.0	69.0	18.0	0.020	3Ag	27.0	26.0	5.0	1.2
clayey silt, 5Y 4.5/1	3.0	89.0	11.0	89.0	0.0		3Ag	31.0			
silt, 5Y 4.5/1	3.5	97.0	3.0	75.0	22.0	0.016	3Ag				
silt, 5Y 4.5/1, (CL-ML)	4.5	98.0	2.0	78.0	20.0	0.020	3Ag	43.0	28.0	6.0	3.5
sandy silt, 2.5Y 3/2, (ML)	5.8	56.0	44.0	44.0	12.0	0.056	3Ag	28.0			
silt, 2.5Y 3/2, (CL)	7.3	96.0	4.0	78.0	18.0	0.025	3Ag	34.0	30.0	9.0	1.6
sandy silt, 10YR 4/2, ML	9.0	63.0	37.0	53.0	10.0	0.056	3Ag				
sandy silt, 10YR 4/2, ML	9.5	56.0	44.0	46.0	10.0	0.057	3Ag				
silty sand, 10YR 4/2, SM	***11.4***	***31.0***	***69.0***	***26.0***	***5.0***	***0.086***	***3Ag***				
sand, 10YR 4/2, (SM)	***13.5***	***22.0***	***78.0***	***19.0***	***3.0***	***0.095***	***3Ag***				
silty sand, 10YR 4/2, SM	***15.0***	***26.0***	***74.0***	***23.0***	***3.0***	***0.088***	***3Ag***				
silty sand, 10YR 4/2, SM	***18.0***	***31.0***	***69.0***	***26.0***	***5.0***	***0.086***	***3Ag***				
silty sand, 10YR 3/3,SM	***19.5***	***49.0***	***51.0***	***43.0***	***6.0***	***0.063***	***3Ag***				
sand, 10YR 3/3, (SM)	***21.0***	***21.0***	***79.0***	***18.0***	***3.0***	***0.109***	***3Ag***				
clayey silt, 10YR 4/2, CL	22.8	96.0	4.0	66.0	30.0	0.012	3Ag	30.0	36.0	16.0	0.6
clayey silt, 10YR 4/2	24.5	97.0	3.0	71.0	26.0	0.013	3Ag	30.0			
silty clay, SYR 4/2	25.5	97.0	3.0	41.0	56.0	0.003	3Ag	28.0			
silty clay, SYR 4/2	27.5	99.0	1.0	28.0	71.0	0.001	3Ag	29.0			
clay, SYR 4/2, (CH)	30.0	98.0	2.0	23.0	75.0	0.001	3Ag	27.0	68.0	41.0	0.0
silty clay, SYR 4/2	33.0	98.0	2.0	29.0	69.0	0.002	3Ag	28.0			
clay, SYR 4/2, (CH)	36.0	99.0	1.0	11.0	88.0	0.001	3Ag	26.0	68.0	39.0	-0.1
silty clay, SYR 4/2	37.0	92.0	8.0	26.0	66.0	0.002	3Ag	31.0			
silt, (ML)	40.0	88.0	12.0	75.0	13.0	0.046	3Ag	26.0			
clayey silt	41.0	98.0	2.0	56.0	42.0	0.007	3Ag	25.0			
silt, 5Y 4/2, (ML)	44.0	97.0	3.0	79.0	18.0	0.023	3Ag	27.0	28.0	4.0	1.0
silt, 5Y 4/2, (ML)	46.5	96.0	4.0	86.0	10.0	0.030	3Ag	28.0			
clayey silt, 10YR 3.5/2	49.0	88.0	12.0	74.0	14.0	0.028	3Ag	30.0			
silt, 10YR 3.5/2, (ML)	51.5	96.0	4.0	84.0	12.0	0.022	3Ag	31.0			
silt, 10YR 3.5/2, (ML)	53.3	95.0	5.0	82.0	13.0	0.028	3Ag	29.0			
sandy silt, 10YR 3.5/2,	56.0	85.0	15.0	71.0	14.0	0.034	3Ag				
sandy silt, 10YR 3.5/2,	58.0	66.0	34.0	56.0	10.0	0.050	3Ag				
silty clay, SYR 4/2	58.8	95.0	5.0	31.0	64.0	0.002	3Ag				
silty sand, SYR 4/3, (SM)	59.5	49.0	51.0	39.0	10.0	0.063	3Ag				
clayey silt, SYR 4/2.5	61.0	94.0	6.0	66.0	28.0	0.015	3Ag	24.0			
clayey silt, SYR 4/2.5	62.5	97.0	3.0	73.0	24.0	0.018	3Ag	28.0			
sand, (SM)	66.0	14.0	86.0	14.0		0.114	3Ag				
silty sand, 7. SYR 4/2, (SM)	68.0	34.0	66.0	28.0	6.0	0.088	3Ag				
silty sand, 7. SYR 4/2, (SM)	70.0	53.0	47.0	41.0	12.0	0.056	3Ag				
silt, 7. SYR 4/2, (ML)	72.0	96.0	4.0	82.0	14.0	0.023	3Ag	31.0			
clayey silt, 7. SYR 4/2	73.0	96.0	4.0	69.0	27.0	0.013	3Ag	31.0			
clayey silt, SYR 4/2.5, (CL)	74.5	95.0	5.0	61.0	34.0	0.009	3Ag	31.0	33.0	12.0	0.8
clayey silt, SYR 4/2.5	76.5	90.0	10.0	61.0	29.0	0.013	3Ag				
sandy silt, (ML)	78.0	80.0	20.0	66.0	14.0	0.041	3Ag	24.0			
silty sand, (SM)	80.0	29.0	71.0	23.0	6.0	0.088	3Ag				
clayey silt	82.0	85.0	15.0	65.0	20.0	0.036	3Ag	25.0			
silty clay, 7. SYR 4/2	83.0	96.0	4.0	42.0	54.0	0.003	3Ag	33.0			
clayey silt, 7. SYR 4/2	84.0	99.0	1.0	59.0	40.0	0.010	3Ag	27.0			
silty clay, 7. SYR 4/2, (CH)	85.0	99.0	1.0	39.0	60.0	0.002	3Ag	32.0	51.0	27.0	0.3
silty clay, 7. SYR 4/2	86.5	98.0	2.0	48.0	50.0	0.004	3Ag	35.0			
Mean:		27.4	72.6	24.8	2.6	0.089					
St. Dev.		9.0	9.0	7.8	2.2	0.012					

Case number:	418
Earthquake:	2012 Brawley Earthquake Swarm M=5.44
Magnitude:	5.44 http://www.nees.ucsb.edu/facilities/wla
Location:	Wildlife Array Greenfield (2018), El-Sekelly et al 2017, Mccrink et al 2011, USGS, NGL Project
References:	Bennett et al. (1984) and Fear et al. (1995), Youd and Wieczorek (1984),Bierschwale (1984),
Nature of Failure:	co-located piezometric recordings indicates no liquefaction ru~0.05-0.16
GPS LAT	33.0976
GPS LONG	-115.5306
Liq. layer consist of:	Silty Sand
Geological Unit:	Holocene floodplain
Site Response Anlaysis:	Yes
Comments:	Cetin (2000) "Imperial Valley lies in the southern part of the Salton Basin, which was formed by northward extension of the crustal rifting that opened the Gulf of California. The basin is underlain by as much ad 20,000 ft of Tertiary and Quaternary marine, continental, and lacustrine sediment. Holocene sediment is as thick as 330 ft. The site is very closely monitored. Strong ground motion seismometers were installed at the surface and at 6.7 m depth. Piezometers were installed almost at every meter along the potentially liquefiable layer of thickness 4 m. A: very loose and very soft interbedded micaceous sandy silt, silt and clayey silts (0-2.5 m) flood plain deposits B: very loose to loose moderately sorted sandy silt (2.5-6.8m); point bar deposits C: silty clay (medium to very stiff) and clayey silt (medium to stiff); lacustrine deposit. Vs1=145–155 m/s. Energy ratio ~68 %." The Brawley Seismic Zone is a northeast-striking transition zone between the Imperial and San Andreas faults. A field visit on 8/27/12 by a Caltech geologist found no evidence of surface rupture or liquefaction (by Martha Merriam of Caltrans)
	Upper silty clayey layer is very soft (SPT-N=1) hence it is difficult to estimate rd. As a result site response analysis is performed to estimate rd.
	https://earthquake.usgs.gov/earthquakes/eventpage/ci15200401/executive
	Mag: 5.44 Lat: 33.019 Lon: -115.54 Depth: 8.2km SampleInterval: 0.0050s Starttime: 2012-08-26 20:57:48.2945
Gravel Content (%):	0
CPT available:	Yes
Vs available:	Yes





N_{H1}	20.3
N_{H2}	16.8
N_{gm}	18.5
PGA_{H1}	0.189
PGA_{H2}	0.204
PGA	0.196
M_w	5.44
$M_{w,cycle}$	7.2
Untill Liquefaction	
$N_{H1,L}$	-
$N_{H2,L}$	-
$N_{gm,L}$	-
PGA_{H1}	-
PGA_{H2}	-
PGA_L	-
$M_{w,eq}$	-
t_L	-

Summary of Input Data

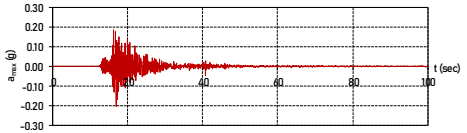
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No*
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	2.7 - 7.0
d_{crt} (m)	-	-	-	-	4.9
GWT (m)	-	-	-	-	1.2 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	15.7 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	87.9 ± 13.7
σ_v' (kPa)	-	-	-	-	52.0 ± 6.8
a_{max} (g)	-	-	-	-	0.196 ± 0.010
r_d	-	-	-	-	0.66 ± 0.034
CSR	-	-	-	-	0.142 ± 0.011
M_w	-	-	-	-	5.44
D_{50}	-	-	-	-	0.089 ± 0.012
% Fines	-	-	-	-	27.4 ± 9.0
% PI	-	-	-	-	0
N	-	-	-	-	8.0 ± 3.5
C_R	-	-	-	-	0.92
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.13
C_N	-	-	-	-	1.40
$(N_1)_{60}$	-	-	-	-	11.6 ± 5.1
V_{s30m} (m/s)	-	-	-	-	179.0
V_{s12m} (m/s)	-	-	-	-	131.0

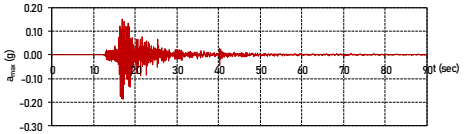
EVENT PARAMETERS

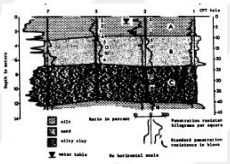
2012 Brawley Earthquake Swarm M=5.44			epicentral distanc
Magnitude: 5.44	USGS		8.9
Fault Type: northeast striki	Z_{tor} (km): NAV	R_{rup} (km): NAV	
Dip: 81-85	Width (km): NAV	R_{jb} (km): NAV	

ACCELERATION TIME HISTORY

Full Record

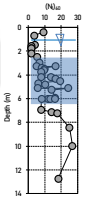


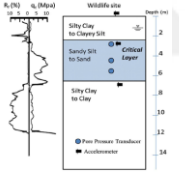


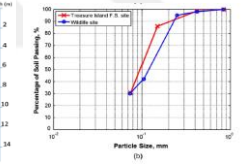




El-Sekelly et al 2017







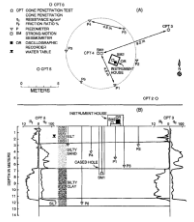


FIG. 3. Plan and Cross Section of Wildlife Site Showing Sediment Stratigraphy and Locations of Accelerometers and Piezometers (Bennett et al. 1984): (a) Plan View; and (b) Profile

	Depth (m)	Depth (ft)	CSR	N	C_N	C_E	$(N1)_{60}$		
A	0.40	1.3		5	2.00	0.80	9.1	silt, ML	2Ng1
	0.69	2.3		2	2.00	0.81	3.7	silty to silty sand	5Ng
	1.45	4.8		2	2.00	0.84	3.8	clayey silt	5Ng
B	*1.58*	*5.2*		*1*	*2.00*	*0.85*	*1.9*	silty clay, ML	2Ng1
A	*1.75*	*5.8*		*1*	*2.00*	*0.85*	*1.9*	*silt*	1Ns
	1.75	*5.8*		*1*	*2.00*	*0.85*	*1.9*	*silt*	3Ns
	2.21	*7.3*		*1*	*1.90*	*0.86*	*1.9*	*silt*	5Ng
C	2.50	8.2		3	1.82	0.87	5.4	sandy silt, ML	2Ng1
	2.97	***9.8***		***4***	***1.70***	***0.88***	***6.8***	***sandy silt***	5Ng
B	***3.28***	***10.8***		***3***	***1.64***	***0.89***	***5.0***	***sand to silty sand***	1Ns
	3.28	***10.8***		***10***	***1.64***	***0.89***	***16.6***	***sand to silty sand***	3Ns
C	***3.41***	***11.2***		***5***	***1.61***	***0.89***	***8.2***	***sand, SM***	2Ng1
	3.48	***11.4***		***6***	***1.60***	***0.90***	***9.8***	***silty sand***	2Ng3
	3.58	***11.8***		***6***	***1.58***	***0.90***	***9.7***	***silty sand***	2Ng2
	3.73	***12.2***		***5***	***1.56***	***0.90***	***8.0***	***very fine sand***	5Ng
B	***4.19***	***13.8***		***5***	***1.49***	***0.91***	***7.7***	***sand to silty sand***	1Ns
	4.19	***13.8***		***9***	***1.49***	***0.91***	***13.8***	***sand to silty sand***	3Ns
	4.33	***14.2***		***11***	***1.47***	***0.91***	***16.7***	***sand, SM***	2Ng1
	4.50	***14.8***		***13***	***1.44***	***0.92***	***19.5***	***very fine sand***	5Ng
	4.70	***15.4***		***4***	***1.42***	***0.92***	***5.9***	***silty sand***	2Ng3
	4.80	***15.8***		***7***	***1.40***	***0.92***	***10.3***	***silty sand***	2Ng2
B	***5.11***	***16.8***		***4***	***1.37***	***0.93***	***5.7***	***sand to silty sand***	1Ns
	5.11	***16.8***		***17***	***1.37***	***0.93***	***24.4***	***sand to silty sand***	3Ns
	5.26	***17.3***		***10***	***1.35***	***0.93***	***14.2***	***very fine sand***	5Ng
	5.91	***19.4***		***12***	***1.28***	***0.94***	***16.4***	***silty sand***	2Ng3
B	***6.02***	***19.8***		***9***	***1.27***	***0.94***	***12.2***	***sand to silty sand***	1Ns
	6.02	***19.8***		***10***	***1.27***	***0.94***	***13.5***	***silty sand***	2Ng2
	6.02	***19.8***		***12***	***1.27***	***0.94***	***16.3***	***sand to silty sand***	3Ns
	6.02	***19.8***		***6***	***1.27***	***0.94***	***8.1***	***silty sand***	5Ng
	6.93	***22.8***		***6***	***1.20***	***0.95***	***7.7***	***sand, SM***	2Ng1
	7.12	23.4		11	1.18	0.95	14.0	clayey silt	2Ng3
	7.24	23.8		14	1.17	0.95	17.7	silty sand	2Ng2
	8.46	27.8		21	1.09	0.96	25.1	silty clay, CH	2Ng1
	9.98	32.8		24	1.02	0.97	26.9	clayey silt, MH	2Ng1
	12.73	41.8		18	0.91	0.98	18.2	silt, ML	2Ng1
						Mean:	11.6		
						St. Dev.	5.1		

	Depth (ft)	FC	Sand	Silt	Clay	D_{50}		wn	wl	PI	LI
sandy silt, ML	0.6	82.0	18.0	72.0	10.0	0.046	2Ng1				
silt ML	1.3	99.0	1.0	87.0	12.0	0.015	2Ng1	32.0			
silt	4.3	98.0	2.0	76.0	22.0	0.011	2Ng1	28.0			
silt ML	4.7	93.0	7.0	76.0	17.0	0.038	2Ng1	31.0	30.0	5.0	1.6
silty clay ML	5.2	99.0	1.0	41.0	58.0	0.003	2Ng1	33.0	38.0	11.0	0.4
silt ML	7.5	89.0	11.0	76.0	13.0	0.034	2Ng1				
sandy silt ML	8.2	70.0	30.0	66.0	4.0	0.052	2Ng1				
silty sand ML	***10.5***	***34.0***	***66.0***	***34.0***	***0.0***	***0.076***	***2Ng1***				
sand SM	***11.2***	***17.0***	***83.0***	***17.0***	***0.0***	***0.096***	***2Ng1***				
silty sand SM	***13.5***	***27.0***	***73.0***	***26.0***	***1.0***	***0.090***	***2Ng1***				
sand SM	***14.2***	***20.0***	***80.0***	***20.0***	***0.0***	***0.100***	***2Ng1***				
silty sand SM	***18.3***	***33.0***	***67.0***	***29.0***	***4.0***	***0.082***	***2Ng1***				
sand SM	***22.8***	***18.0***	***82.0***	***17.0***	***1.0***	***0.102***	***2Ng1***				
silty clay CH	27.8	100.0	0.0	34.0	66.0	0.002	2Ng1	26.0	64.0	26.0	-0.5
clayey silt MH	32.8	100.0	0.0	57.0	43.0	0.005	2Ng1	24.0	57.0	22.0	-0.5
silt ML	41.8	100.0	1.0	84.0	16.0	0.026	2Ng1	24.0	30.0	4.0	-0.5
clayey silt, SYR 4/2, (CL-ML)	1.3	87.0	13.0	69.0	18.0	0.020	3Ag	27.0	26.0	5.0	1.2
clayey silt, 5Y 4.5/1	3.0	89.0	11.0	89.0	0.0		3Ag	31.0			
silt, 5Y 4.5/1	3.5	97.0	3.0	75.0	22.0	0.016	3Ag				
silt, 5Y 4.5/1, (CL-ML)	4.5	98.0	2.0	78.0	20.0	0.020	3Ag	43.0	28.0	6.0	3.5
sandy silt, 2.5Y 3/2, (ML)	5.8	56.0	44.0	44.0	12.0	0.056	3Ag	28.0			
silt, 2.5Y 3/2, (CL)	7.3	96.0	4.0	78.0	18.0	0.025	3Ag	34.0	30.0	9.0	1.6
sandy silt, 10YR 4/2, ML	9.0	63.0	37.0	53.0	10.0	0.056	3Ag				
sandy silt, 10YR 4/2, ML	9.5	56.0	44.0	46.0	10.0	0.057	3Ag				
silty sand, 10YR 4/2, SM	***11.4***	***31.0***	***69.0***	***26.0***	***5.0***	***0.086***	***3Ag***				
sand, 10YR 4/2, (SM)	***13.5***	***22.0***	***78.0***	***19.0***	***3.0***	***0.095***	***3Ag***				
silty sand, 10YR 4/2, SM	***15.0***	***26.0***	***74.0***	***23.0***	***3.0***	***0.088***	***3Ag***				
silty sand, 10YR 4/2, SM	***18.0***	***31.0***	***69.0***	***26.0***	***5.0***	***0.086***	***3Ag***				
silty sand, 10YR 3/3,SM	***19.5***	***49.0***	***51.0***	***43.0***	***6.0***	***0.063***	***3Ag***				
sand, 10YR 3/3, (SM)	***21.0***	***21.0***	***79.0***	***18.0***	***3.0***	***0.109***	***3Ag***				
clayey silt, 10YR 4/2, CL	22.8	96.0	4.0	66.0	30.0	0.012	3Ag	30.0	36.0	16.0	0.6
clayey silt, 10YR 4/2	24.5	97.0	3.0	71.0	26.0	0.013	3Ag	30.0			
silty clay, SYR 4/2	25.5	97.0	3.0	41.0	56.0	0.003	3Ag	28.0			
silty clay, SYR 4/2	27.5	99.0	1.0	28.0	71.0	0.001	3Ag	29.0			
clay, SYR 4/2, (CH)	30.0	98.0	2.0	23.0	75.0	0.001	3Ag	27.0	68.0	41.0	0.0
silty clay, SYR 4/2	33.0	98.0	2.0	29.0	69.0	0.002	3Ag	28.0			
clay, SYR 4/2, (CH)	36.0	99.0	1.0	11.0	88.0	0.001	3Ag	26.0	68.0	39.0	-0.1
silty clay, SYR 4/2	37.0	92.0	8.0	26.0	66.0	0.002	3Ag	31.0			
silt, (ML)	40.0	88.0	12.0	75.0	13.0	0.046	3Ag	26.0			
clayey silt	41.0	98.0	2.0	56.0	42.0	0.007	3Ag	25.0			
silt, 5Y 4/2, (ML)	44.0	97.0	3.0	79.0	18.0	0.023	3Ag	27.0	28.0	4.0	1.0
silt, 5Y 4/2, (ML)	46.5	96.0	4.0	86.0	10.0	0.030	3Ag	28.0			
clayey silt, 10YR 3.5/2	49.0	88.0	12.0	74.0	14.0	0.028	3Ag	30.0			
silt, 10YR 3.5/2, (ML)	51.5	96.0	4.0	84.0	12.0	0.022	3Ag	31.0			
silt, 10YR 3.5/2, (ML)	53.3	95.0	5.0	82.0	13.0	0.028	3Ag	29.0			
sandy silt, 10YR 3.5/2,	56.0	85.0	15.0	71.0	14.0	0.034	3Ag				
sandy silt, 10YR 3.5/2,	58.0	66.0	34.0	56.0	10.0	0.050	3Ag				
silty clay, SYR 4/2	58.8	95.0	5.0	31.0	64.0	0.002	3Ag				
silty sand, SYR 4/3, (SM)	59.5	49.0	51.0	39.0	10.0	0.063	3Ag				
clayey silt, SYR 4/2.5	61.0	94.0	6.0	66.0	28.0	0.015	3Ag	24.0			
clayey silt, SYR 4/2.5	62.5	97.0	3.0	73.0	24.0	0.018	3Ag	28.0			
sand, (SM)	66.0	14.0	86.0	14.0		0.114	3Ag				
silty sand, 7. SYR 4/2, (SM)	68.0	34.0	66.0	28.0	6.0	0.088	3Ag				
silty sand, 7. SYR 4/2, (SM)	70.0	53.0	47.0	41.0	12.0	0.056	3Ag				
silt, 7. SYR 4/2, (ML)	72.0	96.0	4.0	82.0	14.0	0.023	3Ag	31.0			
clayey silt, 7. SYR 4/2	73.0	96.0	4.0	69.0	27.0	0.013	3Ag	31.0			
clayey silt, SYR 4/2.5, (CL)	74.5	95.0	5.0	61.0	34.0	0.009	3Ag	31.0	33.0	12.0	0.8
clayey silt, SYR 4/2.5	76.5	90.0	10.0	61.0	29.0	0.013	3Ag				
sandy silt, (ML)	78.0	80.0	20.0	66.0	14.0	0.041	3Ag	24.0			
silty sand, (SM)	80.0	29.0	71.0	23.0	6.0	0.088	3Ag				
clayey silt	82.0	85.0	15.0	65.0	20.0	0.036	3Ag	25.0			
silty clay, 7. SYR 4/2	83.0	96.0	4.0	42.0	54.0	0.003	3Ag	33.0			
clayey silt, 7. SYR 4/2	84.0	99.0	1.0	59.0	40.0	0.010	3Ag	27.0			
silty clay, 7. SYR 4/2, (CH)	85.0	99.0	1.0	39.0	60.0	0.002	3Ag	32.0	51.0	27.0	0.3
silty clay, 7. SYR 4/2	86.5	98.0	2.0	48.0	50.0	0.004	3Ag	35.0			
Mean:	27.4	72.6	24.8	2.6	0.089						
St. Dev.	9.0	9.0	7.8	2.2	0.012						

Case number:	388
Earthquake:	2012 Emilia Earthquake
Magnitude:	Mw=6 (USGS) (ML=5.9) https://earthquake.usgs.gov/earthquakes/eventpage/usp000jkn8/executive
Location:	San Carlo M#5 BHM8 replace with BHM1-2, also included in "093-12 Mirabello stratigrafie.pdf") BH-614a,b,c
References:	Facciorusso et al. (2015)
Nature of Failure:	Noniquefied (May 20, 2020)-Nonliquefied (May 29, 2020)
GPS LAT	44.83
GPS LONG	11.464
Liq. layer consist of:	silty sand
Geological Unit:	paleo-Reno river levees (paleochannel)
Site Response Anlaysis:	No
Comments:	2012 Emilia Earthquake occured on May 20, 2012 in Northern Italy. The earthquake was followed by aftersocks including an aftershock on May 29 of magnitude Mw=5.8. Nonplastic silty sand layer is selected as the critical layer which is located at 15.5-24.5 m depth. PI and FC are assigned for the silty sand. USGS shakemap suggest relatively lower PGA values. However, the author suggests amax=0.16 g which is used in the analysis. No information regarding hammer type was provided. Hence it is assumed that a saftey hammer is used and an average value ofhammer efficiency value of 66% is assigned.
Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	No

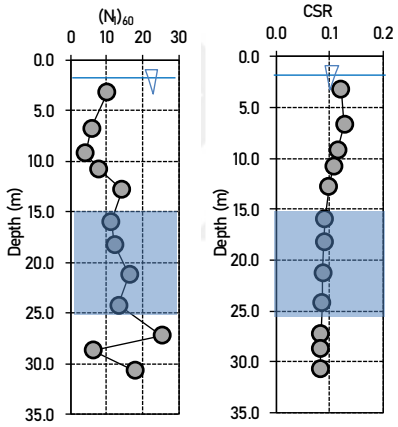
Summary of Input Data

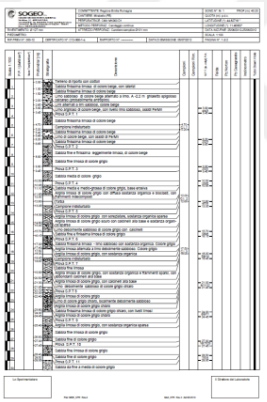
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	C
d_{crtc} range (m)	-	-	-	-	15.5 - 24.5
d_{crt} (m)	-	-	-	-	20.0
GWT (m)	-	-	-	-	2.0 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.4 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	406.3 ± 32.1
σ_v' (kPa)	-	-	-	-	229.4 ± 18.3
a_{max} (g)	-	-	-	-	0.160 ± 0.032
r_d	-	-	-	-	0.48 ± 0.149
CSR	-	-	-	-	0.089 ± 0.033
M_w	-	-	-	-	6.00
D_{50}	-	-	-	-	NAV
% Fines	-	-	-	-	12.0-50.0 ± 10.0
% PI	-	-	-	-	0-7
N	-	-	-	-	18.2 ± 3.0
C_R	-	-	-	-	1.00
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.10
C_N	-	-	-	-	0.67
$(N_1)_{60}$	-	-	-	-	13.3 ± 2.2
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	164.6

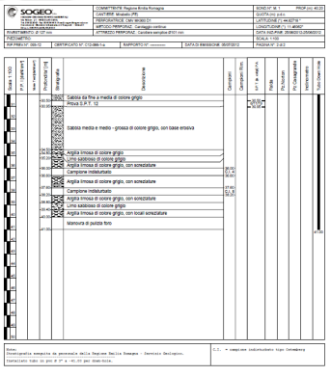
EVENT PARAMETERS

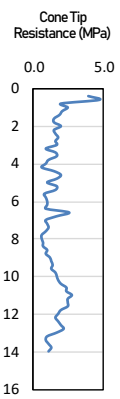
2012 Emilia Earthquake	Carydis et al. (2016)		R_x (km): 2.7
Magnitude: 6.00	depth (km): 6.3 (Nardis et al 2014,	hanging wall site	
Fault Type: upper crustal t	Z_{tor} (km): 0.5		R_{rup} (km): 2.4
Dip: 50	Width (km): 20		R_{jb} (km): 0.0

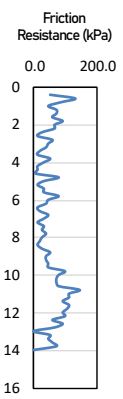
ACCELERATION TIME HISTORY

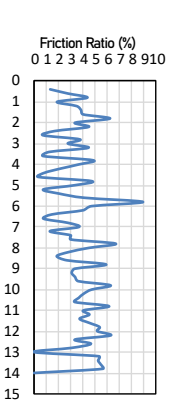












	Depth (m)	Depth (ft)	rd	CSR	N	C_N	C_R	$(N1)_{60}$	
clayey silt-fine silty sand	3.2	10.5	0.938	0.12	7	1.46	0.90	10.0	RF>3 %
silt	6.7	22.0	0.803	0.13	5	1.09	0.95	5.7	transition zone, clayey ?
sand	9.2	30.2	0.685	0.12	4	0.95	0.97	4.1	RF>3 %
silty clay-sand	10.7	35.1	0.623	0.11	8	0.89	0.98	7.6	
silty clay-sand	12.8	42.0	0.558	0.10	16	0.82	0.99	14.2	
silty sand	***15.9***	***52.2***	***0.507***	***0.09***	***14***	***0.74***	***0.99***	***11.3***	
silty sand	***18.2***	***59.7***	***0.490***	***0.09***	***16***	***0.70***	***1.00***	***12.2***	
silty sand	***21.2***	***69.6***	***0.478***	***0.09***	***23***	***0.65***	***1.00***	***16.3***	
silty sand	***24.2***	***79.4***	***0.464***	***0.09***	***20***	***0.61***	***1.00***	***13.4***	
silty sand	27.2	89.2	0.450	0.08	40	0.58	1.00	25.3	outlier
silty sand	28.7	94.2	0.443	0.08	10	0.56	1.00	6.2	outlier
sand	30.7	100.7	0.434	0.08	30	0.54	1.00	17.9	
							Mean:	13.3	
							St. Dev.	2.2	

limo=silt
sabbida=sand
argilla=clay
ghiaia=gravel

Case number:	389
Earthquake:	2012 Emilia Earthquake-AS
Magnitude:	Mw=5.8 (ML=5.8)
Location:	San Carlo M#5 BHM8 replace with BHM1-2, also included in "093-12 Mirabello stratigrafie.pdf") BH-614a,b,c
References:	Facciorusso et al 2015
Nature of Failure:	Noniquefied (May 20, 2020)-Nonliquefied (May 29, 2020)
GPS LAT	44.83
GPS LONG	11.464
Liq. layer consist of:	silty sand
Geological Unit:	paleo-Reno river levees (paleochannel)
Site Response Anlaysis:	No
Comments:	2012 Emilia Earthquake occured on May 20, 2012 in Northern Italy. The earthquake was followed by aftersocks including an aftershock on May 29 of magnitude Mw=5.8. Nonplastic silty sand layer is selected as the critical layer which is located at 15.5-24.5 m depth. PI and FC are assigned for the silty sand. USGS shakemap suggest relatively lower PGA values. However, the author suggests amax=0.08 g which is used in the analysis. No information regarding hammer type was provided. Hence it is assumed that a saftey hammer is used and an average value ofhammer efficiency value of 66% is assigned.
Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	No

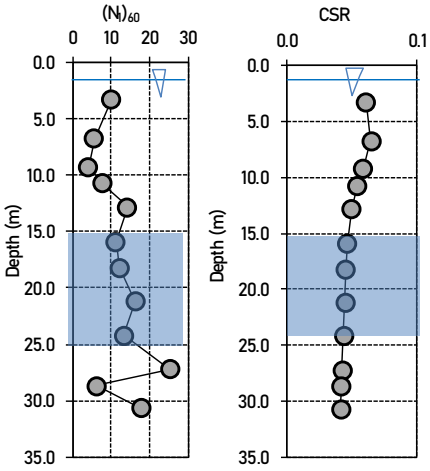
Summary of Input Data

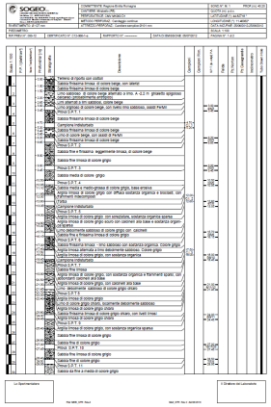
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	C
d_{crtc} range (m)	-	-	-	-	15.5 - 24.5
d_{crt} (m)	-	-	-	-	20.0
GWT (m)	-	-	-	-	2.0 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.4 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	406.3 ± 32.1
σ_v' (kPa)	-	-	-	-	229.4 ± 18.3
a_{max} (g)	-	-	-	-	0.080 ± 0.016
r_d	-	-	-	-	0.49 ± 0.149
CSR	-	-	-	-	0.045 ± 0.016
M_w	-	-	-	-	5.80
D_{50}	-	-	-	-	NAV
% Fines	-	-	-	-	12.0-50.0 ± 10.0
% PI	-	-	-	-	0-7
N	-	-	-	-	18.2 ± 3.0
C_R	-	-	-	-	1.00
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.10
C_N	-	-	-	-	0.67
$(N_1)_{60}$	-	-	-	-	13.3 ± 2.2
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	164.6

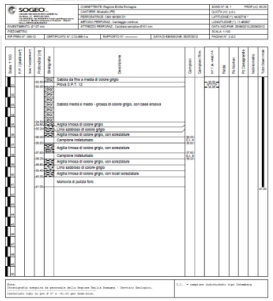
EVENT PARAMETERS

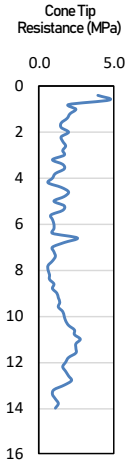
2012 Emilia Earthquake-AS	Carydis et al 2016	R_x (km): -
Magnitude: 5.80	depth (km): 10 (Nardis et al 2014)	hanging wall site
Fault Type: upper crustal tl	Z_{tor} (km): 1	R_{rup} (km): 20.8
Dip: 64	Width (km): 20	R_{jb} (km): 20.8

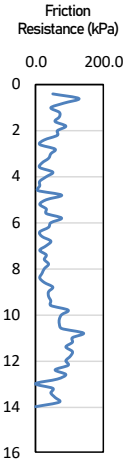
ACCELERATION TIME HISTORY

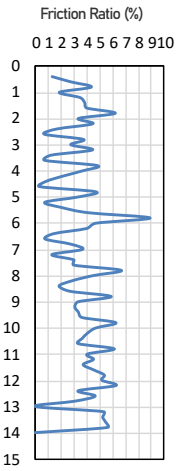












	Depth (m)	Depth (ft)	rd	CSR	N	C_N	C_R	$(N1)_{60}$	
clay-fine silty sand	3.2	10.5	0.938	0.06	7	1.46	0.90	10.0	RF>3 %
silt	6.7	22.0	0.804	0.06	5	1.09	0.95	5.7	transition zone, clayey ?
sand	9.2	30.2	0.686	0.06	4	0.95	0.97	4.1	RF>3 %
silty clay-sand	10.7	35.1	0.624	0.05	8	0.89	0.98	7.6	
silty clay-sand	12.8	42.0	0.560	0.05	16	0.82	0.99	14.2	
silty sand	***15.9***	***52.2***	***0.509***	***0.05***	***14***	***0.74***	***0.99***	***11.3***	
silty sand	***18.2***	***59.7***	***0.492***	***0.05***	***16***	***0.70***	***1.00***	***12.2***	
silty sand	***21.2***	***69.6***	***0.480***	***0.04***	***23***	***0.65***	***1.00***	***16.3***	
silty sand	***24.2***	***79.4***	***0.466***	***0.04***	***20***	***0.61***	***1.00***	***13.4***	
silty sand	27.2	89.2	0.452	0.04	40	0.58	1.00	25.3	outlier
silty sand	28.7	94.2	0.445	0.04	10	0.56	1.00	6.2	outlier
sand	30.7	100.7	0.436	0.04	30	0.54	1.00	17.9	
							Mean:	13.3	
							St. Dev.	2.2	

limo=silt
sabbida=sand
argilla=clay
ghiaia=gravel

Case number:	367
Earthquake:	2013 Obihiro - Hokkaido Earthquake
Magnitude:	6.9
Location:	Hakodate
References:	Iai. et. al. (1989), Greenfield (2017, 2018), NGL Project
GPS LAT	42.8542
GPS LONG	143.8579
Liq. layer consist of:	Silt
Geological Unit:	Quaternary terrace deposits of the Shiranuka Formation
Site Response Anlaysis:	No
Nature of Failure:	No liquefaction observations
Comments:	Greenfield (2018) "A strong motion recorder, HKD086, was installed near the Chokubetsu Train Station as part of Japan's National Research Institute for Earth Science and Disaster Resilience (NIED) K-net strong motion network. The K-net database lists the shear wave velocity in the upper 30 m, vs,30, of the HKD086 site as 205 m/s. This vs,30 value indicates HKD086 is founded on site class D soil. NIED performed an investigation prior to the installation of HKD086..... The Mw = 6.9 Obihiro, Japan earthquake occurred on February 2, 2013. According to the USGS ShakeMap, the initial rupture of the 2013 Obihiro, Japan earthquake occurred at a depth of 107 km. The epicenter of the rupture was 63 km east of HKD086. The event was very deep and is not listed in the NGA West-2 database for shallow crustal ground motions. The strong motion recorder HKD086 recorded ground motions during the 2013 Obihiro, Japan earthquake and these motions have processed and cataloged in the K-net database...."
	SPT procedures were not clearly documented. However, on page 66 in Iai et. al. for comparison with Seed et. al. 1985, an average Japanese SPT energy ratio of 73% was reported to be used. On the basis of this, with some uncertainty Iai et. al. N values may be adopted as N73 values. Note that Seed et. al. (1985) adopted an energy ratio of 73% for liquefied cases. The rationale behind this choice could be field data which is unknown to us or simply a conservative engineering judgement. Back in 2018 the site was rejected due to missing soil layering information, now it is available thus the site is included. Greenfield (2018) reported amax as 0.356g. Greenfield (2017) performed analysis to determine the time of liquefaction which in turn calculated as 35 s. The number of cycles and corresponding M is calculated. amax is determined from the a-t histories as 0.34 g and 0.377 g geometric mean of whic is 0.358 g. This values is used in the analysis. This value is very high to perform deconvolution analysis (limitiation of EQL analysis) as a result CSR is estimated by simplified procedure. PI info were not available hence assigned based on USCS.
Gravel Content (%):	NAV
CPT available:	No
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{cr1c} range (m)	-	-	-	-	2.5 - 14.0
d_{cr1} (m)	-	-	-	-	8.3
GWT (m)	-	-	-	-	1.6 ± 0.5
g_{moist} (kN/m^3)	-	-	-	-	18.1 ± 0.5
g_{sat} (kN/m^3)	-	-	-	-	19.6 ± 0.5
s_v (kPa)	-	-	-	-	159.9 ± 37.9
s_v' (kPa)	-	-	-	-	94.5 ± 19.6
a_{max} (g)	-	-	-	-	0.358 ± 0.018
r_d	-	-	-	-	0.57 ± 0.107
CSR	-	-	-	-	0.223 ± 0.046
M_w	-	-	-	-	6.90
D_{50}	-	-	-	-	NAV
% Fines	-	-	-	-	50.7 ± 41.6
% PI	-	-	-	-	NAV
N	-	-	-	-	9.1 ± 3.6
C_R	-	-	-	-	0.97
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.37
C_N	-	-	-	-	1.04
$(N_1)_{60}$	-	-	-	-	12.5 ± 4.9
V_{s30m} (m/s)	-	-	-	-	205.0
V_{s12m} (m/s)	-	-	-	-	127.4

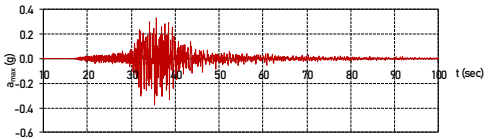
EVENT PARAMETERS

2013 Obihiro - Hokkaido Earthquake — The epicenter of the rupture was 63 km
Magnitude: 6.90 — https://earthquake.usgs.gov/earthquakes/eventpage/usc00
Fault Type: subcrustal and — Z_{tor} (km): - — R_{rup} (km): NAV
Dip: 6--86 — Width (km): - — R_{jb} (km): NAV

ACCELERATION TIME HISTORY

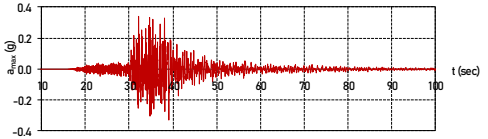
Full Record

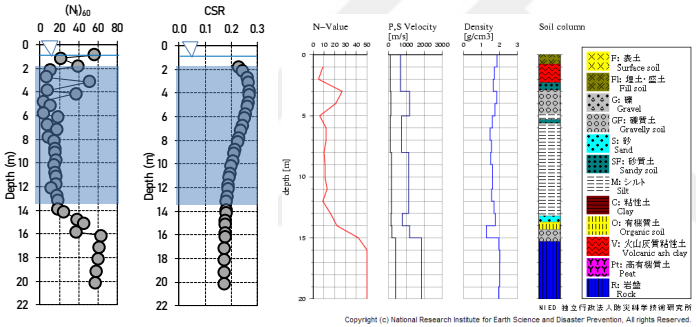
N_{H1}	42.1
N_{H2}	29.1
N_{gm}	35.0
PGA_{H1}	0.340
PGA_{H2}	0.377
PGA	0.358
M_w	6.9
$M_{w,cycle}$	8.7

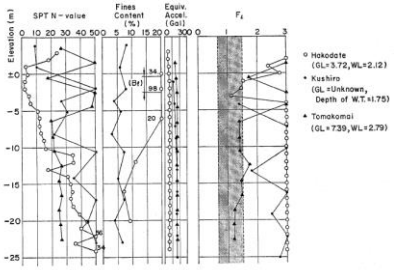


Untill Liquefaction

$N_{H1,L}$	
$N_{H2,L}$	
$N_{gm,L}$	
PGA_{H1}	
PGA_{H2}	
PGA_L	
$M_{w,eq}$	
t_L	







(b) Hakodate, Kushiro, and Tomakomai (Nonliquefied)

Fig. 13. Ground conditions and resulted liquefaction potentials at other strong-motion observation stations

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	FC		
lai. et. al. (1989)	0.86	2.81	NA	24	2.00	0.85	56	-		
From K-net boring log	1.15	3.77	NA	9	2.00	0.86	21	-	Volcanic Ash Clay	
lai. et. al. (1989)	1.81	5.94	0.23	18	1.81	0.88	39	-		
From K-net boring log	2.15	7.05	0.24	5	1.72	0.89	10	-	Volcanic Ash Clay	
lai. et. al. (1989)	***2.74***	***8.98***	***0.26***	***3***	***1.59***	***0.90***	***6***	***-***		
From K-net boring log	***3.15***	***10.33***	***0.27***	***27***	***1.51***	***0.91***	***51***	***-***	***Silty gravel***	outlier
lai. et. al. (1989)	***3.85***	***12.63***	***0.27***	***4***	***1.41***	***0.92***	***7***	***34***		
From K-net boring log	***4.15***	***13.62***	***0.27***	***21***	***1.37***	***0.92***	***36***	***-***	***Silty gravel***	outlier
lai. et. al. (1989)	***4.78***	***15.69***	***0.27***	***2***	***1.30***	***0.93***	***3***	***-***		
From K-net boring log	***5.15***	***16.90***	***0.26***	***6***	***1.26***	***0.94***	***10***	***-***	***Silt***	
lai. et. al. (1989)	***5.79***	***19.00***	***0.26***	***2***	***1.20***	***0.95***	***3***	***98***		
From K-net boring log	***6.15***	***20.18***	***0.25***	***12***	***1.17***	***0.95***	***18***	***-***	***Silty Sand***	
lai. et. al. (1989)	***6.75***	***22.16***	***0.24***	***5***	***1.13***	***0.96***	***7***	***-***		
From K-net boring log	***7.15***	***23.46***	***0.24***	***12***	***1.10***	***0.96***	***17***	***-***	***Silt***	
lai. et. al. (1989)	***7.78***	***25.54***	***0.23***	***6***	***1.06***	***0.96***	***8***	***-***		
From K-net boring log	***8.15***	***26.74***	***0.22***	***10***	***1.04***	***0.97***	***14***	***-***	***Silt***	
lai. et. al. (1989)	***8.81***	***28.91***	***0.22***	***11***	***1.01***	***0.97***	***15***	***-***		
From K-net boring log	***9.15***	***30.02***	***0.21***	***11***	***0.99***	***0.97***	***14***	***-***	***Silt***	
lai. et. al. (1989)	***9.74***	***31.97***	***0.21***	***12***	***0.96***	***0.98***	***15***	***20***		
From K-net boring log	***10.15***	***33.30***	***0.20***	***11***	***0.95***	***0.98***	***14***	***-***	***Silt***	
lai. et. al. (1989)	***10.81***	***35.46***	***0.20***	***12***	***0.92***	***0.98***	***15***	***-***		
From K-net boring log	***11.15***	***36.58***	***0.19***	***13***	***0.91***	***0.98***	***16***	***-***	***Silt***	
lai. et. al. (1989)	***11.79***	***38.67***	***0.19***	***13***	***0.89***	***0.98***	***15***	***-***		
From K-net boring log	***12.15***	***39.86***	***0.19***	***9***	***0.87***	***0.99***	***11***	***-***	***Silt***	
lai. et. al. (1989)	***12.80***	***42.00***	***0.18***	***15***	***0.85***	***0.99***	***17***	***-***		
From K-net boring log	***13.15***	***43.14***	***0.18***	***16***	***0.84***	***0.99***	***18***	***-***	***Silt***	
lai. et. al. (1989)	***13.92***	***45.67***	***0.18***	***16***	***0.82***	***0.99***	***18***	***-***		
From K-net boring log	14.15	46.42	0.18	22	0.82	0.99	24	-	Organic soil	
lai. et. al. (1989)	14.78	48.48	0.18	35	0.80	0.99	38	-		
From K-net boring log	15.15	49.70	0.18	42	0.79	0.99	45	-	Silty Gravel	
lai. et. al. (1989)	15.83	51.94	0.18	35	0.77	0.99	37	-		
From K-net boring log	16.15	52.99	0.18	60	0.77	0.99	63	-	Rock	
From K-net boring log	17.15	56.27	0.17	60	0.75	0.99	61	-	Rock	
From K-net boring log	18.15	59.55	0.17	60	0.73	1.00	59	-	Rock	
From K-net boring log	19.15	62.83	0.17	60	0.71	1.00	58	-	Rock	
From K-net boring log	20.15	66.11	0.17	60	0.69	1.00	57	-	Rock	
					Mean:		**12.5**	**50.7**		
					St. Dev.		**4.9**	**41.6**		

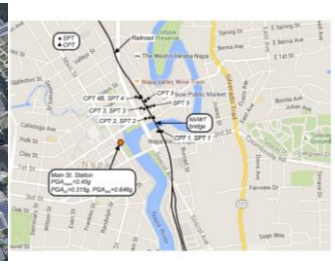
GWT (m)

1.6	lai et al Borehole
4	Inferred from increased P-wave velocity in B-1

Depth (m)	Vs (m/s)	Vp (m/s)	time (s)
1	105	670	0.0095
2	105	670	0.0095
3	105	670	0.0095
4	135	1180	0.0074
5	135	1180	0.0074
6	110	730	0.0091
7	110	730	0.0091
8	110	730	0.0091
9	170	1130	0.0059
10	170	1130	0.0059
11	170	1130	0.0059
12	170	1130	0.0059
13	170	1130	
14	150	770	
15	190	1180	
16	400	1850	
17	400	1850	
18	400	1850	
19	400	1850	
20	400	1850	
		$V_{S,12m}$ (m/s)	127.4

Case number:	341
Earthquake:	2014 Napa Earthquake
Magnitude:	6.0
Location:	Napa Valley Wine Train (NVWT) bridge
References:	Darby et al. (2017), GEER (2014)
Nature of Failure:	There were ground deformations, cracks, or differential settlements at or near the bridge abutments on either side of the channel after 2014 Napa Earthquake. No sand boils or water ejecta was reported by GEER 2014.
GPS LAT	38.2989
GPS LONG	-122.282139
Liq. layer consist of:	poorly graded clayey sand
Geological Unit:	fluvial deposits
Site Response Anlaysis:	No
Comments:	CPT and SPT data are available for the site. Equivalent linear site response analyses were performed by Darby et al. (2017). NAPA earthquake produced PGA ranging from 0.36-0.65 g at three recording station within 5 km of the bridge. PGA at the sites is estimated about 0.47 g by USGS-CISN ShakeMap. The closest station is USGS-NCSN station N016 which is 270 m away from the site and recorded two horizantal component as 0.315 g and 0.646 g. The geometric mean is calculated as 0.451 g which is used in the analysis. Vs12m is calculated based on the correlation between Vs-SPTN. "5 CPT and 5 borehole data are avaiable for the site (Taber 2007). 10.2 cm diameter continuous flight auger for shallow holes above GWT and 7.6 cm diamater mud rotary drilling for greater depths were used. The SPT tests were obtained using 5.1 cm outside diameter standard split spoon samplers with liners. An automatic-trip hammer with and energy ration of 74% was used. CPT is peformed accordingly with ASTM D5778. CPT 1 is referred as point bar side and CPT3 as cut bank side. Qa3 (poorly graded clayeyd sand FC=9-16 %) is determined as the critical layer. Qa3: poorly graded clayey sand, FC=9-15 %...."Darby et al. (2017). Vs measurements were available at the SMS. Focal dept was 10.7 km and co-seismic surface rupture length was greater than 12.5 km (USGS).





Gravel Content (%):	NAV
CPT available:	Yes
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	A
d_{crtc} range (m)	-	-	-	-	5.9 - 12.1
d_{crt} (m)	-	-	-	-	9.0
GWT (m)	-	-	-	-	4.9 ± 0.2
γ_{moist} (kN/m^3)	-	-	-	-	20.0 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	21.5 ± 0.5
σ_v (kPa)	-	-	-	-	186.0 ± 22.4
σ_v' (kPa)	-	-	-	-	145.5 ± 12.6
a_{max} (g)	-	-	-	-	0.451 ± 0.023
r_d	-	-	-	-	0.98 ± 0.115
CSR	-	-	-	-	0.369 ± 0.049
M_w	-	-	-	-	6.00
D_{50}	-	-	-	-	NAV
% Fines	-	-	-	-	12.0 ± 4.2
% PI	-	-	-	-	0
N	-	-	-	-	32.2 ± 7.8
C_R	-	-	-	-	0.97
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.23
C_N	-	-	-	-	0.84
$(N_1)_{60}$	-	-	-	-	32.1 ± 7.8
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	274.3

EVENT PARAMETERS

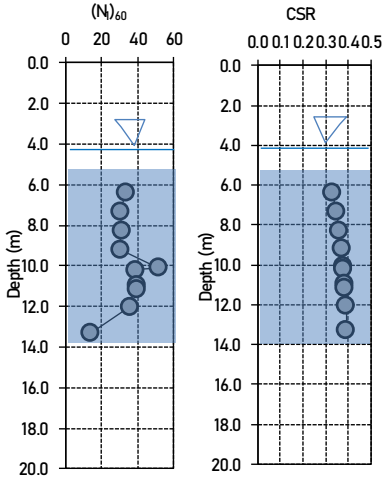
2014 Napa Earthquake

Magnitude: 6.00

Fault Type: Right-lateral st | Z_{tor} (km): 0 | R_{rup} (km): 4.5

Dip: 82 | Width (km): 7? Floyd et al (2016) | R_{jb} (km): 4.5

ACCELERATION TIME HISTORY



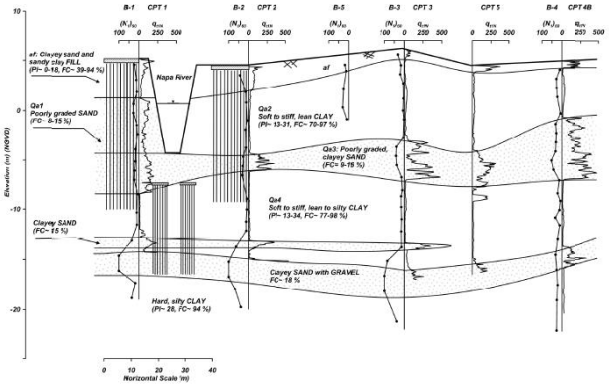


Figure 3. Cross section along the bridge and railroad alignment.

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$			
6.39	***21.0***	***0.329***	***30***	***0.94***	***0.95***	***33.2***	***B-4***	***Qa3***	poorly graded clayey sand FC=9-15 %
7.29	***23.9***	***0.346***	***28***	***0.90***	***0.96***	***30.0***	***B-4***	***Qa3***	poorly graded clayey sand FC=9-15 %
8.28	***27.2***	***0.360***	***30***	***0.86***	***0.96***	***30.9***	***B-4***	***Qa3***	poorly graded clayey sand FC=9-15 %
9.18	***30.1***	***0.371***	***30***	***0.83***	***0.97***	***29.9***	***B-4***	***Qa3***	poorly graded clayey sand FC=9-15 %
10.09	*33.1*	0.379	53	0.80	0.97	51.2	B-4	Qa3	poorly graded clayey sand FC=9-15 %
10.18	***33.4***	***0.380***	***40***	***0.80***	***0.98***	***38.6***	***B-3***	***Qa3***	poorly graded clayey sand FC=9-15 %
10.96	***36.0***	***0.385***	***42***	***0.78***	***0.98***	***39.0***	***B-4***	***Qa3***	poorly graded clayey sand FC=9-15 %
11.13	***36.5***	***0.386***	***42***	***0.77***	***0.98***	***38.7***	***B-3***	***Qa3***	poorly graded clayey sand FC=9-15 %
12.03	***39.5***	***0.389***	***39***	***0.75***	***0.98***	***35.2***	***B-3***	***Qa3***	poorly graded clayey sand FC=9-15 %
13.30	***43.6***	***0.391***	***16***	***0.72***	***0.99***	***13.8***	***B-3***	***Qa3***	poorly graded clayey sand FC=9-15 %
					Mean:	32.1			
					St. Dev.	7.8			

af: clayey sand and sandy clay FILL, PI= 0-18, FC=39-94 %
Qa1: poorly graded sand FC: 8-15 %
Qa2: Soft to stiff, lean clay PI=13-31, FC=70-97 %
Qa3: poorly graded clayey sand, FC=9-15 %
Qa4: soft to stiff, lean to silty clay PI=13-34, FC=77-98 %
Clayey sand FC=15 %
Clayey sand with gravel FC=18 %
Hard, silty clay PI=28, FC=94 %

B-4 SPT	B-4 depth
9	0.83
29	1.81
29	2.68
23	3.67
5	5.33
30	6.39
28	7.29
30	8.28
30	9.18
53	10.09
42	10.96
11	12.06
22	13.38
7	14.14
11	15.04
34	15.84
9	16.59
20	17.95
32	19.50
26	21.02
20	22.56
25	24.11
25	27.14

B-3 SPT	B-3 depth
34	0.91
19	1.94
22	2.87
5	3.79
5	5.34
7	6.55
4	7.45
8	9.32
40	10.18
42	11.13
39	12.03
16	13.30
12	14.63
17	15.17
16	16.29
14	17.53
17	18.73
14	20.27
84	21.65
99	23.16
100	24.68
40	27.78

	GWT	
SPT-1	4.6	m
SPT-2	3.9	m
SPT-3	5.4	m
SPT-4	4.3	m

Case number:	371
Earthquake:	2015 Gorkha (Nepal) Earthquake
Magnitude:	7.8
Location:	Duwakot
References:	Sharma et al. (2017), Wei et al. (2018)
Nature of Failure:	Extensive liquefaction was observed in Duwakot
GPS LAT	27.75495
GPS LONG	85.31559
Liq. layer consist of:	Silty sand (SM)
Geological Unit:	lacustral and fluvial in origin, sand pit site
Site Response Anlaysis:	No
Comments:	The following information is retrieved from Sharma et al. (2017). "Extensive liquefaction was observed in Duwakot near Nepal Engineering College on the left bank of Manohara River. The survey team travelled around the Kathmandu Valley during April 28 and 9 May 2015, and observed that the liquefaction triggered by the 2015 Gorkha earthquake appeared to be very limited. The localised areas where liquefaction was observed are Manamaiju, Ramkota, Bungmati, Hattiban, Imadol, Mulpani and Duwakot. Liquefied sites during the main shock of Gorkha earthquake were revisited after Mw 7.3 aftershock on May 12. However, none of the sites showed the recurrent liquefaction phenomenon.". "...There are only several accelerogram stations in the Kathmandu Valley when the earthquake occurred. ATNP station was established by US Geological Survey (USGS) at Kanti Path, Kathmandu and the acceleration records are publicly available. The KATNP station is located on the top of a thick soft sedimentary soil layer of about 300 m thickness. The shear wave velocity Vs30 at the KATNP station is 250 m/s.". amax is estimated as 0.47g from USGS map. KATNP is the closest SMS located 4.5 km away from the site and SMS is located on soil site. (also free field, some of the stations are located in the basement of buildings hence not used). PGA is recorded at the SMS as 0.164 g (geometric mean of 158 and 164 cm/s2). Both site and SMS have Rrup as 0 km and has similar Vs values hence PGA is taken as same.
	https://earthquake.usgs.gov/earthquakes/eventpage/us20002926/executive
	
Gravel Content (%):	0
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.2 - 8.0
d_{crt} (m)	-	-	-	-	5.1
GWT (m)	-	-	-	-	1.5 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	17.3 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	18.9 ± 0.5
σ_v (kPa)	-	-	-	-	94.1 ± 18.4
σ_v' (kPa)	-	-	-	-	58.3 ± 9.0
a_{max} (g)	-	-	-	-	0.164 ± 0.049
r_d	-	-	-	-	0.89 ± 0.071
CSR	-	-	-	-	0.152 ± 0.048
M_w	-	-	-	-	7.80
D_{50}	-	-	-	-	0.200 ± 0.050
% Fines	-	-	-	-	18.0 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	5.7 ± 0.5
C_R	-	-	-	-	0.93
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.22
C_N	-	-	-	-	1.32
$(N_1)_{60}$	-	-	-	-	8.5 ± 0.8
V_{s30m} (m/s)	-	-	-	-	NA
V_{s12m} (m/s)	-	-	-	-	159.7

EVENT PARAMETERS

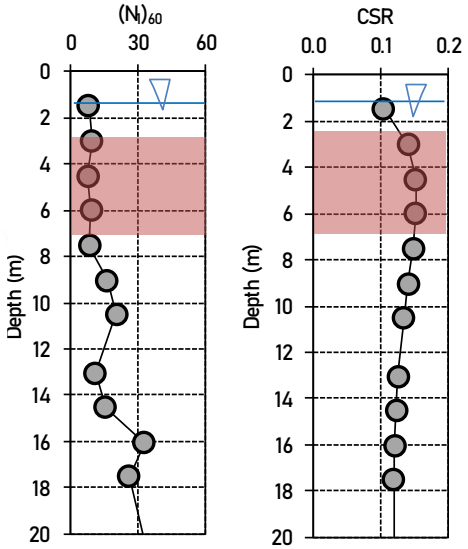
2015 Gorkha (Nepal) Earthquake

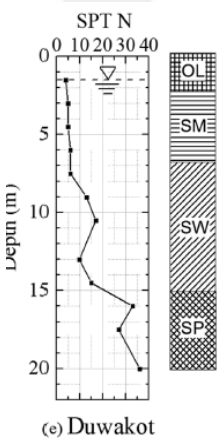
Magnitude: 7.80 Kobayashi et al 2015 and USGS

Fault Type: thrust faulting Z_{tor} (km): unknown R_{rup} (km): NAV

Dip: 10 Width (km): 50-100 R_{jb} (km): 0.0

ACCELERATION TIME HISTORY





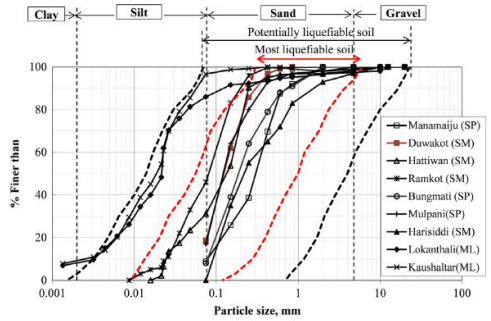
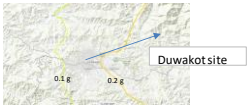


Figure 12. Particle size distribution of the ejected soil samples obtained at surveyed sites. Soils are classified according to USCS. Range of most liquefiable soil and potentially liquefiable soil after Tsuchida and Hayashi (1971).

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
OL	1.5	4.80	0.105	4	2.00	0.85	8.0
SM	***3.0***	***9.88***	***0.140***	***5***	***1.61***	***0.89***	***9.4***
SM	***4.5***	***14.82***	***0.151***	***5***	***1.38***	***0.92***	***7.5***
SM	***6.0***	***19.61***	***0.152***	***6***	***1.24***	***0.94***	***8.9***
SW	***7.5***	***24.69***	***0.147***	***6***	***1.12***	***0.96***	***8.3***
SW	9.0	29.63	0.141	13	1.04	0.97	16.1
SW	10.5	34.43	0.134	17	0.97	0.98	20.1
SW	13.0	42.76	0.125	10	0.88	0.99	10.9
SW	14.5	47.70	0.123	15	0.84	0.99	15.5
SP	16.0	52.63	0.121	34	0.80	0.99	32.7
SP	17.5	57.43	0.120	28	0.77	0.99	25.7
SP	20.0	65.76	0.119	36	0.72	1.00	32.0
						Mean:	8.5
						St. Dev.	0.8

Sharma et al. (2017) "The soil investigations were conducted nearby the liquefied sites or on the same flood plain of the liquefied sites. Although the investigated sites were not exactly located at the liquefied soil sites reported in present research, the subsurface conditions provide an insight into the soil characteristics of liquefied sites and the subsequent assessment of the liquefaction susceptibility can therefore be conducted." The SPT is located 270 m away from the site.

Case number:	372
Earthquake:	2015 Gorkha (Nepal) Earthquake Aftershock
Magnitude:	7.3
Location:	Duwakot
References:	Sharma et al 2017, USGS
Nature of Failure:	Extensive liquefaction was found in Duwakot
GPS LAT	27.75495
GPS LONG	85.31559
Liq. layer consist of:	Silty sand (SM)
Geological Unit:	lacustral and fluvial in origin, sand pit site
Site Response Anlaysis:	No
Comments:	The following information is retrieved from Sharma et al. (2017). "Extensive liquefaction was observed in Duwakot near Nepal Engineering College on the left bank of Manohara River. The survey team travelled around the Kathmandu Valley during April 28 and 9 May 2015, and observed that the liquefaction triggered by the 2015 Gorkha earthquake appeared to be very limited. The localised areas where liquefaction was observed are Manamaiju, Ramkota, Bungmati, Hattiban, Imadol, Mulpani and Duwakot. Liquefied sites during the main shock of Gorkha earthquake were revisited after Mw 7.3 aftershock on May 12. However, none of the sites showed the recurrent liquefaction phenomenon.". "...There are only several accelerogram stations in the Kathmandu Valley when the earthquake occurred. ATNP station was established by US Geological Survey (USGS) at Kanti Path, Kathmandu and the acceleration records are publicly available. The KATNP station is located on the top of a thick soft sedimentary soil layer of about 300 m thickness. The shear wave velocity Vs30 at the KATNP station is 250 m/s.". amax is estimated as 0.15 g from USGS map. KATNP is the closest SMS located 4.5 km away from the site and SMS is located on soil site. (also free field, some of the stations are located in the basement of buildings hence not used). PGA is recorded at the SMS as 0.078 g (geometric mean of 0.071 g and 0.087 g). Both site and SMS Rrup 0 and has similar Vs values hence PGA is taken as same.
	https://earthquake.usgs.gov/earthquakes/eventpage/us20002ejl/executive#general_summary
	
Gravel Content (%):	0
CPT available:	No
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.2 - 8.0
d_{crt} (m)	-	-	-	-	5.1
GWT (m)	-	-	-	-	1.5 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	19.6 ± 0.5
σ_v (kPa)	-	-	-	-	99.2 ± 19.1
σ_v' (kPa)	-	-	-	-	63.5 ± 9.7
a_{max} (g)	-	-	-	-	0.078 ± 0.023
r_d	-	-	-	-	0.88 ± 0.071
CSR	-	-	-	-	0.070 ± 0.022
M_w	-	-	-	-	7.30
D_{50}	-	-	-	-	0.200 ± 0.050
% Fines	-	-	-	-	18.0 ± 2.0
% PI	-	-	-	-	0
N	-	-	-	-	5.7 ± 0.5
C_R	-	-	-	-	0.90
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.22
C_N	-	-	-	-	1.27
$(N_1)_{60}$	-	-	-	-	7.9 ± 0.7
$V_{s,30m}$ (m/s)	-	-	-	-	NA
$V_{s,12m}$ (m/s)	-	-	-	-	159.7

EVENT PARAMETERS

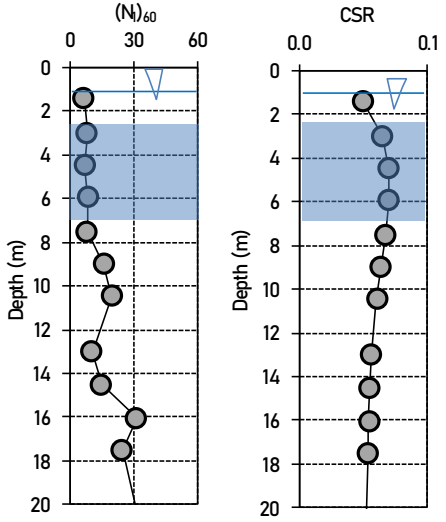
2015 Gorkha (Nepal) Earthquake Aftershock

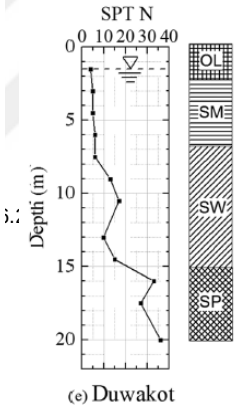
Magnitude: 7.30 Kobayashi et al 2015 and USGS

Fault Type: thrust faulting Z_{tor} (km): unknown R_{rup} (km): NAV

Dip: 10 Width (km): 50-100 R_{jb} (km): 0.0

ACCELERATION TIME HISTORY





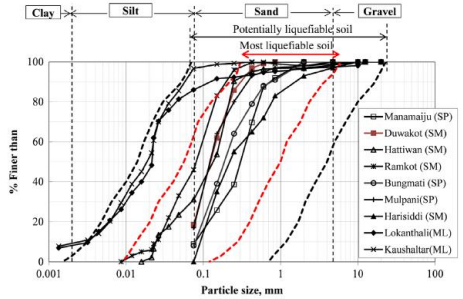


Figure 12. Particle size distribution of the ejected soil samples obtained at surveyed sites. Soils are classified according to *USCS*. Range of most liquefiable soil and potentially liquefiable soil after Tsuchida and Hayashi (1971).

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$
OL	1.5	4.8	0.05	4	1.92	0.72	7
SM	***3.0***	***9.9***	***0.07***	***5***	***1.54***	***0.82***	***8***
SM	***4.5***	***14.8***	***0.07***	***5***	***1.33***	***0.88***	***7***
SM	***6.0***	***19.6***	***0.07***	***6***	***1.19***	***0.93***	***8***
SW	***7.5***	***24.7***	***0.07***	***6***	***1.08***	***0.98***	***8***
SW	9.0	29.6	0.06	13	1.00	1.00	16
SW	10.5	34.4	0.06	17	0.93	1.00	20
SW	13.0	42.8	0.06	10	0.85	1.00	11
SW	14.5	47.7	0.05	15	0.81	1.00	15
SP	16.0	52.6	0.05	34	0.77	1.00	32
SP	17.5	57.4	0.05	28	0.74	1.00	25
SP	20.0	65.8	0.05	36	0.69	1.00	31
						Mean:	7.9
						St. Dev.	0.7

Sharma et al. (2017) "The soil investigations were conducted nearby the liquefied sites or on the same flood plain of the liquefied sites. Although the investigated sites were not exactly located at the liquefied soil sites reported in present research, the subsurface conditions provide an insight into the soil characteristics of liquefied sites and the subsequent assessment of the liquefaction susceptibility can therefore be conducted." The SPT is located 270 m away from the site.

Case number:	348
Earthquake:	2016 Kaikoura Earthquake
Magnitude:	7.8
Location:	Centre Port Wellington King's Wharf
References:	Bray et al. (2018, 2019), Cubrinovski et al. (2018), Brendon et al. (2017)
Nature of Failure:	"....significant liquefaction of reclaimed land and liquefaction induced ground deformations..." Bray et al. (2018)
GPS LAT	-41.2791906 approximate coordinates
GPS LONG	174.7850573 approximate coordinates
Liq. layer consist of:	Sand-Fines-Gravel
Geological Unit:	reclaimed land
Site Response Anlaysis:	No
Comments:	Significant liquefaction was observed in the reclaimed land in CentrePort Wellington after 2016 Kaikoura earthquake (Mw=7.8). The liquefaction caused settlement of the fill and lateral movement. "..Seaward displacements along Kings Wharf were measured to be 0.5 m to 1.4 m, along Thorndon Wharf to be 0.3 m to 1.0 m, and along Thorndon Extension to be 1.0 m to 1.5 m." Bray et al. (2018). Following information is retrieved also from Bray et al. (2018): Site investigation is performed after the earthquake event. SPT, CPT and Vs data are available. The reclaimed land is constructed with two method: 1) hydraulic fills constructed using dredged material (sandy and silty soils) from the original seabed. 2) end-tipping, in which gravelly soils from nearby quarries were dumped into the sea from truck and barge operations The thickness of the fill is about 10 m thick in the south of the buried seawall and increases to 20 m southwards. The fill is underlained by 1-5 m thick marine sediments which is underlained by 75-135 m Wellington Alluvium. GEER teams conducted field studies after the earthquake. Surface manifestations in the form of soil ejecta was observed. Thorndon Container Wharf and Kings Wharf suffered liuefaction induced damage. Samples are collected from the ejected soils. The grain size distribution curves on ejected samples reveals that reclamation fill is liquefied At Thorndon's Wharf. Samples suggests that marine deposit most likely liquefied at King's wharf Cubrinovski et al. (2018) suggests peak ground accelerations (PGA) from 0.074 g at the rock outcrop was amplified to 0.15-0.20 g at the native soils sites, and 0.24 g at the reclaimed sites. CPLB station is located 150 m and 400 m away from King's and Thorndon's Wharves located on the same reclamied area. Geometric mean of the two horizantal component is 0.235 g which is used in the analysis.
Gravel Content (%):	0-20
CPT available:	Yes
Vs available:	No

Summary of Input Data

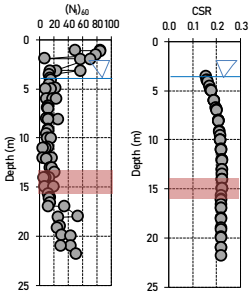
Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	11.5 - 16.5
d_{crt} (m)	-	-	-	-	14.0
GWT (m)	-	-	-	-	3.5 ± 0.9
γ_{moist} (kN/m^3)	-	-	-	-	20.0 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	286.6 ± 18.0
σ_v' (kPa)	-	-	-	-	183.2 ± 13.4
a_{max} (g)	-	-	-	-	0.235 ± 0.047
r_d	-	-	-	-	0.93 ± 0.149
CSR	-	-	-	-	0.222 ± 0.058
M_w	-	-	-	-	7.80
D_{50}	-	-	-	-	0.4-0.6 ± 0.050
% Fines	-	-	-	-	12.0-38.0 ± 7.0
% PI	-	-	-	-	0
N	-	-	-	-	12.4 ± 6.5
C_R	-	-	-	-	0.99
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.00
C_N	-	-	-	-	0.74
$(N_1)_{60}$	-	-	-	-	9.1 ± 4.8
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	253.0

EVENT PARAMETERS

2016 Kaikoura Earthquake		a shallow dipping thrust fault connecting two shallow strike-slip faults			
Magnitude:	7.80		Wang et al (2018)		Geonet
Fault Type:	subduction syst	Z_{tor} (km):	0	R_{rup} (km):	-
Dip:	33.00	Width (km):	20.00	R_{jb} (km):	64.0

ACCELERATION TIME HISTORY

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
BH 3	1.07	3.51	NA	29	2.00	0.84	49	Compacted reclamation fill
BH1	1.07	3.51	NA	50	2.00	0.84	84	Compacted reclamation fill
BH 4	1.1	3.61	NA	50	2.00	0.84	84	Compacted reclamation fill
BH3	1.51	4.95	NA	50	1.83	0.85	78	Compacted reclamation fill
BH1	1.91	6.27	NA	5	1.63	0.86	7	Reclamation fill
BH 3	1.95	6.40	NA	41	1.61	0.87	57	Compacted reclamation fill
BH 4	1.95	6.40	NA	50	1.61	0.87	70	Compacted reclamation fill
BH 3	3.12	10.24	NA	20	1.28	0.89	23	Reclamation fill
BH 4	3.12	10.24	NA	12	1.28	0.89	14	Reclamation fill
BH3	3.12	10.24	NA	50	1.28	0.89	57	Compacted reclamation fill
BH1	3.56	11.68	0.15	12	1.20	0.90	13	Reclamation fill
BH 3	3.89	12.76	0.16	13	1.17	0.91	14	Reclamation fill
BH 4	4.03	13.22	0.16	15	1.16	0.91	16	Reclamation fill
BH3	4.55	14.93	0.17	12	1.12	0.92	12	Reclamation fill
BH1	4.84	15.88	0.18	21	1.10	0.93	21	Reclamation fill
BH 4	4.95	16.24	0.18	15	1.09	0.93	15	Reclamation fill
BH 3	5.02	16.47	0.18	8	1.09	0.93	8	Reclamation fill
BH 3	5.98	19.62	0.19	10	1.03	0.94	10	Reclamation fill
BH 4	5.98	19.62	0.19	18	1.03	0.94	17	Reclamation fill
BH3	6.01	19.72	0.19	24	1.02	0.94	23	Reclamation fill
BH1	6.67	21.88	0.20	13	0.99	0.95	12	Reclamation fill
BH 3	6.93	22.74	0.20	11	0.97	0.95	10	Reclamation fill
BH 4	6.96	22.83	0.20	12	0.97	0.95	11	Reclamation fill
BH 3	7.99	26.21	0.21	10	0.93	0.96	9	Reclamation fill
BH 4	7.99	26.21	0.21	14	0.93	0.96	12	Reclamation fill
BH3	8.06	26.44	0.21	29	0.92	0.96	26	Reclamation fill
BH1	8.1	26.57	0.21	13	0.92	0.96	12	Reclamation fill
BH 4	9.05	29.69	0.21	13	0.88	0.97	11	Reclamation fill
BH 3	9.2	30.18	0.21	14	0.88	0.97	12	Reclamation fill
BH1	9.53	31.27	0.22	11	0.87	0.97	9	Reclamation fill
BH 3	10	32.81	0.22	14	0.85	0.97	12	Reclamation fill
BH 4	10.04	32.94	0.22	12	0.85	0.97	10	Reclamation fill
BH3	10.04	32.94	0.22	19	0.85	0.97	16	Reclamation fill
BH 4	10.92	35.83	0.22	14	0.82	0.98	11	Reclamation fill
BH1	10.99	36.06	0.22	10	0.82	0.98	8	Reclamation fill
BH 3	11.03	36.19	0.22	5	0.82	0.98	4	Reclamation fill
BH3	11.98	39.30	0.22	22	0.79	0.98	17	Reclamation fill
BH 3	12.02	***39.44***	***0.22***	***5***	***0.79***	***0.98***	***4***	Marine sediment
BH 4	12.06	39.57	0.22	12	0.79	0.98	9	Reclamation fill
BH 3	12.97	42.55	0.22	18	0.77	0.99	14	Wellington Alluvium
BH 4	13.01	42.68	0.22	22	0.77	0.99	17	Reclamation fill
BH1	13.48	44.23	0.22	27	0.76	0.99	20	Reclamation fill
BH 3	14.03	46.03	0.22	18	0.74	0.99	13	Wellington Alluvium
BH 4	14.03	46.03	0.22	11	0.74	0.99	8	Reclamation fill
BH3	14.03	46.03	0.22	8	0.74	0.99	6	Reclamation fill
BH 3	14.95	49.05	0.22	19	0.72	0.99	14	Wellington Alluvium
BH 4	14.95	***49.05***	***0.22***	***9***	***0.72***	***0.99***	***6***	Marine sediment
BH1	14.95	49.05	0.22	27	0.72	0.99	19	Reclamation fill
BH3	15.64	***51.31***	***0.22***	***16***	***0.71***	***0.99***	***11***	Marine sediment
BH 4	16.05	***52.66***	***0.22***	***21***	***0.70***	***0.99***	***15***	Marine sediment
BH 3	16.08	52.76	0.22	18	0.70	0.99	13	Wellington Alluvium
BH1	16.56	54.33	0.22	21	0.69	0.99	14	Reclamation fill
BH 3	16.93	55.54	0.22	18	0.69	0.99	12	Wellington Alluvium
BH 4	16.96	55.64	0.22	51	0.69	0.99	35	Wellington Alluvium
BH 4	17.99	59.02	0.22	80	0.67	1.00	53	Wellington Alluvium
BH 3	18.06	59.25	0.22	38	0.67	1.00	25	Wellington Alluvium
BH 4	18.98	62.27	0.22	43	0.65	1.00	28	Wellington Alluvium
BH 3	19.12	62.73	0.22	37	0.65	1.00	24	Wellington Alluvium
BH 3	19.89	65.26	0.22	48	0.64	1.00	31	Wellington Alluvium
BH 4	19.97	65.52	0.22	68	0.64	1.00	43	Wellington Alluvium
BH 4	20.96	68.77	0.22	69	0.63	1.00	43	Wellington Alluvium
BH 3	20.99	68.86	0.22	47	0.63	1.00	29	Wellington Alluvium
BH 4	21.83	71.62	0.22	83	0.62	1.00	51	Wellington Alluvium
						Mean:	**9.1**	
						St. Dev.	**4.8**	



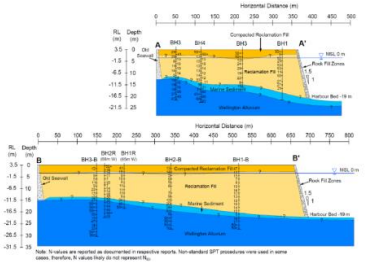


Figure 2.3: Schematic soil cross sections illustrating key layers and their thicknesses at CentrePort; note the different horizontal and vertical scales for the cross sections.

Depth (m)	N	
1.07	29	BH 3
1.95	41	BH 3
3.12	20	BH 3
3.89	13	BH 3
5.02	8	BH 3
5.98	10	BH 3
6.93	11	BH 3
7.99	10	BH 3
9.2	14	BH 3
10	14	BH 3
11.03	5	BH 3
12.02	5	BH 3
12.97	18	BH 3
14.03	18	BH 3
14.95	19	BH 3
16.08	18	BH 3
16.93	18	BH 3
18.06	38	BH 3
19.12	37	BH 3
19.89	48	BH 3
20.99	47	BH 3

Depth (m)	N	
1.1	50	BH 4
1.95	50	BH 4
3.12	12	BH 4
4.03	15	BH 4
4.95	15	BH 4
5.98	18	BH 4
6.96	12	BH 4
7.99	14	BH 4
9.05	13	BH 4
10.04	12	BH 4
10.92	14	BH 4
12.06	12	BH 4
13.01	22	BH 4
14.03	11	BH 4
14.95	9	BH 4
16.05	21	BH 4
16.96	51	BH 4
17.99	80	BH 4
18.98	43	BH 4
19.97	68	BH 4
20.96	69	BH 4
21.83	83	BH 4

Depth (m)	N	
1.51	50	BH3
3.12	50	BH3
4.55	12	BH3
6.01	24	BH3
8.06	29	BH3
10.04	19	BH3
11.98	22	BH3
14.03	8	BH3
15.64	16	BH3

Depth (m)	N	
1.07	50	BH1
1.91	5	BH1
3.56	12	BH1
4.84	21	BH1
6.67	13	BH1
8.1	13	BH1
9.53	11	BH1
10.99	10	BH1
13.48	27	BH1
14.95	27	BH1
16.56	21	BH1

LEGEND
- Compacted reclamation fill
- Reclamation fill
- Marine sediment
- Wellington Alluvium

Case number:	348
Earthquake:	2016 Kaikoura Earthquake
Magnitude:	7.8
Location:	Centre Port Wellington Thorndon's Wharf
References:	Bray et al. (2018, 2019), Cubrinovski et al. (2018), Brendon et al. (2017)
Nature of Failure:	"....significant liquefaction of reclaimed land and liquefaction induced ground deformations..." Bray et al. (2018)
GPS LAT	-41.2791906 approximate coordinates
GPS LONG	174.7850573 approximate coordinates
Liq. layer consist of:	Gravelly reclamation fill (Gravel-sand-fines)
Geological Unit:	reclaimed land
Site Response Anlaysis:	No
Comments:	Significant liquefaction was observed in the reclaimed land in CentrePort Wellington after 2016 Kaikoura earthquake (Mw=7.8). The liquefaction caused settlement of the fill and lateral movement. "..Seaward displacements along Kings Wharf were measured to be 0.5 m to 1.4 m, along Thorndon Wharf to be 0.3 m to 1.0 m, and along Thorndon Extension to be 1.0 m to 1.5 m." Bray et al. (2018). Following information is retrieved also from Bray et al. (2018): Site investigation is performed after the earthquake event. SPT, CPT and Vs data are available. The reclaimed land is constructed with two method: 1) hydraulic fills constructed using dredged material (sandy and silty soils) from the original seabed. 2) end-tipping, in which gravelly soils from nearby quarries were dumped into the sea from truck and barge operations The thickness of the fill is about 10 m thick in the south of the buried seawall and increases to 20 m southwards. The fill is underlained by 1-5 m thick marine sediments which is underlained by 75-135 m Wellington Alluvium. GEER teams conducted field studies after the earthquake. Surface manifestations in the form of soil ejecta was observed. Thorndon Container Wharf and Kings Wharf suffered liuefaction induced damage. Samples are collected from the ejected soils. The grain size distribution curves on ejected samples reveals that reclamation fill is liquefied At Thorndon's Wharf. Samples suggests that marine deposit most likely liquefied at King's wharf Cubrinovski et al. (2018) suggests peak ground accelerations (PGA) from 0.074 g at the rock outcrop was amplified to 0.15-0.20 g at the native soils sites, and 0.24 g at the reclaimed sites. CPLB station is located 150 m and 400 m away from King's and Thorndon's Wharves located on the same reclamied area. Geometric mean of the two horizantal component is 0.235 g which is used in the analysis.
Gravel Content (%):	25-75
CPT available:	Yes
Vs available:	No

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	Yes
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	3.4 - 14.0
d_{crt} (m)	-	-	-	-	8.7
GWT (m)	-	-	-	-	3.4 ± 0.1
γ_{moist} (kN/m^3)	-	-	-	-	18.9 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	20.6 ± 0.5
σ_v (kPa)	-	-	-	-	173.2 ± 36.7
σ_v' (kPa)	-	-	-	-	120.8 ± 19.4
a_{max} (g)	-	-	-	-	0.235 ± 0.047
r_d	-	-	-	-	0.84 ± 0.112
CSR	-	-	-	-	0.183 ± 0.045
M_w	-	-	-	-	7.80
D_{50}	-	-	-	-	4.500 ± NAV
% Fines	-	-	-	-	0-20 ± 5.0
% PI	-	-	-	-	0
N	-	-	-	-	11.2 ± 4.2
C_R	-	-	-	-	0.97
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.00
C_N	-	-	-	-	0.92
$(N_1)_{60}$	-	-	-	-	9.9 ± 3.7
V_{s30m} (m/s)	-	-	-	-	NAV
V_{s12m} (m/s)	-	-	-	-	182.9

EVENT PARAMETERS

2016 Kaikoura Earthquake — a shallow dipping thrust fault connecting two shallow strike-slip faults

Magnitude: 7.80 — Wang et al (2018) — Geonet

Fault Type: subduction syst — Z_{tor} (km): 0 — R_{rup} (km): -

Dip: 33.00 — Width (km): 20.00 — R_{jb} (km): 64.0

ACCELERATION TIME HISTORY

	Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
BH1R	0.43	1.41	NA	41	2.00	0.82	67	Compacted reclamation fill
BH1B	0.8	2.62	NA	15	2.00	0.83	25	Reclamation fill
BH3-B	0.84	2.76	NA	12	2.00	0.83	20	Compacted reclamation fill
BH2R	1.16	3.81	NA	18	2.00	0.84	30	Compacted reclamation fill
BH2-6	1.34	4.40	NA	14	2.00	0.85	24	Compacted reclamation fill
BH1R	1.8	5.91	NA	19	1.73	0.86	28	Compacted reclamation fill
BH2R	***2.13***	***6.99***	***NA***	***14***	***1.59***	***0.87***	***19***	Reclamation fill
BH1B	***2.3***	***7.55***	***NA***	***15***	***1.53***	***0.87***	***20***	Reclamation fill
BH2-6	***2.93***	***9.61***	***NA***	***5***	***1.35***	***0.89***	***6***	Reclamation fill
BH1R	***3.35***	***10.99***	***0.15***	***9***	***1.27***	***0.90***	***10***	Reclamation fill
BH2R	***3.59***	***11.78***	***0.15***	***11***	***1.24***	***0.90***	***12***	Reclamation fill
BH3-B	***3.72***	***12.20***	***0.16***	***9***	***1.23***	***0.91***	***10***	Reclamation fill
BH1B	***3.72***	***12.20***	***0.16***	***7***	***1.23***	***0.91***	***8***	Reclamation fill
BH2-6	***4.44***	***14.57***	***0.17***	***6***	***1.16***	***0.92***	***6***	Reclamation fill
BH1R	***4.9***	***16.08***	***0.17***	***10***	***1.13***	***0.93***	***10***	Reclamation fill
BH2R	***5.05***	***16.57***	***0.17***	***7***	***1.12***	***0.93***	***7***	Reclamation fill
BH3-B	***5.13***	***16.83***	***0.17***	***5***	***1.11***	***0.93***	***5***	Reclamation fill
BH1B	***5.53***	***18.14***	***0.18***	***8***	***1.08***	***0.94***	***8***	Reclamation fill
BH2-6	***6.16***	***20.21***	***0.18***	***6***	***1.04***	***0.94***	***6***	Reclamation fill
BH1R	***6.63***	***21.75***	***0.18***	***9***	***1.01***	***0.95***	***9***	Reclamation fill
BH2R	***6.73***	***22.08***	***0.18***	***10***	***1.01***	***0.95***	***10***	Reclamation fill
BH3-B	***6.9***	***22.64***	***0.18***	***11***	***1.00***	***0.95***	***10***	Reclamation fill
BH1B	***6.91***	***22.67***	***0.18***	***10***	***1.00***	***0.95***	***10***	Reclamation fill
BH2-6	***7.49***	***24.57***	***0.18***	***6***	***0.97***	***0.96***	***6***	Reclamation fill
BH2R	***7.66***	***25.13***	***0.18***	***7***	***0.96***	***0.96***	***6***	Reclamation fill
BH1R	***8***	***26.25***	***0.18***	***11***	***0.95***	***0.96***	***10***	Reclamation fill
BH3-B	***8.23***	***27.00***	***0.18***	***9***	***0.94***	***0.96***	***8***	Reclamation fill
BH1B	***8.32***	***27.30***	***0.18***	***16***	***0.93***	***0.96***	***14***	Reclamation fill
BH2R	***9.3***	***30.51***	***0.18***	***14***	***0.89***	***0.97***	***12***	Reclamation fill
BH1R	***9.51***	***31.20***	***0.18***	***11***	***0.88***	***0.97***	***9***	Reclamation fill
BH3-B	***9.78***	***32.09***	***0.18***	***23***	***0.87***	***0.97***	***20***	Reclamation fill
BH1B	***9.82***	***32.22***	***0.18***	***11***	***0.87***	***0.97***	***9***	Reclamation fill
BH2R	***10.14***	***33.27***	***0.18***	***14***	***0.86***	***0.98***	***12***	Reclamation fill
BH2-6	***10.5***	***34.45***	***0.18***	***7***	***0.85***	***0.98***	***6***	Reclamation fill
BH1R	***10.88***	***35.70***	***0.18***	***11***	***0.84***	***0.98***	***9***	Reclamation fill
BH3-B	***11.2***	***36.75***	***0.18***	***13***	***0.83***	***0.98***	***11***	Reclamation fill
BH1B	***11.38***	***37.34***	***0.17***	***13***	***0.82***	***0.98***	***10***	Reclamation fill
BH2R	***11.6***	***38.06***	***0.17***	***18***	***0.82***	***0.98***	***14***	Reclamation fill
BH2-6	***11.96***	***39.24***	***0.17***	***9***	***0.81***	***0.98***	***7***	Reclamation fill
BH1R	***12.47***	***40.91***	***0.17***	***9***	***0.79***	***0.98***	***7***	Reclamation fill
BH3-B	***12.66***	***41.54***	***0.17***	***12***	***0.79***	***0.99***	***9***	Reclamation fill
BH1B	***12.84***	***42.13***	***0.17***	***10***	***0.78***	***0.99***	***8***	Reclamation fill
BH2R	12.97	42.55	0.17	50	0.78	0.99	38	Marine sediment
BH2-6	***13.56***	***44.49***	***0.17***	***12***	***0.76***	***0.99***	***9***	Reclamation fill
BH1R	14.02	46.00	0.17	24	0.75	0.99	18	Marine sediment
BH2R	14.17	46.49	0.17	50	0.75	0.99	37	Wellington Alluvium
BH3-B	14.25	46.75	0.17	27	0.75	0.99	20	Marine sediment
BH1B	14.47	47.47	0.17	15	0.74	0.99	11	Reclamation fill
BH2R	15.19	49.84	0.16	13	0.73	0.99	9	Wellington Alluvium
BH2-6	15.19	49.84	0.16	20	0.73	0.99	14	Reclamation fill
BH1R	15.48	50.79	0.16	45	0.72	0.99	32	Wellington Alluvium
BH3-B	15.85	52.00	0.16	50	0.72	0.99	36	
BH1B	16.02	52.56	0.16	14	0.71	0.99	10	Reclamation fill
BH2-6	16.43	53.90	0.16	24	0.70	0.99	17	Marine sediment
BH2R	16.65	54.63	0.16	44	0.70	0.99	31	Wellington Alluvium
BH1R	16.86	55.31	0.16	50	0.70	0.99	35	Wellington Alluvium
BH3-B	17.13	56.20	0.16	50	0.69	0.99	34	
BH1B	17.35	56.92	0.16	15	0.69	0.99	10	Reclamation fill
BH2-6	18.02	59.12	0.16	43	0.68	1.00	29	Wellington Alluvium
BH2R	18.2	59.71	0.16	40	0.67	1.00	27	Wellington Alluvium
BH1B	18.94	62.14	0.16	5	0.66	1.00	3	Marine sediment
BH2R	19.57	64.21	0.16	50	0.65	1.00	33	Wellington Alluvium
BH2-6	19.62	64.37	0.16	9	0.65	1.00	6	Wellington Alluvium
						Mean:	**9.9**	
						St. Dev.	**3.7**	

This fill is noted as compacted gravelly fill crust by Bray et al. (2018)

LEGEND
- Compacted reclamation fill
- Reclamation fill
- Marine sediment
- Wellington Alluvium

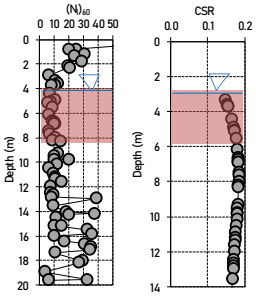
Depth (m)	N	
0.84	12	BH3-B
3.72	9	BH3-B
5.13	5	BH3-B
6.9	11	BH3-B
8.23	9	BH3-B
9.78	23	BH3-B
11.2	13	BH3-B
12.66	12	BH3-B
14.25	27	BH3-B
15.85	50	BH3-B
17.13	50	BH3-B

Depth (m)	N	
3.35	9	BH1R
4.9	10	BH1R
6.63	9	BH1R
8	11	BH1R
9.51	11	BH1R
10.88	11	BH1R
12.47	9	BH1R
14.02	24	BH1R
15.48	45	BH1R
16.86	50	BH1R

Depth (m)	N	
-0.39	50	BH2R
1.16	18	BH2R
2.13	14	BH2R
3.59	11	BH2R
5.05	7	BH2R
6.73	10	BH2R
7.66	7	BH2R
9.3	14	BH2R
10.14	14	BH2R
11.6	18	BH2R
12.97	50	BH2R
14.17	50	BH2R
15.19	13	BH2R
16.65	44	BH2R
18.2	40	BH2R
19.57	50	BH2R
21.03	19	BH2R
0.43	41	BH1R
1.8	19	BH1R

Depth (m)	N	
-0.13	13	BH2-6
1.34	14	BH2-6
2.93	5	BH2-6
4.44	6	BH2-6
6.16	6	BH2-6
7.49	6	BH2-6
10.5	7	BH2-6
11.96	9	BH2-6
13.56	12	BH2-6
15.19	20	BH2-6
16.43	24	BH2-6
18.02	43	BH2-6
19.62	9	BH2-6
20.99	50	BH2-6
22.49	50	BH2-6
24.23	50	BH2-6

Depth (m)	N	
-0.71	47	BH1B
0.8	15	BH1B
2.3	15	BH1B
3.72	7	BH1B
5.53	8	BH1B
6.91	10	BH1B
8.32	16	BH1B
9.82	11	BH1B
11.38	13	BH1B
12.84	10	BH1B
14.47	15	BH1B
16.02	14	BH1B
17.35	15	BH1B
18.94	5	BH1B
20.27	14	BH1B
21.82	17	BH1B
23.28	50	BH1B
24.88	50	BH1B



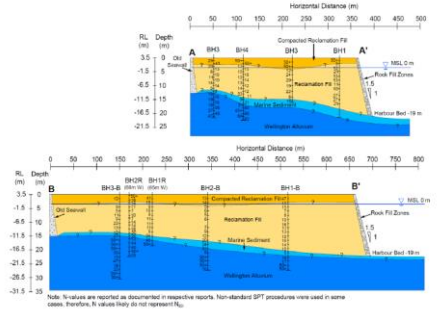
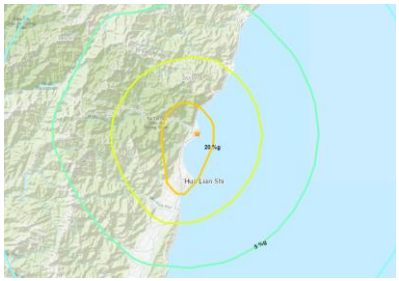


Figure 2.3: Schematic soil cross sections illustrating key layers and their thicknesses at CentrePort; note the different horizontal and vertical scales for the cross sections.

Case number:	345
Earthquake:	2018 Hualien Earthquake
Magnitude:	6.4 (USGS)
Location:	Hualien Port N-1
References:	Deng et al. (2019)
Nature of Failure:	Liquefaction is not observed.
GPS LAT	23.977248 approximate locations
GPS LONG	121.626316
Liq. layer consist of:	Gravel
Geological Unit:	Fill
Site Response Anlaysis:	No
Comments:	An earthquake occured on 6 February 2018 (Mw=6.4) at 23:50:42.6 (utc+8) in Taiwan offshore Hualien county.
	Liquefaction is observed in the gravel backfills at Hualien horbour.
	Settlement were also observed at the port up to 50-60 cm was reported.
	This case history is obtained from the non-liquefied part of the port.
	SPT and Vs tests were available at that location.
	HWA062 station recorded the ground motion which is located 600 m away from the site and has Vs30 value is 605.69 m/s.
	The Vs data for the site is available untill 22 m depth.
	If the Vs profile at the site is assumed to extend up to 30 m with 390 m/s, Vs30 of the site is estimated as 220 m/s.
	A scale factor is calculated as 1.5 and PGA at the site is estimated as 0.3 g.
	USGS Shakemap suggest amax>0.2 g.
	No information regarding hammer type was given.
	Hence it is assumed that a saftey hammer is used with an average hammer efficiency value of 66% is assigned.
	https://earthquake.usgs.gov/earthquakes/eventpage/us1000chhc/executive



Gravel Content (%):	50-100
CPT available:	No
Vs available:	Yes

Summary of Input Data

Parameters	Seed et. al. (1984)	Cetin et al. (2004)	Idriss & Boulanger (2010)	Cetin et al. (2018)	This study
Liquefied?	-	-	-	-	No
Data Class	-	-	-	-	B
d_{crtc} range (m)	-	-	-	-	2.5 - 17.0
d_{crt} (m)	-	-	-	-	9.8
GWT (m)	-	-	-	-	1.0 ± 0.9
γ_{moist} (kN/m^3)	-	-	-	-	19.6 ± 0.5
γ_{sat} (kN/m^3)	-	-	-	-	21.2 ± 0.5
σ_v (kPa)	-	-	-	-	205.7 ± 51.6
σ_v' (kPa)	-	-	-	-	119.7 ± 28.9
a_{max} (g)	-	-	-	-	0.300 ± 0.060
r_d	-	-	-	-	0.58 ± 0.123
CSR	-	-	-	-	0.194 ± 0.059
M_w	-	-	-	-	6.40
D_{50}	-	-	-	-	3.550 ± 0.050
% Fines	-	-	-	-	<5 ± 8.6
% PI	-	-	-	-	0
N	-	-	-	-	27.0 ± 9.3
C_R	-	-	-	-	0.97
C_S	-	-	-	-	1.00
C_B	-	-	-	-	1.00
C_E	-	-	-	-	1.10
C_N	-	-	-	-	0.92
$(N_1)_{60}$	-	-	-	-	26.6 ± 9.2
$V_{s,30m}$ (m/s)	-	-	-	-	NAV
$V_{s,12m}$ (m/s)	-	-	-	-	147.8

EVENT PARAMETERS

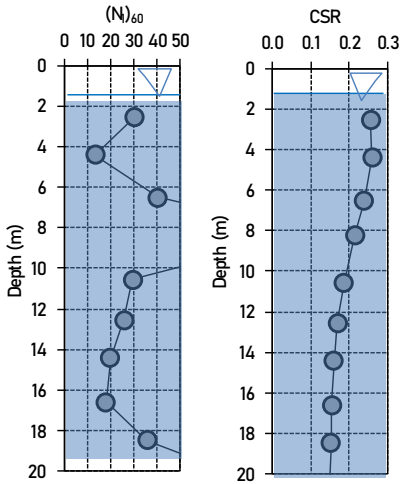
2018 Hualien Earthquake — Huang and Huang 20128 and USGS

Magnitude: 6.40

Fault Type: oblique fault v — Z_{tor} (km): 0 — R_{rup} (km): -

Dip: 69-73 — Width (km): 3--11 — R_{jb} (km): 0.0

ACCELERATION TIME HISTORY



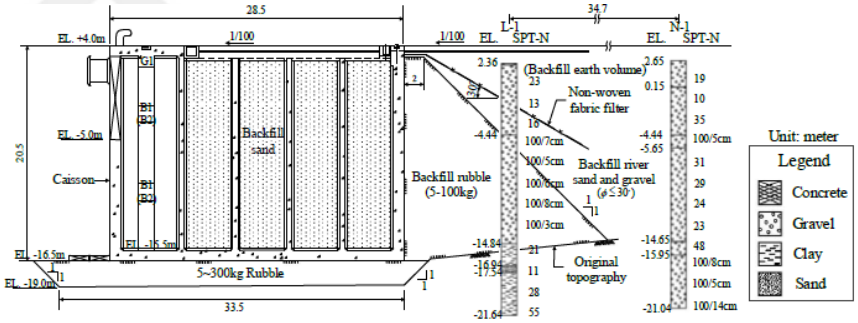


Figure 2. The design profile of wharf no. 25 in Hualien Harbor (Chen et al, 2000) and the boring logs

Depth (m)	Depth (ft)	CSR	N	C_N	C_R	$(N1)_{60}$	
2.56	***8.40***	***0.26***	***19***	***1.65***	***0.88***	***30.31***	***Gravel fill with sand layers***
4.41	***14.47***	***0.26***	***10***	***1.32***	***0.92***	***13.30***	***Gravel fill with sand layers***
6.51	***21.36***	***0.24***	***35***	***1.11***	***0.95***	***40.43***	***Gravel fill with sand layers***
8.24	27.03	0.21	100	1.00	0.96	105.50	Gravel fill v outlier
10.55	***34.61***	***0.19***	***31***	***0.89***	***0.98***	***29.58***	***Gravel fill with sand layers***
12.56	***41.21***	***0.17***	***29***	***0.82***	***0.98***	***25.70***	***Gravel fill with sand layers***
14.42	***47.31***	***0.16***	***24***	***0.77***	***0.99***	***20.02***	***Gravel fill with sand layers***
16.60	***54.46***	***0.15***	***23***	***0.72***	***0.99***	***18.00***	***Gravel fill with sand layers***
18.49	60.66	0.15	48	0.68	1.00	35.75	original strata
20.07	65.85	0.15	100	0.65	1.00	71.68	original strata
					Mean:	**26.6**	
					St. Dev.	**9.2**	

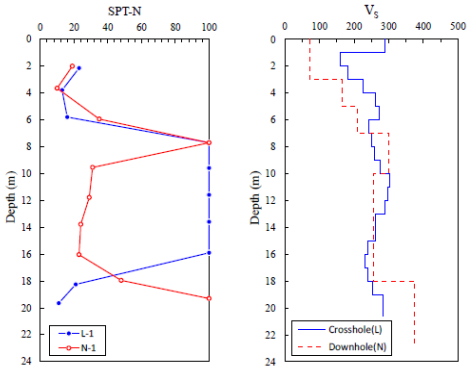


Figure 3. V_S and SPT-N profiles of the L and N sites

CURRICULUM VITAE

EDUCATION

Degree	Institution	Year of Graduation
MS	METU Civil Engineering	2015
BS	METU Civil Engineering	2012
High School	Dr. Rıdvan Ege & Dr. Binnaz Ege Anadolu High School, Ankara	2007

WORK EXPERIENCE

Year	Place	Enrollment
2019-Present	METU Dept. of Civil Eng.	Research Assistant
2018-2019	Univ. of California Berkeley Dept. of Environ. And Civil Eng.	Visiting Scholar
2013-2019	METU Dept. of Civil Eng.	Research Assistant
2012	Northeastern Univ. Dept. of Civil Eng.	Research Assistant

FOREIGN LANGUAGES

Turkish (Native Speaker), English (Fluent)

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