



**T.C.
ISTANBUL UNIVERSITY-CERRAHPASA
INSTITUTE OF GRADUATE STUDIES**



M.Sc. THESIS

**BEHAVIOR OF BUILDINGS WITH STRUCTURAL SYSTEMS
SENSITIVE TO VERTICAL GROUND MOTIONS UNDER NEAR-
FAULT EARTHQUAKES**

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FOREWORD

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	Explanation
a	: Acceleration
g	: Acceleration of gravity
I	: Importance factor
M_w	: Moment magnitude
PGA	: Peak ground acceleration
PGV	: Peak ground velocity
R	: Response modification factor
S_{av}	: Design vertical response spectral acceleration
S_{D1}	: Design spectral response acceleration parameter at a period of 1 sec
S_{DS}	: Design spectral response acceleration parameter at short periods
T	: Natural period
T_L	: Long-period transition period
T_v	: Natural vertical period

Abbreviation	Explanation
AF_(axial)	: The vertical amplification factor of axial force
AF_(moment)	: The vertical amplification factor of bending moment
AF_(shear)	: The vertical amplification factor of shear force
AF_(dis)	: The vertical amplification factor of vertical displacement
AF_(acc)	: The vertical amplification factor of vertical-absolute acceleration
Dis_(H+V)	: The vertical displacement due to bi-directional component
Dis_(H)	: The vertical displacement due to only-horizontal component
HGM	: The horizontal component of ground motion
VGM	: The vertical component of ground motion

$\mathbf{M}_{(H+V)}$	: The bending moment due to bi-directional component
$\mathbf{M}_{(H)}$	: The bending moment due to only horizontal component
$\mathbf{N}_{(H+V)}$	: The axial force due to bi-directional component
$\mathbf{N}_{(H)}$	: The axial force due to only horizontal component
$\mathbf{V}_{(H+V)}$	: The shear force due to bi-directional component
$\mathbf{V}_{(H)}$	: The shear force due to only horizontal component



ÖZET

YÜKSEK LİSANS TEZİ

DÜŞEY YER HAREKETLERİNE DUYARLI YAPISAL SİSTEMLERE SAHİP BİNALARIN YAKIN-FAY DEPREMLERİ ALTINDAKİ DAVRANIŞI

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Son zamanlarda gerçekleşen depremlerde güçlü düşey yer hareketleri gözlemlenmiştir. Bu depremlerin bazıları için dikey/yatay ivme oranı sismik kodlarda kabul edilen değeri aşmaktadır. Ayrıca, birçok çalışmada şiddetli düşey yer hareketlerinin çoğu mühendislik yapısında önemli hasarlara neden olabileceği bildirilmiştir. Bu çalışmada, düşey yer hareketlerine duyarlı taşıyıcı sistemlere sahip binaların yakın fay depremleri altındaki davranışları incelenmiştir. Türkiye Bina Deprem Yönetmeliği'nde (TBDY-2018) düşey yer hareketlerine duyarlı yapı sistemleri olarak sınıflandırılan dört çeşit yapı üzerinde yakın fay deprem kayıtları serisi için doğrusal zaman tanım alanı analizleri yapılmıştır. Zaman tanım alanı analizleri için SAP2000 yazılımı kullanılmıştır. Her durum için sadece yatay, sadece dikey ve çift eksenli (yatay + dikey) olmak üzere üç yük durumu dikkate alınmıştır. Daha sonra, kritik elemanlar için kuvvet ve yer değiştirme ile ilgili talep parametreleri (eksenel kuvvet, eğilme momenti, kesme kuvveti, kat ötelemesi, düşey yer değiştirme) değerlendirilmiştir. Sonuçlar, yakın fay bölgesindeki binaların yapısal tepkilerinde düşey yer hareketlerinin etkilerinin önemli katkısının olacağını vurgulamaktadır. Ayrıca, yüksek dikey/yatay ivme oranları için sismik

kodlar, düşey yer hareketleri altındaki yapısal tepkiyi hafife alabilir ve yapının zarar görmesine neden olabilir.

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Anahtar kelimeler: yakın-fay depremleri, düşey yer hareketi, zaman geçmişi analizi, bina düzensizliği, TBDY 2018



SUMMARY

M.Sc. THESIS

BEHAVIOR OF BUILDINGS WITH STRUCTURAL SYSTEMS SENSITIVE TO VERTICAL GROUND MOTIONS UNDER NEAR-FAULT EARTHQUAKES

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Strong vertical components of the ground motions were observed in recent earthquakes. The ratio of peak vertical to horizontal acceleration for some of these earthquakes exceeds the adopted values in seismic codes. Furthermore, many studies warned that the strong vertical ground motions may cause notable damage to most types of structures. In this study, the behavior of buildings that have structural systems sensitive to vertical ground motions is investigated under near-fault earthquakes. Linear time-history analyses for a series of near-fault records are performed on four types of structures classified as sensitive structures to vertical ground motions in the Turkish Seismic Code (TSC-2018). SAP2000 software is used for time history analyses. For each case, three load cases including only horizontal, only vertical, and bi-directional (horizontal + vertical) are performed. Then, the related engineering demand parameters (axial force, bending moment, shear force, story drift, vertical displacement) for critical elements are evaluated and discussed. The results highlight that buildings in the near-fault area will experience a more significant contribution of the effects of the vertical

component of ground motion to the response of the structure. In addition, for high ratios of the vertical to horizontal acceleration, seismic codes could underestimate the structural response and lead to damage to the structure.

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Keywords: Near-fault earthquakes, vertical ground motion, time history analysis, building irregularity, TSC-2018



1. INTRODUCTION

It is commonly known that during earthquake events, the engineering structures expose to three ground motion components, two components in horizontal directions and one in the vertical direction. However, during the structural design, engineers mainly focus on the effects of the horizontal component, HGM whereas the effect of the vertical ground motion component, VGM, is often neglected or underestimated. Recently, most of the seismic codes tend to simplify the effect of VGM by adopting the ratio of peak vertical to horizontal acceleration (V/H) between $1/3$ and $2/3$.

Strong VGMs were observed in many recent earthquake events where (V/H) ratio may exceed the adopted value in seismic codes up to 4 times (e.g. the 1979 Imperial Valley Earthquake). Furthermore, many analytical and experimental studies, as well as field investigations, reported that VGMs may cause significant damage to all types of engineering structures like bridges and buildings. VGMs can modify the structural response and the structural collapse mechanism. For example, VGM leads to a significant variation in axial forces in bridge piers, which induces a reduction of the shear capacity for these piers (Papazoglou and Elnashai, 1996). Another example is the Clock Tower of Finale Emilia in Italy. It was constructed from unreinforced masonry. In this tower, VGM induced a shear-flexural hinge in the tower's lower part, which led to the collapse of the tower (Acito, 2014).

Recent studies emphasize that the effects of VGMs can be higher at near-fault zones, generally at a distance of about 20 km from the fault (Bray and Marek, 2004). It can be the characteristics of near-fault ground motion, which includes a high amplitude velocity pulse with a long period and permanent ground displacement and the high vertical peak ground acceleration values (Elnashai and Papazoglou, 1997). Furthermore, the response of a structure to an earthquake is mainly dependent on the earthquake characteristics, building materials, and building configuration. Structures with uniform and simple configurations may face lesser damage and collapse compared with irregular ones, which are now widely built for architectural-related purposes.

Modern seismic design codes differentiate between sensitive and insensitive structures to vertical ground motions. During design procedures, the effect of vertical seismic ground motion

is considered using a simple method as a ratio of dead load effect in insensitive structures whereas, for the design of sensitive structures to vertical ground motions like suspended structures or structures with long cantilevers, the effect of vertical seismic ground motion should be incorporated by following more restricted provisions. For this purpose, a vertical design response spectrum is developed based on previous studies and investigations.

Turkish Seismic Code 2018, TSC 2018, defines four cases of structures as sensitive structures to vertical ground motions. According to TSC 2018, the effects of vertical seismic ground motions for the analyses and design of these cases shall be performed using the vertical response spectrum defined in the code. These cases can be classified as follows:

1. Structures with beams with a 20m span length and more.
2. Structures with cantilevers with a 5m span length or more.
3. Structures with planted columns on transfer elements.
4. Structures with inclined columns.

This study aims to investigate the behavior of buildings that have structural systems sensitive to vertical ground motions, as defined in TSC 2018, under the vertical ground motion excitation in near-fault earthquakes and to find out how the vertical component of ground motion affects the seismic response and engineering demand parameters. For this purpose, linear time-history analyses for a series of near-fault records are performed on sets of 2D frames, representing the above-described cases, using SAP2000 V23.1 (CSI, 2021) software. The records are selected taking into consideration the ratio of vertical-to-horizontal peak ground acceleration is more than one. For each case, three load cases are defined including only horizontal, only vertical, and both (horizontal + vertical) components. Then, the related engineering demand parameters (bending moments, shear forces, axial forces, story drifts, vertical displacements, horizontal accelerations, and vertical accelerations) in the critical elements are evaluated and discussed. In addition, the response spectrum analysis results using the TSC-2018 vertical response spectrum are evaluated and compared with linear time-history analysis results for our study cases.

The limitations of this study includes following: The effects of VGMs are based on linear time history analyses. Non-linear behavior of the frames is not considered. Soil-structure interaction

is neglected and all supports are considered as fixed. Three dimensional behavior is not investigated.

This thesis is structured as follows: Chapter two gives a general review of the significant previous studies performed about the effects of VGMs on engineering structures and a brief review of VGMs in international seismic codes. Chapter 3 describes the frame configurations, as well as the selected near-fault earthquake records and modeling criteria. Chapter 4 and 5 present the structural analysis results and the discussion, respectively. The final chapter, Chapter 6, presents the conclusion and recommendations of this study. The appendices contain the detaild structural analysis results like demand parameters results tables for all study cases.



2. LITERATURE REVIEW

2.1. OVERVIEW

Earthquake disaster investigations have shown that near-fault earthquake is one of the most dangerous ground motions. It can cause extensive damage to engineering structures. These kinds of ground motion are generally observed at a distance of about 20 km from the fault (Bray and Marek, 2004). Near-fault ground motions are significantly different than far-fault motions. Near-fault ground motions often contain a velocity pulse with a long period and permanent ground displacement. A comparison between the velocity records of a near-fault ground motion and far-fault ground motion is illustrated in Figure 2.1.

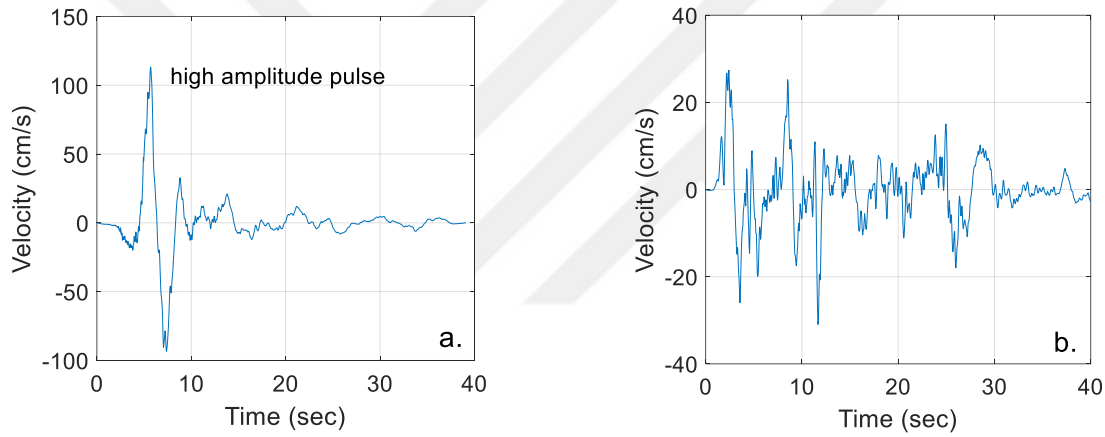


Figure 2.1: The velocity time-histories of far-fault and near-fault ground motions, a. Near-fault ground motion (El Centro Array #6, 1979 Imperial Valley-06), b. Far-fault ground motion (Carroll College, 1935 Helena Montana-01).

The available historical near-field earthquake records may be inadequate for carrying out specific parametric studies. To cover the need of these studies, several models for synthetic near-field earthquake records are suggested (Öncü and Alhan, 2016). Among pulse models, there are two popular models used in various research studies, one suggested by (Makris, 1997) and the other model by (Agrawal and He 2002).

Pulse-like near-fault ground motions can be notably affected by the mechanism of the rupture and slip-direction relative to the site (Bray and Marek, 2004). The site can be classified after an earthquake event as forward-directivity, backward-directivity, or neutral-directivity effects. Forward directivity demonstrates when the angle between the direction from the hypocenter to the site and the fault line is small and propagation of the rupture toward the site. The reverse

directivity effect is demonstrated when propagation of the rupture away from the site. Finally, the neutral-directivity effect is demonstrated when the site is approximately perpendicular to the fault from the hypocenter (Cox and Ashford, 2002). Near fault ground motions at neutral directivity zone are nearly the same as the ground motions of far-fault earthquakes (Harati and others, 2016). Figure 2.2 illustrates the classification of the site according to the directivity type.

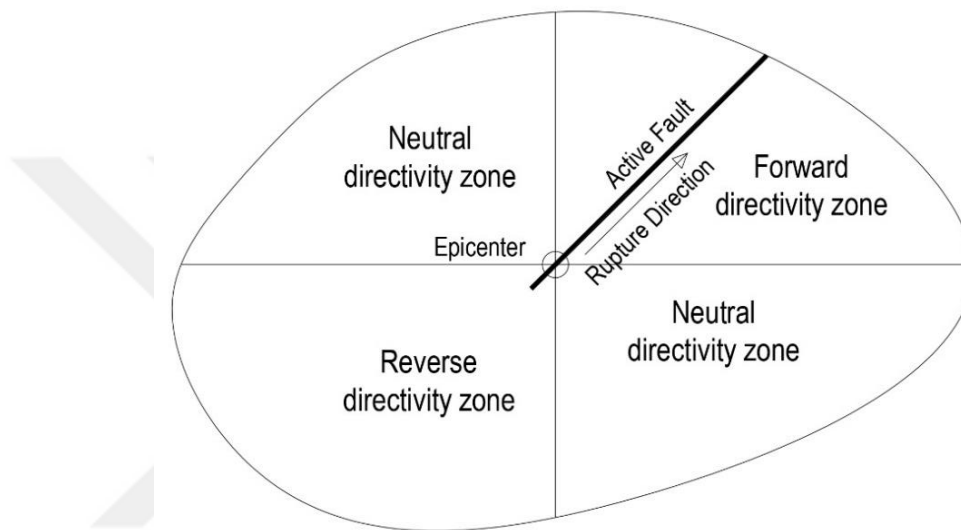


Figure 2.2: Classification the site as neutral directivity, reverse directivity, or forward directivity (modified from Cox and Ashford, 2002).

Furthermore, in near-fault regions, the ratio of the vertical to the horizontal tends to be more than two-thirds of the horizontal one recommended in some seismic code provisions to specify the vertical component. This ratio for sites within a distance not more than 5 km to the source can get a value of more than 1.0 (Memarpour and others, 2016). Elnashai and Papazoglou (1997) discussed the reasons for the strong vertical ground motion in near-fault regions. They demonstrated that the vertical ground motion component is not affected by the non-linear site properties and does not show any sign of elongation of the period and decay of the amplitude. They explained that the reason behind this is that even badly compacted soils can transfer compressional waves that cause high vertical accelerations. In addition, high vertical accelerations, as well as horizontal components, can be significantly affected by the source mechanism. Normal-mechanisms and thrust-mechanisms generally tend to produce a higher

vertical ground motion for a given horizontal displacement (Ambraseys and Simpson,1989). These reasons may clarify that the vertical ground motions of some near-fault earthquakes can have an important detrimental impact on the structural behavior of several types of structural systems.

The seismic performance of a structure is highly influenced by its configuration. The buildings with regular configuration and uniformly distributed stiffness and masses in plans and elevations experience lesser damage compared to the buildings having irregular geometries. Some structure configurations, like long-span beams and slanted columns, may make the structure more sensitive to vertical ground motions and may be more affected by the vertical seismic excitation.

Therefore, the relationship between horizontal and vertical ground motions assumed by seismic codes may be unreasonable in near-fault regions, and alternative analysis procedures may be needed in these regions.

2.2. PREVIOUS STUDIES

In the last years, a handful of significant research studies about the effects of the vertical component of ground motions on the seismic structural response of many types of engineering structures have been performed.

The structural effects of strong vertical ground motion on bridges, buildings, and other structures are investigated by (Papazoglou and Elnashai, 1996). They collected the field evidence from the 1995 Kobe earthquake, the 1994 Northridge earthquake, and the 1986 Kalamata earthquake. The collated field evidence and dynamic analysis outcomes have shown that a lot of structures experienced considerable damage ascribable to high vertical ground motions. Results showed that the column failure could occur due to high axial column forces or failure due to direct tension induced by vertical ground motions. In addition, they stressed that vertical ground motion could induce shear and flexure failure because of the axial force fluctuations that reduce the shear resistance ductility of RC columns.

The sensitivity of code-compliant reinforced concrete buildings under bi-directional (horizontal and vertical) seismic loading was estimated by Mwafy and Elnashai (2006). 12 RC buildings with heights ranging between 24 to 36 m and different structural systems were investigated

under strong multi-axial ground motions. It was observed that the story-drift of the collapse limit state was commonly reached when the vertical component was involved. The results indicated that the global response parameters may increase by about 22% at the design peak ground acceleration when the effect of vertical component is considered.

Kim et al. (2018) performed an analytical investigation of the effect of the vertical component of ground motion on a series of reinforced concrete frames having various geometric configurations. They indicated that reinforced concrete structures subjected to bi-directional (horizontal and vertical) could experience more damage than those under horizontal-only ground motion. It was observed in the study that the shear capacity on the RC columns adversely decreases because of the great axial force variation that increases up to about 240% at the first story when the vertical component was included. The shear capacity reduction is directly proportional to the V/H ratio in addition to the length of spans. It was observed, also, the vertical component of ground motion has no considerable effect on the story drift of frames.

Bayraktar et al. (2018) studied the effects of vertical ground motion on seismic damage propagation of rectangular masonry minarets. He observed that horizontal and vertical displacement at the top of the minaret was slightly affected when the vertical strong ground motion was considered in the linear seismic analyses.

The failure probability of RC chimneys under horizontal and vertical components was examined by Guo et al. (2018). A 120 m height RC chimney performance was investigated under a series of near-fault ground motions including vertical ground components. After structural analysis, a seismic fragility analysis was performed to define the probability of chimney collapse or damage. In this study, it was found that the influence of the combination of the vertical and horizontal components has significant effects on the chimney failure probability when the horizontal component intensity of the is greater than a specific value (equals to 1.0g in this study). The author recommended considering the vertical component effects in the safety evaluation of chimneys at near-fault zones.

Vertical acceleration demand at columns and beams of steel elastic moment-resisting frames and their correlation with vertical and horizontal ground motions, nonstructural components, and seismic masses distribution methods were investigated by Gremer et al. (2019). Time history analyses were performed on a series of frame structures with a variety of heights. The

study showed that vertical peak floor accelerations could be about 4.8 times comparing with horizontal peak ground acceleration. Vertical peak floor acceleration depends on the structure height, nonstructural component location on the frame, and the distribution method of seismic masses. Moreover, the maximum amplification was observed at the center of spans, while the minimum one was at the interior columns.

The fluctuations of force due to vertical components were evaluated by Bovo and Savoia (2019) on reinforced concrete precast structures. In this study, non-linear time-history analysis was performed on 48 models including the popular existing precast structures and section shapes. The expected failure mechanisms for the studied cases were strong-connection and weak-column failure mechanisms. Both near-fault and far-fault records were used. The analyses results were compared with EC8 code provisions. According to this study, the vertical force fluctuations could be underestimated when EC8 spectral response analysis was used. The study also showed that floor slabs and beams in structures having vertical periods ranging from 0.05s to 0.15s tend to lift from the supports under the far-fault vertical excitation. Moreover, vertical force fluctuations were considerably increased with pulse-like velocity records compared with the non-pulse-velocity records. The study emphasized that the vertical dynamic behavior of each story was independent of other stories, and there is no correlation between this the intensity of the horizontal excitation.

Sun et al. (2019) experimentally investigated the effect of VGMs steel columns. Five full-scale steel wide-flange-column specimens were tested under simulated vertical and horizontal seismic loading. The results presented that column axial force induced from simulated earthquake loading could increase up to six times of axial force induced from dead loads. At the same time, the column could undergo tension force due to the decrease of earthquake loading. The authors emphasized that the VGMs effect should be considered in designing steel frames, and neglecting this component could underestimate the response of the structure under seismic loading and lead to damage to the structure.

The seismic performance of unreinforced masonry structures under the vertical seismic component was investigated by Michele et al. (2020). Nonlinear dynamic analyses were performed for masonry structures in three different masonry types to consider the stiffness variation: squared stone masonry, uncut stone masonry with external leaves, and infill core, and hollow brick having a void area ratio less than 45%. 106 unscaled natural records, including

near-fault and far-fault records and several fault rupture types, were used in the study. The study found that vertical ground motion for records for high moment magnitudes and low distances between source and site have a greater effect on the structural response. The effects appear as a variation in axial force in the piers that leads to an extreme decrease in elements' shear and flexural capacities.

The effect of the vertical ground motion on the buckling capacity of steel silos was studied by Mehretehran and Maleki (2021). Three types of steel silos were used for the analyses (Squat, Intermediate slender, and Slender). The study referred to that the vertical component slightly affected the critical buckling values of silos. In addition, normal pressures were almost the same when the only-horizontal component or bi-directional component (vertical+ horizontal) were applied.

The behavior of long-span trusses under the vertical component motion was studied by (Ahiwale and Khartode, 2021). Non-linear analysis was performed for a 25 m long-span steel truss using a series of near-fault records. It was found that for V/H more than 1.0, the structural response of the truss subjected to bi-directional ground motion would be critical and should be considered in design procedures because of the considerable increase in axial forces in columns and bottom chord and base bending moment.

The effects of VGMs on several types of bridges were studied and examined in many research studies. Warn and others (2008) experimentally investigated the vertical component effects on a bridge based on a seismic isolation system. Large-scale models of an isolated bridge with lead-rubber and low-damping rubber bearings were fabricated and tested using earthquake simulators. The results showed that the structural response for both the low-damping rubber and lead-rubber bridges significantly increased. Moreover, the authors explained that using the peak ground acceleration of the vertical ground motion in design procedures would lead to underestimating the vertical component of earthquake load on the isolation system.

Another experimental investigation was performed by Kim et al. (2011) in order to determine the behavior of reinforced concrete bridge piers under bi-directional earthquake motions. Half-scale specimens of the piers were built and studied using hybrid simulation. In this study, it was shown that the variation of piers axial force increased 100% when the vertical component was included. This variation induced a reduction of lateral stiffness that leads to crack and damage.

It was found, also, that VGMs led to an increase in the spiral strains about two times comparing with only the horizontal component effect.

The long-span cable-stayed bridge response to VGMs was investigated by (Shrestha, 2014). A bridge with a single tower and a 500 m total length was analytically studied. A series of linear time-history analyses, using 5 near-fault records, was performed on the bridge to study the effect of vertical excitation on the structural response. It was found that vertical displacement of the bridge deck at the middle of the span could be sensitive to vertical excitation. However, the vertical excitation mainly affected the axial force demand on both the tower and the cable and the shear force demand along the bridge.

Changfeng et al. (2016) investigated vertical component ground motion effects on the structural performance of a sliding friction-isolated bridge. The effects of vertical component ground motion on the structural performance on the various sliding friction-isolated bridge was analytically studied. A 6-span continuous-beam bridge with 32 m span and 22 m pier height was modeled and analyzed under three time-history records. It was found that vertical component effects can be larger on sliding friction-isolated bridges than bridges that use normal bearings. Moreover, the bending moments at the bottom of piers were greater than when vertical excitation was considered.

The effects of vertical excitation on the structural responses and vulnerabilities of the tracked bridge were numerically identified by Wei et al. (2018). They found that the increase of vertical ground motion could increase the damage probabilities of a bridge and track components. In addition, The track components between the adjacent bridges are more sensitive to this increase in the vertical component.

2.3.VERTICAL GROUND MOTION IN SEISMIC CODES

Modern seismic codes stress that the effects of the vertical component shall be considered in engineering structures design. However, the seismic codes tend to simplify the effects of VGMs in typical building design procedures by adopting the peak vertical acceleration to horizontal acceleration ratio (V/H) between $1/3$ and $2/3$. More consideration is given to the effects of vertical excitation on the structures that have special characteristics such as planted columns and long cantilever beams and irregular structures. Seismic codes stress verifying these structures or elements under vertical ground motions using more restricted methods. For this

purpose, vertical response spectra are developed depending on previous studies and investigations.

Turkish Seismic Code 2018 (TSC-2018) defines four types of structures as sensitive structures to vertical ground motions. These types are: the structures containing beams with 20m span length or more, the structures containing cantilevers with 5m span length or more, the structures containing planted columns on transfer elements, and the structures containing inclined columns. TSC-2018 stresses that for seismic design categories 1, 1a, 2, and 2a, these elements shall be analyzed according to vertical elastic acceleration spectrum based on the local vertical vibration modes of these elements where overstrength factor, D , and response modification coefficient, R , to be taken as 1. TSC-2018 vertical elastic acceleration spectrum is defined as follows:

$$\begin{aligned}
 S_{av}(T) &= \left(0.32 + 0.48 \frac{T}{T_{AV}} \right) S_{DS} & (0 \leq T \leq T_{AV}) \\
 S_{av}(T) &= 0.8 S_{DS} & (T_{AV} < T \leq T_{BV}) \\
 S_{av}(T) &= 0.8 S_{DS} \frac{T_{BD}}{T} & (T_{BV} \leq T \leq T_{LV})
 \end{aligned} \tag{2.1}$$

where

$$T_{AV} = \frac{T_A}{3} \quad T_{BV} = \frac{T_B}{3} \quad T_{LV} = \frac{T_L}{2} \tag{2.2}$$

and T is the fundamental period of the building, $T_A = 0.2 S_{D1}/S_{DS}$, $T_B = S_{D1}/S_{DS}$, the long-period transition period is $T_L = 6$ s, S_{DS} is the design spectral response acceleration parameter at short periods, and S_{D1} is the design spectral response acceleration parameter at a period of 1 sec.

Furthermore, TSC-2018 stresses that vertical earthquake effect on buildings other than above described four cases shall be considered without a special account. It shall be approximated as follows:

$$E_v = \left(\frac{2}{3} \right) S_{DS} D \tag{2.3}$$

Where S_{av} is the design vertical response spectral acceleration, D is the dead load effect, and T_v is the vertical period of vibration.

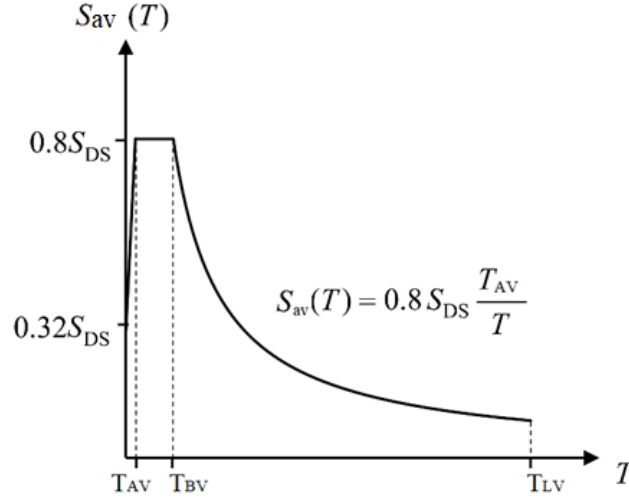


Figure 2.3: TSC-2018 vertical design response spectrum.

Minimum Design Loads for Buildings and Other Structures (ASCE/SEI 7-16) classifies tanks, suspended structures, vessels, and structures with long cantilevers as nonbuilding structures sensitive to vertical ground motions. For these structures, the vertical component effect shall be considered in the analysis and calculated using the vertical response spectra defined in this code. In this case, the response modification factor, R , shall be taken as 1 in the vertical direction. The vertical component of seismic load shall be taken as the following:

$$E_v = 0.2S_{av}D \quad (2.4)$$

S_{av} is the design vertical response spectral acceleration obtained from vertical response spectra defined in this code and shall be taken as two-thirds of the value of vertical response spectral acceleration, S_{aMv} , which is determined as follows:

$$S_{aMv} = 0.3C_vS_{MS} \quad (0 \leq T_v \leq 0.025 \text{ s})$$

$$S_{aMv} = 20C_vS_{MS}(T_v - 0.025) + 0.3C_vS_{MS} \quad (0.025 \text{ s} < T_v \leq 0.05 \text{ s}) \quad (2.5)$$

$$S_{aMv} = 0.8C_vS_{MS} \quad (0.05 \text{ s} < T_v \leq 0.15 \text{ s})$$

$$S_{aMv} = 0.8C_vS_{MS} \left(\frac{0.15}{T_v} \right)^{0.75} \quad (0.15 \text{ s} < T_v \leq 2 \text{ s})$$

Where C_v is defined in terms of the mapped MCE_R spectral response acceleration parameter

at short periods, S_s , given in Table 2.1 and S_{MS} is the maximum considered earthquake spectral response acceleration parameter at short periods. Vertical response spectral acceleration, S_{aMv} , shall not be less than one-half of the corresponding horizontal response spectral acceleration, S_{aM} , determined in ASCE 7-16.

Table 2.1: Values of Vertical Coefficient C_v .

Mapped MCER Spectral Response Parameter at Short Periods	Site Class A, B	Site Class C	Site Class D, E, F
$S_s \geq 2.0$	0.9	1.3	1.5
$S_s = 1.0$	0.9	1.1	1.3
$S_s = 0.6$	0.9	1.0	1.1
$S_s = 0.3$	0.8	0.8	0.9
$S_s \leq 0.2$	0.7	0.7	0.7

For other structures , ASCE 7-16 stresses that The vertical component of seismic load shall be taken as the following:

$$E_v = 0.2S_{DS}D \quad (2.6)$$

Developing the vertical design spectra used in most seismic codes is a sought. Today there are many studies trying to evaluate the efficiency of vertical spectrum formulations in codes and improve them or to define new alternative methods. For example, new methods to develop vertical response spectra using the vertical to horizontal ratio are given by (Gulerce and Abrahamson, 2011). Vertical response spectrum expressions were derived using the V/H ratio and recommended to be used in accordance with the structural response and which ground motion is dominated horizontal or vertical.

Xiang and Huang (2019) calculated the damping modification factors of vertical spectra using several values of damping ratio by taking the ratio 5% benchmarks. They found that the difference of a damping-scaled spectral ordinate is controlled by the probabilistic properties of damping modification factors of vertical spectral as well as the uncertainties of the 5%-damped spectral ordinates.

At last, the main possible reasons that cause the misstatement of vertical spectrum adopted in the modern seismic codes were discussed by Kale and Akkar (2020). Their investigation indicated that the corner period and the short-period vertical spectral acceleration could not be fully represented in code formulations. The authors suggested some formulations to obtain the vertical design spectrum from the horizontal one. For a special soil condition, the vertical design spectrum is computed depending on the rock horizontal design spectrum.



3. MATERIALS AND METHODS

3.1 DESCRIPTION OF STRUCTURAL SYSTEMES

In this study, in order to investigate the effect of the vertical component of ground motion on the response of structural systems, four types of two-dimensional structures are chosen and investigated under vertical ground motion excitations. These structures are defined in the Turkish Seismic Code (TSC 2018) as sensitive structural systems to vertical ground motions. For each structure, a two-dimensional analysis is carried out using SAP2000 software by linear time history analysis method. A series of near-fault earthquake records are used. The first and second cases (i.e., frame with planted column and frame with inclined column) are reinforced concrete (RC) frames, whereas third and fourth cases (i.e., frame with long cantilever and frame with long-span beam) are steel frames since they contain long spans for which steel structures would be efficient as well as economical. The frames are preliminarily analyzed and designed under all expected loads including dead, live, and seismic loads according by following Turkish Building Seismic Code (TSC 2018), Turkish Design Loads for Buildings (TS 498), Turkish Requirements for Design and Construction of Reinforced Concrete Structures (TS 500) for RC frames, and Specification for Structural Steel Buildings (AISC360-05) for steel frames. The detailed design procedures are not shown, however, the main assumptions and design criteria are briefly explained below.

To define seismic parameters for preliminary design, the following assumptions are made: Frames are located in Istanbul where $PGA=0.52g$, $S_s=1.275$, $S_1=0.344$. Response modification factor $R=8$ for both RC and steel frames, importance factor $I=1$, soil class=ZC. Elastic response spectrum analysis is used to define the lateral forces. The damping ratio is considered as 5%. Effective section rigidity is considered in RC frame design as 0.35 for beams and 0.7 for columns. It is also assumed that frames in first and second cases are subjected to dead load=50 kN/m in addition to frame self-weight and live load=10 kN/m (assumed that bay spacing is 5 m, the dead load =10 kN/m², and live load=2.0 kN/m²). The frame in the third case is subjected to dead load=50 kN/m in addition to frame self-weight and live load=25 kN/m (assumed that bay spacing is 5 m, dead load=10.0 kN/m², and live load=5.0 kN/m²). And finally, the frame in the fourth case is subjected to dead load=10 kN/m in addition to frame self-weight and live load=15 kN/m (assumed that the frame is a part of an industrial structure with 10 m bay spacing, dead load =1.0 kN/m², and live load=1.50 kN/m²). The concrete grade is C30/37 with a cylinder compressive strength of 30 N/mm² and the reinforcing bar yield strength is 420 N/mm². The concrete modulus of elasticity equals 32000

N/mm². Steel grade for steel structures is S355 with yield strength=355 MPA and the modulus of elasticity equals to 200000 MPA. The design load combinations are considered as follows:

$$1.4D + 1.6L$$

$$1.0D + 1.0L + 1.0E_h + 0.3E_v \text{ (1.2L instead of 1.0L for steel structures)}$$

$$0.9D + 1.0E_h - 0.3E_v$$

Where D is the applied dead load, L is the applied live load, E_h is the applied horizontal seismic load, and E_v is the vertical seismic load.

3.1.1 Case 1. RC frame with transfer beam

Three, five, and seven-story frames with three equal spans are used. The span length is 5m, the bottom story height is 4 m while the typical story height is 3 m. The middle column is supported on a transfer beam. Column and beam sizes are indicated in Table 3.1. These frames are illustrated in Figure 3.1.

Table 3.1: Column and beam sizes for case 1.

Frame	Column Size (cm)	Beam Size (cm)	Bottom Story Column Size (cm)	Transfer Beam Size (cm)
3 story	60X40	40X60	60X40	40X70
5 story	60X40	40X60	60X40	40X80
7 story	60X40	40X60	80X40	40X100

3.1.2 Case 2. RC frame with slanted column

Three-story frames with three equal spans are used. The span length is 5m, the bottom story height is 4 m while the typical story height is 3 m. The right column is inclined. All columns are 40x50 cm and all beams are 40x50 cm, regarding the angle of inclination of the column, in this case, frames with two different angles are used. These frames are illustrated in Figure 3.2.

3.1.3 Case 3. Steel frame with long-span cantilever

Three-story steel frames with two spans are used. The first span length is 10 m, while the right span is a cantilever. The story height is 4m. In this case, frames with 4, 5, and 6 m cantilever lengths are used. Column and beam sizes are indicated in Table 3.2. These frames are illustrated in Figure 3.3.

Table 3.2: Column and beam sizes for case 3.

Left Span Length (m)	Cantilever Length (m)	Column section	Beam Section
10	4	HE500B	HE500B
10	5	HE550B	HE550B
10	6	HE650B	HE650B

3.1.4 Case 4. Long-span steel frame

One-story two-span steel frames are used. Story height is 8m. Frame span lengths are 15, 20, and 25 m. Column and beam sizes are indicated in Table 3.3. These frames are illustrated in Figure 3.4.

Table 3.3: Column and beam sizes for case 4.

Span Length (m)	Columns section	Beam Section
15	Built up section: flange250X15mm - web620x10mm	Built up section: flange250X15mm -web620x10mm
20	Built up section: flange250X20mm - web720x15mm	Built up section: flange250X20mm -web720x15mm
25	Built up section: flange250X20mm - web900x16mm	Built up section: flange250X20mm -web900x16mm

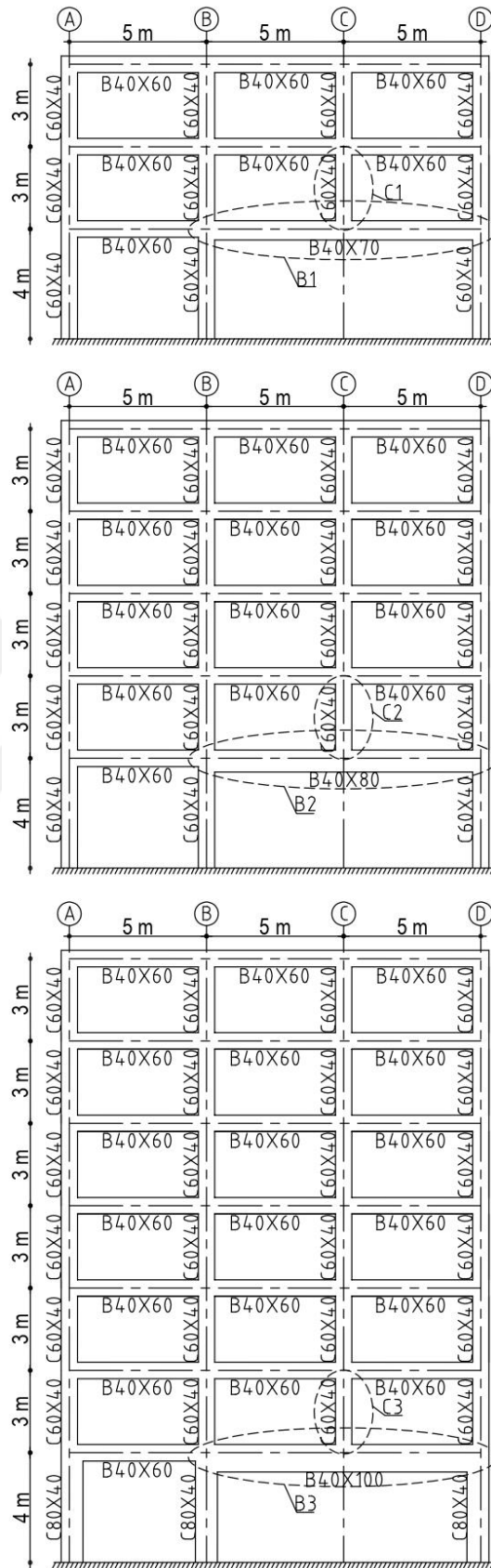


Figure 3.1: Case 1. Frames with transfer beams.

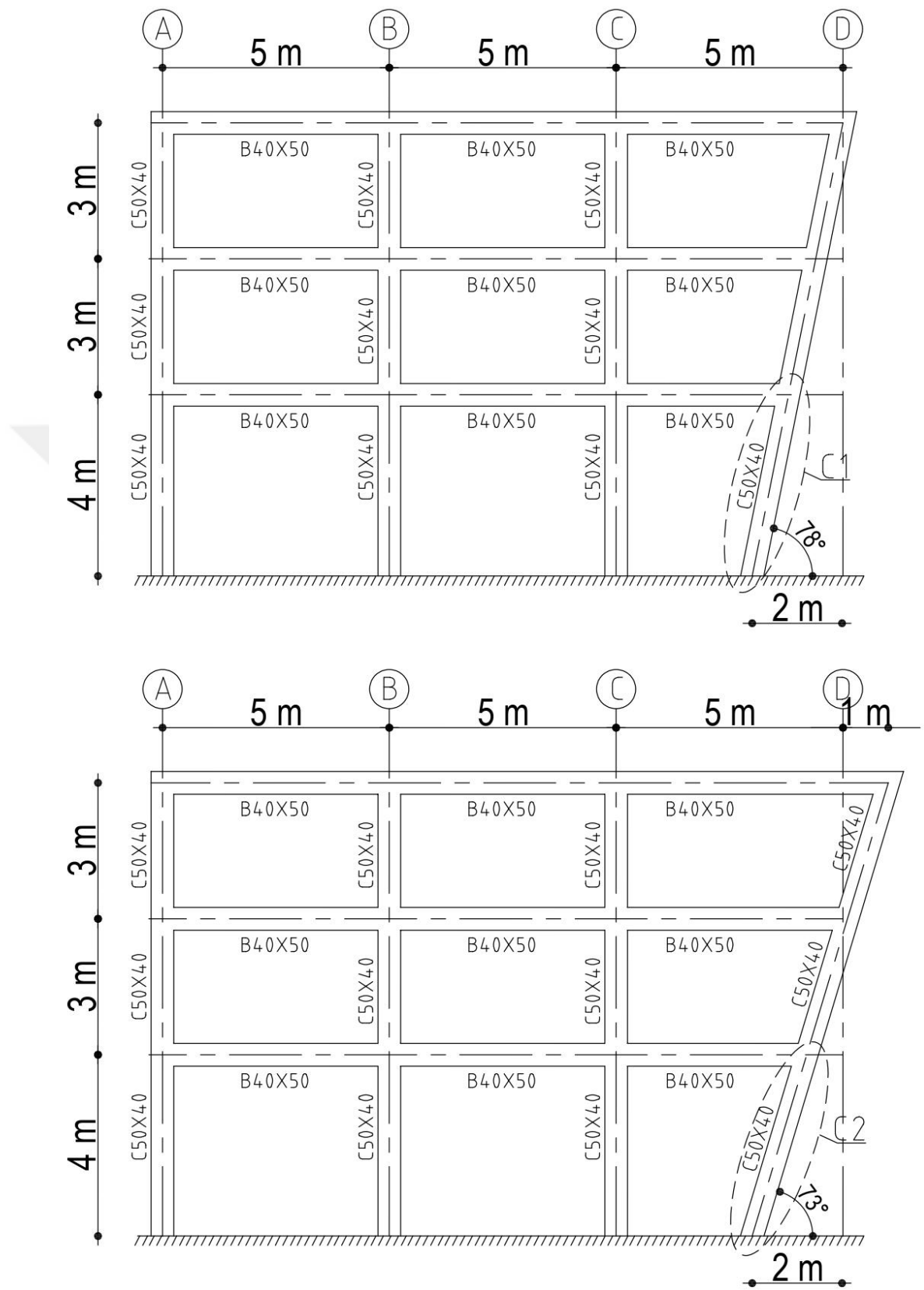


Figure 3.2: Case 2. Frames with slanted columns.

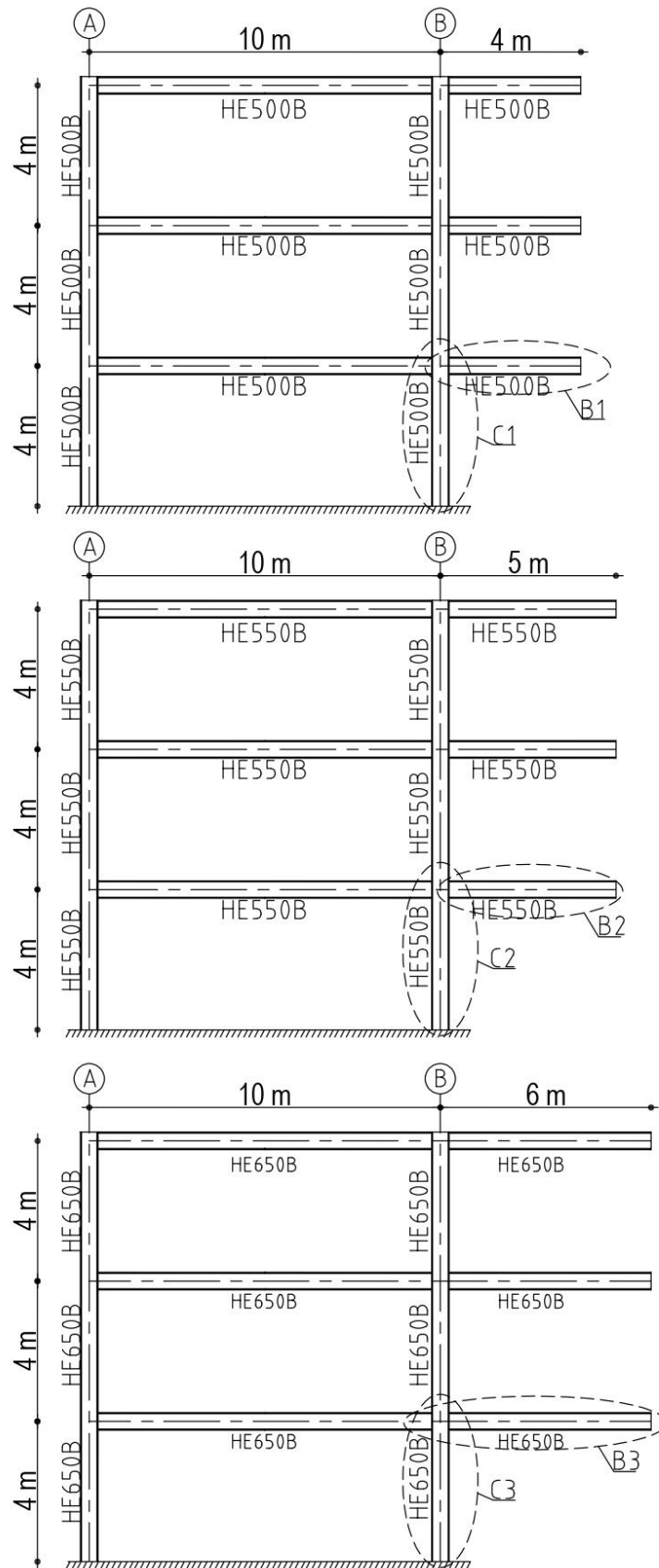


Figure 3.3: Case 3. Frames with long cantilevers.

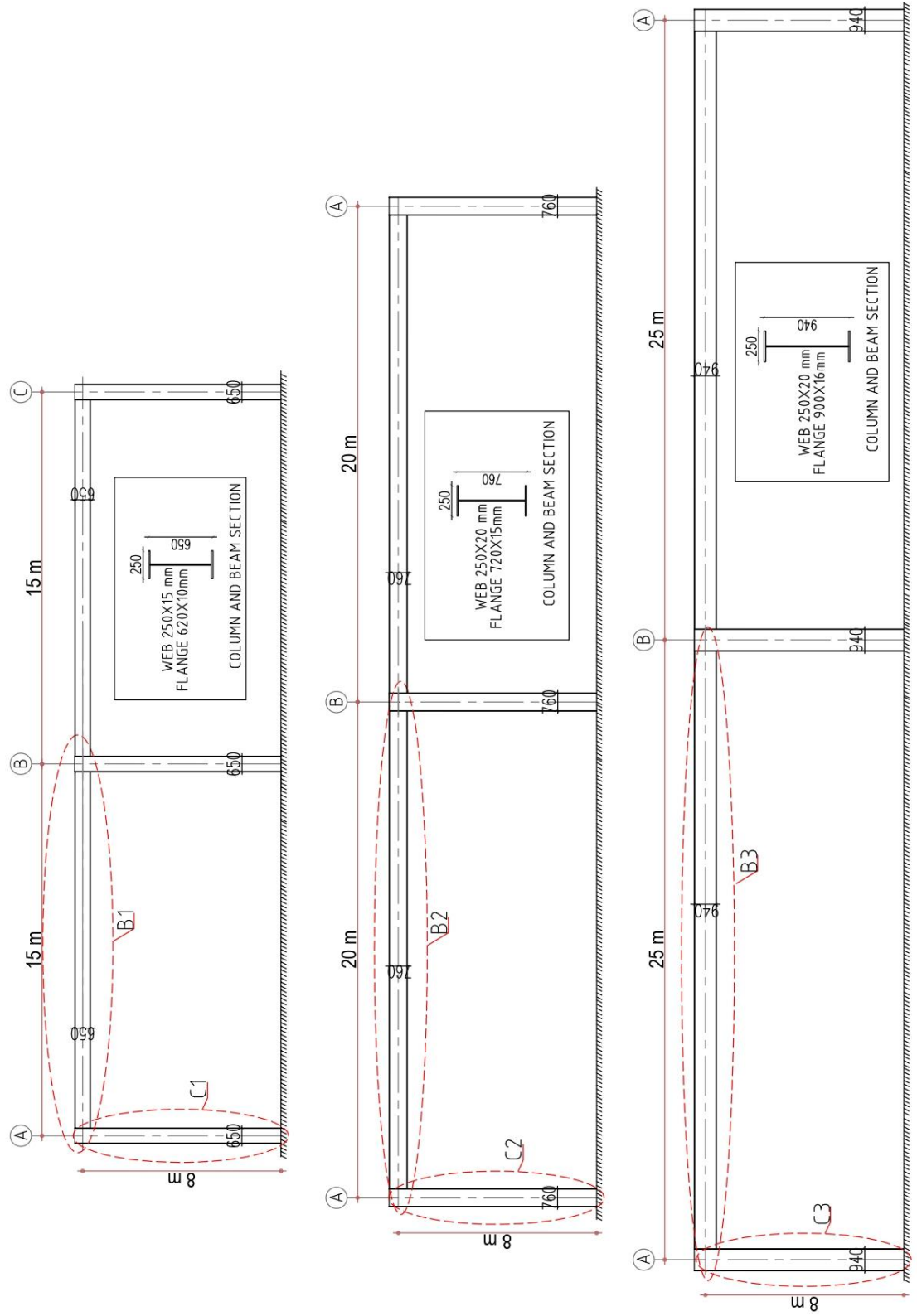


Figure 3.4: Case 4. Long-span frames.

3.2. NEAR-FAULT GROUND MOTION RECORDS

Twelve near-fault ground motion records from five earthquakes and six stations with a moment magnitude (M_w) more than 6.5 were chosen from the Pacific Earthquake Engineering Research database (PEER, 2020). The acceleration, velocity, and other properties of the horizontal and vertical components of the selected near-fault ground motion records obtained from all earthquakes are shown in Table 3.4 and Figures 3.5 to 3.13. The records were selected from stations within 10 km of the fault rupture. All selected earthquakes contain at least one pulse with a minimum peak ground acceleration of 50 cm/s at horizontal components. Moreover, as this study aims to evaluate the effects of vertical components, all records were selected taking into consideration the ratio of vertical to horizontal ground acceleration (V/H) >1 .

Table 3.4: Properties of the near-fault ground motion records.

Record Seq. #	Event	Station	M_w	Rrup (km)	Component	PGA (g)	PGV (cm/s)	PGD (cm)	V/H
1063	1994, Northridge-01	Rinaldi Receiving	6.69	6.5	H1(RRS228)	0.874	148	41.88	1.1
					H2(RRS318)	0.472	74.77	23.1	2.03
					UP(V)	0.958	42.17	3.72	--
879	1992, Landers	Lucerne	7.28	2.19	H1(LCN260)	0.725	133.4	133.9	1.14
					H2(LCN345)	0.789	28.1	25.24	1.04
					UP(V)	0.823	41.09	29.82	--
4040	2003, Bam	Bam	6.6	1.7	H1(L)	0.81	124.1	33.94	1.19
					H2(T)	0.629	60.15	23.15	1.54
					UP(V)	0.967	39.94	8.54	--
8119	2011, Christchurch	Pages Road Pumping	6.2	1.98	H1(PRPCS)	0.596	81.27	38.44	3.19
					H2(PRPCW)	0.67	96.65	40.44	2.84
					UP(V)	1.9	50.47	9.29	--
184	1979, Imperial Valley-06	El Centro Differential Array	6.53	5.09	H1(EDA270)	0.353	75.58	57.15	2.18
					H2(EDA360)	0.481	40.94	16.38	1.6
					UP(V)	0.77	21.57	13.59	--
181	1979, Imperial Valley-06	El Centro Array #6	6.53	1.35	H1(E06140)	0.447	67	27.9	4.25
					H2(E06230)	0.449	113.6	72.89	4.23
					UP(V)	1.89	63.6	23.63	--

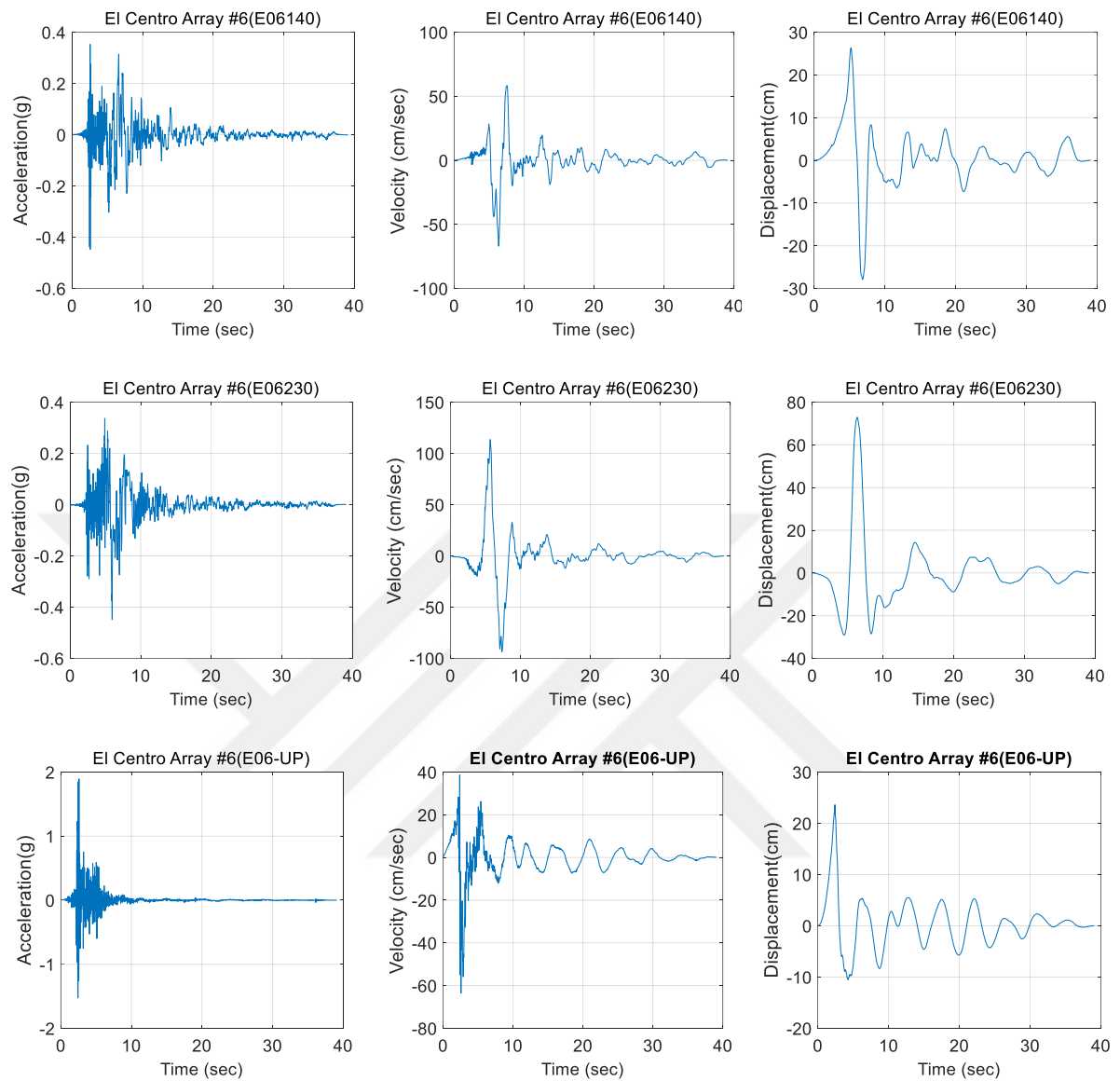


Figure 3.5: Displacement, velocity, and acceleration time-histories-El Centro Array #6 Station Records, 1979 Imperial Valley-06 Earthquake.

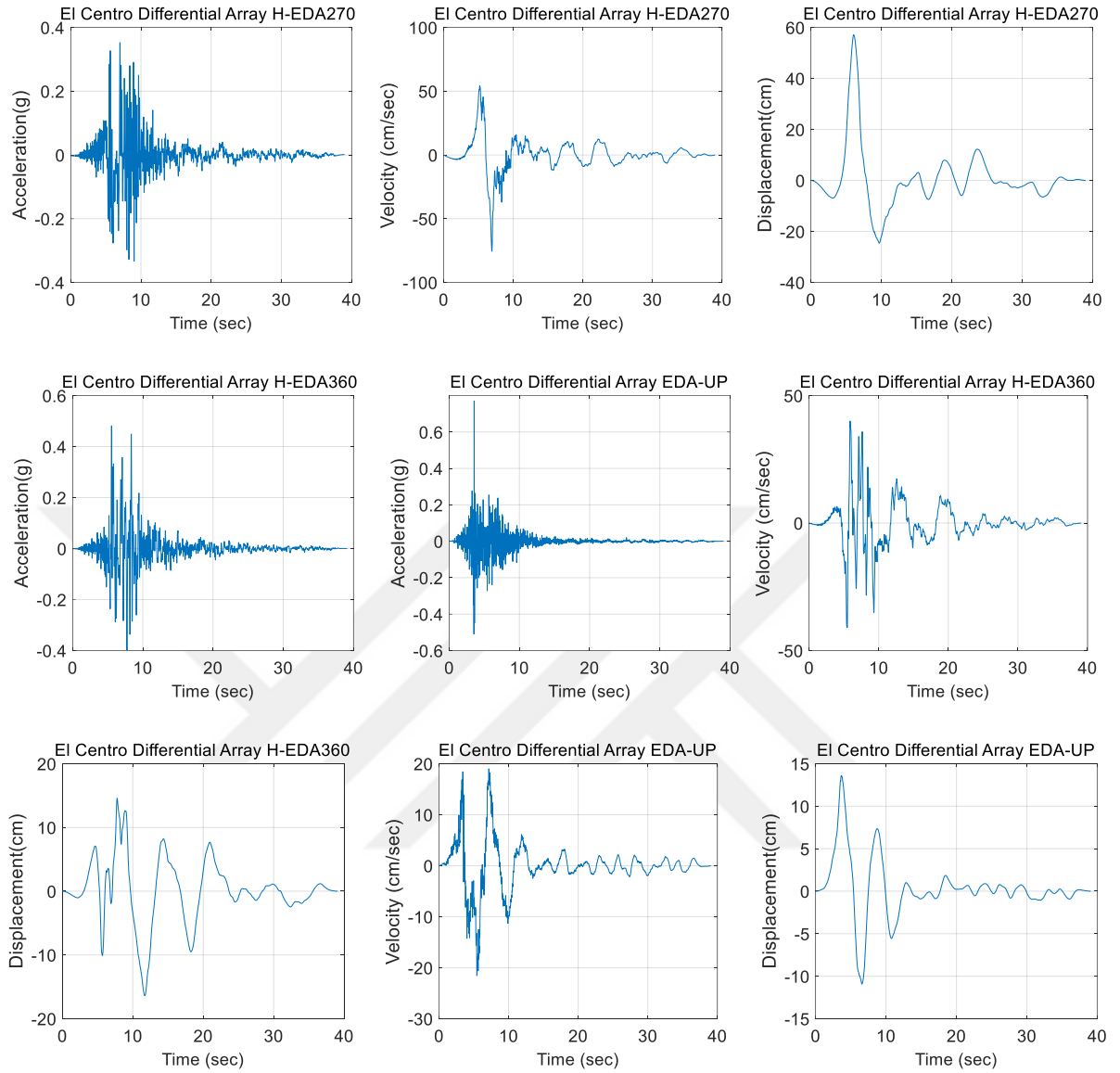


Figure 3.6: Displacement, velocity, and acceleration time-histories-El Centro Differential Array Station Records, 1979 Imperial Valley-06 Earthquake.

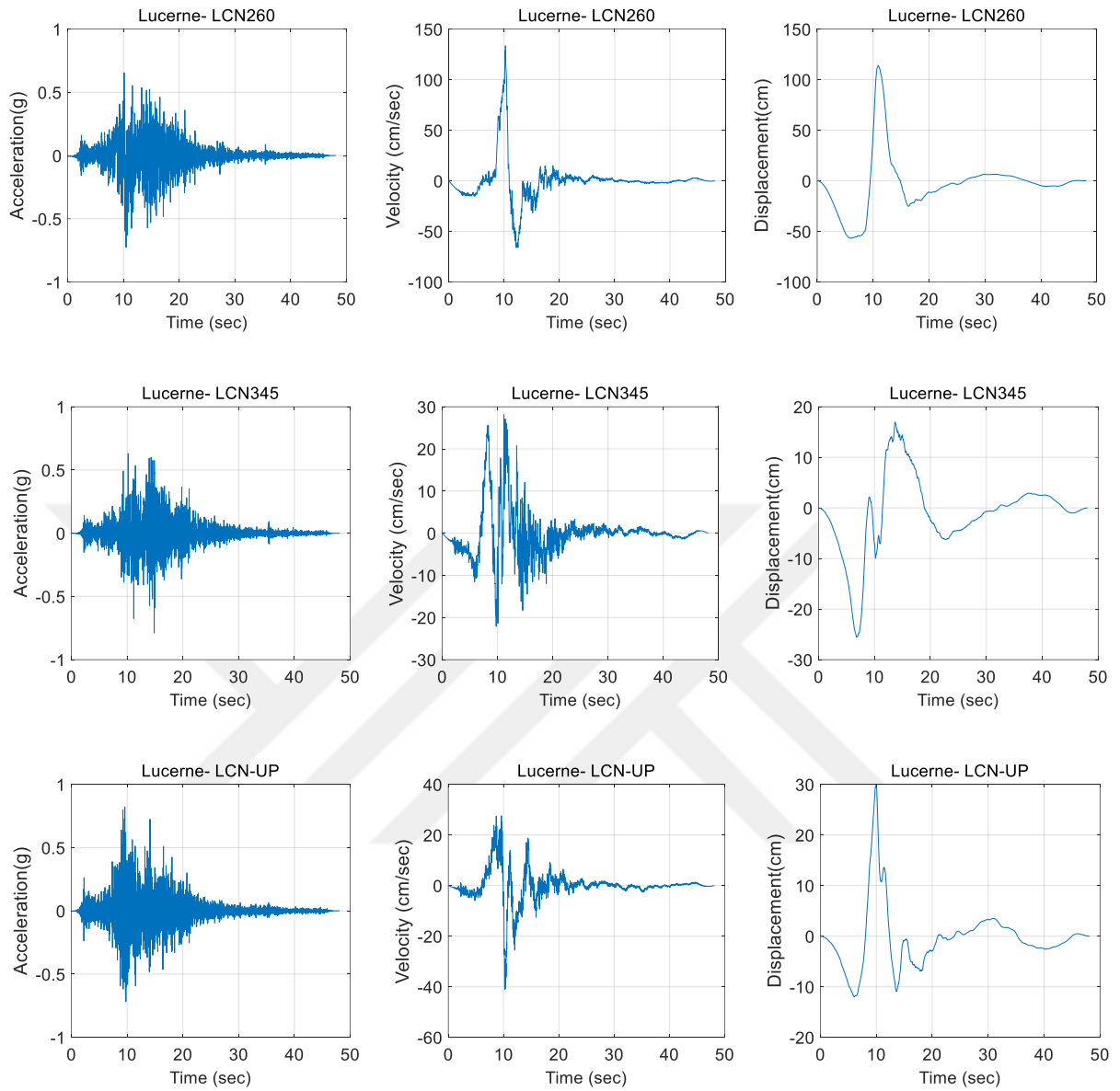


Figure 3.7: Displacement, velocity, and acceleration time-histories- Lucerne Station -Records, 1992 Landers Earthquake.

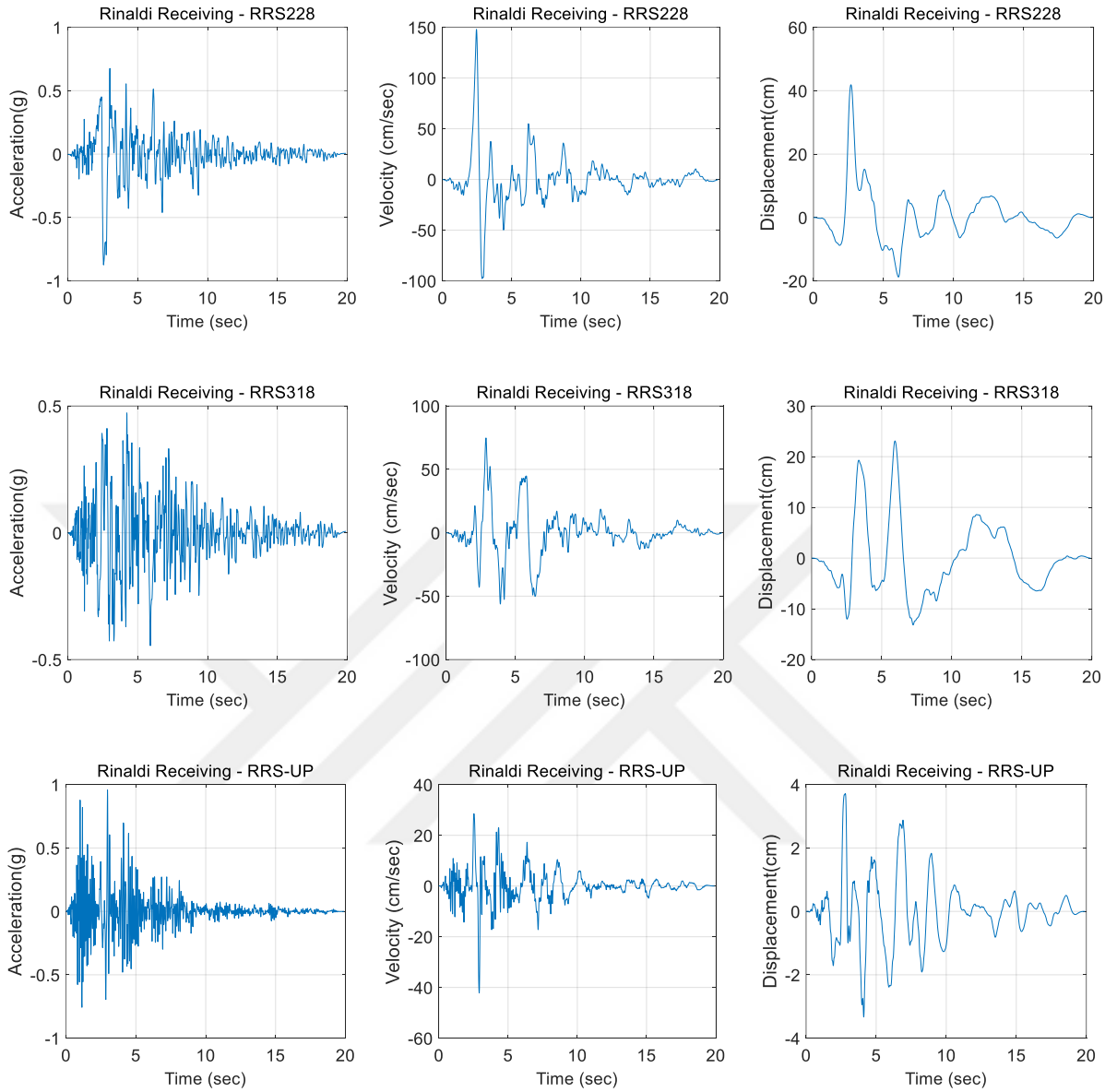


Figure 3.8: Displacement, velocity, and acceleration time-histories- Rinaldi Receiving Station - Records, 1994 Northridge Earthquake.

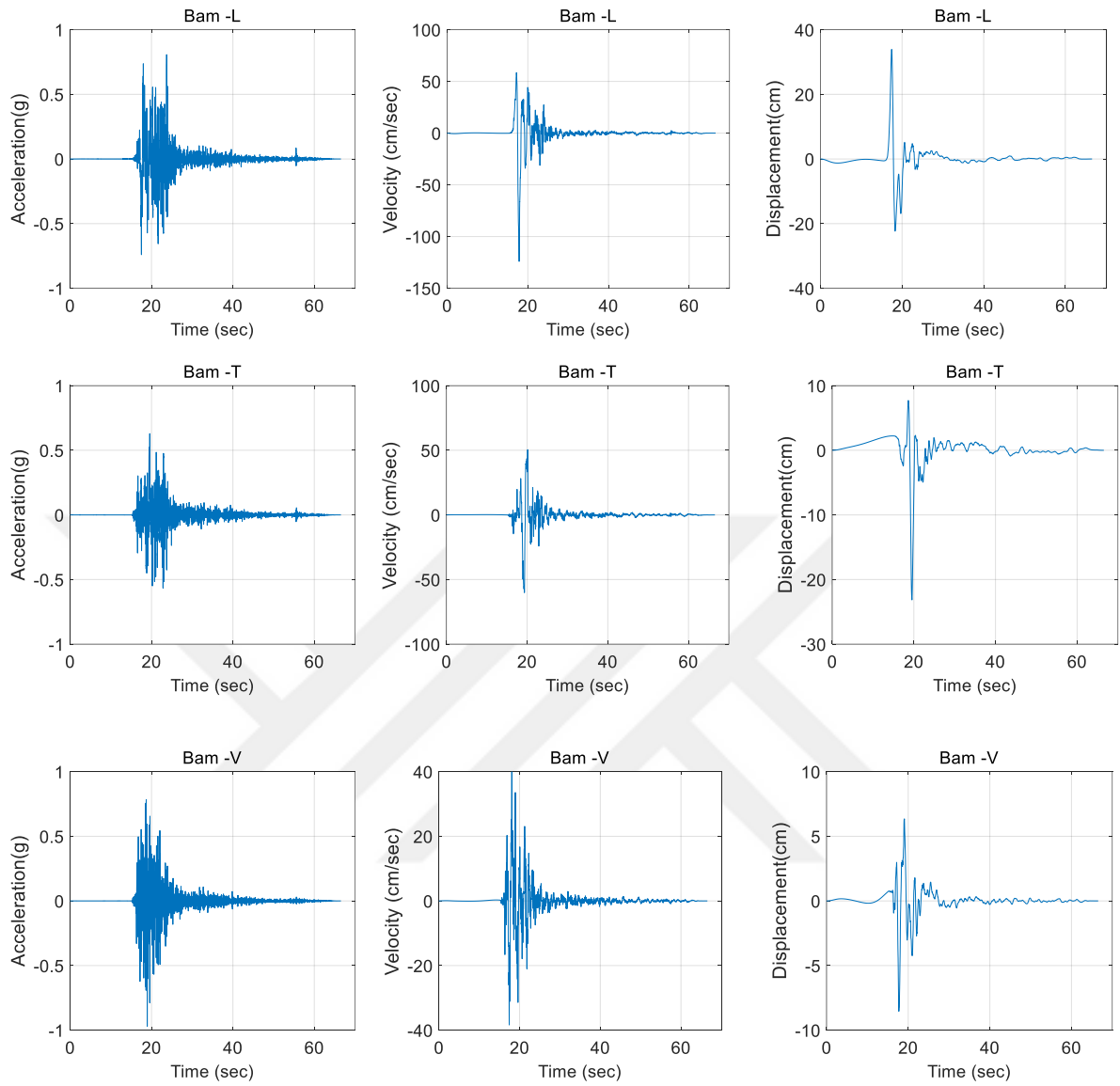


Figure 3.9: Displacement, velocity, and acceleration time-histories- Bam Station - Records, 2003 Bam Earthquake.

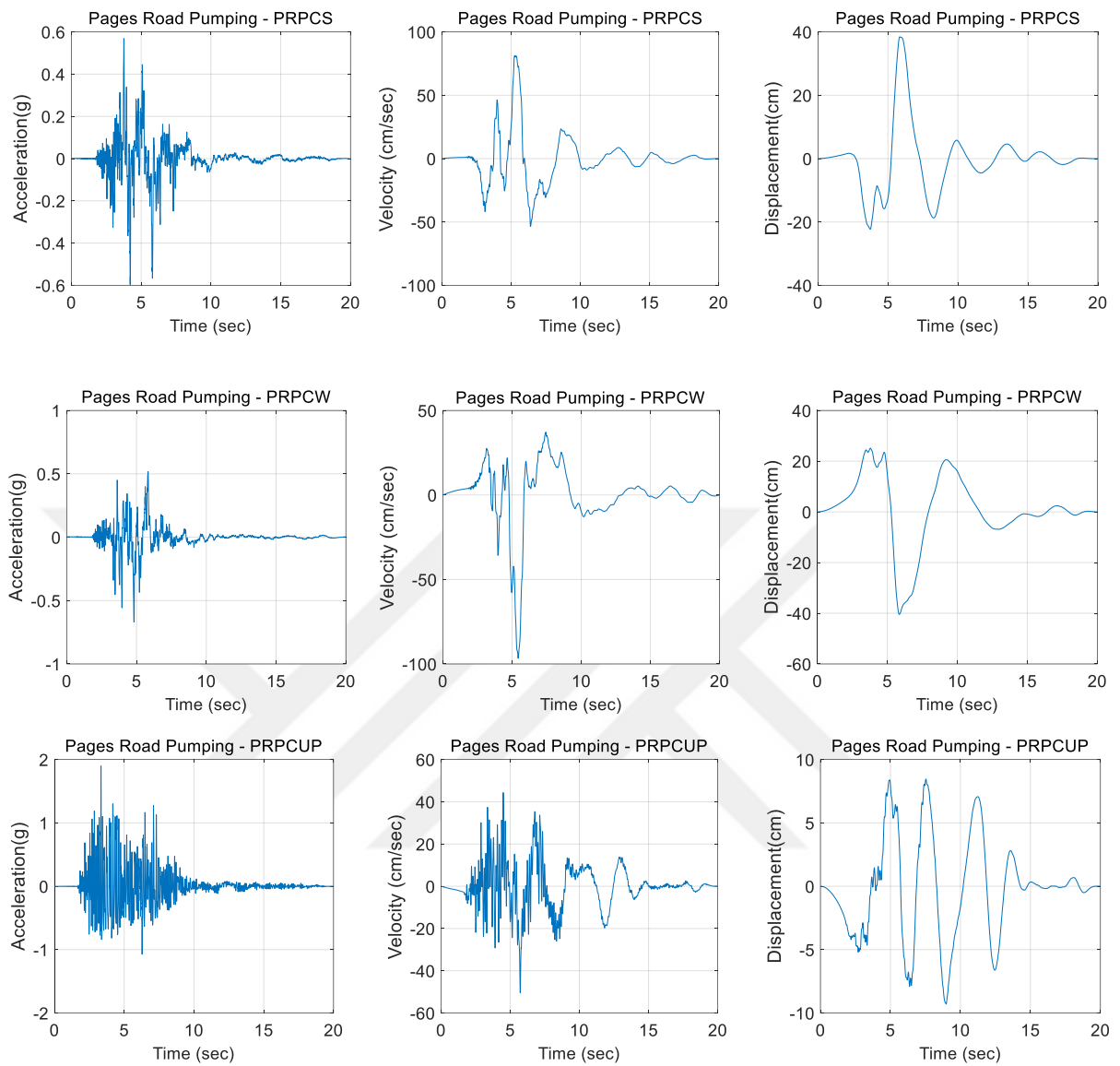


Figure 3.10: Displacement, velocity, and acceleration time-histories- Pages Road Pumping Station Records, 2011 Christchurch Earthquake.

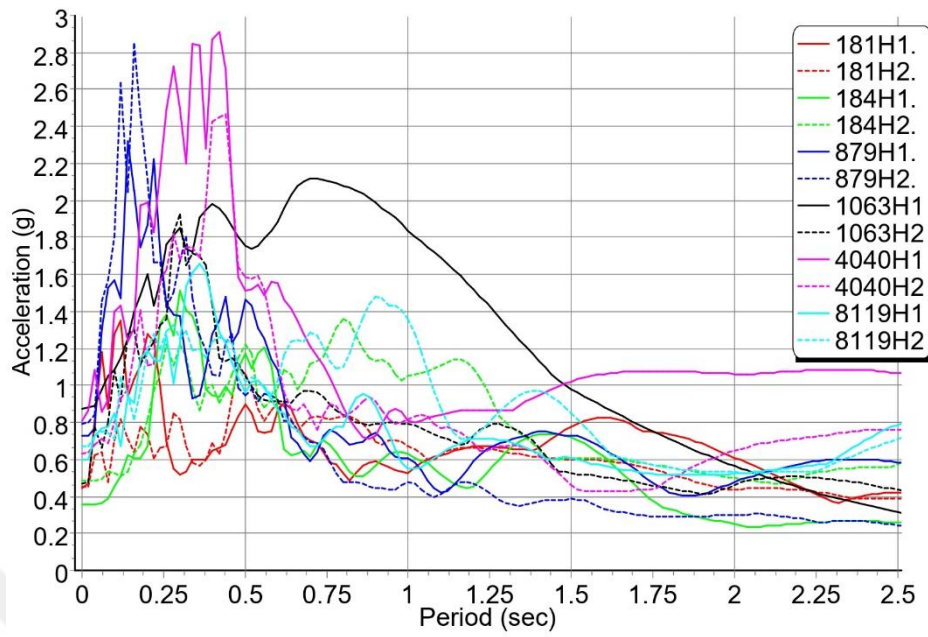


Figure 3.11: Elastic horizontal acceleration response spectra for selected records.

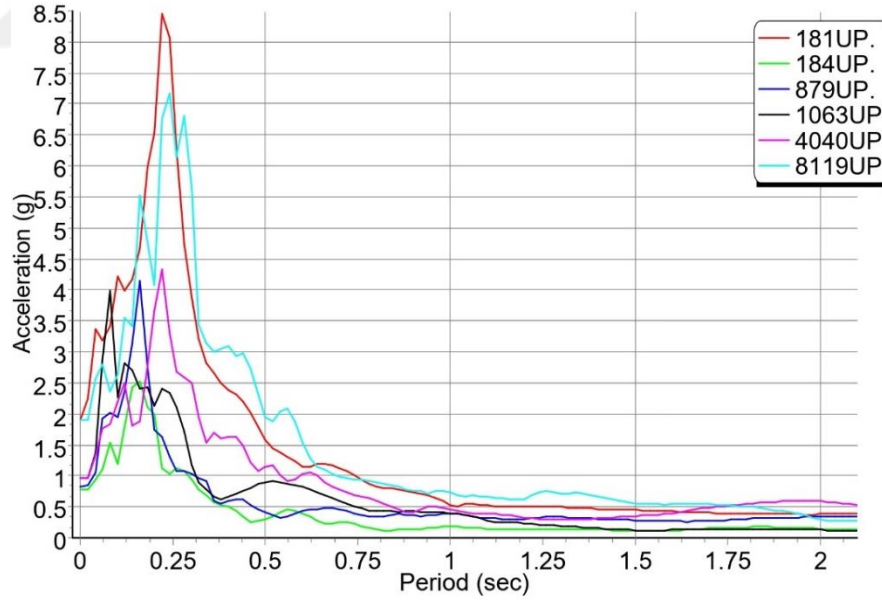


Figure 3.12: Elastic vertical acceleration response spectra for selected records.

3.3. MODELING OF THE FRAMES

The frames described in Section 3.1 are modeled using SAP2000 software. Linear time history analysis is carried out for these frames subjected to three load cases: (a) only horizontal motion component, (b) only vertical motion component, and (c) simultaneous horizontal and vertical ground motions. As an example, Figure 3.11 illustrates the time history function definition for Imperial Valley-06 El Centro Array #6 for both horizontal (E06140) and vertical directions, whereas Figure 3.12 illustrates the definition of time-history load cases for these functions. The case where the horizontal and vertical components are applied on the structures simultaneously as a bi-directional time history load case is shown in Figure 3.13. All records are used without any scaling.

Moreover, linear response-spectrum analysis is carried out for all frames. TSC-2018 response spectra for both horizontal and vertical directions are used with the same parameters that are described in Section 3.1. In this case, similar to the time history analysis, three load cases are defined: (a) only horizontal component, (b) only vertical component, and (c) combination of the horizontal and vertical component. Figure 3.14 illustrates horizontal and vertical response spectra for our site according to the Turkish Seismic Code, whereas Figure 3.15 illustrates the definitions of these load cases.

Turkish Seismic Code (TSC 2018) indicates that the seismic load effect shall be taken as $(E_h \pm 0.3E_v)$, where E_h and E_v are horizontal and vertical seismic load components respectively. This value is used in defining the bi-directional load cases for both linear time history and response spectra analyses. Hence the scale factor for horizontal and vertical components is (I/R) and $(0.3I/R)$ respectively. The phrase “bi-directional (H+V) load case” refers to the value $(E_h \pm 0.3E_v)$ in this study.

The horizontal elements' flexural stiffness is, in general, less than the compressive stiffness of the vertical elements. Thus, the mass vertical displacement depends on its location along the horizontal beams (Abdollahiparsa and others, 2016). Hence, to ensure the acceptable behavior of the frames under vertical ground motion, the masses of the frames must be distributed between the main nodes and one or several nodes within the beams. However, we do not introduce big differences between using lumped or distributed masses. The mass of the elements is defined using element self mass and additional mass which calculated from applied dead

loads and a portion of applied live loads assuming the acceleration of gravity $g=10 \text{ m/s}^2$. (for example: mid-span additional mass for case-1 equals to $2.5 \times (50 + 0.3 \times 10) / 10 = 13.25 \text{ ton}$, where the distance between nodes is 2.5 m and the multiplier of live load is 0.3). Figures 3.16 to 3.19 show the distribution of the additional masses for all cases.

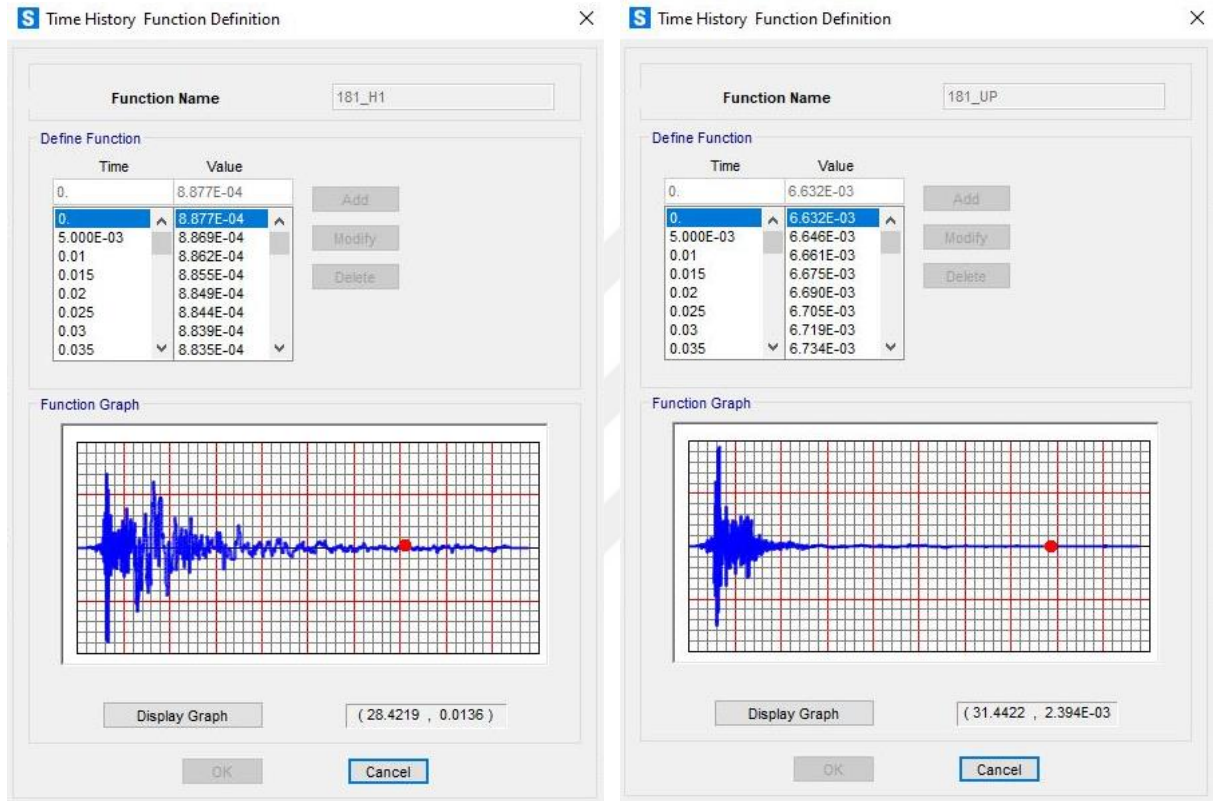


Figure 3.11: Definition of horizontal (H1) and vertical (V) time history functions for Imperial Valley-06 El Centro Array #6 records.

S Load Case Data - Linear Modal History

Load Case Name: 181_H1(TH) Set Def Name Modify/Show...

Initial Conditions:
☒ Zero Initial Conditions - Start from Unstressed State
☐ Continue from State at End of Modal History
 Important Note: Loads from this previous case are included in the current case

Modal Load Case:
 Use Modes from Case: MODAL

Loads Applied

Load Type	Load Name	Function	Scale Factor
Accel	U1	181_H1	1.2263
Accel	U1	181_H1	1.2263

Add Modify Delete

☐ Show Advanced Load Parameters

Time Step Data:
 Number of Output Time Steps: 7817
 Output Time Step Size: 5.000E-03

Other Parameters:
 Modal Damping: Constant at 0.05 Modify/Show...

Load Case Type: Time History Design...

Analysis Type:
☒ Linear
☐ Nonlinear

Solution Type:
☒ Modal
☐ Direct Integration
☐ Frequency Domain

History Type:
☒ Transient
☐ Periodic

Mass Source:
 Previous (MSSSRC1)

OK Cancel

S Load Case Data - Linear Modal History

Load Case Name: 181_V(TH) Set Def Name Modify/Show...

Initial Conditions:
☒ Zero Initial Conditions - Start from Unstressed State
☐ Continue from State at End of Modal History
 Important Note: Loads from this previous case are included in the current case

Modal Load Case:
 Use Modes from Case: MODAL

Loads Applied

Load Type	Load Name	Function	Scale Factor
Accel	U3	181_UP	2.943
Accel	U3	181_UP	2.943

Add Modify Delete

☐ Show Advanced Load Parameters

Time Step Data:
 Number of Output Time Steps: 7815
 Output Time Step Size: 5.000E-03

Other Parameters:
 Modal Damping: Constant at 0.05 Modify/Show...

Load Case Type: Time History Design...

Analysis Type:
☒ Linear
☐ Nonlinear

Solution Type:
☒ Modal
☐ Direct Integration
☐ Frequency Domain

History Type:
☒ Transient
☐ Periodic

Mass Source:
 Previous (MSSSRC1)

OK Cancel

Figure 3.12: Definition of only horizontal (H1) and only vertical time history(V) load cases for Imperial Valley-06 El Centro Array #6 record.

Load Case Data - Linear Modal History

Load Case Name: 181_H1+V(TH) Set Def Name Modify/Show...

Initial Conditions:
☒ Zero Initial Conditions - Start from Unstressed State
☐ Continue from State at End of Modal History ▼
Important Note: Loads from this previous case are included in the current case

Modal Load Case:
 Use Modes from Case: MODAL ▼

Loads Applied

Load Type	Load Name	Function	Scale Factor
Accel	U1	181_H1	1.2263
Accel	U3	181_UP	2.943

Add Modify Delete

☐ Show Advanced Load Parameters

Time Step Data:
 Number of Output Time Steps: 7817
 Output Time Step Size: 5.000E-03

Other Parameters:
 Modal Damping: Constant at 0.05 Modify/Show...

Load Case Type: Time History Design...

Analysis Type:
☒ Linear
☐ Nonlinear

History Type:
☒ Transient
☐ Periodic

Solution Type:
☒ Modal
☐ Direct Integration
☐ Frequency Domain

Mass Source:
 Previous (MSSSRC1)

OK Cancel

Figure 3.13: Definition of bidirectional horizontal and vertical (H1+V) load case for Imperial Valley-06 El Centro Array #6 record.

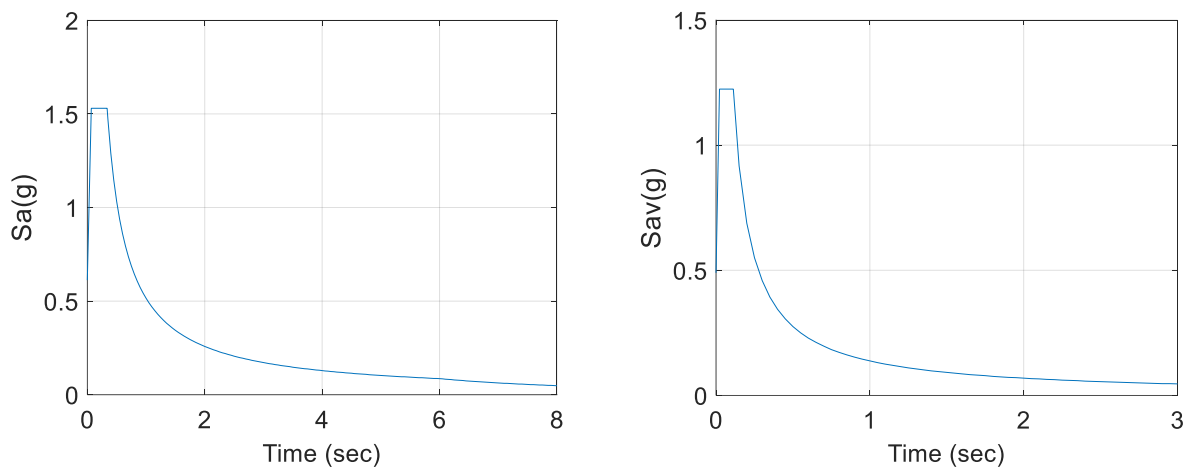


Figure 3.14: Vertical and horizontal response spectra for the site as per the Turkish Seismic Code.

S Load Case Data - Response Spectrum

Load Case Name: Set Def Name Modify/Show...

Notes

Load Case Type: Response Spectrum Design...

Modal Combination

☒ CQC ☐ SRSS ☐ Absolute ☐ GMC ☐ NRC 10 Percent ☐ Double Sum

GMC f1: GMC f2: Periodic + Rigid Type: SRSS

Modal Load Case

Use Modes from this Modal Load Case: MODAL

☒ Standard - Acceleration Loading ☐ Advanced - Displacement Inertia Loading

Directional Combination

☒ SRSS ☐ CQC3 ☐ Absolute

Scale Factor:

Mass Source

Diaphragm Eccentricity

Eccentricity Ratio: Override Eccentricities: Override...

Loads Applied

Load Type	Load Name	Function	Scale Factor
Accel	U1	TSC-H	1.2263
Accel	U1	TSC-H	1.2263

Add Modify Delete

☐ Show Advanced Load Parameters

Other Parameters

Modal Damping: Constant at 0.05 Modify/Show...

OK Cancel

S Load Case Data - Response Spectrum

Load Case Name: Set Def Name Modify/Show...

Notes

Load Case Type: Response Spectrum Design...

Modal Combination

☒ CQC ☐ SRSS ☐ Absolute ☐ GMC ☐ NRC 10 Percent ☐ Double Sum

GMC f1: GMC f2: Periodic + Rigid Type: SRSS

Modal Load Case

Use Modes from this Modal Load Case: MODAL

☒ Standard - Acceleration Loading ☐ Advanced - Displacement Inertia Loading

Directional Combination

☒ SRSS ☐ CQC3 ☐ Absolute

Scale Factor:

Mass Source

Diaphragm Eccentricity

Eccentricity Ratio: Override Eccentricities: Override...

Loads Applied

Load Type	Load Name	Function	Scale Factor
Accel	U1	TSC-H	1.2263
Accel	U1	TSC-H	1.2263
Accel	U3	TSC-V	2.943

Add Modify Delete

☐ Show Advanced Load Parameters

Other Parameters

Modal Damping: Constant at 0.05 Modify/Show...

OK Cancel

Figure 3.15: Definition of horizontal and bidirectional (horizontal + vertical) response spectrum load cases.

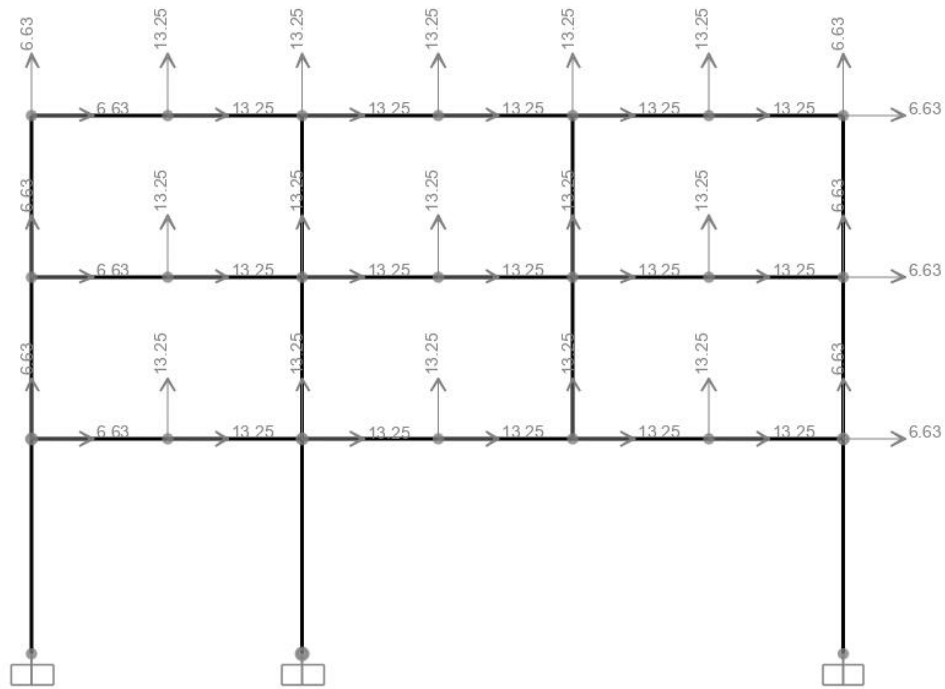


Figure 3.16: Case-1_1 distribution of the additional masses.

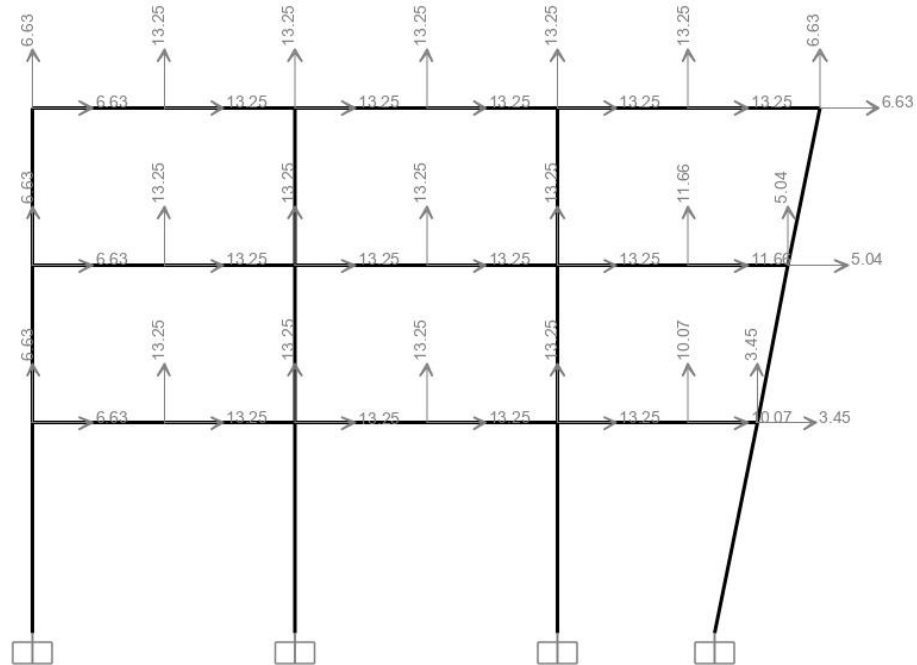


Figure 3.17: Case-2_1 distribution of the additional masses.

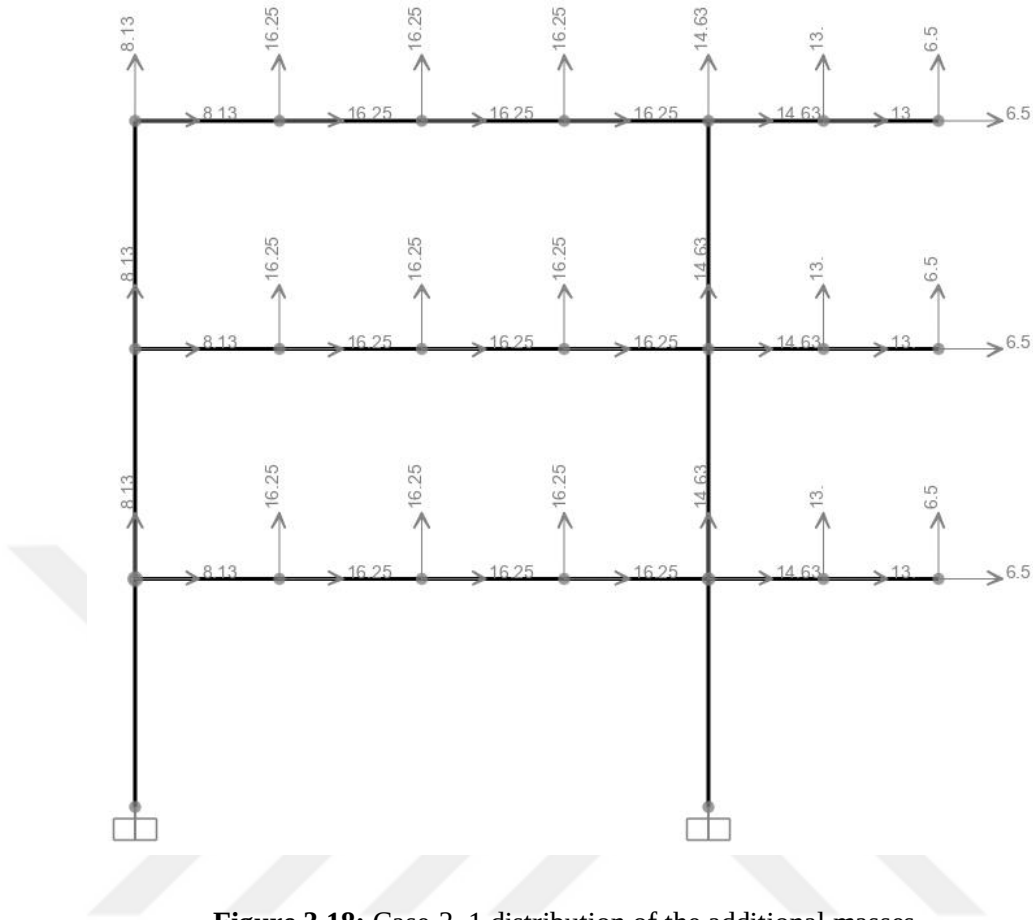


Figure 3.18: Case-3_1 distribution of the additional masses.

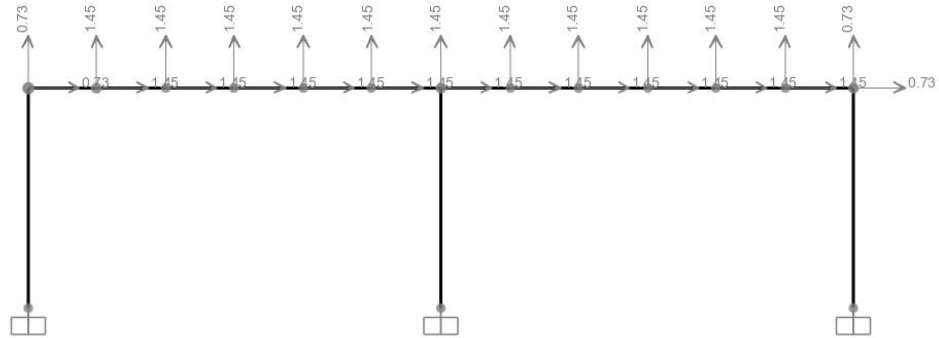


Figure 3.19: Case-4_1 distribution of the additional masses.

Modal analyses are carried out and the neutral dynamic characteristics were determined (i.e frame fundamental mode, frame vertical fundamental mode, etc.). Tables 3.5 to 3.8 show fundamental periods for horizontal and vertical directions for studied cases, whereas Figure 3.20 shows the frame fundamental mode for both horizontal and vertical direction.

Table 3.5: Case-1 fundamental periods.

Frame	Fundamental period (sec)	Vertical fundamental period (sec)
3 story	0.442	0.164
5 story	0.666	0.168
7 story	0.816	0.167

Table 3.6: Case-2 fundamental periods.

Frame	Fundamental period (sec)	Vertical fundamental period (sec)
case 2-1	0.469	0.072
case 2-2	0.517	0.122

Table 3.7: Case-3 fundamental periods.

Cantilever length (m)	Fundamental period (sec)	Vertical fundamental period (sec)
4	1.07	0.241
5	0.881	0.349
6	0.752	0.377

Table 3.8: Case-4 fundamental periods.

Span length (m)	Fundamental period (sec)	Vertical fundamental period (sec)
15	0.373	0.165
20	0.330	0.205
25	0.264	0.209

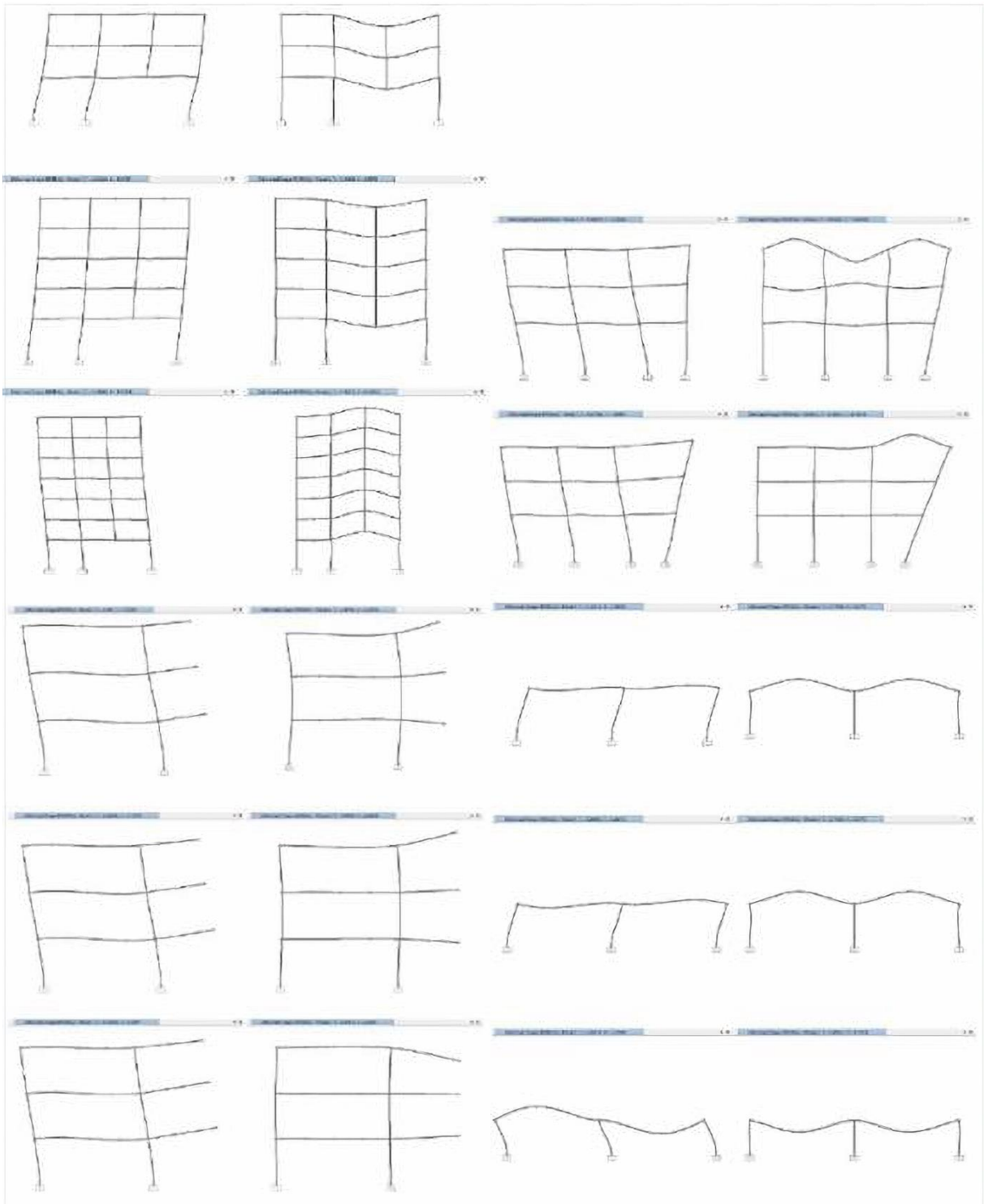


Figure 3.20: Horizontal (left) and vertical (right) fundamental mode shapes for all cases.

4. RESULTS

In order to evaluate the effect of vertical component motion on the structural responses of the frames, below listed maximum response parameters are studied for three load cases (only horizontal component, H, only vertical component, V, and simultaneous (bi-directional) horizontal and vertical component, H+V):

1. Axial forces in columns.
2. Shear forces in beams.
3. Shear forces in slanted columns.
4. Bending moments in beams.
5. Bending moments in slanted columns.
6. Story drifts.
7. Relative vertical displacements.
8. Absolute horizontal and vertical accelerations.

4.1. TIME HISTORY RESULTS

To illustrate the effect of the vertical excitation of the ground motions on the time history results, Figures 4.1 to 4.7 are presented which show the displacements, the accelerations, and the internal forces at the bottom of the planted column (C1) and transfer beam (B1) in Case1-1 for different time-history loading cases (horizontal only and bi-directional) due to El Centro Array #6 Station Records, 1979 Imperial Valley-06 Earthquake whereas Figures 4.8 to 4.10 show more examples for horizontal displacement plots due to this earthquake.

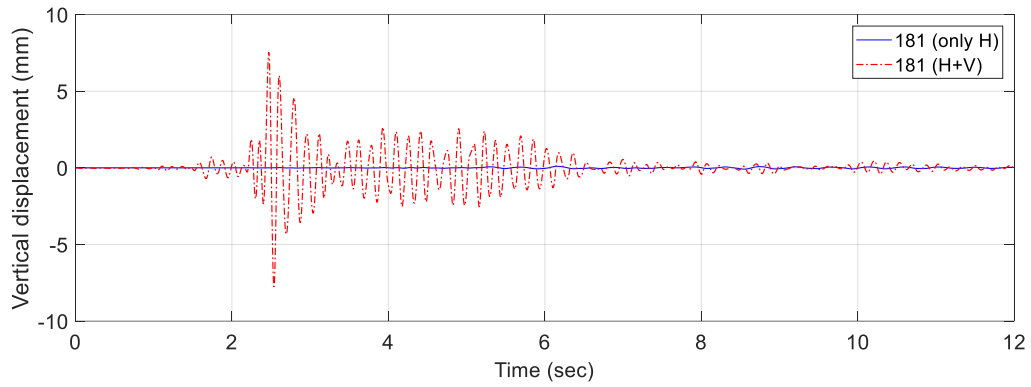


Figure 4.1: Vertical displacement at the bottom of the planted column (C1) for H1 and H1+V - Imperial Valley-06 El Centro Array #6 records.

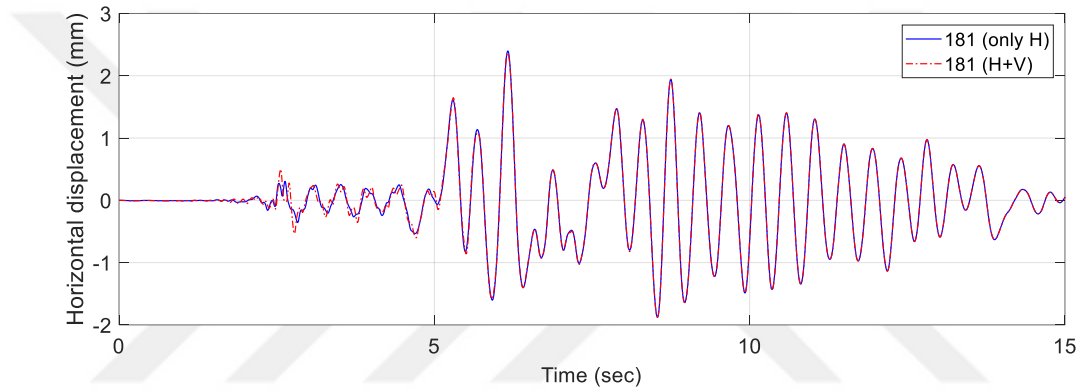


Figure 4.2: Horizontal displacement at the bottom of the planted column (C1) for H1 and H1+V - Imperial Valley-06 El Centro Array #6 records.

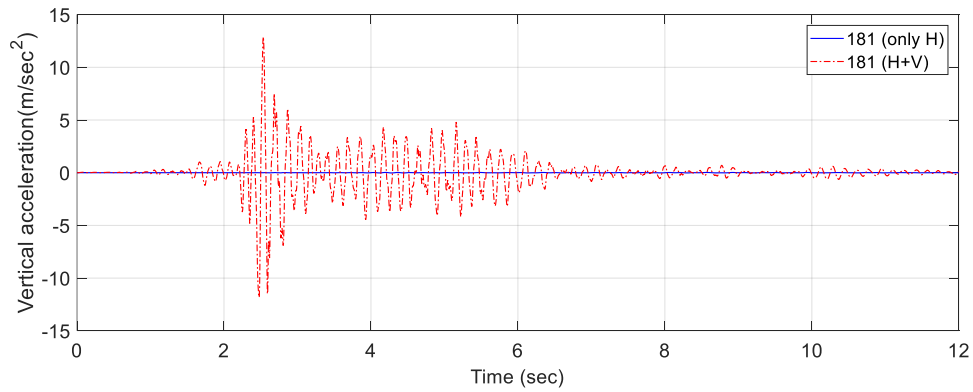


Figure 4.3: Vertical acceleration at the bottom of the planted column (C1) for H1 and H1+V - Imperial Valley-06 El Centro Array #6 records.

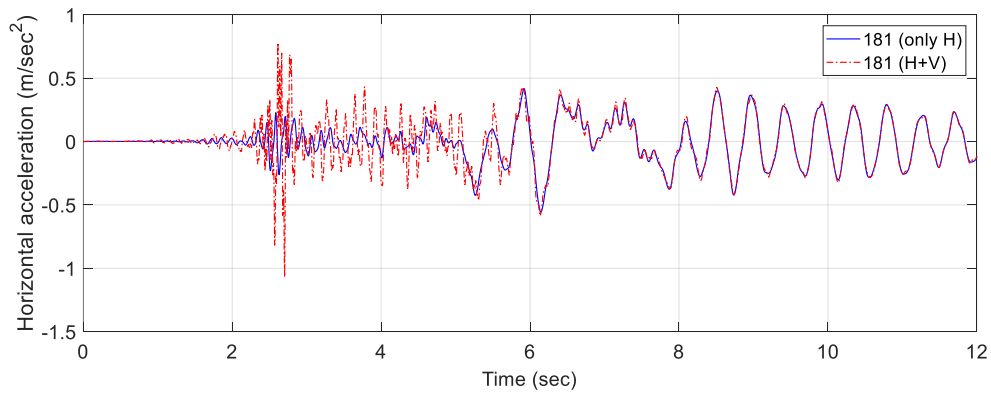


Figure 4.4: Horizontal acceleration at the bottom of the planted column (C1) for H1 and H1+V - Imperial Valley-06 El Centro Array #6 records.

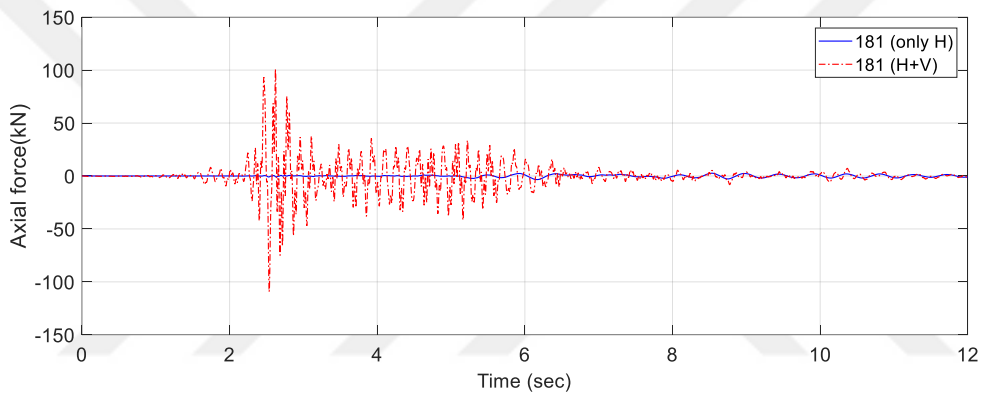


Figure 4.5: Axial force at the bottom of the planted column (C1) for H1 and H1+V - Imperial Valley-06 El Centro Array #6 records.

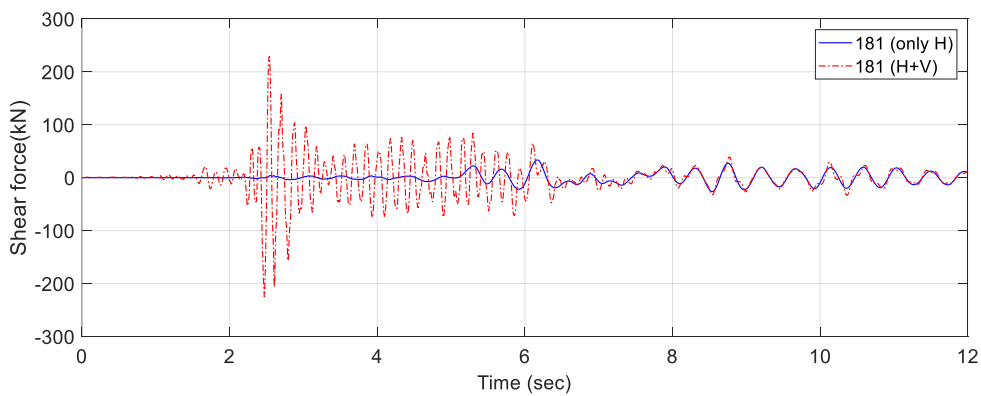


Figure 4.6: Shear force at right support of the transfer beam (B1) for H1 and H1+V - Imperial Valley-06 El Centro Array #6 records.

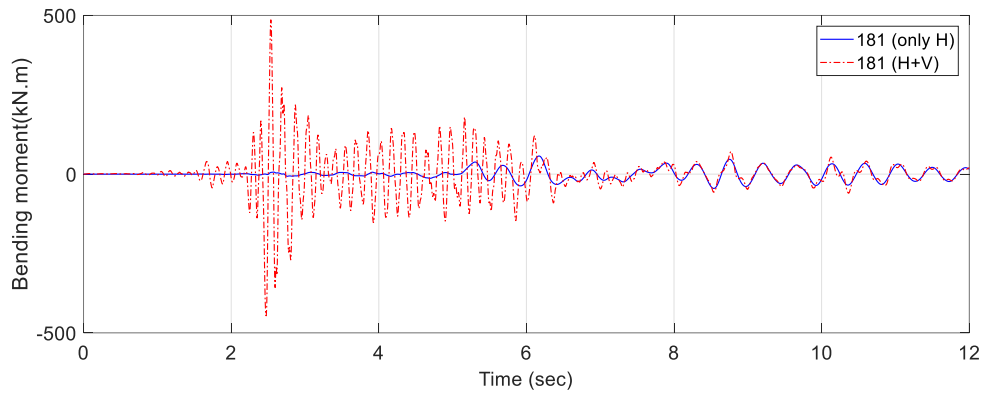


Figure 4.7: Bending moment at mid-span of the transfer beam (B1) for H1 and H1+V - Imperial Valley-06 El Centro Array #6 records.

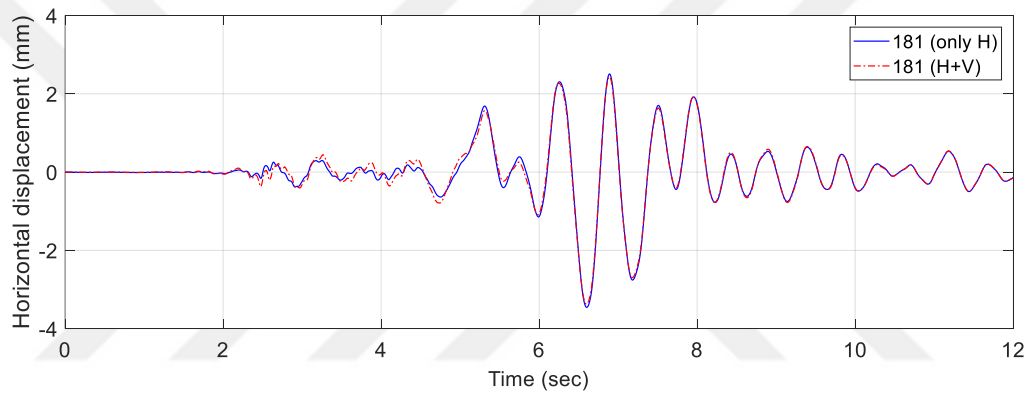


Figure 4.8: Horizontal displacement at the top of the slanted column (C1) for H1 and H1+V - Imperial Valley-06 El Centro Array #6 records.

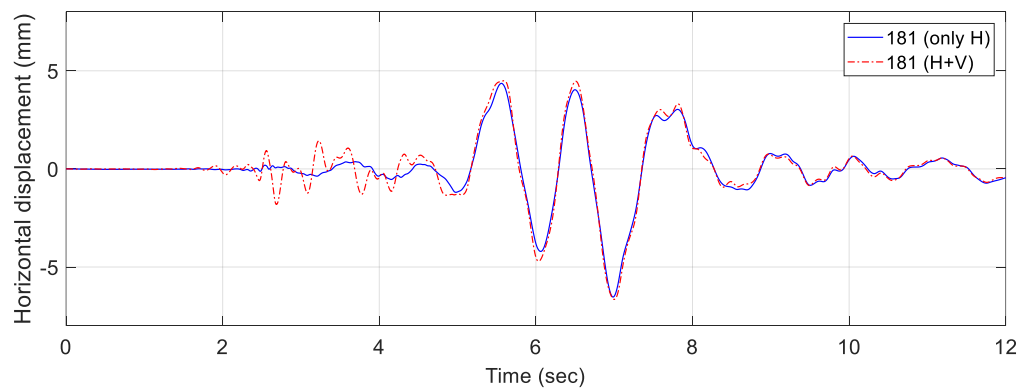


Figure 4.9: Horizontal displacement at the free end of the cantilever beam (B1) for H1 and H1+V - Imperial Valley-06 El Centro Array #6 records.

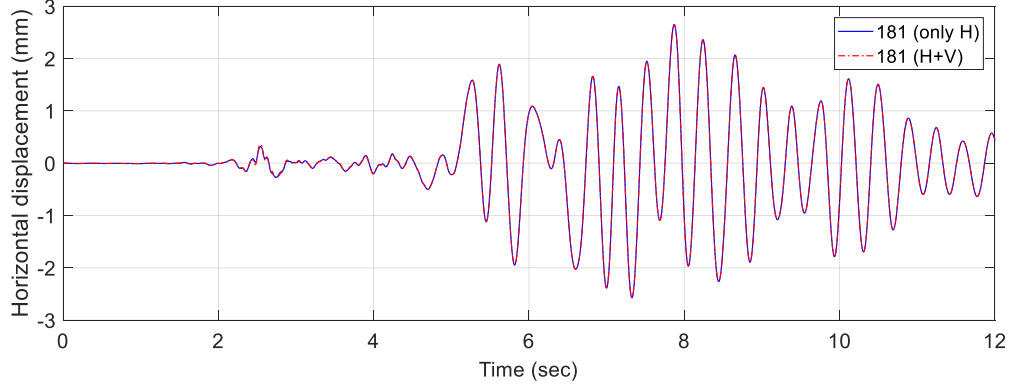


Figure 4.10: Horizontal displacement at mid-span of the 15m long-span beam (B1) for H1 and H1+V - Imperial Valley-06 El Centro Array #6 records.

4.2. AMPLIFICATION FACTORS

In order to further evaluate the effect of the vertical ground motion, dimensionless amplification factors are defined and calculated in this section as follows:

The amplification factor for axial force:

$$AF_{(axial)} = \frac{\text{Max. or Min. } (N_{H+V})}{\text{Max. or Min. } (N_H)} \quad (4.1)$$

Where N_{H+V} and N_H are the axial forces due to bi-directional loading and due to only horizontal only loading, respectively.

The amplification factor of bending moment:

$$AF_{(moment)} = \frac{\text{Max. or Min. } (M_{H+V})}{\text{Max. or Min. } (M_H)} \quad (4.2)$$

Where M_{H+V} and M_H are the bending moments due to bi-directional loading and due to only horizontal only loading, respectively.

The amplification factor for shear force:

$$AF_{(shear)} = \frac{\text{Max. or Min. } (V_{H+V})}{\text{Max. or Min. } (V_H)} \quad (4.3)$$

Where V_{H+V} and V_H are the shear forces due to bi-directional loading and due to only horizontal only loading, respectively.

The amplification factor of vertical displacement:

$$AF_{(dis)} = \frac{\text{Max. or Min. } (Dis_{H+V})}{\text{Max. or Min. } (Dis_H)} \quad (4.4)$$

Where Dis_{H+V} and Dis_H are the vertical displacements due to bi-directional loading and due to only horizontal only loading, respectively.

The amplification factor of vertical-absolute acceleration:

$$AF_{(acc)} = \frac{\text{Max. or Min. } (Acc_{H+V})}{\text{Max. or Min. } (Acc_H)} \quad (4.5)$$

Where Acc_{H+V} and Acc_H are the vertical absolute accelerations due to bi-directional loading and due to only horizontal only loading, respectively.

Figures 4.11 to 4.21 show the amplification factor values for vertical displacement, vertical acceleration, axial force, shear force, and the bending moment under the different time-history load cases (only horizontal and bi-directional) for the relevant critical elements in all cases. The labels of the elements examined are illustrated in Figures 3.1 to 3.4. In addition, the mean (and $\pm$ standard deviation) of the amplification factor values for each subset for time history analyses are shown in comparison with those obtained for TSC-2018 response spectra analyses. These plots clearly show how the vertical component of the ground excitation affects the responses of the frames and how this effect differs depending on the frame configurations. The results are discussed in the next chapter. Details of the results and calculations are given in the appendices.

4.2.1 Frames with transfer beams

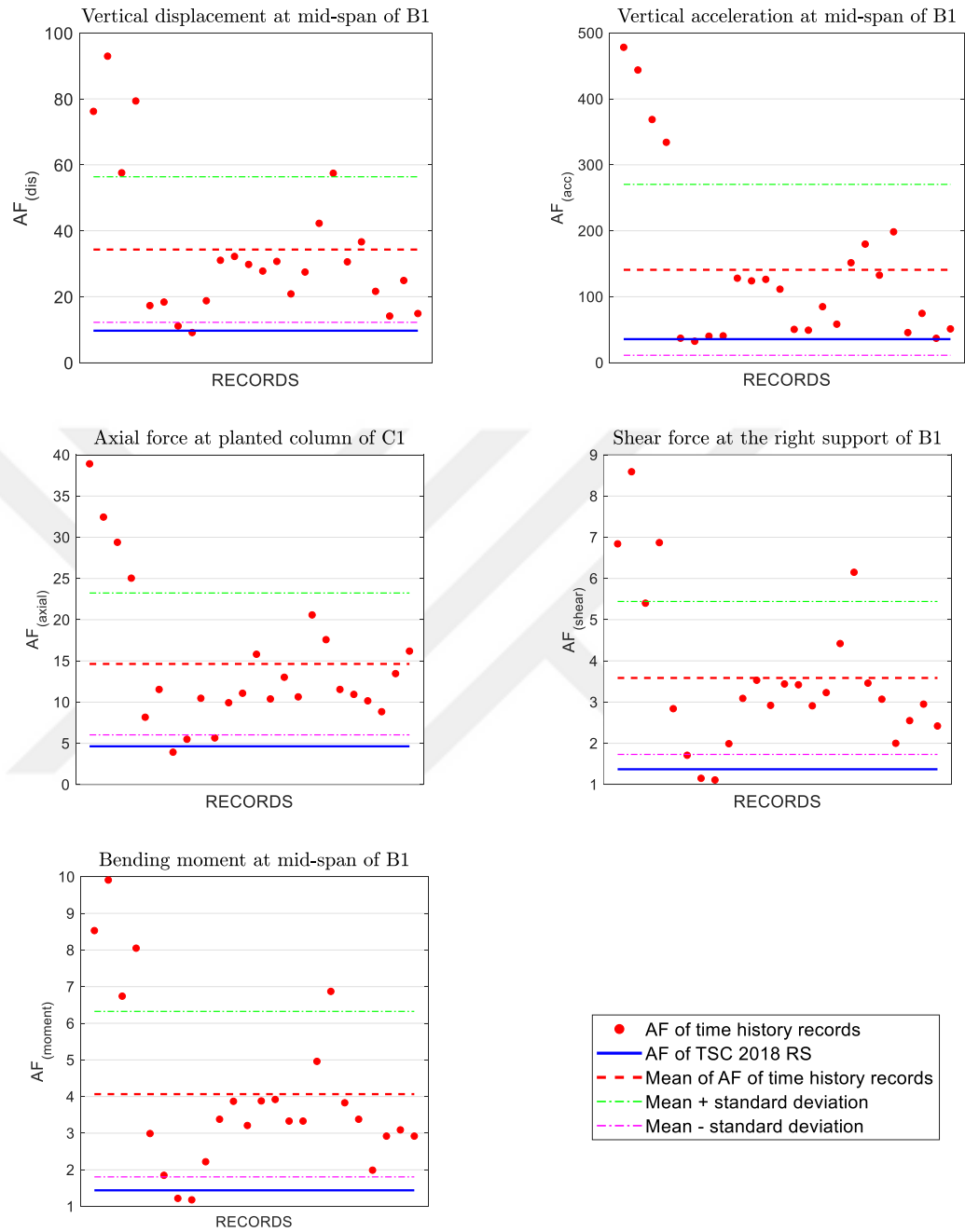


Figure 4.11: The vertical amplification factors in beam B1 and column C1 in Case 1-1 due to different time-history load cases and TSC-2018 response spectra excitation.

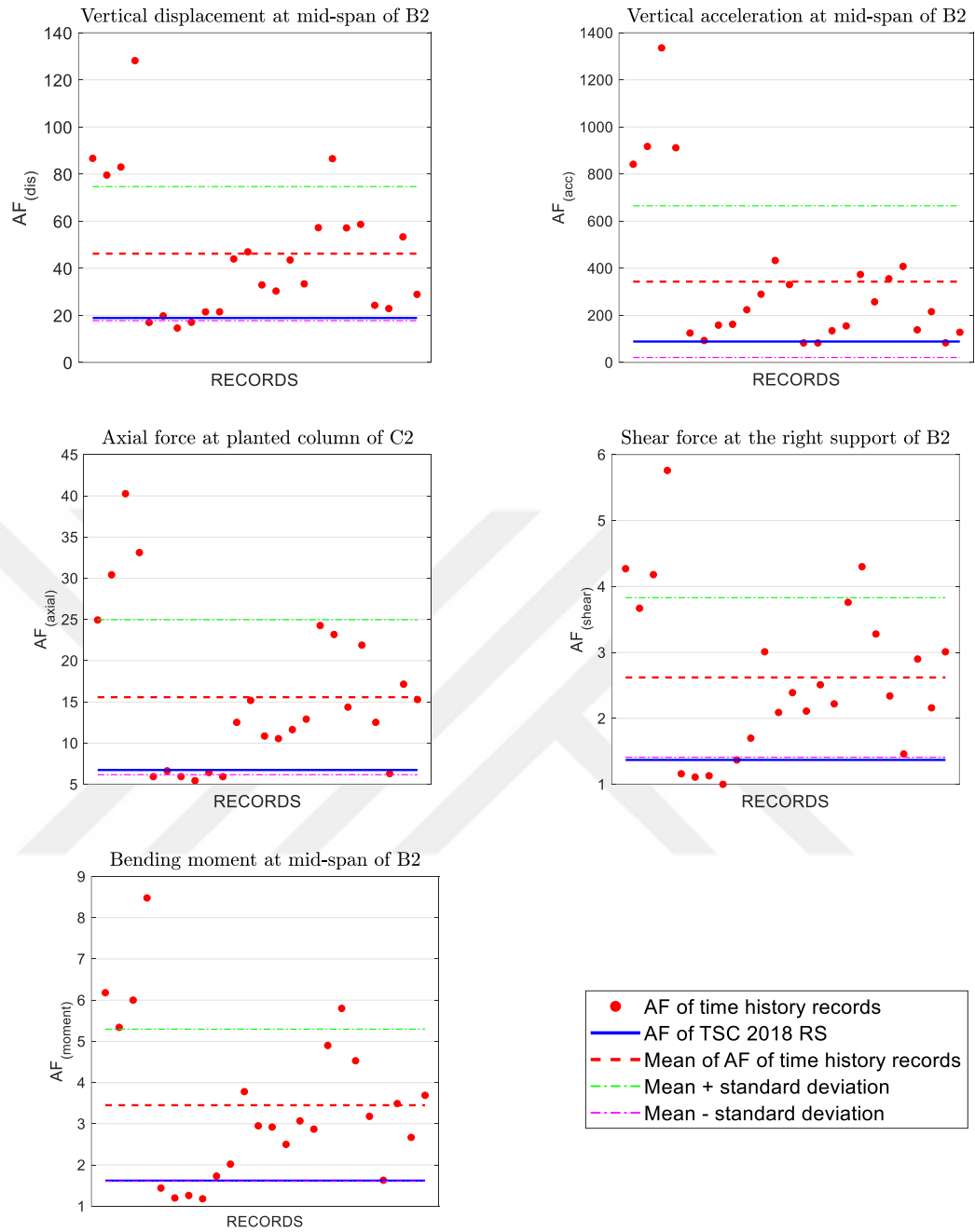


Figure 4.12: The vertical amplification factors in beam B2 and column C2 in Case 1-2 due to different time-history load cases and TSC-2018 response spectra excitation.

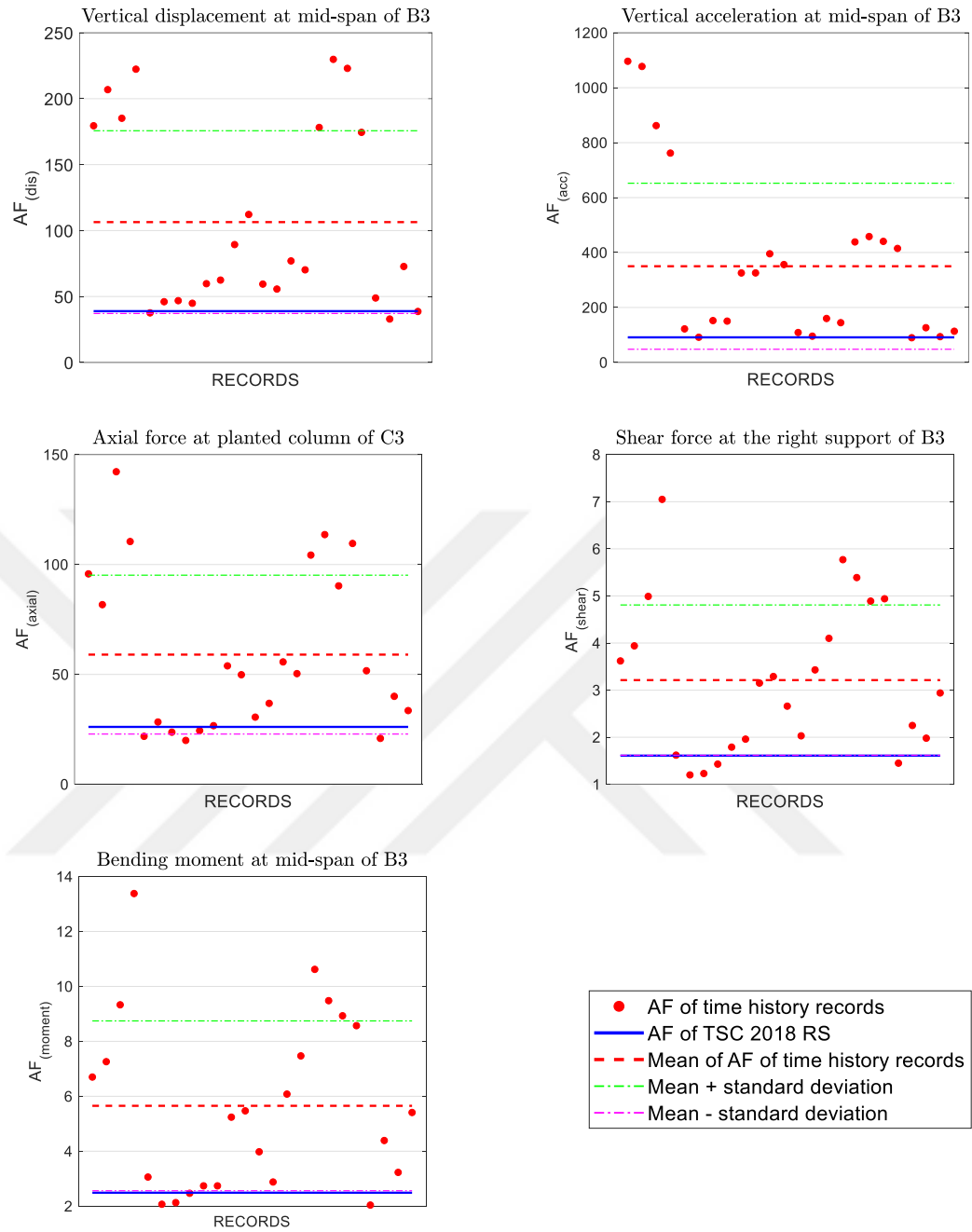


Figure 4.13: The vertical amplification factors in beam B3 and column C3 in Case 1-3 due to different time-history load cases and TSC-2018 response spectra excitation.

4.2.2 Frames with slanted columns

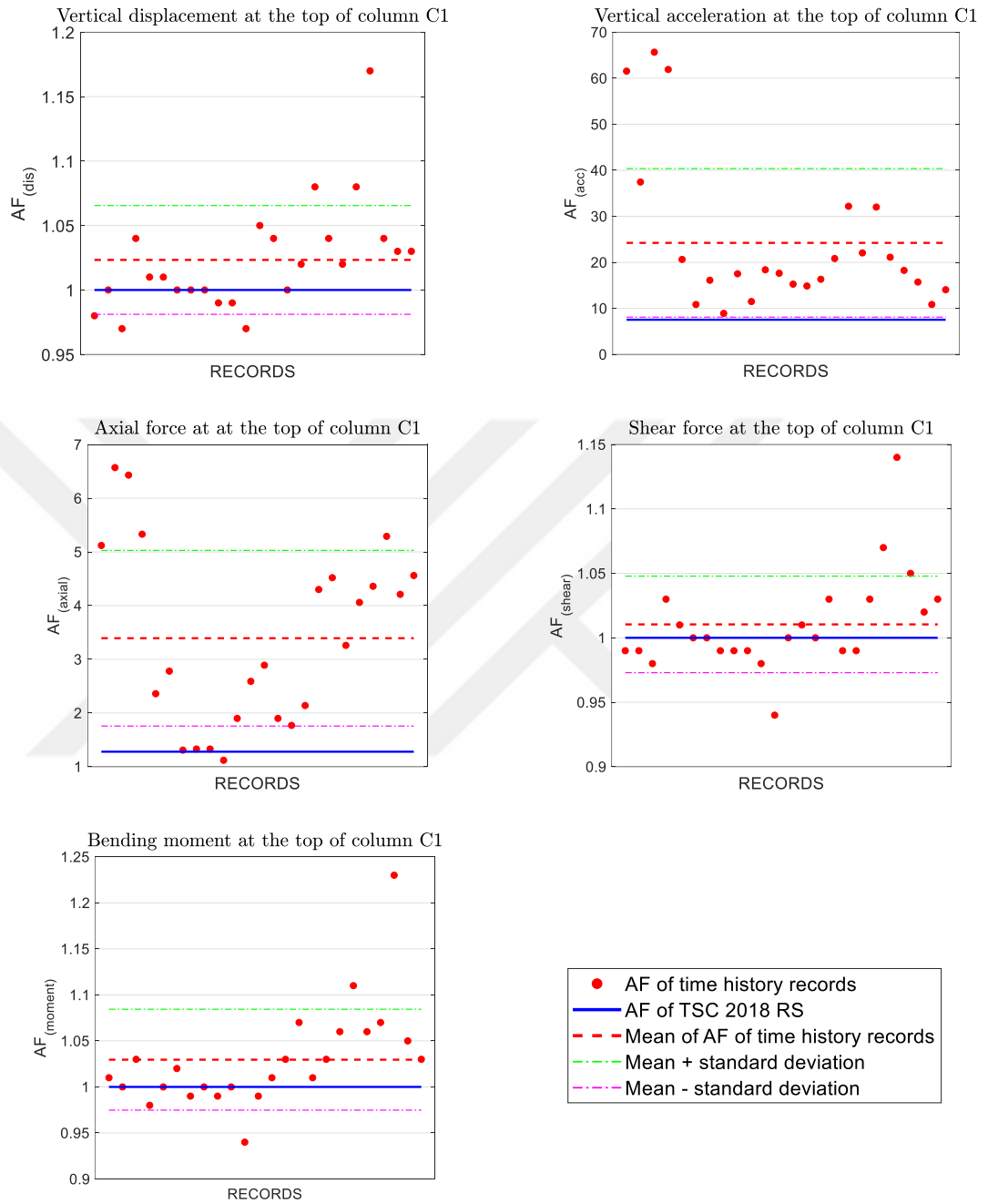


Figure 4.14: The vertical amplification factors in column C1 in Case 2-1 due to different time-history load cases and TSC-2018 response spectra excitation.

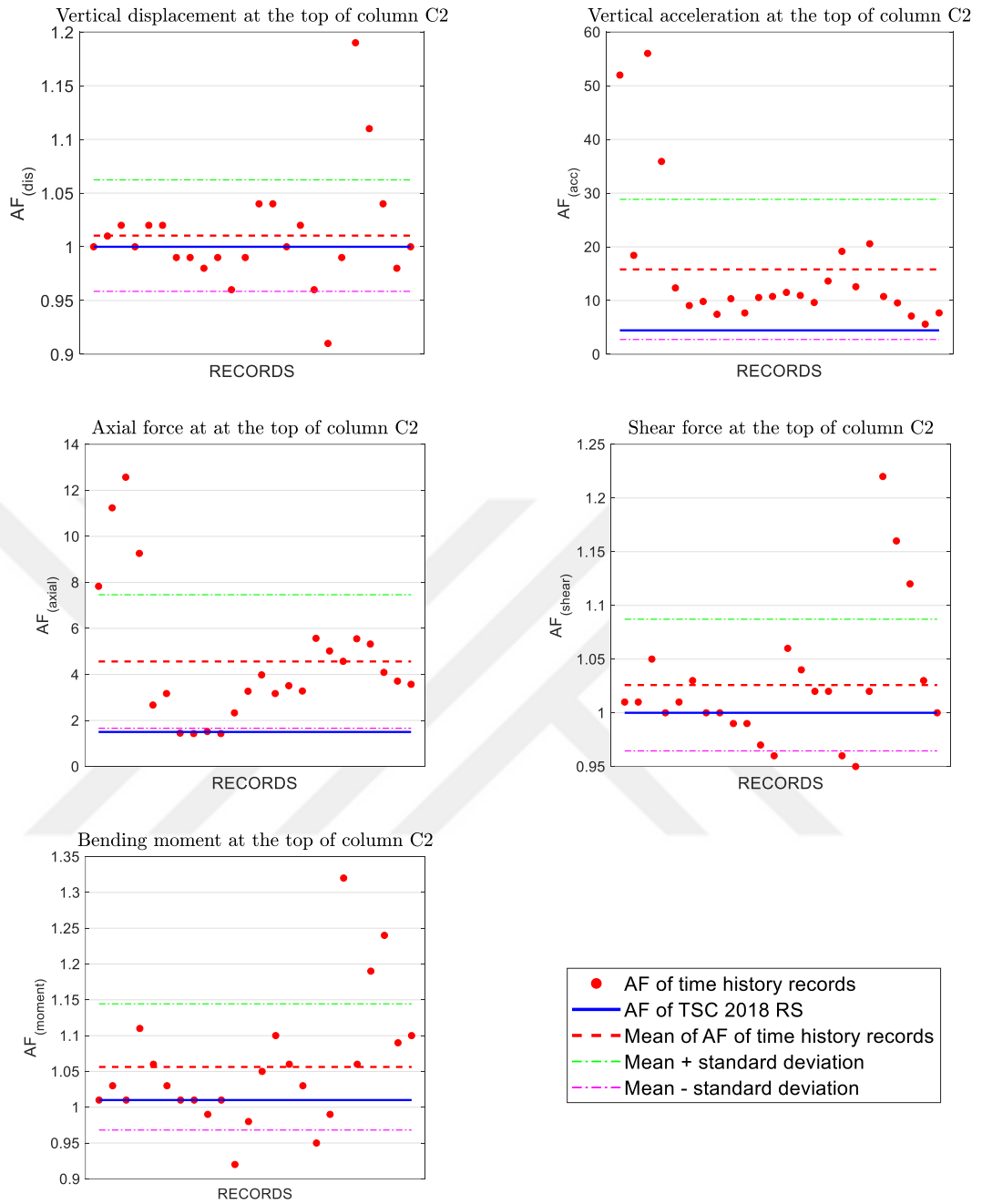


Figure 4.15: The vertical amplification factors in column C2 in Case 2-2 due to different time-history load cases and TSC-2018 response spectra excitation.

4.2.3 Frames with long cantilevers

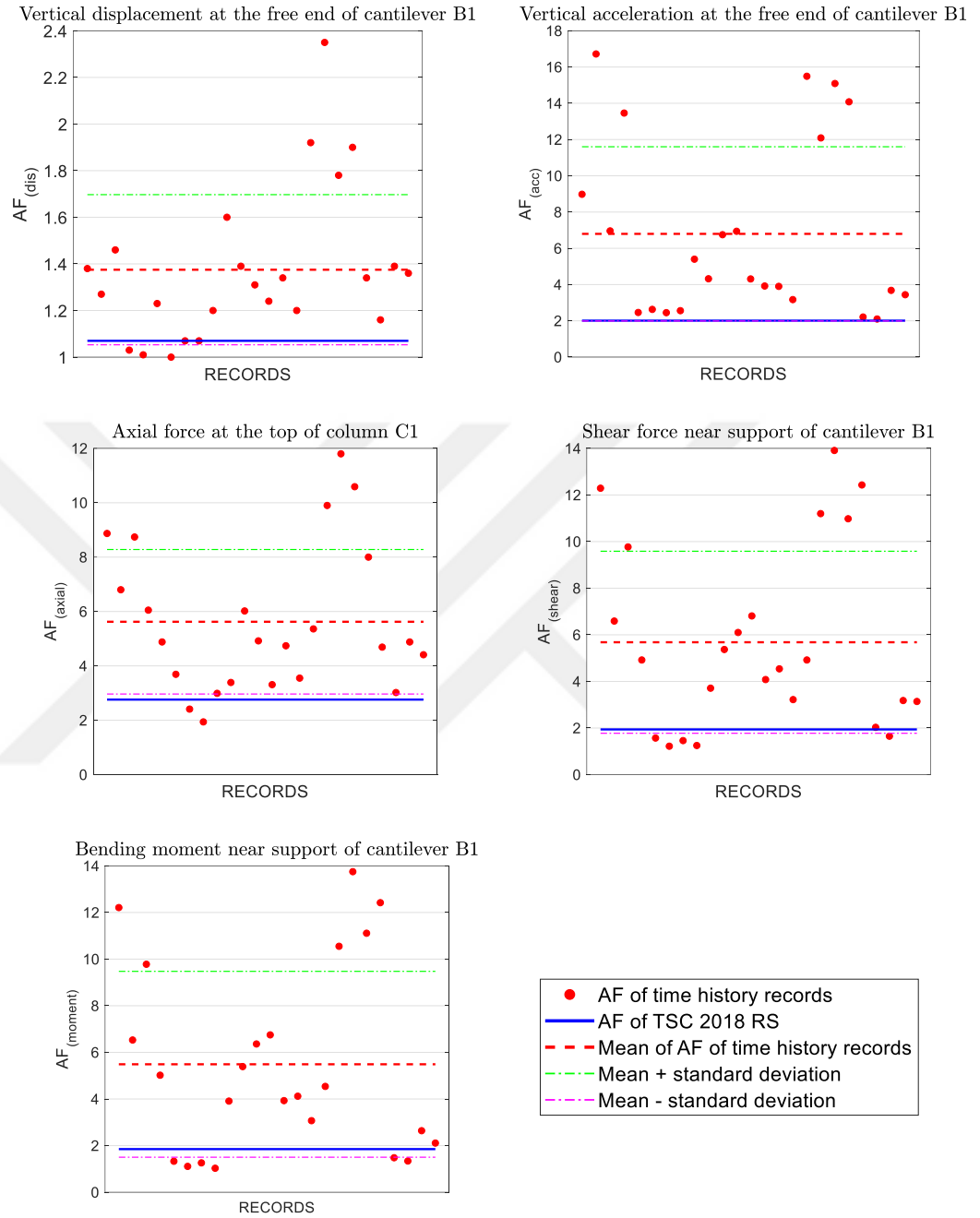


Figure 4.16: The vertical amplification factors in cantilever beam B1 and column C1 in Case 3-1 due to different time-history load cases and TSC-2018 response spectra excitation.

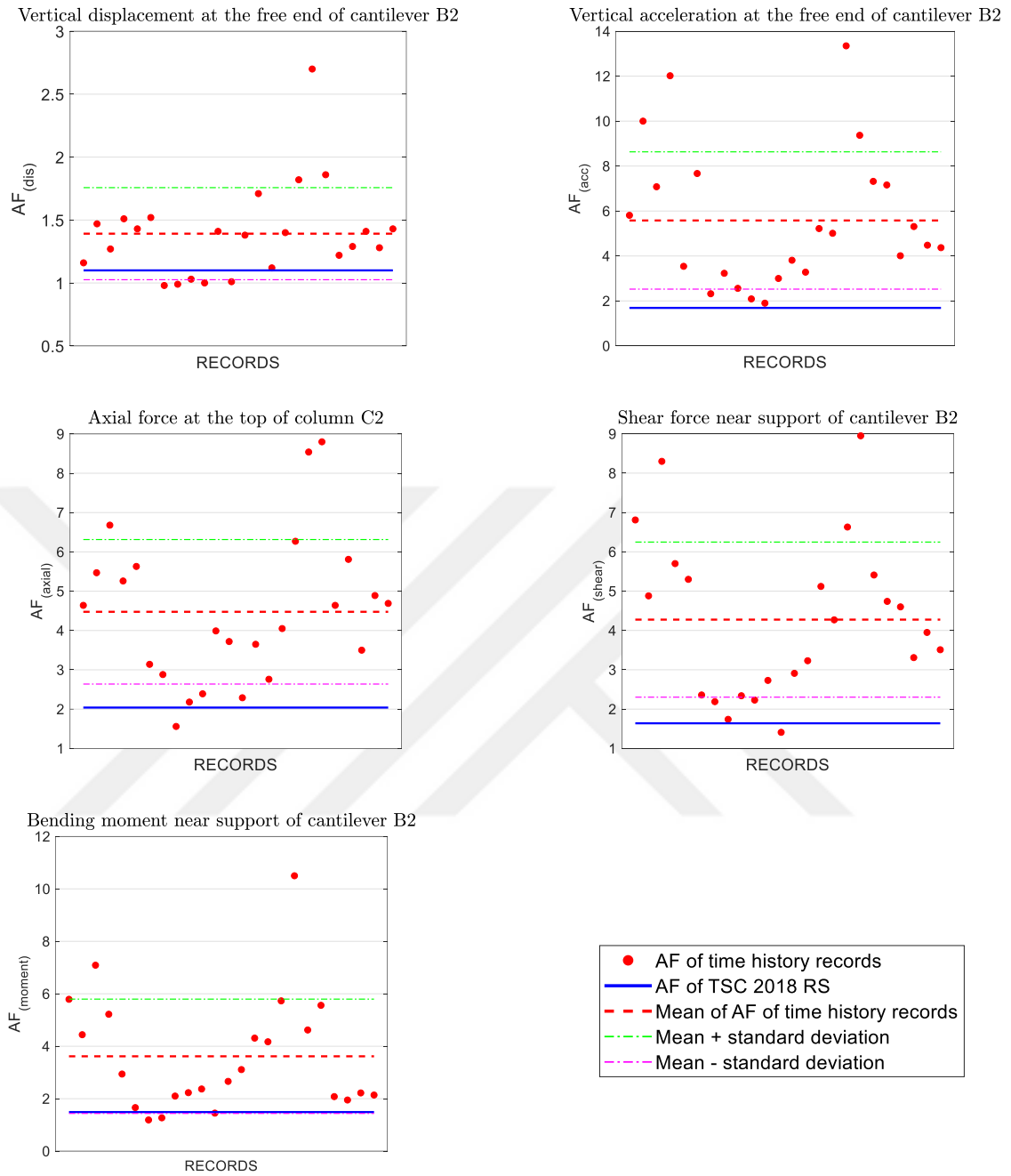


Figure 4.17: The vertical amplification factors in cantilever beam B2 and column C2 in Case 3-2 due to different time-history load cases and TSC-2018 response spectra excitation.

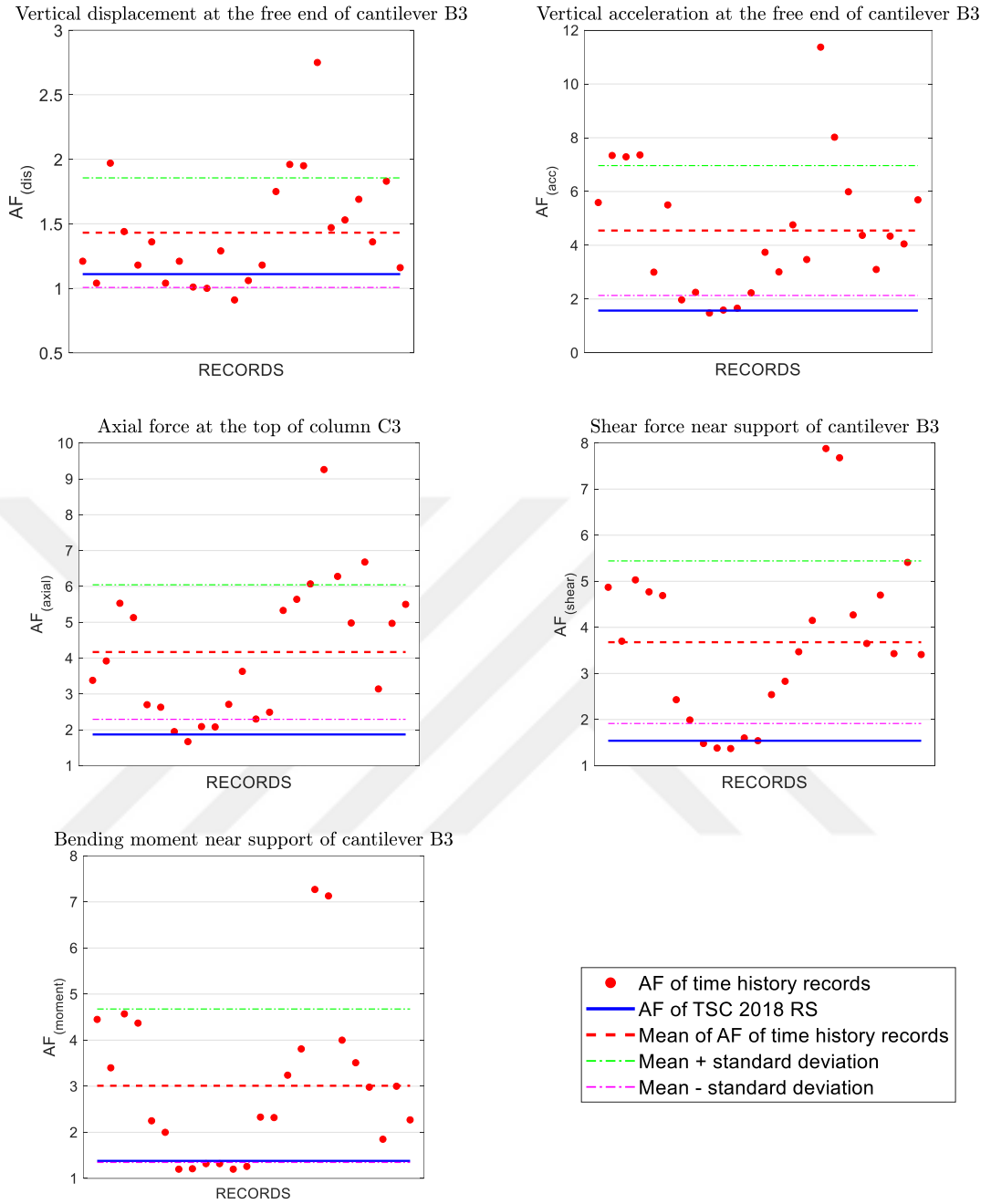


Figure 4.18: The vertical amplification factors in cantilever beam B3 and column C3 in Case 3-3 due to different time-history load cases and TSC-2018 response spectra excitation.

4.2.4 Long-span frames

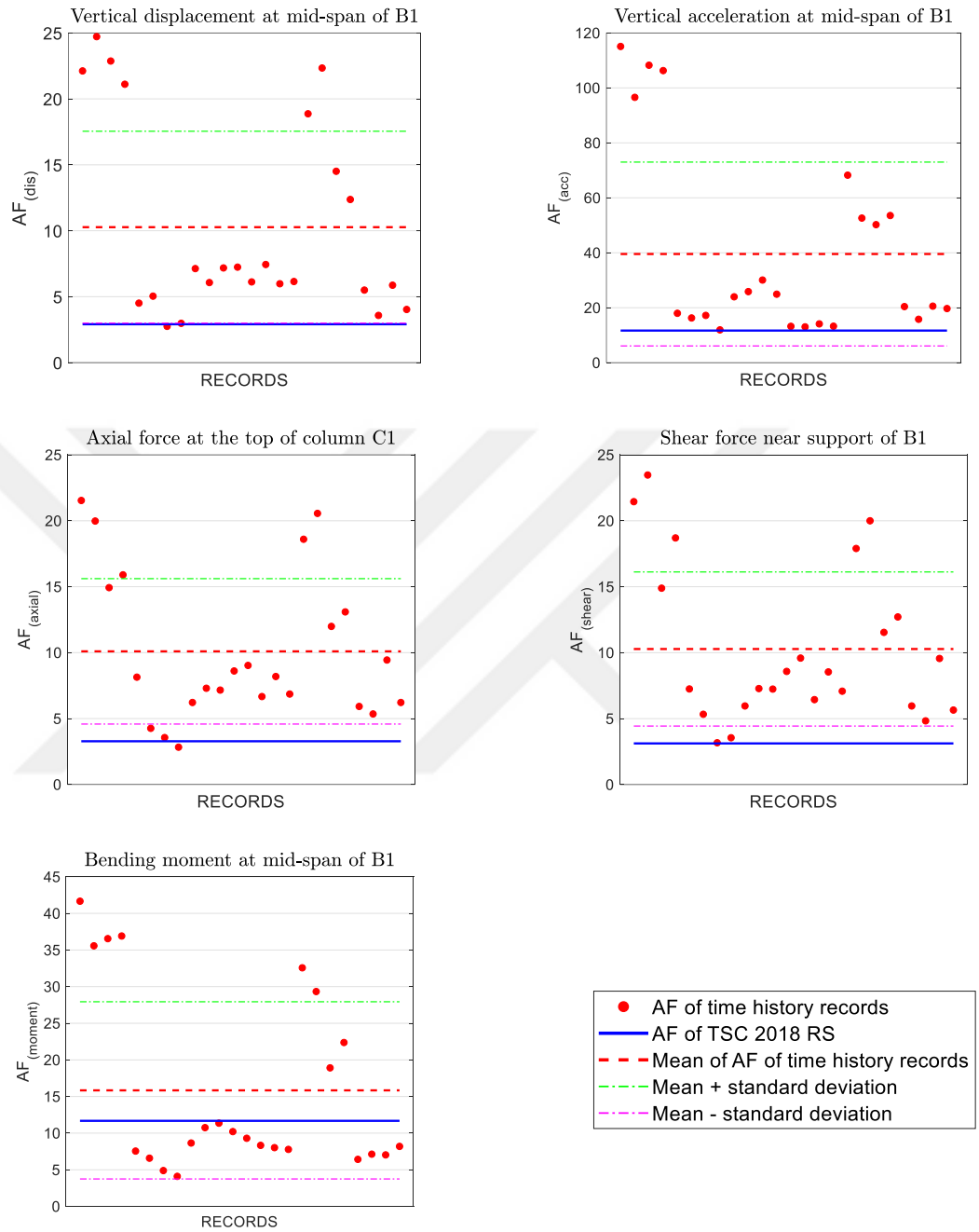


Figure 4.19: The vertical amplification factors in beam B1 and column C1 in Case 4-1 due to different time-history load cases and TSC-2018 response spectra excitation.

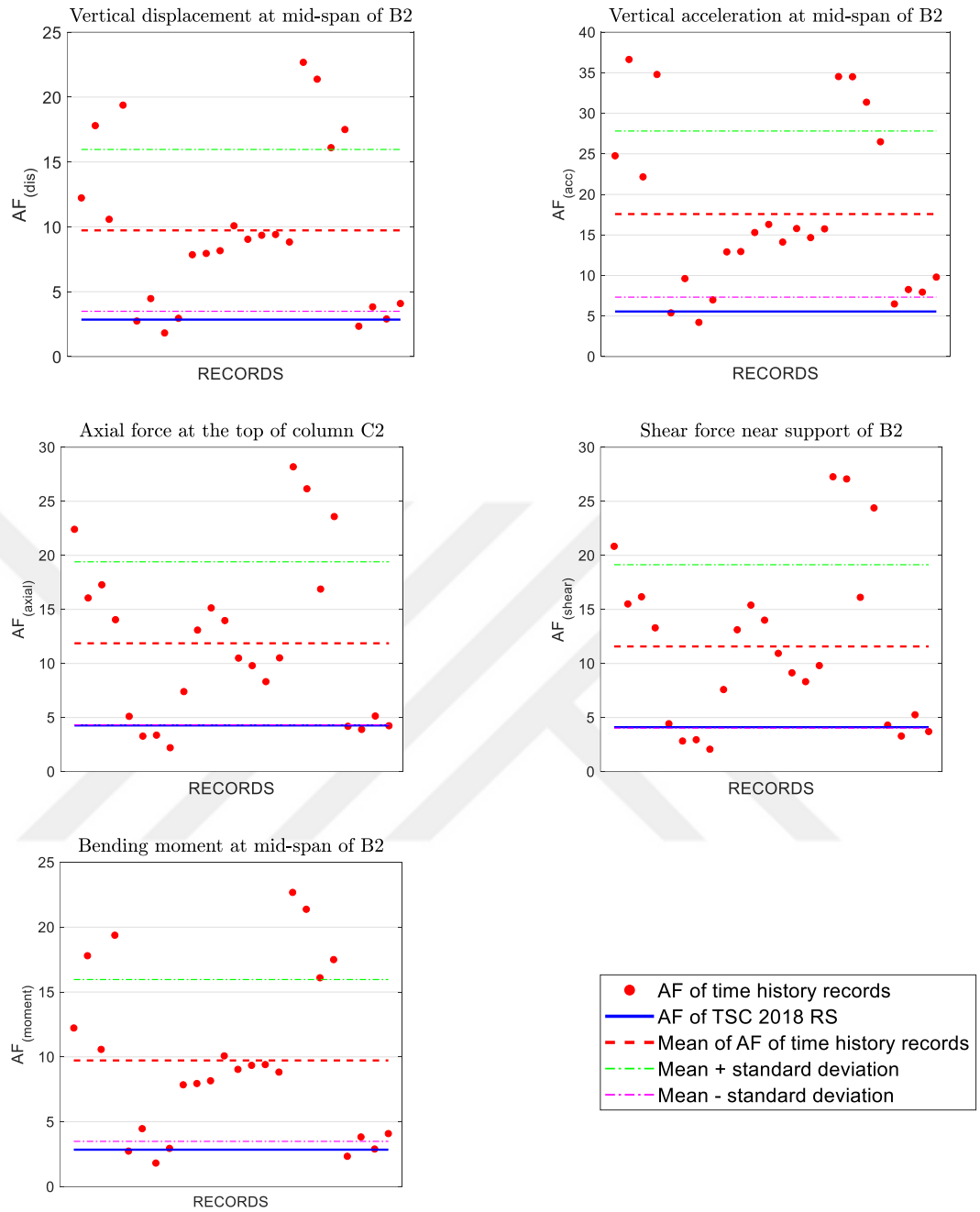


Figure 4.20: The vertical amplification factors in beam B2 and column C2 in Case 4-2 due to different time-history load cases and TSC-2018 response spectra excitation.

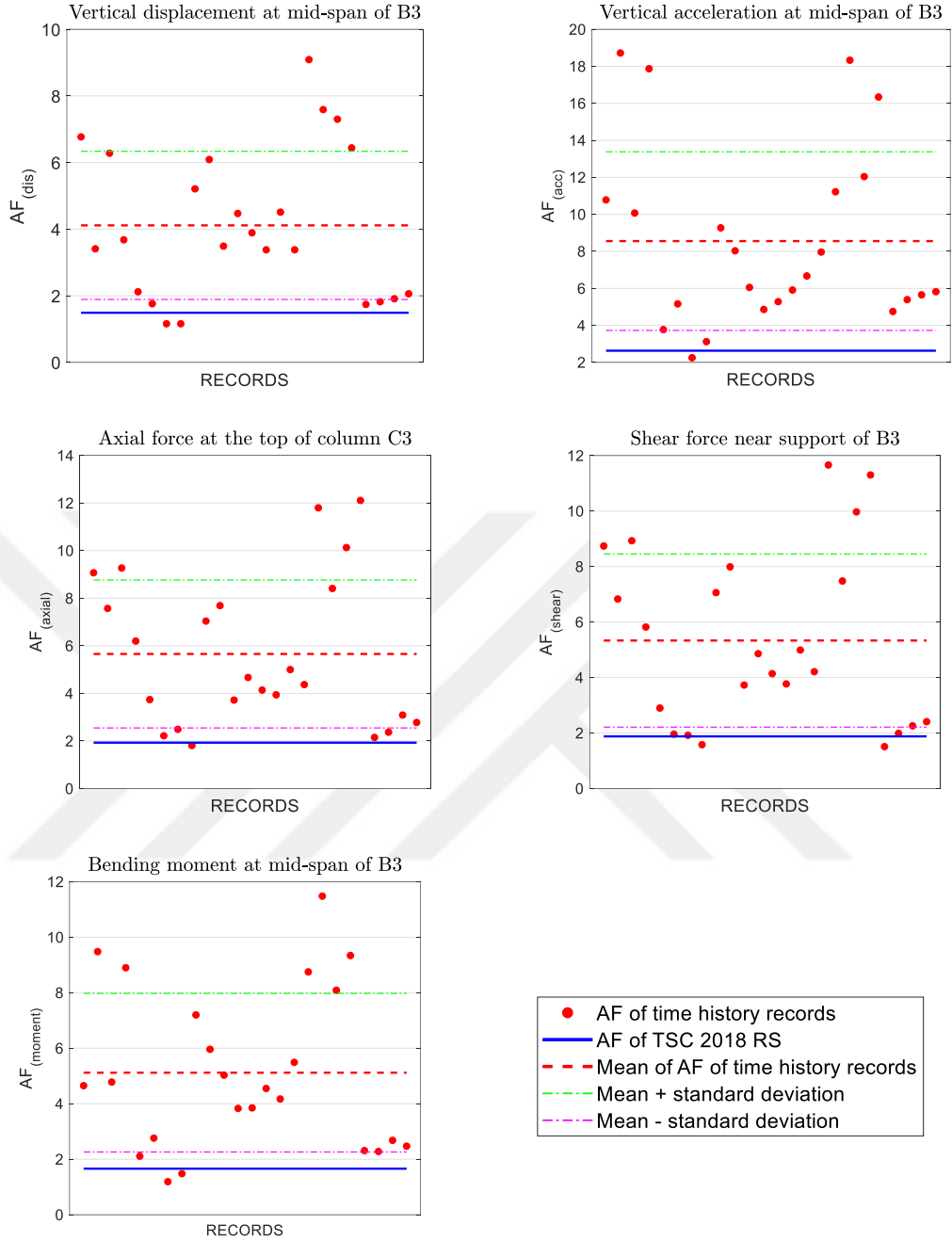


Figure 4.21: The vertical amplification factors in beam B3 and column C3 in Case 4-3 due to different time-history load cases and TSC-2018 response spectra excitation.

4.2.5 Combined plots

Figures 4.22-4.26 show the amplification factor for the examined parameters for all cases in the critical elements in combined plots. The figures show how the frame configurations (like the number of stories, inclination angle, cantilever length, and span length) affect the structural response due to the vertical component of the ground excitation.

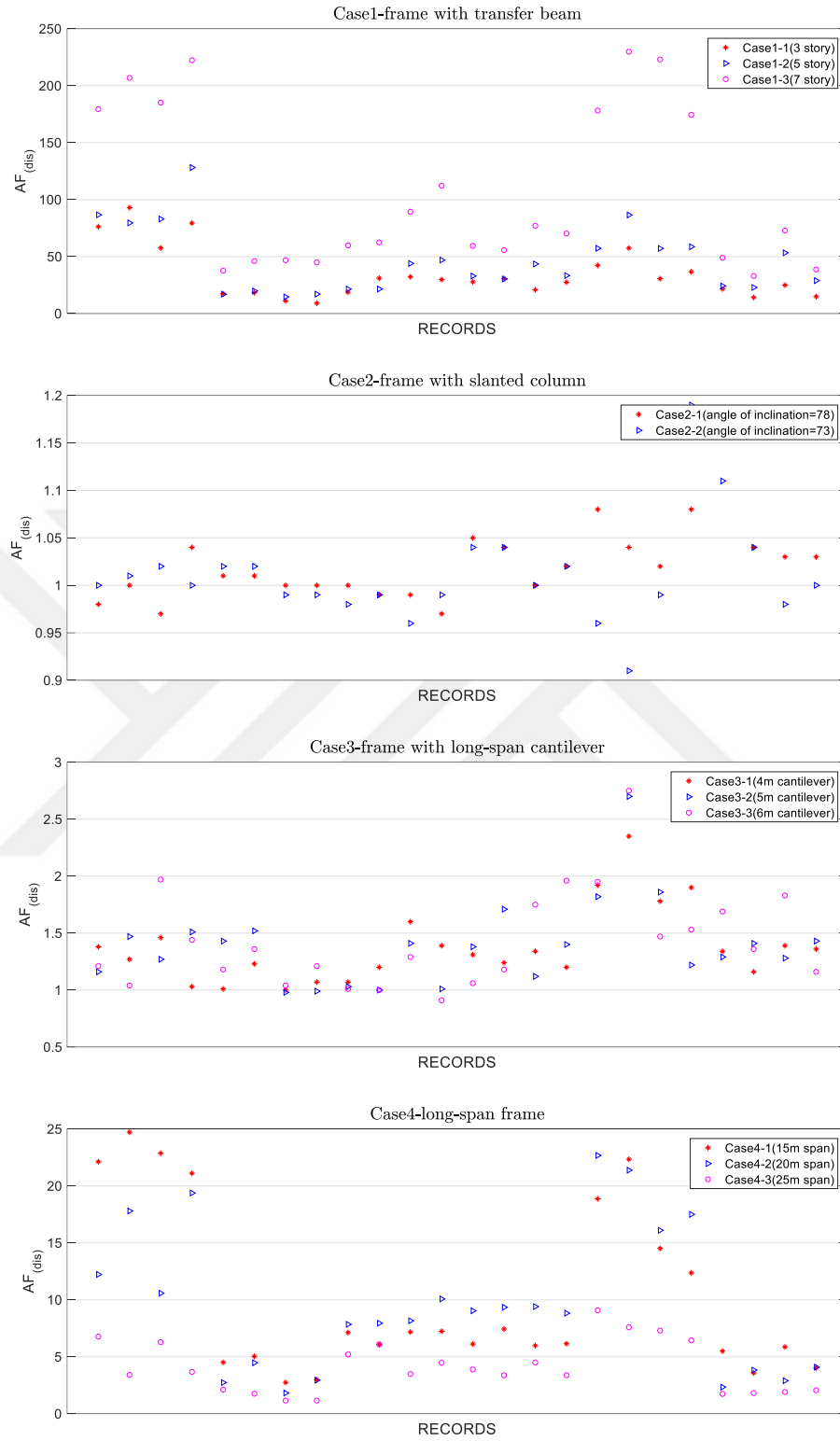


Figure 4.22: The amplification factors of vertical displacement due to different time-history load cases for all frames.

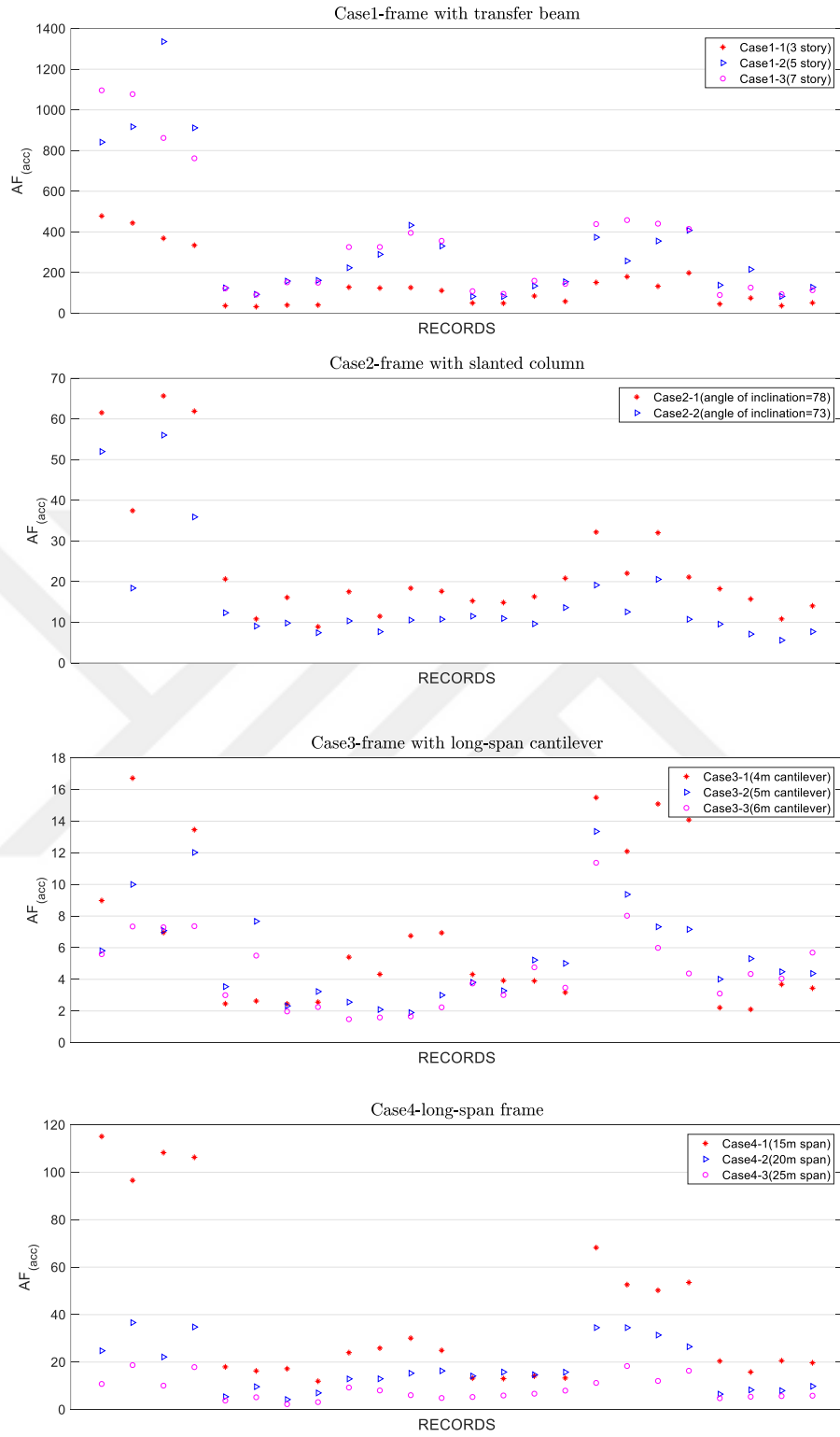


Figure 4.23: The amplification factors of vertical acceleration due to different time-history load cases for all frames.

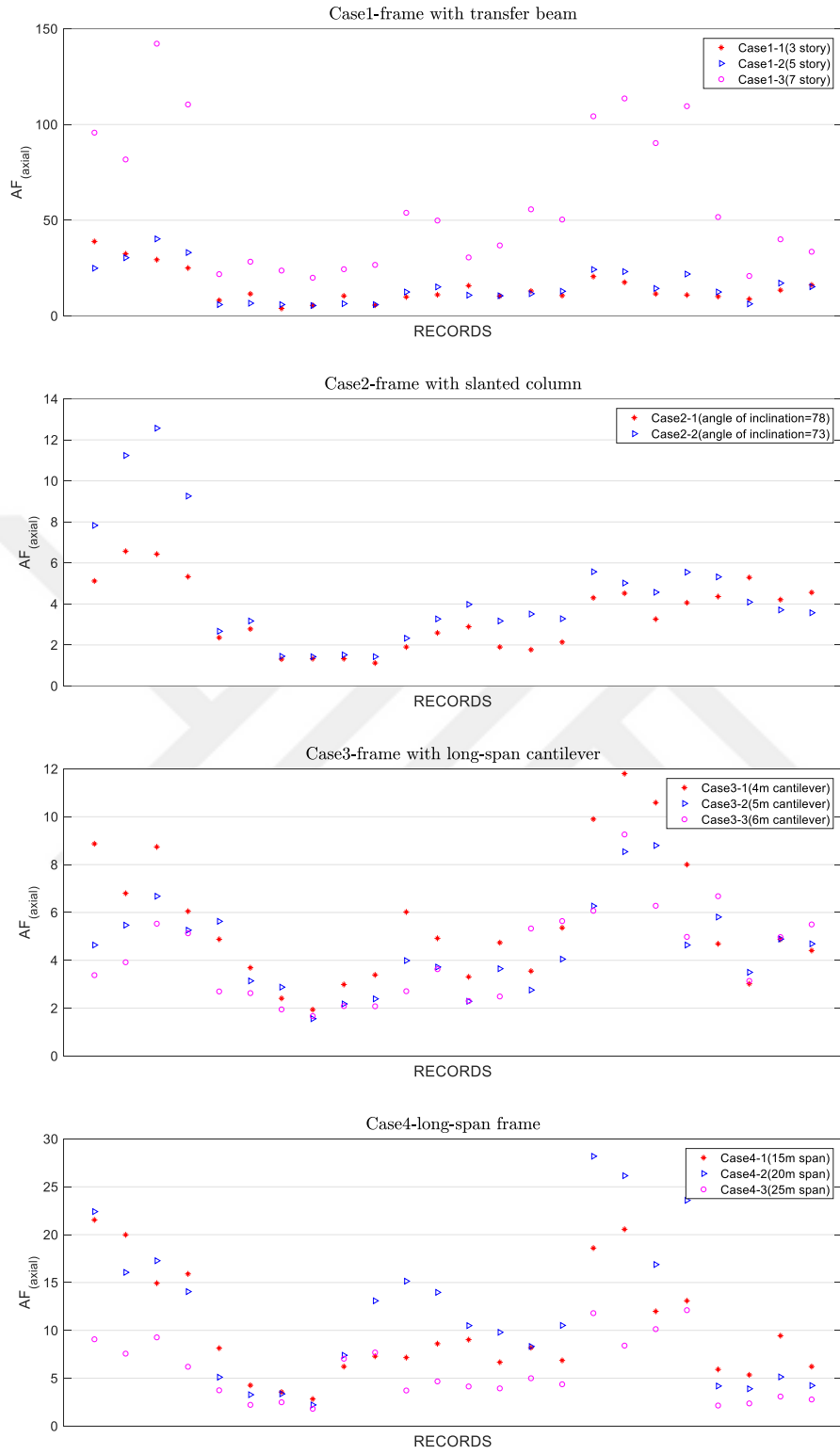


Figure 4.24: The amplification factors of axial force due to different time-history load cases for all frames.

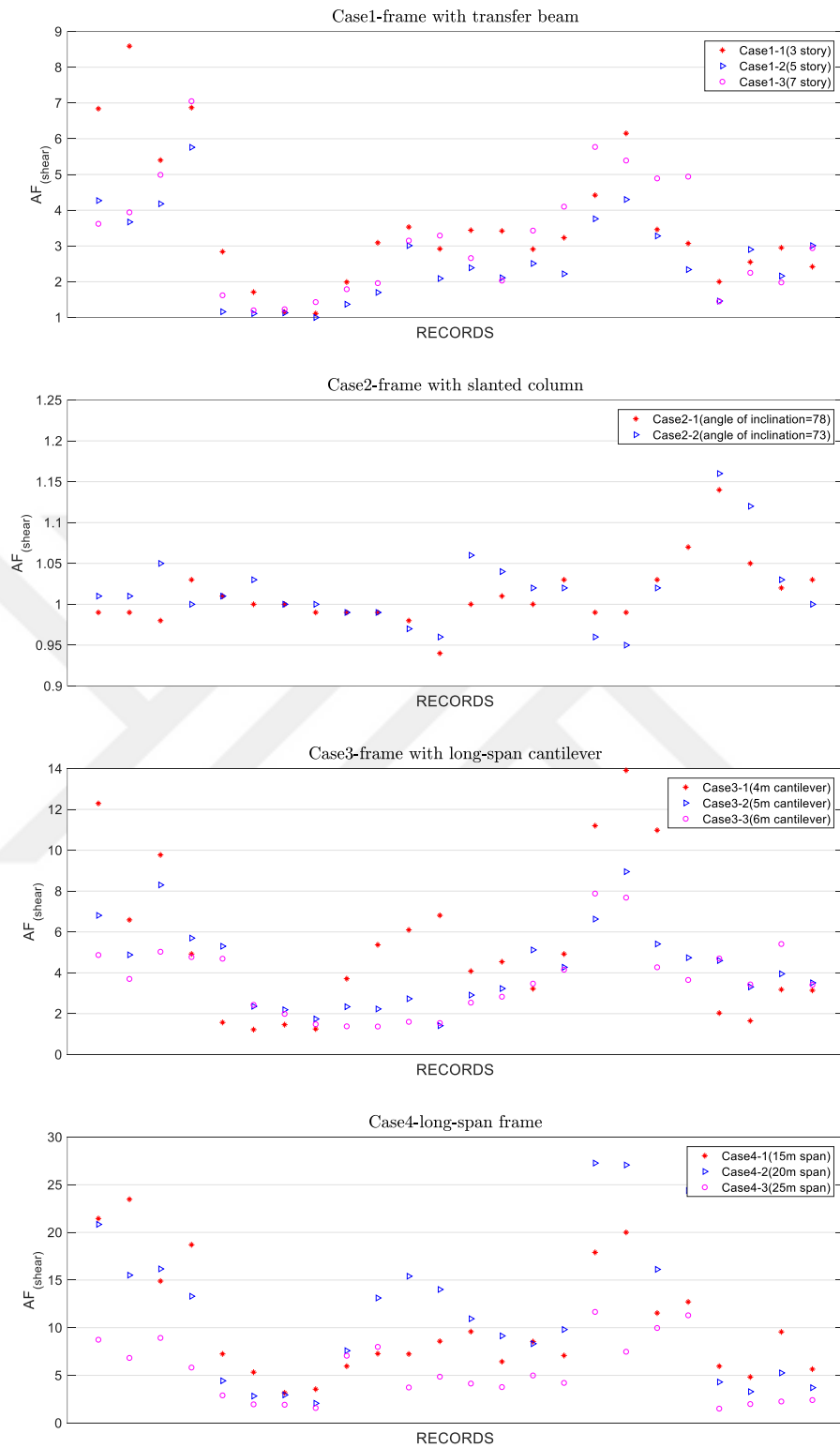


Figure 4.25: The amplification factors of shear force due to different time-history load cases for all frames.

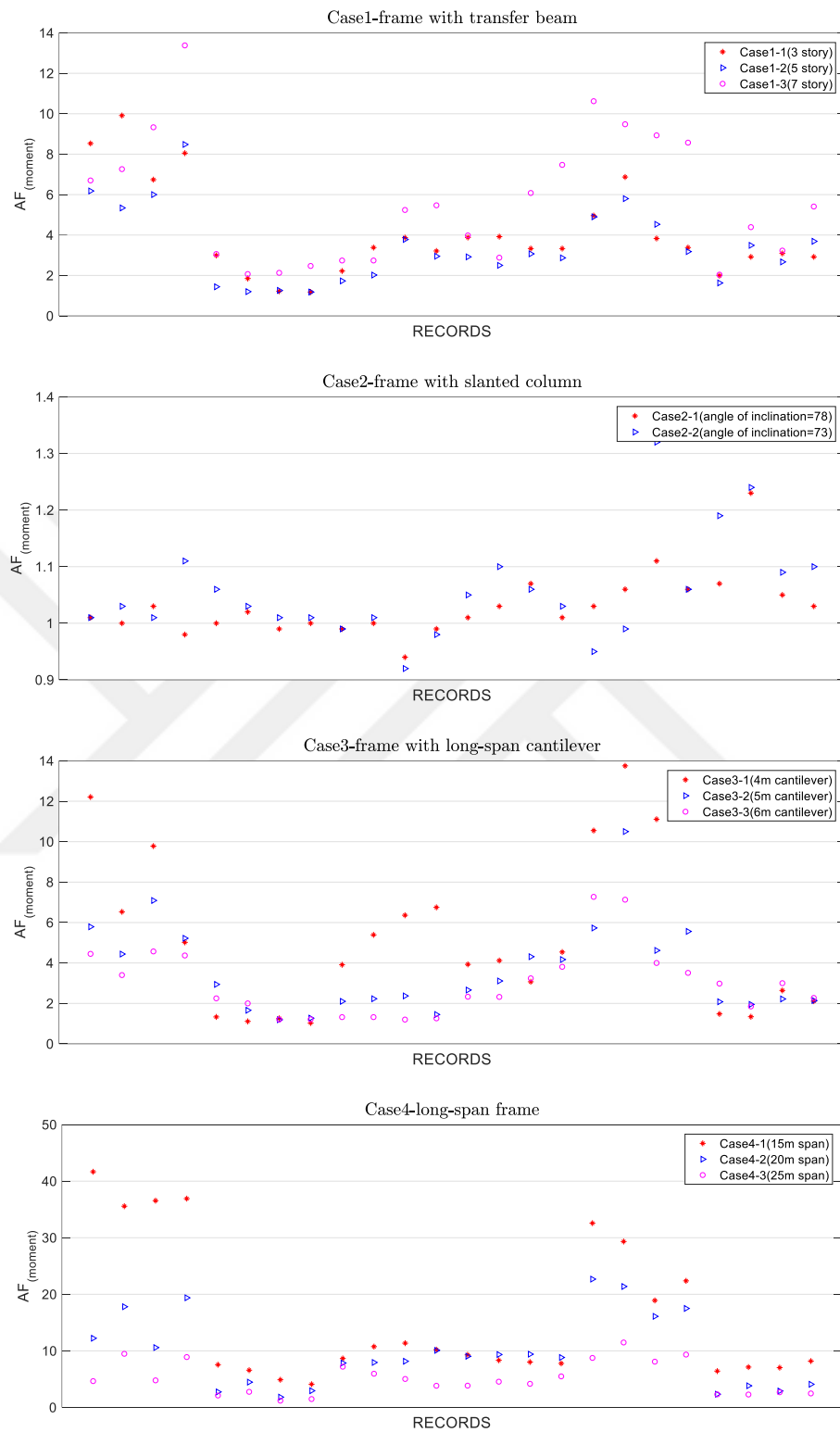


Figure 4.26: The amplification factors for bending moment for all cases due to different time-history load cases for all frames.

5. DISCUSSION

In this study, the responses of the structures with structural systems sensitive to vertical ground motions are investigated under 12 near-fault motion records including vertical and horizontal components. Moreover, the response spectrum analysis results using the Turkish Seismic Code (TSC-2018) vertical response spectrum are evaluated and compared with linear time-history analysis results for all study cases. As it can be seen from the analyses results presented in the previous chapter, the effects of the vertical excitation on the seismic performance of sensitive structures to vertical ground motions are varied according to structure configurations, ground motion record properties, and the inspected demand parameters. observations can be summarized as follows:

5.1. EFFECT OF THE VERTICAL GROUND MOTION COMPONENT ON THE VERTICAL DISPLACEMENT

Vertical displacement at the mid-point of the transfer beam is significantly affected by the vertical excitation. Since only horizontal excitation induces a small vertical displacement, we can observe high values for the vertical amplification factor. Figures 4.11 to 4.13 show that the mean of $AF_{(dis)}$ can reach 100 in the 7-story frame. Whereas we can see some high outliers in some records like Imperial Valley-06 El Centro Array #6 station records having high V/H values. Moreover, the vertical amplification factor of vertical displacement induced by the TSC-2018 vertical response spectrum is much lower than the mean of the vertical amplification factor for time history analysis. It equals approximately the value (mean - standard deviation). As the number of stories increases, the effect on the vertical displacement at the mid-span of the transfer beam increases in both time-history and response spectra analyses.

Vertical displacement at top of the slanted column is slightly affected by vertical component excitation. The ratio of the increase does not exceed 6% as shown in Figures 4.14 and 4.15. Vertical displacement at top of slanted column induced by the TSC-2018 vertical response spectrum is close to time history analyses values.

Figures 4.16 to 4.18 show that vertical displacement at the free end of the 4 m long cantilever is increased 40% by vertical component excitation. Vertical displacement at the free end

induced by the TSC-2018 vertical response spectrum is increased about 10% with no considerable effect when the cantilever length increases.

Vertical displacement at the mid-span of the long-span frame is strongly affected by vertical component excitation. Figures 4.19 to 4.21 show that the mean of $AF_{(dis)}$ can reach 10 in frames with 15m and 20m span lengths, while it decreases to 4 in frames with 25m span lengths. The amplification factor of vertical displacement at the mid-point induced by the TSC-2018 vertical response spectrum is lower than the mean of the vertical amplification factor time history analysis. It equals approximately the value (mean - standard deviation), and it tends to decrease with the increase of the span length as well.

Figure 4.22 depicts the aforementioned effects on the vertical displacement and shows that it is related to the number of stories, inclination angle, cantilever length, and long-span frame length.

5.2. EFFECT OF THE VERTICAL GROUND MOTION COMPONENT ON STORY DRIFT

Vertical component excitation had slight or no effect on story drift for all our study cases. Figure 4.2 illustrates, as an example, the horizontal displacement at the bottom of the planted column (C1) for only horizontal and bidirectional time-history load cases due to El Centro Array #6 Station Record, Imperial Valley-06 Earthquake. The values of the two cases are almost the same. Figures 4.8 to 4.10 assure the same result.

5.3. EFFECT OF THE VERTICAL GROUND MOTION COMPONENT ON THE VERTICAL ACCELERATION DEMAND

Vertical acceleration at the mid-point of the transfer beam is significantly affected by the vertical excitation. Similar to the vertical displacement, when only horizontal excitation is applied, a small vertical acceleration occurs. Therefore we observe high values for the vertical amplification factor. Figures 4.11 to 4.13 show that the mean of $AF_{(acc)}$ can reach 600 in the 7-story frame. The high outliers were observed, similar to the vertical-displacement outliers, in earthquakes with high V/H values. Moreover, the vertical amplification factor of vertical acceleration induced by the TSC-2018 vertical response spectrum is much lower than the mean of the vertical amplification factor for time history analysis, it comes between the mean and (mean - standard deviation) values. It is shown that the effect on the vertical acceleration at the

mid-point of the transfer beam has a general tendency to increase as the number of stories increases in both time history and response spectra analyses.

Figures 4.14 and 4.15 illustrate that the mean of amplification factor of the vertical absolute acceleration, $AF_{(acc)}$, at top of the slanted column can reach 30. As the inclination angle with horizontal decreases, the amplification factor decreases. Figures 4.14 and 4.15 also Show that the amplification factor for vertical acceleration at top of the slanted column induced by TSC-2018 vertical response spectrum is lower than all values obtained by time history analyses.

Figures 4.16 to 4.18 show that the mean of the amplification factor of $AF_{(acc)}$ at the free end of cantilevers ranges from 4-6 for all lengths. Whereas, the vertical amplification factor of vertical acceleration at the free end induced by the TSC-2018 vertical response spectrum ranges from 1.8-2 for all lengths with no considerable effect when the cantilever length increases.

Vertical acceleration at the mid-point of the long-span frame is strongly affected by the vertical component excitation. Figures 4.19 to 4.21 show that the mean of $AF_{(acc)}$ equals 40, 17, and 8 for frames with 15 m, 20 m, and 25 m span lengths, respectively. The amplification factor of vertical acceleration at the mid-point induced by the TSC-2018 vertical response spectrum is lower than all values of the vertical amplification factor values due to time history analyses, and it decreases with the increase of the span length.

Figure 4.23 depicts the aforementioned effects on vertical acceleration and shows that it is related to the number of stories, inclination angle, cantilever length, and long-span frame length.

5.4. EFFECT OF THE VERTICAL GROUND MOTION COMPONENT ON THE HORIZONTAL ACCELERATION DEMAND

Horizontal acceleration values are affected by vertical component excitation slightly or none for all our study cases. Figures 4.4 shows, as an example, the horizontal acceleration at the bottom of the planted column (C1) for only horizontal and bidirectional time-history load cases due to El Centro Array #6 Station Record, 1979 Imperial Valley-06 Earthquake. The values of the two cases are almost the same.

5.5. EFFECT OF THE VERTICAL GROUND MOTION COMPONENT ON THE AXIAL FORCE

It is observed that the axial force demand is strongly affected by the vertical component excitation in all study cases. Vertical component excitation amplifies the compression force in columns, and it induces considerable tension forces as well. Figures 4.11 to 4.13 show that the mean of the vertical amplification factor of axial force, $AF_{(axial)}$, at the planted columns ranges from 15 to 60. The high outliers in records with high V/H can reach 150. The amplification factor of axial force induced by the TSC-2018 vertical response spectrum is about half of the mean of the vertical amplification factor for time-history analysis for all cases. As the number of stories increases, the effect on the axial force at the planted column tends to increase in both time-history and response spectra analyses.

Figures 4.14 and 4.15 show that the mean of the vertical amplification factor of axial force at top of the slanted column ranges from 3 to 5. As the inclination angle with horizon decreases, the amplification factor tends to increase. Figures 4.14 and 4.15 show, also, that the vertical amplification factor for the axial force at top of the slanted column induced by the TSC-2018 vertical response spectrum is lower than all values of the vertical amplification factor for time history analyses. It ranges from 1.25 to 1.5.

Figures 4.16 to 4.18 show that the mean of the vertical amplification factor of axial force at the free end of the cantilever beams ranges from 4 to 6. Whereas the vertical amplification factor of the axial force at the free end induced by the TSC-2018 vertical response spectrum ranges from 2 to 3 with no considerable effect when the cantilever length increases.

Figures 4.19 to 4.21 show that the mean of the vertical amplification factor of axial force can reach 12. The vertical amplification factor for the axial force at the column induced by the TSC-2018 vertical response spectrum is lower than 90% of values of the vertical amplification factor values due to time history analyses.

5.6.EFFECT OF THE VERTICAL GROUND MOTION COMPONENT ON THE SHEAR FORCE

The shear force at the transfer beam is strongly affected by the vertical component excitation. It is increased by about 350% when the vertical component is applied. Moreover, the vertical

amplification factor of shear force induced by the TSC-2018 vertical response spectrum is lower than the mean of the vertical amplification factor for time-history analysis. It ranges from 1.5 to 1.75.

Figures 4.14 and 4.15 show that shear force at top of the slanted column is slightly affected by the vertical component excitation.

Figures 4.16 to 4.18 show that the mean of the vertical amplification factor of shear force at the free end of the cantilever beams ranges from 3.5 to 6. Whereas the vertical amplification factor for the shear force at the free end induced by TSC-2018 vertical response spectrum ranges from 1.5 to 2. As the cantilever length increases, the effect on the shear force at the free end of the cantilever generally tends to decrease in both time-history and response spectra analyses.

Shear force at the support of the long-span frame is strongly affected by vertical component excitation. Figures 4.19 to 4.21 show that the mean of $AF_{(shear)}$ can reach 15. The vertical amplification factor of shear force induced by the TSC-2018 vertical response spectrum is lower than 90% of the vertical amplification factor values due to time-history analyses.

5.7.EFFECT OF THE VERTICAL GROUND MOTION COMPONENT ON THE BENDING MOMENT

The bending moment at the mid-point of the transfer beam is strongly affected by vertical component excitation. It is increased by about 600% when the vertical component is applied. Moreover, the vertical amplification factor of the bending moment induced by the TSC-2018 vertical response spectrum is lower than the mean of the vertical amplification factor for time-history analysis. It ranges from 1.5 to 1.75, as shown in Figures 4.11 to 4.13. Moreover, we can observe some high outliers in some records especially in Imperial Valley-06 El Centro Array #6 station record with having high V/H values.

The bending moments at top of the slanted columns are slightly affected by the vertical component excitation. The ratio of the increase does not exceed 3% as shown in Figures 4.14 and 4.15. Vertical displacement at top of the slanted column induced by the TSC-2018 vertical response spectrum is too close to time history analyses values.

Figures 4.16 to 4.18 show that the bending moment near the support of the 4 m long cantilever is increased 550% by vertical component acceleration. As the cantilever length increases, the bending moment generally tends to decrease. The bending moment near the support induced by the TSC-2018 vertical response spectrum increases about 200%, and it decreases when the cantilever length increases as well.

The bending moment at the mid-point of the long-span frame is strongly affected by vertical component excitation. Figures 4.19 to 4.21 show that the mean of $AF_{(moment)}$ equals about 15 and 10 in frames with 15m and 20m span lengths while it decreases to 6 in frames with the 25m span length. The vertical amplification factor for bending moment at the mid-point induced by the TSC-2018 vertical response spectrum is lower than the mean of the vertical amplification factor time-history analysis and it decreases with the increase of span length.

6. CONCLUSION AND RECOMMENDATIONS

In this study, the response of the structures with structural systems sensitive to vertical ground motion is investigated under twelve near-fault ground motion records including vertical and horizontal components. The records are selected taking into consideration the ratio of the vertical to horizontal peak ground acceleration (V/H) to be more than 1. Four two-dimensional frames are chosen and investigated under vertical ground motions excitation. These structures are defined in the Turkish Seismic Code (TSC 2018) as sensitive structural systems to vertical ground motions. They are classified as: structures with beams with a 20m span length and more, structures with cantilevers with a 5m span length or more, structures with planted columns on transfer elements, and structures with inclined columns. For each case, three load cases are defined including only horizontal component, only vertical, and bi-directional (simultaneous horizontal and vertical) one. Moreover, the response spectrum analysis results using the Turkish Seismic Code vertical response spectrum are evaluated and compared with linear time-history analysis results for all study cases. The related force and displacement engineering demand parameters for the critical elements are determined, evaluated, and discussed. Following conclusions can be drawn:

1. The vertical ground motion significantly affects the axial force demand in the columns for all types of frames. It extremely amplifies the compression force and induced high tension force as well.
2. High vertical acceleration demand values are observed in all frames due to the vertical excitation. In addition, horizontal only excitation induces small vertical accelerations.
3. The vertical ground motion has a significant effect on the vertical displacement at the mid-span of the transfer beams and long-span frames. No large effect is observed in the frames with inclined columns. Moreover, the effect in the cantilever frame is relatively small.
4. The results show that the vertical motion component excitation has a slight or no effect on story drift for all types of frames.
5. The results show that the vertical motion component excitation has a significant effect on shear force demand on the transfer beams, long-span beams, and cantilever beams.

6. The vertical ground motion has a slight or no effect on shear force demand on the inclined columns.
7. The results show that the vertical motion component excitation strongly affects the bending moment demand on beams (transfer beams, long-span beams, and cantilever beams). Moreover, it is observed that vertical component excitation induces a high negative moment at the mid-span of beams and a high positive moment at beam supports.
8. The results show that the vertical component excitation has a slight effect on the bending moment demand on the inclined columns.
9. The vertical response spectrum adopted in TSC-2018 seems to underestimate the effect of vertical component excitation for some parameter demands in near-fault earthquakes.
10. The long-span frame with the 15 m span length, which is less than 20 m defined in TSC 2018, behaves in a similar way to the longer frames. Contrarily, the vertical amplification factors for some demands are larger in this frame.
11. The frame with the 4 m long cantilever, which is less than 5 m defined in TSC 2018, behaves similarly to the frames with longer cantilevers.

In a nutshell, this study emphasizes that the vertical ground motion in near-fault zones considerably affects the sensitive structural systems to vertical ground motions. This should be carefully considered when analyzing and designing these types of structures. Neglecting this component or miscalculating it may underestimate structural response under near-fault earthquake motions and lead to damage to the structure. Moreover, developing a vertical response spectrum that better reflects the effects of vertical ground excitation on these structures particularly in case of near-fault earthquakes with high V/H ratios.

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APPENDICES

6.1.TIME HISTORY RESULTS

6.1.1 Frames with transfer beams result tables

6.1.1.1 Case 1-1 (3-story frame)

Table 0.1: The vertical amplification factor of vertical displacement for beam B1 in case 1-1.

Record Seq. #	Event	Station	Direction	Vertical displacement at mid-span of				AF (displacement)
				B1 (mm)				
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	0.10	7.55	7.55	76.21
				Min.	-0.08	-7.75	-7.75	92.95
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	0.13	7.55	7.55	57.58
				Min.	-0.10	-7.75	-7.75	79.36
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	0.10	1.73	1.73	17.30
				Min.	-0.10	-1.92	-1.91	18.37
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	0.16	1.73	1.73	11.10
				Min.	-0.21	-1.92	-1.92	9.12
1063	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	0.31	5.76	5.83	18.76
				Min.	-0.19	-6.09	-6.05	31.04
1063	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	0.18	5.76	5.79	32.21
				Min.	-0.20	-6.09	-6.01	29.78
4040	Bam, Iran	Bam	H1	Max.	0.15	4.24	4.25	27.77
				Min.	-0.13	-3.84	-3.90	30.70
4040	Bam, Iran	Bam	H2	Max.	0.21	4.24	4.30	20.84
				Min.	-0.14	-3.84	-3.84	27.47
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	0.18	7.40	7.41	42.25
				Min.	-0.14	-8.12	-8.12	57.44
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	0.25	7.40	7.50	30.57
				Min.	-0.22	-8.12	-8.02	36.64
879	Landers, USA	Lucerne	H1	Max.	0.12	2.55	2.59	21.62
				Min.	-0.10	-1.48	-1.45	14.12
879	Landers, USA	Lucerne	H2	Max.	0.10	2.55	2.59	24.91
				Min.	-0.10	-1.48	-1.49	14.89
Average	Landers, USA	Lucerne	H3	Max.	0.17	4.87	4.90	31.76
				Min.	-0.14	-4.87	-4.85	36.82

Table 0.2: The vertical amplification factor of vertical acceleration for beam B1 in case 1-1.

Record Seq. #	Event	Station	Direction	Vertical acceleration at mid-span of B1 (m/sec ²)				AF (acc)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	0.03	12.89	12.89	478.24
				Min.	-0.03	-11.83	-11.83	443.81
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	0.03	12.89	12.89	368.72
				Min.	-0.04	-11.83	-11.83	334.17
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	0.09	3.24	3.23	37.08
				Min.	-0.08	-2.48	-2.47	32.48
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	0.08	3.24	3.24	40.19
				Min.	-0.06	-2.48	-2.48	40.71
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	0.07	8.90	8.89	128.07
				Min.	-0.07	-8.68	-8.67	124.06
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	0.07	8.90	8.88	126.34
				Min.	-0.08	-8.68	-8.72	111.46
4040	Bam, Iran	Bam	H1	Max.	0.13	6.42	6.41	50.49
				Min.	-0.13	-6.63	-6.64	49.27
4040	Bam, Iran	Bam	H2	Max.	0.08	6.42	6.40	84.90
				Min.	-0.11	-6.63	-6.61	58.40
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	0.08	12.03	12.00	151.58
				Min.	-0.07	-12.08	-12.05	179.80
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	0.09	12.03	12.04	132.70
				Min.	-0.06	-12.08	-12.12	198.44
879	Landers, USA	Lucerne	H1	Max.	0.07	3.06	3.05	45.65
				Min.	-0.06	-4.16	-4.19	74.73
879	Landers, USA	Lucerne	H2	Max.	0.31	3.06	11.61	36.97
				Min.	-0.32	-4.16	-16.40	51.23
Average	Landers, USA	Lucerne	H3	Max.	0.09	7.76	8.46	140.08
				Min.	-0.09	-7.64	-8.67	141.55

Table 0.3: The vertical amplification factor of the axial force for column C1 in case 1-1.

Record Seq. #	Event	Station	Direction	Axial force at planted column C1 (kN)				AF (axial)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	2.60	101.68	101.08	38.91
				Min.	-3.37	-108.57	-109.45	32.45
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	3.45	101.68	101.44	29.39
				Min.	-4.33	-108.57	-108.43	25.04
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	2.89	23.75	23.62	8.17
				Min.	-2.72	-31.58	-31.35	11.54
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	6.06	23.75	23.78	3.93
				Min.	-5.71	-31.58	-31.41	5.50
1063	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	6.07	62.66	63.55	10.47
				Min.	-11.33	-62.88	-64.11	5.66
1063	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	6.49	62.66	64.45	9.93
				Min.	-5.89	-62.88	-65.21	11.08
4040	Bam, Iran	Bam	H1	Max.	4.34	68.75	68.61	15.81
				Min.	-4.93	-49.18	-51.19	10.39
4040	Bam, Iran	Bam	H2	Max.	5.13	68.75	66.71	13.02
				Min.	-5.03	-49.18	-53.53	10.64
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	4.24	87.87	87.29	20.58
				Min.	-5.10	-90.61	-89.73	17.58
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	7.48	87.87	86.33	11.54
				Min.	-8.71	-90.61	-95.33	10.94
879	Landers, USA	Lucerne	H1	Max.	3.57	36.71	36.24	10.16
				Min.	-4.76	-41.55	-42.08	8.84
879	Landers, USA	Lucerne	H2	Max.	2.71	36.71	36.44	13.46
				Min.	-2.59	-41.55	-41.94	16.19
Average	Landers, USA	Lucerne	H3	Max.	4.59	63.57	63.29	15.45
				Min.	-5.37	-64.06	-65.31	13.82

Table 0.4: The vertical amplification factor of the bending moment for beam B1 in case 1-1.

Record Seq. #	Event	Station	Direction	Bending moment at mid-span (kN.m)				AF (moment)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	57.03	480.82	486.15	8.53
				Min.	-45.02	-446.17	-446.24	9.91
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	71.52	480.82	482.36	6.74
				Min.	-55.24	-446.17	-444.43	8.05
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	39.10	117.50	116.72	2.99
				Min.	-53.07	-96.99	-98.15	1.85
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	95.33	117.50	116.32	1.22
				Min.	-113.35	-96.99	-134.25	1.18
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	185.23	348.89	410.86	2.22
				Min.	-107.36	-334.04	-362.98	3.38
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	100.04	348.89	387.49	3.87
				Min.	-110.34	-334.04	-353.72	3.21
4040	Bam, Iran	Bam	H1	Max.	69.60	230.95	269.85	3.88
				Min.	-65.42	-253.64	-256.42	3.92
4040	Bam, Iran	Bam	H2	Max.	91.71	230.95	305.03	3.33
				Min.	-79.73	-253.64	-265.45	3.33
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	92.00	471.91	456.64	4.96
				Min.	-63.71	-437.19	-437.95	6.87
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	140.13	471.91	536.55	3.83
				Min.	-128.98	-437.19	-436.50	3.38
879	Landers, USA	Lucerne	H1	Max.	72.70	92.13	144.61	1.99
				Min.	-50.23	-157.32	-146.87	2.92
879	Landers, USA	Lucerne	H2	Max.	33.75	92.13	104.23	3.09
				Min.	-46.88	-157.32	-136.82	2.92
Average	Landers, USA	Lucerne	H3	Max.	87.34	290.37	318.07	3.89
				Min.	-76.61	-287.56	-293.31	4.24

Table 0.5: The vertical amplification factor of shear force for beam B1 in case 1-1.

Record Seq. #	Event	Station	Direction	Shear Force at right support of B1 (kN)				AF (shear)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	33.42	225.70	228.67	6.84
				Min.	-26.22	-224.99	-225.21	8.59
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	41.97	225.70	226.47	5.40
				Min.	-32.59	-224.99	-223.78	6.87
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	22.48	64.19	63.92	2.84
				Min.	-30.76	-52.14	-52.65	1.71
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	55.32	64.19	63.62	1.15
				Min.	-65.29	-52.14	-72.17	1.11
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	109.17	184.11	216.77	1.99
				Min.	-62.47	-173.42	-193.23	3.09
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	58.63	184.11	206.88	3.53
				Min.	-64.45	-173.42	-188.19	2.92
4040	Bam, Iran	Bam	H1	Max.	40.85	120.57	140.61	3.44
				Min.	-38.18	-128.63	-130.75	3.42
4040	Bam, Iran	Bam	H2	Max.	53.00	120.57	154.19	2.91
				Min.	-45.70	-128.63	-147.54	3.23
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	53.18	245.50	235.06	4.42
				Min.	-36.73	-220.23	-225.96	6.15
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	82.00	245.50	283.80	3.46
				Min.	-75.28	-220.23	-230.84	3.07
879	Landers, USA	Lucerne	H1	Max.	42.26	57.09	84.47	2.00
				Min.	-28.35	-74.45	-72.41	2.55
879	Landers, USA	Lucerne	H2	Max.	19.80	57.09	58.36	2.95
				Min.	-26.01	-74.45	-62.87	2.42
Average	Landers, USA	Lucerne	H3	Max.	51.01	149.53	163.57	3.41
				Min.	-44.33	-145.64	-152.13	3.76

6.1.1.2 Case 1-1 (5-story frame)

Table 0.6: The vertical amplification factor of vertical displacement for B2 in case 1-2.

Record Seq. #	Event	Station	Direction	Vertical displacement at mid-span of B2 (mm)				AF (displacement)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	0.09	7.77	7.77	86.67
				Min.	-0.10	-8.10	-8.10	79.55
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	0.09	7.77	7.77	82.97
				Min.	-0.06	-8.10	-8.10	128.16
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	0.10	1.73	1.73	16.99
				Min.	-0.10	-2.05	-2.05	19.77
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	0.12	1.73	1.73	14.60
				Min.	-0.12	-2.05	-2.05	17.04
1063	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	0.30	6.47	6.39	21.47
				Min.	-0.33	-6.70	-7.01	21.49
1063	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	0.15	6.47	6.49	43.94
				Min.	-0.14	-6.70	-6.60	46.96
4040	Bam, Iran	Bam	H1	Max.	0.13	4.26	4.38	32.92
				Min.	-0.14	-4.23	-4.18	30.31
4040	Bam, Iran	Bam	H2	Max.	0.10	4.26	4.22	43.51
				Min.	-0.13	-4.23	-4.27	33.37
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	0.13	7.68	7.61	57.24
				Min.	-0.10	-8.52	-8.57	86.53
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	0.14	7.68	7.74	57.14
				Min.	-0.15	-8.52	-8.51	58.64
879	Landers, USA	Lucerne	H1	Max.	0.11	2.76	2.74	24.26
				Min.	-0.07	-1.60	-1.66	22.88
879	Landers, USA	Lucerne	H2	Max.	0.05	2.76	2.75	53.33
				Min.	-0.06	-1.60	-1.61	28.91
Average	Landers, USA	Lucerne	H3	Max.	0.13	5.11	5.11	44.59
				Min.	-0.12	-5.20	-5.23	47.80

Table 0.7: The vertical amplification factor of vertical acceleration for beam B2 in case 1-2.

Record Seq. #	Event	Station	Direction	Vertical acceleration at mid-span of B2 (m/sec ²)				AF (acc)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	0.02	13.08	13.08	841.53
				Min.	-0.01	-11.02	-11.02	917.20
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	0.01	13.08	13.08	1335.81
				Min.	-0.01	-11.02	-11.02	911.74
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	0.03	3.85	3.85	124.87
				Min.	-0.03	-3.14	-3.13	93.13
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	0.02	3.85	3.85	158.30
				Min.	-0.02	-3.14	-3.14	161.93
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	0.04	9.76	9.78	223.78
				Min.	-0.03	-9.39	-9.38	289.78
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	0.02	9.76	9.76	433.06
				Min.	-0.03	-9.39	-9.41	330.50
4040	Bam, Iran	Bam	H1	Max.	0.07	6.01	6.00	82.71
				Min.	-0.07	-6.17	-6.17	82.73
4040	Bam, Iran	Bam	H2	Max.	0.04	6.01	6.01	134.53
				Min.	-0.04	-6.17	-6.15	155.06
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	0.03	11.52	11.51	373.70
				Min.	-0.05	-12.22	-12.20	257.40
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	0.03	11.52	11.52	355.23
				Min.	-0.03	-12.22	-12.25	407.73
879	Landers, USA	Lucerne	H1	Max.	0.02	3.12	3.12	138.51
				Min.	-0.02	-4.66	-4.67	215.61
879	Landers, USA	Lucerne	H2	Max.	0.04	3.12	3.12	83.22
				Min.	-0.04	-4.66	-4.67	128.12
Average	Landers, USA	Lucerne	H3	Max.	0.03	7.89	7.89	357.10
				Min.	-0.03	-7.77	-7.77	329.24

Table 0.8: The vertical amplification factor of the axial force for column C2 in case 1-2

Record Seq. #	Event	Station	Direction	Axial Force at Planted Column (kN)				AF (axial)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	8.75	217.72	218.21	24.94
				Min.	-7.86	-238.66	-239.10	30.42
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	5.40	217.72	217.46	40.26
				Min.	-7.21	-238.66	-238.73	33.12
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	9.73	57.94	57.78	5.94
				Min.	-8.01	-53.41	-53.18	6.64
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	9.76	57.94	58.02	5.94
				Min.	-9.78	-53.41	-53.31	5.45
1063	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	26.35	164.08	169.50	6.43
				Min.	-25.64	-162.53	-151.98	5.93
1063	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	13.05	164.08	163.33	12.52
				Min.	-11.20	-162.53	-170.02	15.18
4040	Bam, Iran	Bam	H1	Max.	10.78	121.53	117.11	10.86
				Min.	-11.14	-110.74	-117.53	10.55
4040	Bam, Iran	Bam	H2	Max.	10.59	121.53	123.30	11.64
				Min.	-8.43	-110.74	-108.74	12.91
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	8.23	195.30	199.86	24.27
				Min.	-9.76	-231.48	-226.17	23.18
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	13.29	195.30	190.87	14.37
				Min.	-10.71	-231.48	-234.47	21.89
879	Landers, USA	Lucerne	H1	Max.	6.56	79.40	82.18	12.52
				Min.	-10.28	-65.80	-64.71	6.30
879	Landers, USA	Lucerne	H2	Max.	4.73	79.40	81.13	17.15
				Min.	-4.33	-65.80	-66.13	15.29
Averag e	Landers, USA	Lucerne	H3	Max.	10.60	139.33	139.90	15.57
				Min.	-10.36	-143.77	-143.67	15.57

Table 0.9: The vertical amplification factor of the bending moment for beam B2 in case 1-2.

Record Seq. #	Event	Station	Direction	Bending Moment at Mid-span of B2 (kN.m)				AF (moment)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	112.60	692.88	696.31	6.18
				Min.	-121.77	-647.03	-649.81	5.34
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	115.72	692.88	694.01	6.00
				Min.	-76.05	-647.03	-644.86	8.48
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	119.43	173.33	171.93	1.44
				Min.	-131.47	-132.90	-158.01	1.20
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	140.57	173.33	176.99	1.26
				Min.	-141.23	-132.90	-167.33	1.18
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	361.00	539.45	623.04	1.73
				Min.	-388.18	-528.17	-784.55	2.02
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	176.02	539.45	665.61	3.78
				Min.	-173.28	-528.17	-510.83	2.95
4040	Bam, Iran	Bam	H1	Max.	161.50	337.76	471.28	2.92
				Min.	-159.63	-348.99	-399.38	2.50
4040	Bam, Iran	Bam	H2	Max.	108.90	337.76	334.80	3.07
				Min.	-132.64	-348.99	-381.10	2.87
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	130.33	697.54	638.53	4.90
				Min.	-119.45	-633.56	-692.58	5.80
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	159.80	697.54	724.20	4.53
				Min.	-179.24	-633.56	-569.61	3.18
879	Landers, USA	Lucerne	H1	Max.	132.82	150.69	215.97	1.63
				Min.	-74.55	-218.95	-259.83	3.49
879	Landers, USA	Lucerne	H2	Max.	52.71	150.69	140.63	2.67
				Min.	-66.16	-218.95	-244.32	3.69
Average	Landers, USA	Lucerne	H3	Max.	147.62	431.94	462.77	3.34
				Min.	-146.97	-418.27	-455.18	3.56

Table 0.10: The vertical amplification factor of shear force for beam B2 in case 1-2.

Record Seq. #	Event	Station	Direction	Shear Force at right support of B1 (kN)				AF (shear)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	70.49	298.73	301.22	4.27
				Min.	-75.77	-276.06	-277.85	3.67
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	71.55	298.73	299.19	4.18
				Min.	-47.69	-276.06	-274.67	5.76
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	74.25	81.75	86.19	1.16
				Min.	-82.14	-71.92	-91.50	1.11
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	87.31	81.75	98.66	1.13
				Min.	-87.67	-71.92	-88.01	1.00
1063	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	226.31	248.92	309.46	1.37
				Min.	-242.49	-238.68	-413.06	1.70
1063	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	108.25	248.92	326.34	3.01
				Min.	-109.14	-238.68	-228.49	2.09
4040	Bam, Iran	Bam	H1	Max.	100.43	157.86	239.73	2.39
				Min.	-98.96	-154.23	-208.97	2.11
4040	Bam, Iran	Bam	H2	Max.	68.86	157.86	172.49	2.51
				Min.	-83.81	-154.23	-185.77	2.22
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	81.99	310.41	308.68	3.76
				Min.	-74.17	-283.16	-319.25	4.30
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	99.22	310.41	325.15	3.28
				Min.	-112.69	-283.16	-264.11	2.34
879	Landers, USA	Lucerne	H1	Max.	82.61	62.60	120.58	1.46
				Min.	-46.84	-107.00	-136.03	2.90
879	Landers, USA	Lucerne	H2	Max.	32.55	62.60	70.45	2.16
				Min.	-40.75	-107.00	-122.68	3.01
Average	Landers, USA	Lucerne	H3	Max.	91.99	193.38	221.51	2.56
				Min.	-91.84	-188.51	-217.53	2.68

6.1.1.3 Case 1-1 (7-story frame)

Table 0.11: The vertical amplification factor of vertical displacement for B3 in case 1-3.

Record Seq. #	Event	Station	Direction	Vertical displacement at mid-span of				AF (displacement)
				B3 (mm)				
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	0.04	7.91	7.91	179.47
				Min.	-0.04	-8.11	-8.11	206.86
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	0.04	7.91	7.91	185.16
				Min.	-0.04	-8.11	-8.11	222.38
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	0.05	1.86	1.86	37.60
				Min.	-0.04	-1.97	-1.97	46.06
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	0.04	1.86	1.86	46.84
				Min.	-0.04	-1.97	-1.97	44.89
1063	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	0.11	6.30	6.34	59.73
				Min.	-0.10	-6.32	-6.38	62.46
1063	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	0.07	6.30	6.26	89.37
				Min.	-0.06	-6.32	-6.31	112.20
4040	Bam, Iran	Bam	H1	Max.	0.07	4.05	4.09	59.42
				Min.	-0.07	-4.06	-4.08	55.65
4040	Bam, Iran	Bam	H2	Max.	0.05	4.05	4.04	76.99
				Min.	-0.06	-4.06	-4.07	70.23
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	0.04	7.46	7.43	178.18
				Min.	-0.04	-8.16	-8.13	229.83
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	0.03	7.46	7.48	223.00
				Min.	-0.05	-8.16	-8.18	174.48
879	Landers, USA	Lucerne	H1	Max.	0.05	2.60	2.61	48.89
				Min.	-0.04	-1.40	-1.41	32.93
879	Landers, USA	Lucerne	H2	Max.	0.04	2.60	2.62	72.77
				Min.	-0.04	-1.40	-1.40	38.66
Average	Landers, USA	Lucerne	H3	Max.	0.05	5.03	5.03	104.79
				Min.	-0.05	-5.00	-5.01	108.05

Table 0.12: The vertical amplification factor of vertical acceleration for beam B3 in case 1-3.

Record Seq. #	Event	Station	Direction	Vertical acceleration at mid-span of B3 (m/sec ²)				AF (acc)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	0.01	13.67	13.67	1096.24
				Min.	-0.01	-12.84	-12.84	1077.34
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	0.02	13.67	13.67	862.02
				Min.	-0.02	-12.84	-12.84	761.97
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	0.03	3.48	3.48	122.04
				Min.	-0.03	-2.97	-2.97	91.59
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	0.02	3.48	3.48	152.25
				Min.	-0.02	-2.97	-2.97	150.35
1063	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	0.03	9.10	9.10	325.59
				Min.	-0.03	-9.28	-9.28	325.78
1063	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	0.02	9.10	9.11	395.48
				Min.	-0.03	-9.28	-9.28	356.20
4040	Bam, Iran	Bam	H1	Max.	0.06	6.60	6.58	108.77
				Min.	-0.06	-5.95	-5.95	95.55
4040	Bam, Iran	Bam	H2	Max.	0.04	6.60	6.61	159.93
				Min.	-0.04	-5.95	-5.94	144.61
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	0.03	11.43	11.40	438.57
				Min.	-0.03	-11.64	-11.62	458.15
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	0.03	11.43	11.45	440.60
				Min.	-0.03	-11.64	-11.66	414.90
879	Landers, USA	Lucerne	H1	Max.	0.03	2.85	2.86	89.86
				Min.	-0.03	-4.01	-4.01	126.36
879	Landers, USA	Lucerne	H2	Max.	0.03	2.85	2.84	93.79
				Min.	-0.04	-4.01	-4.02	113.49
Average	Landers, USA	Lucerne	H3	Max.	0.03	7.85	7.85	357.10
				Min.	-0.03	-7.78	-7.78	343.02

Table 0.13: The vertical amplification factor of the axial force for column C3 in case 1-3.

Record Seq. #	Event	Station	Direction	Axial Force at Planted Column C3(kN)				AF (axial)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	5.92	566.63	567.15	95.75
				Min.	-7.08	-578.34	-578.91	81.74
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	3.98	566.63	566.17	142.22
				Min.	-5.24	-578.34	-578.36	110.46
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	5.84	127.79	127.51	21.83
				Min.	-4.79	-136.10	-135.63	28.34
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	5.39	127.79	127.82	23.71
				Min.	-6.81	-136.10	-135.98	19.97
1063	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	17.72	443.12	432.76	24.42
				Min.	-15.99	-440.14	-426.63	26.68
1063	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	8.34	443.12	449.51	53.89
				Min.	-8.93	-440.14	-444.91	49.85
4040	Bam, Iran	Bam	H1	Max.	9.19	284.09	280.86	30.56
				Min.	-7.60	-281.70	-280.06	36.84
4040	Bam, Iran	Bam	H2	Max.	5.09	284.09	283.47	55.69
				Min.	-5.56	-281.70	-280.22	50.36
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	5.03	524.65	524.99	104.29
				Min.	-5.09	-579.46	-577.73	113.61
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	5.82	524.65	525.64	90.29
				Min.	-5.30	-579.46	-580.34	109.58
879	Landers, USA	Lucerne	H1	Max.	3.48	179.78	179.71	51.67
				Min.	-5.59	-117.89	-116.78	20.89
879	Landers, USA	Lucerne	H2	Max.	4.53	179.78	181.12	40.03
				Min.	-3.52	-117.89	-117.97	33.54
Average	Landers, USA	Lucerne	H3	Max.	6.69	354.34	353.89	61.20
				Min.	-6.79	-355.60	-354.46	56.82

Table 0.14: The vertical amplification factor of the bending moment for beam B3 in case 1-3.

Record Seq. #	Event	Station	Direction	Bending moment at mid-span of B3(kN.m)				AF (moment)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	195.05	1300.40	1306.43	6.70
				Min.	-171.24	-1240.37	-1243.37	7.26
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	139.50	1300.40	1301.99	9.33
				Min.	-92.33	-1240.37	-1235.83	13.38
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	102.60	318.45	313.55	3.06
				Min.	-137.60	-283.42	-284.59	2.07
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	148.94	318.45	317.96	2.13
				Min.	-114.96	-283.42	-284.05	2.47
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	431.09	977.92	1181.59	2.74
				Min.	-486.60	-976.53	-1332.18	2.74
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	215.92	977.92	1130.71	5.24
				Min.	-202.55	-976.53	-1108.02	5.47
4040	Bam, Iran	Bam	H1	Max.	190.80	620.80	759.10	3.98
				Min.	-239.26	-630.18	-689.85	2.88
4040	Bam, Iran	Bam	H2	Max.	104.81	620.80	637.35	6.08
				Min.	-86.72	-630.18	-647.55	7.47
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	116.88	1257.39	1241.45	10.62
				Min.	-128.25	-1174.08	-1216.34	9.48
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	138.89	1257.39	1240.85	8.93
				Min.	-140.39	-1174.08	-1203.33	8.57
879	Landers, USA	Lucerne	H1	Max.	155.03	221.90	316.96	2.04
				Min.	-82.97	-402.53	-364.25	4.39
879	Landers, USA	Lucerne	H2	Max.	76.91	221.90	248.12	3.23
				Min.	-75.80	-402.53	-409.81	5.41
Average	Landers, USA	Lucerne	H3	Max.	168.03	782.81	833.01	5.34
				Min.	-163.22	-784.52	-834.93	5.97

Table 0.15: The vertical amplification factor of shear force for beam B3 in case-1-3.

Record Seq. #	Event	Station	Direction	Shear Force at right support of B3(kN)				AF (shear)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	138.55	498.10	502.10	3.62
				Min.	-121.49	-476.37	-478.16	3.94
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	100.03	498.10	499.27	4.99
				Min.	-67.10	-476.37	-473.25	7.05
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	74.44	124.03	120.25	1.62
				Min.	-98.64	-117.50	-118.25	1.20
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	107.19	124.03	132.35	1.23
				Min.	-84.20	-117.50	-120.56	1.43
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	307.91	385.57	552.41	1.79
				Min.	-345.86	-383.04	-678.11	1.96
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	156.20	385.57	491.31	3.15
				Min.	-145.95	-383.04	-480.51	3.29
4040	Bam, Iran	Bam	H1	Max.	135.75	249.94	360.45	2.66
				Min.	-168.81	-246.15	-343.36	2.03
4040	Bam, Iran	Bam	H2	Max.	75.60	249.94	259.01	3.43
				Min.	-62.77	-246.15	-257.28	4.10
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	83.44	493.29	481.62	5.77
				Min.	-89.67	-454.37	-483.18	5.39
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	98.53	493.29	482.30	4.89
				Min.	-100.43	-454.37	-496.30	4.94
879	Landers, USA	Lucerne	H1	Max.	109.61	91.28	158.90	1.45
				Min.	-59.59	-155.96	-133.97	2.25
879	Landers, USA	Lucerne	H2	Max.	54.74	91.28	108.27	1.98
				Min.	-54.87	-155.96	-161.49	2.94
Average	Landers, USA	Lucerne	H3	Max.	120.17	307.04	345.69	3.05
				Min.	-116.62	-305.56	-352.03	3.38

6.1.2 Frames with slanted columns result tables

6.1.2.1 Case 2-1

Table 0.16: The vertical amplification factor of vertical displacement column C1 in case-2-1.

Record Seq. #	Event	Station	Direction	Vertical displacement at top of slanted column C1 (mm)				AF (displacement)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	0.73	0.23	0.72	0.98
				Min.	-0.54	-0.18	-0.53	1.00
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	0.48	0.23	0.46	0.97
				Min.	-0.73	-0.18	-0.76	1.04
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	0.57	0.10	0.57	1.01
				Min.	-0.58	-0.09	-0.58	1.01
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	1.09	0.10	1.09	1.00
				Min.	-1.26	-0.09	-1.26	1.00
1063	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	1.86	0.12	1.86	1.00
				Min.	-2.06	-0.14	-2.03	0.99
1063	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	1.06	0.12	1.05	0.99
				Min.	-0.78	-0.14	-0.76	0.97
4040	Bam, Iran	Bam	H1	Max.	0.71	0.10	0.74	1.05
				Min.	-0.99	-0.10	-1.03	1.04
4040	Bam, Iran	Bam	H2	Max.	0.87	0.10	0.87	1.00
				Min.	-0.83	-0.10	-0.84	1.02
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	0.52	0.16	0.57	1.08
				Min.	-0.79	-0.20	-0.82	1.04
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	0.97	0.16	0.99	1.02
				Min.	-0.72	-0.20	-0.78	1.08
879	Landers, USA	Lucerne	H1	Max.	0.44	0.13	0.51	1.17
				Min.	-0.51	-0.16	-0.53	1.04
879	Landers, USA	Lucerne	H2	Max.	0.51	0.13	0.53	1.03
				Min.	-0.48	-0.16	-0.50	1.03
Average	Landers, USA	Lucerne	H3	Max.	0.82	0.14	0.83	1.03
				Min.	-0.86	-0.15	-0.87	1.02

Table 0.17: The vertical amplification factor of vertical acceleration for column C1 in case 2-1.

Record Seq. #	Event	Station	Direction	Vertical acceleration at top of slanted column C1 (m/sec ²)				AF (acc)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	0.10	5.89	5.88	61.54
				Min.	-0.15	-5.82	-5.80	37.45
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	0.09	5.89	5.96	65.66
				Min.	-0.09	-5.82	-5.81	61.90
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	0.14	2.87	2.89	20.63
				Min.	-0.16	-1.71	-1.73	10.84
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	0.18	2.87	2.89	16.11
				Min.	-0.19	-1.71	-1.72	8.91
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	0.18	3.07	3.11	17.52
				Min.	-0.25	-2.87	-2.88	11.48
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	0.17	3.07	3.08	18.38
				Min.	-0.16	-2.87	-2.86	17.63
4040	Bam, Iran	Bam	H1	Max.	0.21	3.21	3.16	15.26
				Min.	-0.25	-3.56	-3.73	14.86
4040	Bam, Iran	Bam	H2	Max.	0.20	3.21	3.27	16.32
				Min.	-0.17	-3.56	-3.54	20.83
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	0.18	5.92	5.93	32.18
				Min.	-0.18	-3.92	-3.94	22.05
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	0.18	5.92	5.86	32.01
				Min.	-0.18	-3.92	-3.84	21.11
879	Landers, USA	Lucerne	H1	Max.	0.17	3.11	3.03	18.25
				Min.	-0.20	-3.15	-3.09	15.72
879	Landers, USA	Lucerne	H2	Max.	0.28	3.11	3.01	10.84
				Min.	-0.22	-3.15	-3.06	14.05
Average	Landers, USA	Lucerne	H3	Max.	0.17	4.01	4.01	27.06
				Min.	-0.18	-3.50	-3.50	21.40

Table 0.18: The vertical amplification factor of axial force for column C1 in case 2-1.

Record Seq. #	Event	Station	Directio n	Axial force at top of slanted column C1 (kN)				AF (axial)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	60.61	311.53	310.19	5.12
				Min.	-52.64	-344.35	-345.98	6.57
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	48.32	311.53	310.88	6.43
				Min.	-64.60	-344.35	-344.28	5.33
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	58.79	140.10	138.81	2.36
				Min.	-57.01	-157.85	-158.47	2.78
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	107.46	140.10	140.84	1.31
				Min.	-118.29	-157.85	-156.99	1.33
1063	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	159.73	183.36	212.13	1.33
				Min.	-174.99	-195.34	-196.00	1.12
1063	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	96.28	183.36	183.00	1.90
				Min.	-74.90	-195.34	-194.05	2.59
4040	Bam, Iran	Bam	H1	Max.	63.86	163.04	184.30	2.89
				Min.	-85.17	-154.67	-161.63	1.90
4040	Bam, Iran	Bam	H2	Max.	86.98	163.04	154.36	1.77
				Min.	-79.88	-154.67	-170.83	2.14
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	53.93	228.42	231.66	4.30
				Min.	-65.80	-290.46	-297.66	4.52
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	85.49	228.42	278.79	3.26
				Min.	-71.20	-290.46	-288.82	4.06
879	Landers, USA	Lucerne	H1	Max.	44.90	196.97	195.69	4.36
				Min.	-46.28	-222.44	-244.73	5.29
879	Landers, USA	Lucerne	H2	Max.	45.28	196.97	190.64	4.21
				Min.	-51.93	-222.44	-236.90	4.56
Averag e	Landers, USA	Lucerne	H3	Max.	75.97	203.90	210.94	3.27
				Min.	-78.56	-227.52	-233.03	3.52

Table 0.19: The vertical amplification factor of bending moment for column C1 in case 2-1.

Record Seq. #	Event	Station	Direction	Bending moment at top of slanted column C1(kN.m)				AF (moment)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	48.80	20.25	49.05	1.01
				Min.	-70.53	-22.72	-70.45	1.00
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	68.97	20.25	71.21	1.03
				Min.	-44.75	-22.72	-43.69	0.98
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	56.06	8.09	56.15	1.00
				Min.	-56.84	-8.85	-58.06	1.02
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	117.08	8.09	116.22	0.99
				Min.	-100.06	-8.85	-99.80	1.00
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	197.32	12.39	195.27	0.99
				Min.	-179.90	-9.70	-179.12	1.00
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	74.55	12.39	70.33	0.94
				Min.	-99.54	-9.70	-98.08	0.99
4040	Bam, Iran	Bam	H1	Max.	96.55	13.59	97.36	1.01
				Min.	-67.03	-12.47	-68.72	1.03
4040	Bam, Iran	Bam	H2	Max.	80.55	13.59	85.99	1.07
				Min.	-79.23	-12.47	-79.76	1.01
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	81.64	18.17	84.20	1.03
				Min.	-51.70	-14.62	-54.92	1.06
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	69.96	18.17	77.43	1.11
				Min.	-94.20	-14.62	-99.39	1.06
879	Landers, USA	Lucerne	H1	Max.	52.55	19.24	56.32	1.07
				Min.	-41.56	-13.08	-51.28	1.23
879	Landers, USA	Lucerne	H2	Max.	47.63	19.24	50.00	1.05
				Min.	-53.86	-13.08	-55.74	1.03
Average	Landers, USA	Lucerne	H3	Max.	82.64	15.29	84.13	1.03
				Min.	-78.27	-13.57	-79.92	1.03

Table 0.20: The vertical amplification factor of shear forces for column C1 in case 2-1.

Record Seq. #	Event	Station	Direction	Shear force at top of slanted column C1 (kN)			AF (shear)	
				Step Type	H	V		H+V
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	46.25	9.61	45.69	0.99
				Min.	-32.69	-6.50	-32.37	0.99
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	29.56	9.61	28.87	0.98
				Min.	-45.55	-6.50	-46.89	1.03
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	36.49	3.61	36.88	1.01
				Min.	-36.57	-2.81	-36.45	1.00
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	66.88	3.61	66.72	1.00
				Min.	-77.95	-2.81	-77.56	0.99
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	117.92	5.48	116.49	0.99
				Min.	-	-6.79	-128.45	0.99
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	65.87	5.48	64.54	0.98
				Min.	-49.00	-6.79	-46.11	0.94
4040	Bam, Iran	Bam	H1	Max.	44.22	4.60	44.32	1.00
				Min.	-63.01	-5.31	-63.73	1.01
4040	Bam, Iran	Bam	H2	Max.	52.89	4.60	52.98	1.00
				Min.	-52.70	-5.31	-54.29	1.03
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	33.27	6.66	32.79	0.99
				Min.	-52.09	-7.27	-51.69	0.99
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	61.48	6.66	63.35	1.03
				Min.	-45.76	-7.27	-48.89	1.07
879	Landers, USA	Lucerne	H1	Max.	27.21	4.89	30.93	1.14
				Min.	-33.45	-7.42	-35.08	1.05
879	Landers, USA	Lucerne	H2	Max.	34.23	4.89	34.82	1.02
				Min.	-30.82	-7.42	-31.89	1.03
Average	Landers, USA	Lucerne	H3	Max.	51.35	5.81	51.53	1.01
				Min.	-54.11	-6.01	-54.45	1.01

6.1.2.2 Case 2-2

Table 0.21: The vertical amplification factor of vertical displacement column C2 in case 2-2.

Record Seq. #	Event	Station	Direction	Vertical displacement at top of slanted column C2 (mm)				AF (displacement)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	1.20	0.38	1.20	1.00
				Min.	-0.86	-0.24	-0.87	1.01
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	0.63	0.38	0.65	1.02
				Min.	-1.19	-0.24	-1.19	1.00
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	0.79	0.11	0.81	1.02
				Min.	-0.80	-0.07	-0.82	1.02
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	1.61	0.11	1.59	0.99
				Min.	-2.03	-0.07	-2.02	0.99
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	3.20	0.23	3.14	0.98
				Min.	-3.35	-0.26	-3.33	0.99
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	1.64	0.23	1.58	0.96
				Min.	-1.18	-0.26	-1.16	0.99
4040	Bam, Iran	Bam	H1	Max.	1.10	0.14	1.14	1.04
				Min.	-1.58	-0.14	-1.65	1.04
4040	Bam, Iran	Bam	H2	Max.	1.25	0.14	1.26	1.00
				Min.	-1.35	-0.14	-1.37	1.02
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	1.01	0.23	0.96	0.96
				Min.	-1.33	-0.27	-1.20	0.91
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	1.31	0.23	1.30	0.99
				Min.	-1.03	-0.27	-1.23	1.19
879	Landers, USA	Lucerne	H1	Max.	0.71	0.18	0.78	1.11
				Min.	-0.98	-0.15	-1.01	1.04
879	Landers, USA	Lucerne	H2	Max.	0.89	0.18	0.88	0.98
				Min.	-0.81	-0.15	-0.81	1.00
Average	Landers, USA	Lucerne	H3	Max.	1.28	0.21	1.27	1.00
				Min.	-1.37	-0.19	-1.39	1.02

Table 0.22: The vertical amplification factor of vertical acceleration for column C2 in case 2-2.

Record Seq. #	Event	Station	Direction	Vertical acceleration at top of slanted column C2 (m/sec ²)				AF(acc)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	0.14	7.39	7.27	51.98
				Min.	-0.26	-4.83	-4.81	18.41
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	0.13	7.39	7.39	56.02
				Min.	-0.13	-4.83	-4.84	35.90
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	0.21	2.57	2.59	12.35
				Min.	-0.21	-1.87	-1.89	9.07
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	0.26	2.57	2.59	9.82
				Min.	-0.25	-1.87	-1.88	7.44
1063	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	0.28	2.88	2.93	10.34
				Min.	-0.38	-2.93	-2.94	7.69
1063	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	0.28	2.88	2.92	10.56
				Min.	-0.27	-2.93	-2.93	10.76
4040	Bam, Iran	Bam	H1	Max.	0.26	3.05	3.04	11.51
				Min.	-0.36	-3.69	-3.96	10.95
4040	Bam, Iran	Bam	H2	Max.	0.33	3.05	3.13	9.63
				Min.	-0.27	-3.69	-3.63	13.63
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	0.31	5.92	5.95	19.16
				Min.	-0.25	-3.09	-3.17	12.57
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	0.28	5.92	5.82	20.57
				Min.	-0.28	-3.09	-3.06	10.75
879	Landers, USA	Lucerne	H1	Max.	0.30	2.89	2.89	9.56
				Min.	-0.37	-2.69	-2.64	7.11
879	Landers, USA	Lucerne	H2	Max.	0.50	2.89	2.81	5.60
				Min.	-0.34	-2.69	-2.60	7.70
Average	Landers, USA	Lucerne	H3	Max.	0.27	4.12	4.11	18.93
				Min.	-0.28	-3.18	-3.20	12.67

Table 0.23: The vertical amplification factor of axial force for column C2 in case2-2.

Record Seq. #	Event	Station	Direction	Axial force at top of slanted column C2 (kN)				AF (axial)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	49.83	392.93	390.12	7.83
				Min.	-43.08	-487.36	-484.05	11.24
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	31.24	392.93	392.65	12.57
				Min.	-52.75	-487.36	-488.28	9.26
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	43.37	117.12	115.97	2.67
				Min.	-41.82	-131.68	-132.38	3.17
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	81.26	117.12	117.97	1.45
				Min.	-92.25	-131.68	-131.49	1.43
1063	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	137.67	171.29	209.70	1.52
				Min.	-134.28	-182.42	-192.27	1.43
1063	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	72.47	171.29	168.49	2.33
				Min.	-57.66	-182.42	-188.46	3.27
4040	Bam, Iran	Bam	H1	Max.	61.24	232.25	243.57	3.98
				Min.	-67.25	-194.10	-213.49	3.17
4040	Bam, Iran	Bam	H2	Max.	61.44	232.25	215.52	3.51
				Min.	-63.22	-194.10	-207.41	3.28
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	49.66	260.21	276.46	5.57
				Min.	-59.17	-313.41	-297.01	5.02
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	54.92	260.21	251.09	4.57
				Min.	-56.33	-313.41	-312.89	5.55
879	Landers, USA	Lucerne	H1	Max.	33.08	183.28	176.10	5.32
				Min.	-42.80	-158.31	-174.90	4.09
879	Landers, USA	Lucerne	H2	Max.	47.52	183.28	176.14	3.71
				Min.	-47.30	-158.31	-168.62	3.57
Averag e	Landers, USA	Lucerne	H3	Max.	60.31	226.18	227.81	4.59
				Min.	-63.16	-244.55	-249.27	4.54

Table 0.24: The vertical amplification factor of bending moment for column C2 in case 2-2.

Record Seq. #	Event	Station	Direction	Bending moment at top of slanted column C2(kN.m)				AF (moment)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	48.86	32.99	49.49	1.01
				Min.	-71.97	-29.02	-73.86	1.03
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	68.96	32.99	69.39	1.01
				Min.	-36.40	-29.02	-40.28	1.11
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	49.01	6.88	52.01	1.06
				Min.	-50.41	-12.57	-51.95	1.03
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	118.63	6.88	119.26	1.01
				Min.	-94.48	-12.57	-95.34	1.01
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	200.42	17.66	198.89	0.99
				Min.	-189.69	-19.90	-190.82	1.01
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	71.52	17.66	66.09	0.92
				Min.	-97.03	-19.90	-94.86	0.98
4040	Bam, Iran	Bam	H1	Max.	96.29	21.77	101.39	1.05
				Min.	-67.93	-19.48	-74.72	1.10
4040	Bam, Iran	Bam	H2	Max.	82.19	21.77	86.91	1.06
				Min.	-76.01	-19.48	-77.94	1.03
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	85.18	26.79	81.21	0.95
				Min.	-60.98	-18.42	-60.09	0.99
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	62.39	26.79	82.66	1.32
				Min.	-81.03	-18.42	-85.95	1.06
879	Landers, USA	Lucerne	H1	Max.	61.79	16.64	73.40	1.19
				Min.	-43.61	-15.52	-53.97	1.24
879	Landers, USA	Lucerne	H2	Max.	50.76	16.64	55.09	1.09
				Min.	-55.77	-15.52	-61.14	1.10
Average	Landers, USA	Lucerne	H3	Max.	83.00	20.46	86.32	1.06
				Min.	-77.11	-19.15	-80.08	1.06

Table 0.25: The vertical amplification factor of shear force for column C2 in case 2-2.

Record Seq. #	Event	Station	Direction	Shear force at top of slanted column C2 (kN)				AF (shear)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	47.70	12.83	48.38	1.01
				Min.	-33.13	-10.70	-33.39	1.01
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	24.56	12.83	25.89	1.05
				Min.	-46.33	-10.70	-46.22	1.00
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	32.64	4.90	33.00	1.01
				Min.	-32.21	-2.04	-33.34	1.03
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	63.13	4.90	63.33	1.00
				Min.	-79.54	-2.04	-79.50	1.00
1063	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	126.20	8.70	124.86	0.99
				Min.	-133.12	-9.63	-132.03	0.99
1063	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	64.66	8.70	62.59	0.97
				Min.	-47.11	-9.63	-45.28	0.96
4040	Bam, Iran	Bam	H1	Max.	44.49	7.27	47.19	1.06
				Min.	-63.37	-8.27	-65.82	1.04
4040	Bam, Iran	Bam	H2	Max.	49.16	7.27	50.02	1.02
				Min.	-54.10	-8.27	-54.95	1.02
8119	Christchurch New Zealand	Pages Road Pumping	H1	Max.	39.78	8.35	38.01	0.96
				Min.	-54.80	-11.59	-51.85	0.95
8119	Christchurch New Zealand	Pages Road Pumping	H2	Max.	52.89	8.35	54.02	1.02
				Min.	-41.22	-11.59	-50.29	1.22
879	Landers, USA	Lucerne	H1	Max.	28.54	6.08	33.02	1.16
				Min.	-39.99	-6.89	-44.63	1.12
879	Landers, USA	Lucerne	H2	Max.	36.30	6.08	37.27	1.03
				Min.	-32.87	-6.89	-32.81	1.00
Average	Landers, USA	Lucerne	H3	Max.	50.84	8.02	51.46	1.02
				Min.	-54.82	-8.19	-55.84	1.03

6.1.3 Frames with long cantilevers result tables

6.1.3.1 Case 3-1 (4m cantilever)

Table 0.26: The vertical amplification factor of vertical displacement at the free end of cantilever beam B1 in case 3-1.

Record Seq. #	Event	Station	Direction	Vertical displacement at cantilever free End (mm)				AF (displacement)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	7.96	10.98	10.97	1.38
				Min.	-6.02	-6.40	-7.62	1.27
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	7.34	10.98	10.72	1.46
				Min.	-6.46	-6.40	-6.63	1.03
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	4.65	1.95	4.71	1.01
				Min.	-3.65	-1.66	-4.47	1.23
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	7.64	1.95	7.62	1.00
				Min.	-7.70	-1.66	-8.24	1.07
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	25.88	11.84	27.60	1.07
				Min.	-26.07	-9.96	-31.35	1.20
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	10.17	11.84	16.29	1.60
				Min.	-11.47	-9.96	-15.92	1.39
4040	Bam, Iran	Bam	H1	Max.	17.35	6.92	22.79	1.31
				Min.	-14.38	-6.99	-17.85	1.24
4040	Bam, Iran	Bam	H2	Max.	11.18	6.92	15.03	1.34
				Min.	-10.82	-6.99	-13.00	1.20
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	8.21	11.12	15.73	1.92
				Min.	-6.96	-13.29	-16.33	2.35
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	7.48	11.12	13.32	1.78
				Min.	-7.39	-13.29	-14.06	1.90
879	Landers, USA	Lucerne	H1	Max.	5.23	3.01	6.99	1.34
				Min.	-8.45	-2.01	-9.78	1.16
879	Landers, USA	Lucerne	H2	Max.	4.99	3.01	6.92	1.39
				Min.	-4.56	-2.01	-6.19	1.36
Average	Landers, USA	Lucerne	H3	Max.	9.84	7.64	13.22	1.38
				Min.	-9.49	-6.72	-12.62	1.37

Table 0.27: The vertical amplification factor of vertical acceleration at the free end of cantilever beam B1 in case 3-1.

Record Seq. #	Event	Station	Direction	Vertical acceleration at cantilever free end(m/sec ²)				AF (acc)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	0.81	7.38	7.32	8.98
				Min.	-0.75	-12.56	-12.47	16.72
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	1.06	7.38	7.40	6.96
				Min.	-0.93	-12.56	-12.54	13.46
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	1.27	3.11	3.13	2.46
				Min.	-1.33	-3.46	-3.50	2.63
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	1.26	3.11	3.10	2.45
				Min.	-1.35	-3.46	-3.47	2.56
1063	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	1.78	8.83	9.60	5.40
				Min.	-2.28	-9.93	-9.82	4.32
1063	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	1.25	8.83	8.41	6.75
				Min.	-1.32	-9.93	-9.18	6.94
4040	Bam, Iran	Bam	H1	Max.	1.59	6.24	6.85	4.31
				Min.	-1.64	-5.45	-6.42	3.92
4040	Bam, Iran	Bam	H2	Max.	1.59	6.24	6.20	3.90
				Min.	-1.82	-5.45	-5.79	3.17
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	0.89	13.56	13.78	15.49
				Min.	-0.99	-12.34	-11.96	12.09
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	0.88	13.56	13.32	15.09
				Min.	-0.87	-12.34	-12.29	14.08
879	Landers, USA	Lucerne	H1	Max.	1.63	3.27	3.60	2.21
				Min.	-1.50	-3.03	-3.15	2.10
879	Landers, USA	Lucerne	H2	Max.	1.01	3.27	3.73	3.68
				Min.	-0.87	-3.03	-3.00	3.44
Average	Landers, USA	Lucerne	H3	Max.	1.25	7.07	7.20	6.47
				Min.	-1.31	-7.79	-7.80	7.12

Table 0.28: The vertical amplification factor of the axial force for column C1 in case 3-1.

Record Seq. #	Event	Station	Directio n	Axial force at column C1 (kN)				AF (axial)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	94.42	836.44	837.73	8.87
				Min.	-80.62	-547.01	-548.51	6.80
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	95.48	836.44	834.41	8.74
				Min.	-90.89	-547.01	-550.24	6.05
184	Imperial Valley-06, USA	El Centro Differential 1 Array	H1	Max.	49.41	237.45	241.19	4.88
				Min.	-40.79	-143.92	-150.60	3.69
184	Imperial Valley-06, USA	El Centro Differential 1 Array	H2	Max.	98.79	237.45	238.16	2.41
				Min.	-94.22	-143.92	-183.00	1.94
1063	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	323.31	811.54	967.44	2.99
				Min.	-330.72	-836.52	-1120.05	3.39
1063	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	142.92	811.54	860.84	6.02
				Min.	-174.04	-836.52	-855.75	4.92
4040	Bam, Iran	Bam	H1	Max.	202.96	506.60	671.61	3.31
				Min.	-174.02	-673.84	-824.92	4.74
4040	Bam, Iran	Bam	H2	Max.	148.18	506.60	526.37	3.55
				Min.	-124.24	-673.84	-665.54	5.36
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	108.76	1048.11	1076.65	9.90
				Min.	-84.48	-1029.96	-996.49	11.80
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	99.49	1048.11	1053.73	10.59
				Min.	-129.97	-1029.96	-1040.23	8.00
879	Landers, USA	Lucerne	H1	Max.	73.24	291.36	343.29	4.69
				Min.	-100.90	-263.73	-304.40	3.02
879	Landers, USA	Lucerne	H2	Max.	62.90	291.36	307.07	4.88
				Min.	-67.00	-263.73	-295.56	4.41
Averag e	Landers, USA	Lucerne	H3	Max.	124.99	621.92	663.21	5.90
				Min.	-124.32	-582.49	-627.94	5.34

Table 0.29: The vertical amplification factor of bending moment for cantilever beam B1 in case 3-1.

Record Seq. #	Event	Station	Direction	Bending moment at cantilever support (kN.m)				AF (moment)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	28.44	349.53	347.29	12.21
				Min.	-30.61	-201.94	-199.76	6.53
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	35.64	349.53	348.45	9.78
				Min.	-40.34	-201.94	-202.37	5.02
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	49.79	64.42	66.04	1.33
				Min.	-47.11	-46.14	-52.17	1.11
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	51.09	64.42	64.33	1.26
				Min.	-47.53	-46.14	-49.00	1.03
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	88.49	353.32	345.82	3.91
				Min.	-68.40	-332.87	-368.72	5.39
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	50.91	353.32	323.78	6.36
				Min.	-46.46	-332.87	-313.50	6.75
4040	Bam, Iran	Bam	H1	Max.	59.49	194.70	233.81	3.93
				Min.	-57.45	-231.00	-236.74	4.12
4040	Bam, Iran	Bam	H2	Max.	66.47	194.70	203.99	3.07
				Min.	-58.08	-231.00	-263.63	4.54
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	37.36	358.14	394.23	10.55
				Min.	-33.35	-434.01	-458.48	13.75
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	31.62	358.14	351.16	11.11
				Min.	-33.14	-434.01	-411.60	12.42
879	Landers, USA	Lucerne	H1	Max.	56.37	89.42	83.65	1.48
				Min.	-60.91	-64.17	-81.87	1.34
879	Landers, USA	Lucerne	H2	Max.	33.16	89.42	87.49	2.64
				Min.	-37.14	-64.17	-78.31	2.11
Average	Landers, USA	Lucerne	H3	Max.	49.07	234.92	237.50	5.64
				Min.	-46.71	-218.35	-226.34	5.34

Table 0.30: The vertical amplification factor of shear force for cantilever beam B1 in case 3-1.

Record Seq. #	Event	Station	Direction	Shear force at cantilever support (kN)				AF (shear)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	9.16	113.22	112.62	12.29
				Min.	-9.93	-65.02	-65.43	6.59
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	11.56	113.22	112.91	9.77
				Min.	-13.07	-65.02	-64.33	4.92
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	15.97	24.28	25.02	1.57
				Min.	-15.10	-17.77	-18.44	1.22
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	16.47	24.28	24.00	1.46
				Min.	-15.39	-17.77	-19.23	1.25
1063	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	28.86	110.02	107.17	3.71
				Min.	-22.37	-107.92	-120.12	5.37
1063	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	16.45	110.02	100.34	6.10
				Min.	-14.93	-107.92	-101.64	6.81
4040	Bam, Iran	Bam	H1	Max.	18.86	64.23	77.02	4.08
				Min.	-18.18	-80.46	-82.46	4.54
4040	Bam, Iran	Bam	H2	Max.	21.06	64.23	67.79	3.22
				Min.	-18.44	-80.46	-90.80	4.92
8119	Christchurch New Zealand	Pages Road Pumping	H1	Max.	12.02	122.89	134.56	11.20
				Min.	-10.62	-139.94	-147.69	13.91
8119	Christchurch New Zealand	Pages Road Pumping	H2	Max.	10.31	122.89	113.17	10.98
				Min.	-10.64	-139.94	-132.23	12.43
879	Landers, USA	Lucerne	H1	Max.	18.11	31.51	36.79	2.03
				Min.	-19.63	-27.79	-32.41	1.65
879	Landers, USA	Lucerne	H2	Max.	10.70	31.51	34.03	3.18
				Min.	-11.94	-27.79	-37.54	3.14
Averag e	Landers, USA	Lucerne	H3	Max.	15.79	77.69	78.79	5.80
				Min.	-15.02	-73.15	-76.03	5.56

6.1.3.2 Case 3-2 (5m cantilever)

Table 0.31: The vertical amplification factor of vertical displacement at the free end of cantilever beam B2 in case 3-2.

Record Seq. #	Event	Station	Direction	Vertical displacement at cantilever free End (mm)				AF (displacement)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	9.56	11.13	11.10	1.16
				Min.	-7.81	-11.64	-11.51	1.47
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	8.38	11.13	10.61	1.27
				Min.	-7.60	-11.64	-11.44	1.51
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	4.15	3.27	5.94	1.43
				Min.	-3.99	-2.12	-6.09	1.52
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	7.49	3.27	7.35	0.98
				Min.	-8.05	-2.12	-8.00	0.99
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	29.28	7.31	30.29	1.03
				Min.	-29.68	-6.29	-29.75	1.00
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	13.69	7.31	19.27	1.41
				Min.	-17.26	-6.29	-17.50	1.01
4040	Bam, Iran	Bam	H1	Max.	18.02	9.45	24.93	1.38
				Min.	-13.69	-10.53	-23.44	1.71
4040	Bam, Iran	Bam	H2	Max.	10.79	9.45	12.05	1.12
				Min.	-9.18	-10.53	-12.86	1.40
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	9.66	9.95	17.61	1.82
				Min.	-7.41	-12.90	-20.03	2.70
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	6.82	9.95	12.71	1.86
				Min.	-10.66	-12.90	-13.00	1.22
879	Landers, USA	Lucerne	H1	Max.	5.11	4.60	6.61	1.29
				Min.	-8.48	-5.89	-11.98	1.41
879	Landers, USA	Lucerne	H2	Max.	5.68	4.60	7.29	1.28
				Min.	-5.49	-5.89	-7.87	1.43
Average	Landers, USA	Lucerne	H3	Max.	10.72	7.62	13.81	1.34
				Min.	-10.77	-8.23	-14.46	1.45

Table 0.32: The vertical amplification factor of vertical acceleration at the free end of cantilever beam B2 in case 3-2.

Record Seq. #	Event	Station	Direction	Vertical acceleration at cantilever free end(m/sec ²)				AF (acc)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	1.00	5.85	5.80	5.81
				Min.	-0.86	-8.66	-8.62	10.00
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	0.82	5.85	5.83	7.08
				Min.	-0.72	-8.66	-8.67	12.02
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	0.73	2.60	2.59	3.54
				Min.	-0.51	-3.86	-3.91	7.67
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	1.11	2.60	2.59	2.32
				Min.	-1.20	-3.86	-3.88	3.23
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	2.02	3.82	5.15	2.56
				Min.	-2.18	-4.17	-4.57	2.09
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	1.95	3.82	3.69	1.90
				Min.	-1.55	-4.17	-4.65	3.00
4040	Bam, Iran	Bam	H1	Max.	1.46	4.95	5.58	3.81
				Min.	-1.44	-4.48	-4.73	3.28
4040	Bam, Iran	Bam	H2	Max.	1.04	4.95	5.41	5.22
				Min.	-0.96	-4.48	-4.79	5.01
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	0.62	7.80	8.27	13.35
				Min.	-0.71	-6.95	-6.63	9.37
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	1.11	7.80	8.14	7.32
				Min.	-1.03	-6.95	-7.35	7.16
879	Landers, USA	Lucerne	H1	Max.	0.88	3.48	3.52	4.01
				Min.	-0.81	-4.17	-4.29	5.31
879	Landers, USA	Lucerne	H2	Max.	0.84	3.48	3.75	4.48
				Min.	-0.95	-4.17	-4.15	4.37
Average	Landers, USA	Lucerne	H3	Max.	1.13	4.75	5.03	5.12
				Min.	-1.08	-5.38	-5.52	6.04

Table 0.33: The vertical amplification factor of the axial force for column C2 in case 3-2.

Record Seq. #	Event	Station	Direction	Axial force at column C2 (kN)				AF (axial)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	144.77	669.85	671.62	4.64
				Min.	-99.25	-541.85	-543.34	5.47
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	99.94	669.85	667.55	6.68
				Min.	-103.87	-541.85	-546.10	5.26
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	49.01	271.84	275.82	5.63
				Min.	-56.11	-180.25	-176.45	3.14
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	94.35	271.84	272.18	2.88
				Min.	-114.73	-180.25	-179.15	1.56
1063	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	403.23	587.84	879.58	2.18
				Min.	-425.00	-698.31	-1015.64	2.39
1063	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	161.52	587.84	644.11	3.99
				Min.	-188.18	-698.31	-699.25	3.72
4040	Bam, Iran	Bam	H1	Max.	263.08	381.53	602.27	2.29
				Min.	-184.49	-490.38	-673.58	3.65
4040	Bam, Iran	Bam	H2	Max.	146.31	381.53	403.33	2.76
				Min.	-116.66	-490.38	-472.74	4.05
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	129.31	803.33	810.52	6.27
				Min.	-95.05	-720.67	-811.36	8.54
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	95.09	803.33	836.59	8.80
				Min.	-149.78	-720.67	-694.44	4.64
879	Landers, USA	Lucerne	H1	Max.	66.89	360.61	388.71	5.81
				Min.	-96.19	-311.78	-336.45	3.50
879	Landers, USA	Lucerne	H2	Max.	78.40	360.61	383.61	4.89
				Min.	-68.75	-311.78	-322.15	4.69
Averag e	Landers, USA	Lucerne	H3	Max.	144.32	512.50	569.66	4.74
				Min.	-141.50	-490.54	-539.22	4.22

Table 0.34: The vertical amplification factor of the bending moment for cantilever beam B2 in case 3-2.

Record Seq. #	Event	Station	Direction	Bending moment at cantilever support (kN.m)				AF (moment)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	51.83	300.08	300.05	5.79
				Min.	-56.97	-254.90	-253.19	4.44
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	41.93	300.08	297.15	7.09
				Min.	-48.39	-254.90	-252.79	5.22
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	29.26	84.43	86.03	2.94
				Min.	-41.54	-55.76	-69.10	1.66
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	70.06	84.43	83.48	1.19
				Min.	-65.63	-55.76	-83.27	1.27
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	130.75	218.12	274.15	2.10
				Min.	-120.76	-181.75	-269.85	2.23
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	92.63	218.12	219.75	2.37
				Min.	-116.72	-181.75	-169.26	1.45
4040	Bam, Iran	Bam	H1	Max.	87.11	219.70	232.04	2.66
				Min.	-83.11	-218.44	-258.17	3.11
4040	Bam, Iran	Bam	H2	Max.	55.13	219.70	237.66	4.31
				Min.	-59.32	-218.44	-247.30	4.17
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	42.55	267.71	243.79	5.73
				Min.	-35.00	-342.51	-367.34	10.50
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	57.68	267.71	266.74	4.62
				Min.	-65.54	-342.51	-364.12	5.56
879	Landers, USA	Lucerne	H1	Max.	46.68	98.74	97.05	2.08
				Min.	-51.79	-107.16	-101.10	1.95
879	Landers, USA	Lucerne	H2	Max.	52.70	98.74	116.80	2.22
				Min.	-50.11	-107.16	-107.01	2.14
Average	Landers, USA	Lucerne	H3	Max.	63.19	198.13	204.56	3.59
				Min.	-66.24	-193.42	-211.87	3.64

Table 0.35: The vertical amplification factor of shear force for cantilever beam B2 in case 3-2.

Record Seq. #	Event	Station	Direction	Shear force at cantilever support (kN)				AF (shear)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	13.31	90.49	90.63	6.81
				Min.	-14.63	-71.76	-71.36	4.88
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	10.82	90.49	89.77	8.30
				Min.	-12.48	-71.76	-71.11	5.70
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	7.39	38.89	39.18	5.30
				Min.	-10.47	-21.05	-24.68	2.36
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	17.93	38.89	39.29	2.19
				Min.	-17.07	-21.05	-29.77	1.74
1063	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	34.12	65.71	79.75	2.34
				Min.	-31.56	-43.39	-70.50	2.23
1063	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	24.03	65.71	65.65	2.73
				Min.	-30.28	-43.39	-42.63	1.41
4040	Bam, Iran	Bam	H1	Max.	22.49	61.48	65.41	2.91
				Min.	-21.58	-58.67	-69.62	3.23
4040	Bam, Iran	Bam	H2	Max.	13.94	61.48	71.43	5.12
				Min.	-15.14	-58.67	-64.64	4.27
8119	Christchurch New Zealand	Pages Road Pumping	H1	Max.	11.11	73.43	73.69	6.63
				Min.	-8.87	-73.78	-79.31	8.95
8119	Christchurch New Zealand	Pages Road Pumping	H2	Max.	14.47	73.43	78.31	5.41
				Min.	-16.92	-73.78	-80.19	4.74
879	Landers, USA	Lucerne	H1	Max.	12.07	53.23	55.53	4.60
				Min.	-13.26	-43.71	-43.95	3.31
879	Landers, USA	Lucerne	H2	Max.	13.15	53.23	51.97	3.95
				Min.	-13.13	-43.71	-46.09	3.51
Averag e	Landers, USA	Lucerne	H3	Max.	16.24	63.87	66.72	4.69
				Min.	-17.12	-52.06	-57.82	3.86

6.1.3.3 Case 3-3 (6m cantilever)

Table 0.36: The vertical amplification factor of vertical displacement at the free end of cantilever beam B2 in case 3-3.

Record Seq. #	Event	Station	Direction	Vertical displacement at cantilever free End (mm)				AF (displacement)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	12.38	15.52	14.98	1.21
				Min.	-13.76	-14.83	-14.32	1.04
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	7.58	15.52	14.96	1.97
				Min.	-10.07	-14.83	-14.54	1.44
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	5.98	3.19	7.04	1.18
				Min.	-6.71	-3.91	-9.11	1.36
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	9.81	3.19	10.23	1.04
				Min.	-10.32	-3.91	-12.48	1.21
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	33.78	5.59	34.14	1.01
				Min.	-29.91	-5.63	-29.83	1.00
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	15.27	5.59	19.70	1.29
				Min.	-15.39	-5.63	-14.08	0.91
4040	Bam, Iran	Bam	H1	Max.	18.13	10.32	19.14	1.06
				Min.	-14.52	-9.50	-17.09	1.18
4040	Bam, Iran	Bam	H2	Max.	6.40	10.32	11.19	1.75
				Min.	-6.57	-9.50	-12.85	1.96
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	8.41	12.00	16.43	1.95
				Min.	-6.41	-12.54	-17.63	2.75
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	10.51	12.00	15.45	1.47
				Min.	-10.67	-12.54	-16.32	1.53
879	Landers, USA	Lucerne	H1	Max.	4.71	6.07	7.95	1.69
				Min.	-8.94	-6.36	-12.19	1.36
879	Landers, USA	Lucerne	H2	Max.	5.18	6.07	9.48	1.83
				Min.	-5.56	-6.36	-6.43	1.16
Average	Landers, USA	Lucerne	H3	Max.	11.51	8.78	15.06	1.45
				Min.	-11.57	-8.79	-14.74	1.41

Table 0.37: The vertical amplification factor of vertical acceleration at the free end of cantilever beam B2 in case-3-3.

Record Seq. #	Event	Station	Direction	Vertical acceleration at cantilever free end(m/sec ²)				AF (acc)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	1.25	7.05	7.00	5.59
				Min.	-0.95	-7.04	-7.00	7.34
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	0.96	7.05	7.03	7.29
				Min.	-0.95	-7.04	-7.03	7.36
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	0.90	2.68	2.69	3.00
				Min.	-0.57	-3.13	-3.12	5.50
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	1.37	2.68	2.69	1.97
				Min.	-1.40	-3.13	-3.15	2.25
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	3.19	3.36	4.72	1.48
				Min.	-2.73	-3.81	-4.33	1.59
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	2.12	3.36	3.51	1.66
				Min.	-2.06	-3.81	-4.59	2.23
4040	Bam, Iran	Bam	H1	Max.	1.33	4.33	4.97	3.74
				Min.	-1.35	-3.78	-4.07	3.01
4040	Bam, Iran	Bam	H2	Max.	0.99	4.33	4.70	4.76
				Min.	-1.12	-3.78	-3.89	3.47
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	0.62	6.83	7.07	11.37
				Min.	-0.65	-5.48	-5.18	8.02
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	1.21	6.83	7.22	5.99
				Min.	-1.37	-5.48	-5.97	4.37
879	Landers, USA	Lucerne	H1	Max.	1.08	3.57	3.34	3.10
				Min.	-0.80	-3.71	-3.45	4.34
879	Landers, USA	Lucerne	H2	Max.	0.82	3.57	3.34	4.05
				Min.	-0.70	-3.71	-3.96	5.69
Average	Landers, USA	Lucerne	H3	Max.	1.32	4.64	4.86	4.50
				Min.	-1.22	-4.49	-4.65	4.60

Table 0.38: The vertical amplification factor of the axial force for column C3 in case-3-3.

Record Seq. #	Event	Station	Direction	Axial force at column C3 (kN)				AF (axial)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	196.15	661.26	663.13	3.38
				Min.	-214.30	-833.17	-839.68	3.92
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	119.21	661.26	658.82	5.53
				Min.	-163.10	-833.17	-836.28	5.13
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	106.19	284.78	286.43	2.70
				Min.	-102.22	-268.98	-268.44	2.63
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	146.86	284.78	285.92	1.95
				Min.	-160.17	-268.98	-268.22	1.67
1063	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	528.77	595.64	1105.48	2.09
				Min.	-470.21	-703.56	-979.77	2.08
1063	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	218.18	595.64	591.05	2.71
				Min.	-242.78	-703.56	-880.10	3.63
4040	Bam, Iran	Bam	H1	Max.	288.84	434.56	664.85	2.30
				Min.	-242.86	-519.62	-605.50	2.49
4040	Bam, Iran	Bam	H2	Max.	88.35	434.56	470.99	5.33
				Min.	-106.71	-519.62	-602.10	5.64
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	136.00	851.28	825.13	6.07
				Min.	-112.09	-942.09	-1037.83	9.26
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	139.47	851.28	876.12	6.28
				Min.	-182.21	-942.09	-907.44	4.98
879	Landers, USA	Lucerne	H1	Max.	74.62	438.22	498.48	6.68
				Min.	-120.36	-406.16	-377.66	3.14
879	Landers, USA	Lucerne	H2	Max.	85.91	438.22	426.67	4.97
				Min.	-74.60	-406.16	-410.67	5.50
Averag e	Landers, USA	Lucerne	H3	Max.	177.38	544.29	612.75	4.17
				Min.	-182.64	-612.26	-667.81	4.17

Table 0.39: The vertical amplification factor of the bending moment for cantilever beam B2 in case-3-3.

Record Seq. #	Event	Station	Direction	Bending moment at cantilever support (kN.m)				AF (moment)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	82.10	370.62	365.43	4.45
				Min.	-107.77	-364.94	-366.69	3.40
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	78.94	370.62	361.03	4.57
				Min.	-82.27	-364.94	-359.12	4.37
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	47.83	90.46	107.45	2.25
				Min.	-76.14	-102.82	-152.20	2.00
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	117.93	90.46	141.37	1.20
				Min.	-112.09	-102.82	-135.83	1.21
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	237.02	171.48	313.98	1.32
				Min.	-275.82	-142.88	-363.15	1.32
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	175.75	171.48	211.36	1.20
				Min.	-174.33	-142.88	-220.24	1.26
4040	Bam, Iran	Bam	H1	Max.	117.27	249.88	272.74	2.33
				Min.	-107.28	-248.11	-249.34	2.32
4040	Bam, Iran	Bam	H2	Max.	88.39	249.88	286.54	3.24
				Min.	-76.62	-248.11	-291.89	3.81
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	54.12	412.15	393.48	7.27
				Min.	-49.23	-332.67	-350.97	7.13
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	111.69	412.15	446.81	4.00
				Min.	-105.08	-332.67	-368.37	3.51
879	Landers, USA	Lucerne	H1	Max.	60.16	148.63	179.36	2.98
				Min.	-83.03	-157.23	-153.96	1.85
879	Landers, USA	Lucerne	H2	Max.	56.17	148.63	168.54	3.00
				Min.	-67.13	-157.23	-152.29	2.27
Average	Landers, USA	Lucerne	H3	Max.	102.28	240.54	270.67	3.15
				Min.	-109.73	-224.78	-263.67	2.87

Table 0.40: The vertical amplification factor of shear force for cantilever beam B3 in case 3-3.

Record Seq. #	Event	Station	Direction	Shear force at cantilever support (kN)				AF (shear)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	17.83	87.42	86.80	4.87
				Min.	-23.30	-86.60	-86.22	3.70
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	16.90	87.42	85.07	5.03
				Min.	-17.78	-86.60	-84.91	4.77
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	10.60	49.89	49.73	4.69
				Min.	-16.28	-34.59	-39.63	2.43
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	25.17	49.89	50.12	1.99
				Min.	-23.56	-34.59	-34.97	1.48
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	51.11	53.72	70.29	1.38
				Min.	-59.94	-46.10	-82.38	1.37
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	37.93	53.72	60.59	1.60
				Min.	-37.09	-46.10	-56.97	1.54
4040	Bam, Iran	Bam	H1	Max.	25.47	60.56	64.81	2.54
				Min.	-22.76	-63.14	-64.44	2.83
4040	Bam, Iran	Bam	H2	Max.	18.22	60.56	63.18	3.47
				Min.	-16.04	-63.14	-66.61	4.15
8119	Christchurch New Zealand	Pages Road Pumping	H1	Max.	11.48	94.30	90.47	7.88
				Min.	-10.49	-82.59	-80.63	7.68
8119	Christchurch New Zealand	Pages Road Pumping	H2	Max.	23.71	94.30	101.24	4.27
				Min.	-22.74	-82.59	-83.00	3.65
879	Landers, USA	Lucerne	H1	Max.	13.07	63.74	61.47	4.70
				Min.	-16.96	-55.98	-58.17	3.43
879	Landers, USA	Lucerne	H2	Max.	11.93	63.74	64.52	5.41
				Min.	-15.33	-55.98	-52.25	3.41
Average	Landers, USA	Lucerne	H3	Max.	21.95	68.27	70.69	3.99
				Min.	-23.52	-61.50	-65.85	3.37

6.1.4 Frames with long span beams result tables

6.1.4.1 Case 4-1 (15m span)

Table 0.41: The vertical amplification factor of vertical displacement at mid-span of beam B1 in case-4-1.

Record Seq. #	Event	Station	Direction	Vertical displacement at mid-span of				AF (displacement)
				B1 (mm)				
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	0.34	7.63	7.61	22.12
				Min.	-0.31	-7.78	-7.79	24.72
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	0.33	7.63	7.61	22.87
				Min.	-0.37	-7.78	-7.78	21.11
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	0.39	1.75	1.75	4.51
				Min.	-0.38	-1.92	-1.91	5.04
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	0.63	1.75	1.74	2.75
				Min.	-0.64	-1.92	-1.90	2.98
1063	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	0.94	5.96	6.71	7.13
				Min.	-1.04	-6.22	-6.33	6.07
1063	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	0.94	5.96	6.71	7.18
				Min.	-0.83	-6.22	-5.98	7.24
4040	Bam, Iran	Bam	H1	Max.	0.65	4.13	4.00	6.12
				Min.	-0.58	-3.90	-4.28	7.44
4040	Bam, Iran	Bam	H2	Max.	0.69	4.13	4.14	5.98
				Min.	-0.63	-3.90	-3.89	6.15
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	0.39	7.38	7.37	18.87
				Min.	-0.37	-8.26	-8.31	22.34
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	0.51	7.38	7.44	14.51
				Min.	-0.67	-8.26	-8.34	12.37
879	Landers, USA	Lucerne	H1	Max.	0.47	2.58	2.60	5.50
				Min.	-0.47	-1.43	-1.67	3.58
879	Landers, USA	Lucerne	H2	Max.	0.40	2.58	2.37	5.87
				Min.	-0.38	-1.43	-1.53	4.03
Average	Landers, USA	Lucerne	H3	Max.	0.56	4.90	5.00	10.28
				Min.	-0.56	-4.92	-4.98	10.26

Table 0.42: The vertical amplification factor of vertical acceleration at mid-span of beam B1 in case-4-1.

Record Seq. #	Event	Station	Direction	Vertical acceleration at mid-span of B1 (m/sec ²)				AF (acc)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	0.12	14.16	14.15	115.09
				Min.	-0.14	-13.91	-13.88	96.57
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	0.13	14.16	14.16	108.26
				Min.	-0.13	-13.91	-13.91	106.30
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	0.19	3.49	3.50	17.97
				Min.	-0.17	-2.69	-2.70	16.27
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	0.20	3.49	3.49	17.20
				Min.	-0.23	-2.69	-2.69	11.93
1063	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	0.37	9.11	8.92	23.97
				Min.	-0.35	-8.86	-9.07	25.86
1063	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	0.30	9.11	8.99	30.07
				Min.	-0.35	-8.86	-8.63	24.92
4040	Bam, Iran	Bam	H1	Max.	0.48	6.37	6.30	13.22
				Min.	-0.48	-6.26	-6.30	13.03
4040	Bam, Iran	Bam	H2	Max.	0.45	6.37	6.38	14.11
				Min.	-0.46	-6.26	-6.13	13.27
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	0.19	12.88	12.98	68.24
				Min.	-0.22	-11.52	-11.50	52.62
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	0.26	12.88	12.81	50.23
				Min.	-0.21	-11.52	-11.49	53.55
879	Landers, USA	Lucerne	H1	Max.	0.23	4.63	4.75	20.41
				Min.	-0.28	-4.27	-4.40	15.79
879	Landers, USA	Lucerne	H2	Max.	0.23	4.63	4.70	20.57
				Min.	-0.22	-4.27	-4.31	19.69
Average	Landers, USA	Lucerne	H3	Max.	0.26	8.44	8.43	41.61
				Min.	-0.27	-7.92	-7.92	37.48

Table 0.43: The vertical amplification factor of axial force for at right column C1 in case-4-1.

Record Seq. #	Event	Station	Direction	Axial force at right column C1 (kN)				AF (axial)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	1.40	30.28	30.22	21.54
				Min.	-1.28	-25.56	-25.56	19.98
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	2.04	30.28	30.42	14.93
				Min.	-1.60	-25.56	-25.44	15.90
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	1.03	8.45	8.42	8.14
				Min.	-1.45	-6.12	-6.19	4.26
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	2.38	8.45	8.46	3.56
				Min.	-2.17	-6.12	-6.14	2.83
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	4.41	24.92	27.41	6.22
				Min.	-3.62	-24.97	-26.42	7.30
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	3.65	24.92	26.18	7.16
				Min.	-3.04	-24.97	-26.20	8.61
4040	Bam, Iran	Bam	H1	Max.	1.84	15.47	16.56	9.03
				Min.	-2.55	-16.71	-17.00	6.67
4040	Bam, Iran	Bam	H2	Max.	1.88	15.47	15.37	8.19
				Min.	-2.38	-16.71	-16.34	6.86
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	1.65	30.87	30.60	18.60
				Min.	-1.66	-33.45	-34.03	20.56
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	2.56	30.87	30.64	11.99
				Min.	-2.45	-33.45	-32.11	13.09
879	Landers, USA	Lucerne	H1	Max.	1.68	10.95	9.94	5.92
				Min.	-1.72	-8.18	-9.22	5.35
879	Landers, USA	Lucerne	H2	Max.	1.18	10.95	11.15	9.44
				Min.	-1.34	-8.18	-8.31	6.22
Average	Landers, USA	Lucerne	H3	Max.	2.14	20.16	20.45	10.39
				Min.	-2.10	-19.16	-19.41	9.80

Table 0.44: The vertical amplification factor of the bending moment at mid-span of beam B1 in case-4-1.

Record Seq. #	Event	Station	Direction	Bending moment at mid-span (kN.m)				AF (moment)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	1.93	80.48	80.50	41.66
				Min.	-2.19	-78.17	-77.98	35.57
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	2.20	80.48	80.50	36.55
				Min.	-2.12	-78.17	-78.06	36.91
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	2.64	19.92	19.93	7.55
				Min.	-2.58	-16.88	-16.94	6.58
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	4.06	19.92	19.83	4.89
				Min.	-4.11	-16.88	-16.83	4.10
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	6.78	60.48	58.66	8.65
				Min.	-5.87	-58.34	-63.08	10.75
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	5.15	60.48	58.50	11.36
				Min.	-6.05	-58.34	-61.73	10.21
4040	Bam, Iran	Bam	H1	Max.	4.45	38.61	41.40	9.30
				Min.	-4.66	-39.41	-38.80	8.33
4040	Bam, Iran	Bam	H2	Max.	4.68	38.61	37.53	8.02
				Min.	-5.13	-39.41	-39.95	7.78
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	2.52	81.52	82.02	32.57
				Min.	-2.49	-73.08	-73.02	29.33
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	4.33	81.52	81.82	18.91
				Min.	-3.26	-73.08	-73.01	22.37
879	Landers, USA	Lucerne	H1	Max.	3.14	18.52	20.13	6.42
				Min.	-3.40	-24.33	-24.25	7.13
879	Landers, USA	Lucerne	H2	Max.	2.75	18.52	19.31	7.03
				Min.	-2.83	-24.33	-23.20	8.19
Average	Landers, USA	Lucerne	H3	Max.	3.72	49.92	50.01	16.08
				Min.	-3.72	-48.37	-48.90	15.60

Table 0.45: The vertical amplification factor of shear force at right support of beam B1 in case 4-1.

Record Seq. #	Event	Station	Direction	Shear force at right support (kN)				AF (shear)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	1.40	30.16	30.07	21.45
				Min.	-1.28	-29.99	-29.99	23.47
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	2.04	30.16	30.31	14.89
				Min.	-1.60	-29.99	-29.88	18.70
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	1.03	7.52	7.48	7.25
				Min.	-1.45	-7.67	-7.74	5.33
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	2.37	7.52	7.52	3.17
				Min.	-2.17	-7.67	-7.69	3.55
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	4.40	23.75	26.24	5.96
				Min.	-3.61	-24.87	-26.32	7.28
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	3.65	23.75	26.42	7.24
				Min.	-3.04	-24.87	-26.09	8.58
4040	Bam, Iran	Bam	H1	Max.	1.83	16.43	17.49	9.59
				Min.	-2.54	-16.62	-16.35	6.44
4040	Bam, Iran	Bam	H2	Max.	1.87	16.43	15.95	8.54
				Min.	-2.37	-16.62	-16.81	7.08
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	1.64	29.70	29.43	17.90
				Min.	-1.65	-32.45	-33.03	20.00
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	2.55	29.70	29.47	11.54
				Min.	-2.45	-32.45	-31.13	12.71
879	Landers, USA	Lucerne	H1	Max.	1.67	10.99	9.97	5.96
				Min.	-1.71	-7.23	-8.26	4.83
879	Landers, USA	Lucerne	H2	Max.	1.17	10.99	11.20	9.56
				Min.	-1.33	-7.23	-7.50	5.65
Average	Landers, USA	Lucerne	H3	Max.	2.14	19.76	20.13	10.25
				Min.	-2.10	-19.81	-20.07	10.30

6.1.4.2 Case 4-2 (20m span)

Table 0.46: The vertical amplification factor of vertical displacement at mid-span of beam B2 in case-4-2.

Record Seq. #	Event	Station	Direction	Vertical displacement at mid-span of B2 (mm)				AF (displacement)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	0.79	9.68	9.65	12.27
				Min.	-0.71	-6.43	-6.45	9.04
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	0.68	9.68	9.66	14.12
				Min.	-0.83	-6.43	-6.42	7.69
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	0.68	2.01	2.03	2.99
				Min.	-0.70	-1.31	-1.33	1.91
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	1.08	2.01	2.03	1.89
				Min.	-1.11	-1.31	-1.31	1.18
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	1.54	8.70	9.38	6.09
				Min.	-1.47	-8.65	-8.82	5.99
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	1.16	8.70	8.57	7.38
				Min.	-1.36	-8.65	-8.31	6.11
4040	Bam, Iran	Bam	H1	Max.	1.04	6.45	7.00	6.75
				Min.	-0.99	-6.33	-7.12	7.21
4040	Bam, Iran	Bam	H2	Max.	0.93	6.45	6.21	6.64
				Min.	-0.85	-6.33	-6.75	7.95
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	0.64	10.74	10.61	16.48
				Min.	-0.71	-12.21	-12.70	17.98
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	0.78	10.74	10.76	13.88
				Min.	-1.01	-12.21	-11.86	11.72
879	Landers, USA	Lucerne	H1	Max.	0.82	2.46	2.37	2.90
				Min.	-0.85	-1.51	-1.68	1.98
879	Landers, USA	Lucerne	H2	Max.	0.81	2.46	2.28	2.82
				Min.	-0.80	-1.51	-1.81	2.26
Average	Landers, USA	Lucerne	H3	Max.	0.91	6.67	6.71	7.85
				Min.	-0.95	-6.07	-6.21	6.75

Table 0.47: The vertical amplification factor of vertical acceleration at mid-span of beam B2 in case-4-2.

Record Seq. #	Event	Station	Direction	Vertical acceleration at mid-span of B2 (m/sec ²)				AF (acc)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	0.33	8.17	8.18	24.76
				Min.	-0.34	-12.47	-12.45	36.64
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	0.37	8.17	8.17	22.16
				Min.	-0.36	-12.47	-12.48	34.79
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	0.40	2.13	2.14	5.39
				Min.	-0.37	-3.51	-3.52	9.62
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	0.50	2.13	2.12	4.22
				Min.	-0.50	-3.51	-3.52	6.99
1063	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	0.64	8.17	8.30	12.91
				Min.	-0.66	-8.40	-8.61	12.95
1063	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	0.50	8.17	7.72	15.30
				Min.	-0.51	-8.40	-8.32	16.30
4040	Bam, Iran	Bam	H1	Max.	0.50	6.84	7.10	14.12
				Min.	-0.50	-7.66	-7.95	15.79
4040	Bam, Iran	Bam	H2	Max.	0.46	6.84	6.80	14.67
				Min.	-0.48	-7.66	-7.51	15.75
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	0.34	11.70	11.86	34.53
				Min.	-0.31	-10.81	-10.74	34.51
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	0.37	11.70	11.56	31.37
				Min.	-0.41	-10.81	-10.77	26.49
879	Landers, USA	Lucerne	H1	Max.	0.49	3.29	3.19	6.49
				Min.	-0.48	-3.78	-3.96	8.27
879	Landers, USA	Lucerne	H2	Max.	0.41	3.29	3.26	7.95
				Min.	-0.39	-3.78	-3.83	9.80
Average	Landers, USA	Lucerne	H3	Max.	0.44	6.72	6.70	16.16
				Min.	-0.44	-7.77	-7.80	18.99

Table 0.48: The vertical amplification factor of axial force at right column C2 in case-4-2.

Record Seq. #	Event	Station	Direction	Axial force at right column C2 (kN)				AF (axial)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	1.49	33.27	33.37	22.41
				Min.	-1.57	-25.30	-25.19	16.06
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	1.93	33.27	33.32	17.28
				Min.	-1.80	-25.30	-25.35	14.05
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	1.49	7.57	7.61	5.11
				Min.	-1.68	-5.48	-5.49	3.28
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	2.26	7.57	7.61	3.37
				Min.	-2.48	-5.48	-5.47	2.21
1063	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	4.01	31.03	29.70	7.40
				Min.	-2.58	-32.61	-33.76	13.09
1063	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	2.01	31.03	30.47	15.14
				Min.	-2.36	-32.61	-32.98	13.97
4040	Bam, Iran	Bam	H1	Max.	2.21	23.61	23.21	10.50
				Min.	-2.81	-27.83	-27.51	9.80
4040	Bam, Iran	Bam	H2	Max.	2.81	23.61	23.35	8.32
				Min.	-2.69	-27.83	-28.26	10.52
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	1.46	40.67	41.08	28.19
				Min.	-1.76	-46.03	-46.02	26.16
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	2.41	40.67	40.60	16.88
				Min.	-1.94	-46.03	-45.85	23.59
879	Landers, USA	Lucerne	H1	Max.	2.45	11.02	10.27	4.19
				Min.	-2.36	-9.55	-9.20	3.90
879	Landers, USA	Lucerne	H2	Max.	2.31	11.02	11.85	5.14
				Min.	-2.20	-9.55	-9.34	4.24
Average	Landers, USA	Lucerne	H3	Max.	2.24	24.53	24.37	11.99
				Min.	-2.19	-24.47	-24.53	11.74

Table 0.49: The vertical amplification factor of bending moment at mid-span of beam B2 in case-4-2.

Record Seq. #	Event	Station	Direction	Bending moment at mid-span (kN.m)				AF (moment)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	6.31	77.05	77.22	12.23
				Min.	-6.82	-121.64	-121.32	17.80
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	7.28	77.05	77.01	10.58
				Min.	-6.27	-121.64	-121.52	19.38
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	6.57	17.83	18.01	2.74
				Min.	-6.28	-28.00	-28.10	4.47
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	9.79	17.83	17.80	1.82
				Min.	-9.55	-28.00	-28.15	2.95
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	12.83	99.02	100.76	7.85
				Min.	-13.34	-100.53	-106.00	7.95
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	11.25	99.02	91.82	8.16
				Min.	-9.83	-100.53	-99.05	10.08
4040	Bam, Iran	Bam	H1	Max.	8.82	73.57	79.77	9.04
				Min.	-8.89	-77.66	-83.12	9.35
4040	Bam, Iran	Bam	H2	Max.	7.89	73.57	74.30	9.41
				Min.	-8.51	-77.66	-75.15	8.83
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	6.29	138.26	142.62	22.68
				Min.	-5.73	-124.62	-122.46	21.38
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	8.40	138.26	135.17	16.10
				Min.	-7.11	-124.62	-124.47	17.50
879	Landers, USA	Lucerne	H1	Max.	8.05	19.26	18.85	2.34
				Min.	-7.79	-30.63	-29.86	3.83
879	Landers, USA	Lucerne	H2	Max.	7.31	19.26	21.21	2.90
				Min.	-7.23	-30.63	-29.54	4.09
Average	Landers, USA	Lucerne	H3	Max.	8.40	70.83	71.21	8.82
				Min.	-8.11	-80.51	-80.73	10.63

Table 0.50: The vertical amplification factor of shear force at right support of beam B2 in case-4-2.

Record Seq. #	Event	Station	Direction	Shear force at right support (kN)				AF (shear)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	1.49	30.96	31.01	20.84
				Min.	-1.57	-24.06	-24.27	15.51
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	1.92	30.96	31.11	16.17
				Min.	-1.80	-24.06	-23.92	13.30
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	1.48	6.56	6.58	4.43
				Min.	-1.67	-4.67	-4.74	2.83
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	2.25	6.56	6.65	2.95
				Min.	-2.47	-4.67	-5.11	2.07
1063	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	4.01	31.89	30.42	7.59
				Min.	-2.57	-32.59	-33.74	13.12
1063	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	2.01	31.89	30.93	15.40
				Min.	-2.35	-32.59	-32.96	14.01
4040	Bam, Iran	Bam	H1	Max.	2.20	23.81	24.04	10.94
				Min.	-2.79	-25.83	-25.51	9.14
4040	Bam, Iran	Bam	H2	Max.	2.80	23.81	23.28	8.32
				Min.	-2.68	-25.83	-26.25	9.81
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	1.46	38.93	39.71	27.27
				Min.	-1.75	-47.35	-47.42	27.07
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	2.40	38.93	38.66	16.12
				Min.	-1.93	-47.35	-47.15	24.39
879	Landers, USA	Lucerne	H1	Max.	2.42	11.17	10.41	4.30
				Min.	-2.33	-8.01	-7.67	3.29
879	Landers, USA	Lucerne	H2	Max.	2.28	11.17	12.00	5.26
				Min.	-2.17	-8.01	-8.03	3.71
Average	Landers, USA	Lucerne	H3	Max.	2.23	23.89	23.73	11.63
				Min.	-2.17	-23.75	-23.90	11.52

6.1.4.3 Case 4-3 (25m span)

Table 0.51: The vertical amplification factor of vertical displacement at mid-span of beam B3 in case-4-3.

Record Seq. #	Event	Station	Direction	Vertical displacement at mid-span of B3 (mm)				AF (displacement)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	1.45	9.84	9.81	6.77
				Min.	-1.58	-5.39	-5.38	3.41
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	1.56	9.84	9.81	6.28
				Min.	-1.46	-5.39	-5.36	3.68
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	1.04	2.16	2.21	2.12
				Min.	-1.06	-1.85	-1.87	1.76
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	2.04	2.16	2.37	1.16
				Min.	-2.00	-1.85	-2.33	1.16
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	2.42	11.14	12.59	5.21
				Min.	-2.42	-14.01	-14.73	6.09
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	3.41	11.14	11.89	3.49
				Min.	-3.44	-14.01	-15.36	4.47
4040	Bam, Iran	Bam	H1	Max.	2.49	7.69	9.69	3.89
				Min.	-2.51	-6.14	-8.48	3.38
4040	Bam, Iran	Bam	H2	Max.	1.78	7.69	8.04	4.51
				Min.	-1.78	-6.14	-6.01	3.38
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	1.36	12.14	12.35	9.09
				Min.	-1.26	-9.93	-9.59	7.59
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	1.66	12.14	12.12	7.30
				Min.	-1.64	-9.93	-10.57	6.44
879	Landers, USA	Lucerne	H1	Max.	1.40	2.01	2.44	1.74
				Min.	-1.38	-2.54	-2.51	1.82
879	Landers, USA	Lucerne	H2	Max.	1.48	2.01	2.82	1.91
				Min.	-1.45	-2.54	-2.98	2.06
Average	Landers, USA	Lucerne	H3	Max.	1.84	7.50	8.01	4.46
				Min.	-1.83	-6.64	-7.10	3.77

Table 0.52: The vertical amplification factor of vertical acceleration at mid-span of beam B3 in case-4-3.

Record Seq. #	Event	Station	Direction	Vertical acceleration at mid-span of B3 (m/sec ²)				AF (acc)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	0.59	6.34	6.35	10.78
				Min.	-0.59	-11.09	-11.07	18.72
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	0.63	6.34	6.32	10.07
				Min.	-0.62	-11.09	-11.09	17.87
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	0.47	1.78	1.77	3.77
				Min.	-0.48	-2.45	-2.47	5.16
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	0.79	1.78	1.77	2.25
				Min.	-0.79	-2.45	-2.47	3.12
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	0.95	8.43	8.83	9.27
				Min.	-0.95	-7.11	-7.60	8.03
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	1.46	8.43	8.85	6.05
				Min.	-1.46	-7.11	-7.08	4.86
4040	Bam, Iran	Bam	H1	Max.	1.06	4.96	5.59	5.28
				Min.	-1.05	-5.31	-6.21	5.91
4040	Bam, Iran	Bam	H2	Max.	0.72	4.96	4.80	6.67
				Min.	-0.68	-5.31	-5.43	7.96
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	0.56	6.48	6.24	11.22
				Min.	-0.55	-9.97	-10.12	18.33
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	0.56	6.48	6.76	12.04
				Min.	-0.61	-9.97	-9.90	16.34
879	Landers, USA	Lucerne	H1	Max.	0.61	3.06	2.88	4.75
				Min.	-0.61	-3.28	-3.26	5.39
879	Landers, USA	Lucerne	H2	Max.	0.55	3.06	3.13	5.65
				Min.	-0.56	-3.28	-3.28	5.82
Average	Landers, USA	Lucerne	H3	Max.	0.75	5.18	5.28	7.32
				Min.	-0.75	-6.53	-6.66	9.79

Table 0.53: The vertical amplification factor of the axial force at right column C3 in case-4-3.

Record Seq. #	Event	Station	Direction	Axial force at right column C3 (kN)				AF (axial)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	3.44	30.26	31.20	9.07
				Min.	-3.00	-22.47	-22.70	7.57
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	3.21	30.26	29.76	9.27
				Min.	-3.58	-22.47	-22.20	6.20
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	2.91	10.74	10.89	3.74
				Min.	-3.30	-7.43	-7.31	2.22
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	4.29	10.74	10.66	2.49
				Min.	-4.07	-7.43	-7.34	1.81
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	5.32	35.41	37.44	7.04
				Min.	-5.89	-40.83	-45.29	7.69
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	9.16	35.41	34.04	3.72
				Min.	-8.93	-40.83	-41.65	4.67
4040	Bam, Iran	Bam	H1	Max.	6.52	22.57	26.96	4.14
				Min.	-5.86	-21.36	-23.13	3.94
4040	Bam, Iran	Bam	H2	Max.	4.82	22.57	24.12	5.00
				Min.	-4.50	-21.36	-19.69	4.37
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	3.25	38.52	38.35	11.80
				Min.	-3.80	-32.07	-31.95	8.41
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	3.84	38.52	38.85	10.13
				Min.	-2.71	-32.07	-32.79	12.11
879	Landers, USA	Lucerne	H1	Max.	6.03	13.82	12.98	2.15
				Min.	-5.23	-11.04	-12.37	2.37
879	Landers, USA	Lucerne	H2	Max.	4.64	13.82	14.34	3.09
				Min.	-4.61	-11.04	-12.84	2.78
Average	Landers, USA	Lucerne	H3	Max.	4.79	25.22	25.80	5.97
				Min.	-4.62	-22.53	-23.27	5.35

Table 0.54: The vertical amplification factor of the bending moment at mid-span of beam B3 in case-4-3.

Record Seq. #	Event	Station	Direction	Bending moment at mid-span (kN.m)				AF (moment)
				Step Type	H	V	H+V	
181	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	14.81	69.11	68.84	4.65
				Min.	-14.07	-133.74	-133.41	9.48
181	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	14.41	69.11	68.88	4.78
				Min.	-15.02	-133.74	-133.58	8.90
184	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	10.66	22.27	22.54	2.11
				Min.	-10.42	-28.25	-28.76	2.76
184	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	19.13	22.27	22.70	1.19
				Min.	-19.41	-28.25	-28.65	1.48
1063	Northridge-01, USA	Rinaldi Receiving	H1	Max.	23.20	158.71	166.96	7.20
				Min.	-23.08	-124.34	-137.56	5.96
1063	Northridge-01, USA	Rinaldi Receiving	H2	Max.	33.89	158.71	170.57	5.03
				Min.	-33.72	-124.34	-129.10	3.83
4040	Bam, Iran	Bam	H1	Max.	24.53	71.92	94.38	3.85
				Min.	-24.11	-89.57	-109.77	4.55
4040	Bam, Iran	Bam	H2	Max.	16.89	71.92	70.43	4.17
				Min.	-16.88	-89.57	-92.59	5.49
8119	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	12.58	114.62	110.12	8.75
				Min.	-12.97	-145.69	-148.87	11.48
8119	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	14.96	114.62	121.00	8.09
				Min.	-15.46	-145.69	-144.31	9.34
879	Landers, USA	Lucerne	H1	Max.	13.67	33.84	31.60	2.31
				Min.	-13.90	-31.45	-31.68	2.28
879	Landers, USA	Lucerne	H2	Max.	13.61	33.84	36.46	2.68
				Min.	-13.99	-31.45	-34.54	2.47
Average	Landers, USA	Lucerne	H3	Max.	17.69	78.41	82.04	4.57
				Min.	-17.75	-92.17	-96.07	5.67

Table 0.55: The vertical amplification factor of the shear force at right support of beam B3 in case-4-3.

Record Seq. #	Event	Station	Direction	Shear force at right support (kN)				AF (shear)
				Step Type	H	V	H+V	
181.00	Imperial Valley-06, USA	El Centro Array #6	H1	Max.	3.44	29.12	30.05	8.74
				Min.	-2.99	-20.71	-20.44	6.83
181.00	Imperial Valley-06, USA	El Centro Array #6	H2	Max.	3.21	29.12	28.63	8.93
				Min.	-3.58	-20.71	-20.79	5.82
184.00	Imperial Valley-06, USA	El Centro Differential Array	H1	Max.	2.91	8.29	8.43	2.90
				Min.	-3.29	-6.50	-6.46	1.96
184.00	Imperial Valley-06, USA	El Centro Differential Array	H2	Max.	4.28	8.29	8.21	1.92
				Min.	-4.06	-6.50	-6.42	1.58
1063.00	Northridge- 01, USA	Rinaldi Receiving	H1	Max.	5.31	35.42	37.45	7.06
				Min.	-5.87	-42.45	-46.90	7.99
1063.00	Northridge- 01, USA	Rinaldi Receiving	H2	Max.	9.13	35.42	34.06	3.73
				Min.	-8.91	-42.45	-43.28	4.86
4040.00	Bam, Iran	Bam	H1	Max.	6.49	22.46	26.92	4.14
				Min.	-5.84	-18.69	-22.04	3.77
4040.00	Bam, Iran	Bam	H2	Max.	4.81	22.46	24.00	4.99
				Min.	-4.49	-18.69	-18.92	4.21
8119.00	Christchurch, New Zealand	Pages Road Pumping	H1	Max.	3.24	37.84	37.80	11.66
				Min.	-3.79	-29.25	-28.34	7.48
8119.00	Christchurch, New Zealand	Pages Road Pumping	H2	Max.	3.83	37.84	38.15	9.97
				Min.	-2.70	-29.25	-30.54	11.30
879.00	Landers, USA	Lucerne	H1	Max.	6.00	9.92	9.08	1.51
				Min.	-5.21	-9.85	-10.38	1.99
879.00	Landers, USA	Lucerne	H2	Max.	4.61	9.92	10.43	2.26
				Min.	-4.58	-9.85	-11.03	2.41
Average	Landers, USA	Lucerne	H3	Max.	4.77	23.84	24.44	5.65
				Min.	-4.61	-21.24	-22.13	5.02

6.2.TSC 2018 RESPONSE SPECTRA RESULTS

6.2.1 Frames with transfer beams result tables

Table 0.56: The vertical amplification factor of engineering demand parameters for beam B1 and column C1 in case 1-1 due to TSC-2018 response spectra excitation.

Demand parameters	RSH	RSH+RSV	AF
Axial Force at Planted Column (kN)	7.27	33.70	4.64
Shear Force at support (kN)	72.12	98.57	1.37
Bending Moment at Mid-span (kN.m)	123.88	178.60	1.44
Vertical Acceleration at Mid-span (m/sec ²)	0.10	3.39	35.58
Vertical Displacement at Mid-span (mm)	0.23	2.21	9.68

Table 0.57: The vertical amplification factor of engineering demand parameters for beam B2 and column C2 in case 1-2 due to TSC-2018 response spectra excitation.

Demand parameters	RSH	RSH+RSV	AF
Axial Force at Planted Column (kN)	10.05	67.73	6.74
Shear Force at support (kN)	91.54	125.51	1.37
Bending Moment at Mid-span (kN.m)	147.43	239.02	1.62
Vertical Acceleration at Mid-span (m/sec ²)	0.04	3.35	88.76
Vertical Displacement at Mid-span (mm)	0.12	2.32	18.89

Table 0.58: The vertical amplification factor of engineering demand parameters for beam B3 and column C3 in case 1-3 due to TSC-2018 response spectra excitation.

Demand parameters	RSH	RSH+RSV	AF
Axial Force at Planted Column (kN)	6.05	158.09	26.12
Shear Force at support (kN)	107.91	173.36	1.61
Bending Moment at Mid-span (kN.m)	151.10	375.72	2.49
Vertical Acceleration at Mid-span (m/sec ²)	0.04	3.34	91.25
Vertical Displacement at Mid-span (mm)	0.06	2.24	38.90

6.2.2 Frames with slanted columns result tables

Table 0.59: The vertical amplification factor of engineering demand parameters in column C1 in case 2-1 due to TSC-2018 response spectra excitation.

Demand parameters	RSH	RSH+RSV	AF
Axial force at top of slanted column C1 (kN)	103.76	132.60	1.28
Shear force at top of slanted column C1 (kN)	69.55	69.55	1.00
Bending moment at top of slanted column C1 (kN.m)	104.99	105.42	1.00
Vertical acceleration at top of slanted column C1 (m/sec ²)	0.21	1.58	7.53
Vertical displacement at top of slanted column C1 (mm)	1.12	1.12	1.00

Table 0.60: The vertical amplification factor of engineering demand parameters for column C2 in case 2-2 due to TSC-2018 response spectra excitation.

Demand parameters	RSH	RSH+RSV	AF
Axial force at top of slanted column C2 (kN)	75.36	112.69	1.50
Shear force at top of slanted column C2 (kN)	63.62	63.80	1.00
Bending moment at top of slanted column C2 (kN.m)	95.24	96.02	1.01
Vertical acceleration at top of slanted column C2 (m/sec ²)	0.31	1.37	4.45
Vertical displacement at top of slanted column C2 (mm)	1.62	1.62	1.00

6.2.3 Frames with long cantilevers result tables

Table 0.61: The vertical amplification factor of engineering demand parameters in cantilever beam B1 and column C1 in case 3-1 due to TSC-2018 response spectra excitation.

Demand parameters	RSH	RSH+RSV	AF
Axial force at column C1 (kN)	103.67	286.11	2.76
Shear force at the support of cantilever B1 (kN)	19.48	37.85	1.94
Bending moment at the support of cantilever B1 (kN.m)	60.57	112.05	1.85
Vertical acceleration at free end of cantilever B1(m/sec ²)	1.62	3.26	2.01
Vertical displacement at free end of cantilever B1 (mm)	7.92	8.45	1.07

Table 0.62: The vertical amplification factor of engineering demand parameters in cantilever beam B2 and column C2 in case 3-2 due to TSC-2018 response spectra excitation.

Demand parameters	RSH	RSH+RSV	AF
Axial force at column C2 (kN)	127.98	260.85	2.04
Shear force at the support of cantilever B2 (kN)	24.25	39.81	1.64
Bending moment at the support of cantilever B2 (kN.m)	94.97	141.05	1.49
Vertical acceleration at free end of cantilever B2(m/sec ²)	1.65	2.78	1.69
Vertical displacement at free end of cantilever B2 (mm)	9.71	10.63	1.1

Table 0.63: The vertical amplification factor of engineering demand parameters in cantilever beam B3 and column C3 in case 3-3 due to TSC-2018 response spectra excitation.

Demand parameters	RSH	RSH+RSV	AF
Axial force at column C3 (kN)	170.17	318.20	1.87
Shear force at the support of cantilever B3 (kN)	30.64	47.08	1.54
Bending moment at the support of cantilever B3 (kN.m)	144.03	199.08	1.38
Vertical acceleration at free end of cantilever B3(m/sec ²)	1.74	2.73	1.57
Vertical displacement at free end of cantilever B3 (mm)	10.84	11.99	1.11

6.2.4 Frames with long span beams result tables

Table 0.64: The vertical amplification factor of engineering demand parameters in beam B1 and column C1 in case 4-1 due to TSC-2018 response spectra excitation.

Demand parameters	RSH	RSH+RSV	AF
Axial force at right column C1 (kN)	3.09	10.13	3.28
Shear force at right support (kN)	3.08	9.62	3.12
Bending moment at mid-span (kN.m)	5.30	22.55	4.25
Vertical acceleration at mid-span of B1 (m/sec ²)	0.32	3.80	11.68
Vertical displacement at mid-span of B1 (mm)	0.82	2.37	2.91

Table 0.65: The vertical amplification factor of engineering demand parameters in beam B2 and column C2 in case 4-2 due to TSC-2018 response spectra excitation.

Demand parameters	RSH	RSH+RSV	AF
Axial force at right column C2 (kN)	2.74	11.70	4.27
Shear force at right support (kN)	2.73	11.20	4.11
Bending moment at mid-span (kN.m)	12.02	34.31	2.85
Vertical acceleration at mid-span of B2 (m/sec ²)	0.62	3.44	5.56
Vertical displacement at mid-span of B2 (mm)	1.38	3.08	2.23

Table 0.66: The vertical amplification factor of engineering demand parameters in beam B3 and column C3 in case 4-3 due to TSC-2018 response spectra excitation.

Demand parameters	RSH	RSH+RSV	AF
Axial force at right column C3 (kN)	7.30	14.09	1.93
Shear force at right support (kN)	7.28	13.66	1.88
Bending moment at mid-span (kN.m)	30.39	50.49	1.66
Vertical acceleration at mid-span of B3 (m/sec ²)	1.27	3.35	2.63
Vertical displacement at mid-span of B3 (mm)	3.15	4.69	1.49