T.R.
GEBZE TECHNICAL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

THE SEISMIC RISK ASSESSMENT OF TUZLA DISTRICT, ISTANBUL

MELİS ERDOGAN
A THESIS SUBMITTED FOR THE DEGREE OF
MASTER OF SCIENCE
CIVIL ENGINEERING DEPARTMENT
EARTHQUAKE AND STRUCTURAL ENGINEERING PROGRAM

GEBZE
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GEBZE TEKNİK ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ

ISTANBUL, TUZLA BÖLGESİ İÇİN SİSMİK RİSK ANALİZİ

MELİS ERDOĞAN
YÜKSEK LİSANS TEZİ
İNŞAAT MÜHENDİSLİĞİ ANABİLİM DALI
DEPREM VE YAPI MÜHENDİSLİĞİ BÖLÜMÜ

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THESIS SUPERVISOR
ASSOC. PROF. DR. ABDULLAH CAN ZULFIKAR

GEBZE
2022

YÜKSEK LİSANS JÜRİ ONAY FORMU

GTÜ Fen Bilimleri Enstitüsü Yönetim Kurulu’nun 10/02/2022 tarih ve 2022/10 sayılı kararıyla oluşturulan jüri tarafından 03/06/2022 tarihinde tez savunma sınavı yapılan Melis ERDOĞAN’ın tez çalışması İnşaat Mühendisliği Anabilim Dalında YÜKSEK LİSANS tezi olarak kabul edilmiştir.

JÜRİ

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ONAY

Gebze Teknik Üniversitesi Fen Bilimleri Enstitüsü Yönetim Kurulu’nun
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ÖZET

Bu çalışma yıllardır süregelen depremlerden de anlaşılacağı gibi depremselliği yüksek olan Türkiye Marmara Bölgesi'nin İstanbul ilinin Tuzla ilçesine ait sismik risk analizini kapsar. Sismik risk analizi için Tuzla Bölge'sindeki bina tipi yapılar incelenmiştir. Sismik risk analizi için bölgedeki betonarme yapı stoğu analiz edilmiştir. Bölgedeki binalar yapı materyali, yapı yüksekliği ve yapım yıllarına göre sınıflandırılmıştır. Bölgedeki betonarme binalar için hasar ve kayıp tahminleri yapılmıştır. Bölgedeki hasar ve kayıpları bulmak için bölgeye uygun ve bölgedeki bina tiplerinin yapısal davranışlarını yansıtabilecek hasar görebilirlik eğrileri ve kırılganlık eğrileri seçilmiştir. Bölgenin depremselliği bulmak adına bölgedeki aktif faylar ve kaynak modelleri belirlenmiş ve sismik tehlike analizi yapılmıştır. Ardından elde edilen bu veriler ışığında bölgenin sismik risk analizi yapılmıştır. Söz konusu sismik hasar ve risk analizi farklı yaklaşımlarla yapılabilir. Bu yaklaşımlar Senaryo bazlı, Olasılıksal gibi sınıflara ayrılabilir. Bu çalışmada Klasik Olasılıksal yaklaşım göz önüne alınarak analizler yapılmış ve sonuçlar incelenmiştir.

Sismik risk analizi risk azaltma ve acil durum planlamaları konularında büyük önem taşır. Bu açıdan bakıldığında bu çalışma depremselliği yüksek olan inceleme bölgesinde olası bir depreme karşı gerek yerel yönetimlerin, devletin gerekse sivil toplum kuruluşlarının Afet Yönetimi konusunda birtakım önlemler alması adına bir veri tabanı oluşturacaktır.

Anahtar Kelimeler: Bina Envanteri, Sismik Tehlike Analizi, Hasar Görebilirlik Eğrileri, Kırılganlık Eğrileri, Kayıp Eğrileri.

SUMMARY

This study involves seismic risk assessment for Tuzla region which has a high seismicity in İstanbul- Marmara region of Turkey. The residential building inventory of Tuzla region has been analyzed and reinforced concrete building has been examined for seismic risk assessment. Residential buildings in the region have been classified according to their material type, height type and year of construction. For obtaining damage and losses on the region fragility curves and vulnerability curves have been assigned that are suitable and reflected structural behavior of the buildings of the target region. Rupture model and source model are determined for mapping the seismicity of the region and the seismic hazard analysis have been performed. Then all the information including the hazard assessment and exposure data have been combined and used for seismic risk analysis. Aforementioned seismic risk analysis may be performed with different approaches. These approaches could be Scenario, Classical Probabilistic and Event-based Probabilistic. In this study damage and loss have been performed by using Classical Probabilistic approaches and the results have been examined.

Earthquake risk assessment has an importance in the risk mitigation and emergency planning. From this standpoint, this study will generate a database for either local authority and government or nongovernmental organizations to take some precautions on disaster management and seismic risk reduction studies against a possible earthquake in the study area that has a high seismic potential.

Key words: Building Inventory, Seismic Hazard Analysis, Seismic Fragility, Vulnerability Curves, Loss Curves, Damage Distribution, Collapse Maps.

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LIST OF ABBREVIATIONS AND ACRONYMS

Abbreviations and Acronyms		**Explanations**
S_a	:	Spectral acceleration
S_d	:	Spectral displacement
PGA	:	Peak ground acceleration
PGV	:	Peak ground velocity
λ_m	:	Rate of earthquakes
a,b	:	Constants for Gutenberg-Richter Recurrence Law
m_{min}	:	Minimum magnitude
m_{max}	:	Maximum magnitude
$F_M\ (m)$	:	Probability of reoccurrence of certain magnitude
$F_R\ (r)$	:	Probability of an epicenter at a distance less than r
r	:	Epicenter
ϕ	:	Standard normal cumulative function
σ_{lnPGA}	:	Standard deviation of σ_{lnPGA}
$\lambda(IM > x)$	:	Probability of exceedance at given intensity measure level
$\overline{lnPGA}$	:	Mean of PGA
$A_{res\_building\_class}$	:	The total area of that building class within the area
$N_{dwellings/building\_class}$	:	The number of buildings for building class
$A_{dwelling/building\_class}$	:	The average floor area per dwelling within that building class
$P_{res\_buildings}$	:	Total population per within that building class
$N_{dwellings/building\_class}$	:	Total number of buildings within that building class
$N_{dwellings/admin}$	:	Total number of buildings
P_{admin}	:	Total population
S_{dp}	:	Inelastic spectral displacement demand
β_k	:	Standard deviation of natural logarithm of

$\overline{S}_{d,k}$: Threshold of the damage state (k)

$S_{d,ds}$: Median value of spectral displacement for that damage state

δ_{ds} : Drift ratio at the threshold of structural damage state

α_2 : Fraction of the building (roof) height at the elevation

H : Roof height of the model building type of interest

β_{ds} : Lognormal standard deviation parameter that describes the total variability of damage states ds

β_c : Lognormal standard deviation parameter that describes the total variability of capacity curve

β_D : Lognormal standard deviation parameter that describes the total variability of demand spectrum

$\beta_{T,ds}$: Lognormal standard deviation parameter that describes the total variability of threshold of damage state, ds

$\overline{S}_{d,ds}$: Median value of spectral displacement at damage state, ds

β_{ds} : Standard deviation of the natural algorithm of spectral displacement for damage state, ds

coV : Coefficient of variation

$P[ds|S_d]$: Probability of exceeding a particular damage state, ds at the given Spectral displacement

$P[L \geq l|E_e]$: Conditional probability that loss exceeds l given that event Ee occurs

$G[L \geq l]$: Rate at which event Ee occurs

$G[L \geq l]$: Probability of exceeding of given loss value

$E[FR]$: Mean of fractions

$SD[FR]$: Standard deviation of fractions

IML : Intensity measure level

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1. INTRODUCTION

1.1. General

As known, Turkey is the one of the countries locating in Alp-Himalayan seismic belt which is one of the most active seismic belts in the World. Marmara region in Turkey, especially İstanbul, has a great importance on hazard and risk in terms of its seismicity. The earthquakes in the past prove that this region has high seismicity.

Accordingly, Istanbul province which is subject of this study is in Marmara Region where the North Anatolian fault passes. In addition, Istanbul is the most developed region which has a lot of remarkable industrial and trading company centers. Important trade routes pass through this area and it makes here more valuable for the country's economy and approximately 20% of the population of Turkey lives in this city. Considering its economical and demographical characteristics, Istanbul functions like the heart of Turkey.

Taking the past earthquakes in consideration, especially as seen in Gölcük Earthquake 1999, this region is not ready to large scale earthquake both economically and residentially. Considering the result of 1999 Gölcük Earthquake, many buildings had extensive damage, some of them even collapsed. Many casualties and injuries occurred. In parallel with these results, it caused severe structural losses which negatively affected the county's economy.

When consequences of earthquakes are considered, seismic hazard and risk assessment is essential for the region and it also will act as a guide for the government to make provisions on related field, emergency planning, policies, insurance.

The aim of these study is to do probabilistic seismic risk assessment for the Tuzla region of Istanbul and to obtain building damages and economical losses and casualties in the region.

There are so many civil engineering structures in the region such as buildings, hospitals, schools, bridges and industrial facilities. In this study residential building is considered and residential reinforced concrete building inventory is examined for subjected area.

There are 3 main steps for achieving regional risk and damage:

- Seismic hazard assessment
- Exposure model
- Fragility/Vulnerability Model

All these steps are explained and examined in detail in the next chapter of this study.

As it is shown below, firstly source model and rupture characteristics were examined and hazard data was analyzed. In the second step, building stock was arranged and classified by some qualifications which most likely affect the structural behaviors of buildings. Then fragility and vulnerability curves were arranged which directly correlated with loss and damages. Thanks to these data, risk analyze, and damage analyze could be accomplished. And the result such as collapse maps, building damages based on the damage states, loss curves were obtained and interpreted.

The risk and damage analysis were performed by using OpenQuake Software, developed by GEM Foundation. Probabilistic approaches are employed.

The results were visualized in ArcGis Software.

The studies within the context of this thesis are presented under several chapters. In Chapter2, components of risk assessment were examined and explained. In chapter 3, the building stock in Tuzla, seismicity and structural behavior of the buildings are mentioned. In Chapter 4, Probabilistic analysis were analyzed, and the results were interpreted. Discussions and recommendations alongside with the findings and observations in this study are delivered in Chapter 5.

1.2. Philosophy of Seismic Risk Assessment

There are so many faults which are effective in terms of seismic activity. Once these faults become active, they generate strong ground motion in the field. Accurately estimation of the time and magnitude of the seismic excitation is quite difficult because occurrence of the earthquake is probabilistic. Thus, probabilistic approach is more suitable for regionally building analysis. Also, calculations of the seismic hazard and seismic risk assessment are mostly based on probabilistic and statistical data, and results are expressed as probabilistic.

Before the seismic risk assessment, it is necessary to mention seismic hazard assessment which will be used in seismic risk assessment process. Seismic hazard is defined as probability of exceedance of the parameter related to ground motion intensity at the construction site within the given time span.

Some regions on the earth have more seismic potential than the others. Some of these regions are more important that they have active socio-economical life. Therefore, an earthquake that may occur in the region will affect the civilization which lives on such land.

Estimation of seismic risk assessment. Seismic risk assessment requires multi-disciplinary study. Soil type, fault type, seismotectonic of the region, seismic hazard of the region, building stock, number of people living on the region are the factors which lead to the risk assessment damage, economic loss, casualties, and injuries as a result of the seismic excitations are subjects of the. All of them should be analyzed by relevant disciplines and ready as inputs for risk assessment. Afterwards, the risk assessment can be performed, and table of the loss and damage for the region can be obtained.

Thanks to these studies the results of the earthquake which is likely to occur in the region can be predicted and significant precautions can be taken by the governments to minimize the consequences of an earthquake [Erdik et al., 2006].
Governments can decide how much of their budgets will be allocated to risk mitigation.

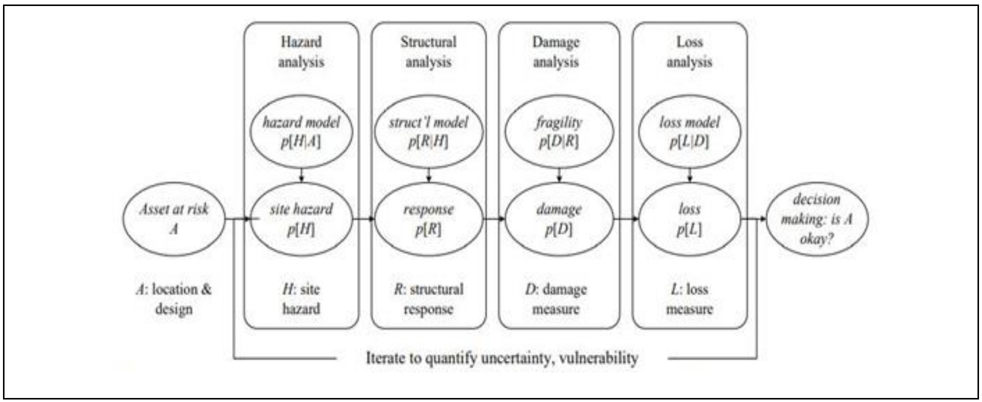


Figure 1.1: Analytical methods for estimating vulnerability.

Seismic vulnerability schema is given above [Porter, 2015]. Seismic vulnerability analysis is one of the essential steps for seismic risk assessment process. Loss ratios is computed by performing vulnerability analysis. Afterwards, loss curves can be obtained by loss ratios multiply with replacement cost. As it is understood each step affects next steps and each of them relates to one another. So, it is essential to assess each step properly.

1.3. Literal Survey

Seismic risk analysis has a great importance for the governments and civilization in financial and social terms, as it is mentioned in the previous section. Thanks to these studies, we can estimate losses and damages. These studies can help improve projects of governments and non-governmental organizations like risk mitigation and planning. Many regional and global projects have been carried out in many counties due to importance of this topic.

Apart from these studies, many software which can be used for hazard and risk analysis have been developed. Developed by GEM Foundation, Openquake Software was employed for this study. Also, there are so many studies which are developed by researchers around the World such as Eler, Selena.

ELER (Earthquake Loss Estimation Routine) is developed by Bogazici University Kandilli Observatory and Earthquake Research Institute. This software provides rapid estimation of earthquake shaking and losses in the Euro-Mediterranean region.

The code has two modules of analysis which are EHA (Earthquake Hazard Assessment) and ELA (Earthquake Loss Assessment) [ELER Manual, 2010]. The analysis types in software can be divided into 4 parts in ELER. These are:

- Hazard-Module

It estimates ground motion intensity and parameters distributions within the given rupture. (Sa, Sd, PGA) [ELER Manual, 2010]

- LEVEL 0

It estimates casualty numbers. This casualty is calculated based on the regionally adjusted intensity-casualty or magnitude-casualty correlations based on the Landscan population distribution inventory. Level 0 analysis shows similarity with the PAGER of USGS. Also, it calculates intensity distribution by means of source model information, ground motion prediction equations, intensity correlations. [ELER Manual, 2010].

- LEVEL 1

Building damages and casualty estimations can be obtained with this module. The inventory is used which consists of the building information for relevant area. The casualty estimation is done through number of damaged buildings. [ELER Manual, 2010].

Building damage estimations are calculated with the help of EM98 Intensity based Vulnerability. In addition, we can calculate loss ratios within this module. This stage shows similarity with SELENA and HAZUS Software [ELER Manual, 2010].

- LEVEL 2

This module was developed to make earthquake loss assessment. It employed ground motion maps for analyzing hazard analysis and it creates ground motion fields. Building inventory is used for this module as in the previous module which is explained above.

The spectral capacity-based vulnerability was used for estimating losses in Level 2 Module. Capacity spectrum method consists of several stages. These can be summarized as follows [ELER Manual, 2010]:

- Seismic demand representation with demand spectrum.
- Structural system representation with capacity spectrum.
- Obtaining performance point with intersection of demand and capacity spectrum.
- Obtaining fragility curves.

Also, there are some methods for analyzing fragility curves:

- Capacity Spectrum Method
- Modified Acceleration-Displacement Response Spectrum Method

- Reduction Factor Method
- Coefficient Method

Loss and damage analysis can be accomplished for region after completing in order for vulnerability or fragility analysis

In addition to these tools, Pipeline damage analysis option is also available for obtaining damages in natural gas lines.

HAZUS is a GIS-based software that is managed by FEMA (Federal Emergency Management Agency) and supported and developed by regional planning authorities, federal agencies, research institutions and it analyzes economic and social effects of natural disaster such as earthquakes, floods and hurricanes. It is developed in 1997 and it serves to the users with its update versions since that date [FEMA, 2003].

HAZUS enables to determine risk results to users by implementing deterministic and probabilistic hazard approaches. Risk results can be calculated either direct or indirect based on the users' decision [FEMA, 2003].

Hazus calculates risk in 3 stages. The first stage involves exposure model of target region. The second considers hazard qualifications of region, and seismic response of region can be obtained. Finally, it completes analysis by combining data obtained from previous stages with appropriate fragility and vulnerability functions.

Analysis results of Hazus can be discussed under different topics [FEMA, 2003]:

- Physical damage to residential and commercial buildings, schools, critical facilities and infrastructure.
- Economic loss, including lost jobs, business interruptions, and repair and reconstruction costs.
- Social impacts, including estimates of displaced households, shelter requirements, and populations exposed to floods, earthquakes, hurricanes and tsunamis.
- Cost-effectiveness of common mitigation strategies, such as elevating structures in a floodplain or retrofitting unreinforced masonry buildings.

Hazus risk analyses are categorized as Basic or Advanced. A Basic (“Level 1”) Hazus analysis produces initial estimates of earthquake, flood, tsunami, or hurricane wind losses. Basic results are based on the generalized national databases and best available information included in Hazus software [FEMA, 2003].

An Advanced (“Level 2” and “Level 3”) Hazus analysis produces more accurate loss estimates by including information on local hazard conditions and replacing generalized national data with more accurate local inventories of buildings, essential facilities, and infrastructure [FEMA, 2003].

SELENA (Seismic Loss Estimation using a Logic Tree Approach) is an open-source software which analyzes engineering approach based seismic loss and risk [Molina et al., 2010].

It utilizes capacity spectrum method for loss and damage estimations because of its engineering-based feature. It considers performance point which obtained from intersections of capacity curve of specific building and demand spectrum curve. [SELENA, Molina et al., 2010].

It enables to do risk analysis by both deterministic and probabilistic approaches. It works with all the Geographic Information System, unlike HAZUS. Also, it enables to users to consider epistemic uncertainties by defining logic trees in inputs [SELENA, Molina et al., 2010].

It is necessary to define some inputs required for doing analysis in SELENA as in the other software. These inputs are common inputs for general risk assessments process such as inventory, soil condition, attenuation relationships, source model, fragility and vulnerability model.

OPENQUAKE software is employed within the scope of this study. Openquake is an open-source seismic hazard and risk analysis tools developed by GEM foundation. GEM foundation is a public-private partnership launched in 2006 to develop open-source risk and hazard assessment software and tools and it is supported by some private or public institutions and organizations [OpenQuake User Manual, 2019].

Openquake is commonly used by scientist, students, and researchers across the world, and it has been supporting users to analyze their data with various type of analysis since its foundation.

GEM Foundation has conducted many seismic hazard and risk projects. Some of these studies are TREQ Project (seismic risk and hazard for Latin America), Sub

Saharan (seismic risk and hazard, assessing and mitigating earthquake risk in the Caribbean and Central America). Hazard and risk maps have been created within global frame.

Many scientists and researchers, institutions from different parts of the world have worked together and many projects have been carried out for creating global hazard and risk maps. Also, workshops have been organized in many countries to inform people interested in hazard and risk assessment and to raise awareness about the subject.

Openquake enables to users to do their analysis in both deterministic and probabilistic ways. Users can create their model with different approaches. There are some different calculation modules in risk part, and these are Scenario damage, Scenario risk, Classical Probabilistic damage, Classical Probabilistic risk, Event-Based risk, and Benefit-Cost ratio. Also, calculation mode can be diversified in hazard assessment such as Scenario based hazard, Event-based hazard and Classical Probabilistic hazard.

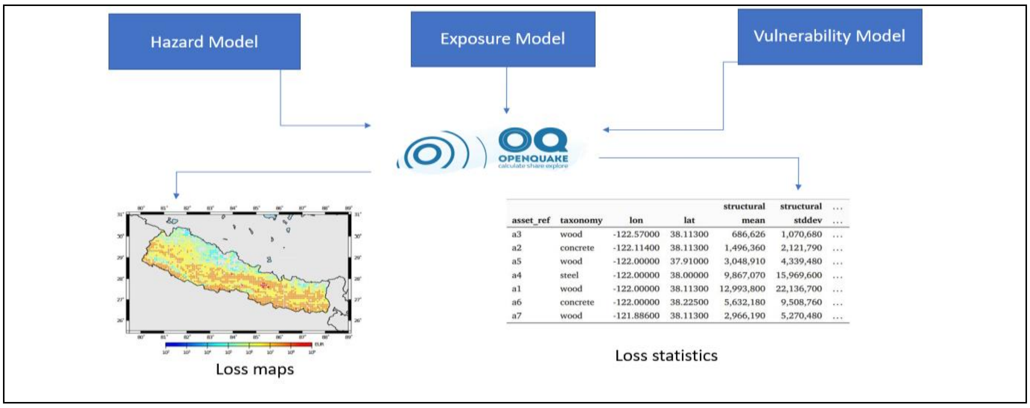
2. COMPONENTS OF SEISMIC RISK ASSESSMENT

Seismic risk and damage assessment form the basis on studies such as risk mitigation, early warning system etc. It requires collaboration of many disciplines. The process of damage and risk assessment consist of several stages. These are hazard assessment, arranging exposure model, performance point and fragility analysis, vulnerability analysis.

Risk assessment can be formulized as follows [Erdik, 2017]:

Risk= Hazard*Exposure*Vulnerability

Probability of exceedance of the response (intensity measure level such as PGA, Sa, Sd) is generated and intensity measure values corresponding to each level of shaking can be reached in hazard assessment. Hazard curve as a result of seismic hazard assessment is combination of response of level of shaking for target area. Exposure model is kind of inventory of building. The whole information such as longitude, latitude, replacement cost, number of buildings within assets, building taxonomies is determined at this section. Such information can be diversified according to analysis' requirements. Fragility curves are related with damage assessment [Openquake Manual, 2019]. These curves are express of probability of exceedance of damage states at given intensity measure level. Vulnerability curves are related with losses. Vulnerability curves can be generated by using fragility curve and consequence functions. Loss types can be generated by combining with fragility curve which are express of damage ratio and consequence model.



asset_ref	taxonomy	lon	lat	structural mean	structural stddev	...
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a2	concrete	-122.11400	38.11300	1,496,360	2,121,790	...
a5	wood	-122.00000	37.91000	3,048,910	4,339,480	...
a4	steel	-122.00000	38.00000	9,867,070	15,969,600	...
a1	wood	-122.00000	38.11300	12,993,800	22,136,700	...
a6	concrete	-122.00000	38.22500	5,632,180	9,508,760	...
a7	wood	-121.88600	38.11300	2,966,190	5,270,480	...

Figure 2.1: Flowchart of Probabilistic Risk Assessment.

2.1. Seismic Hazard Assessment

As it is known, earthquakes release a great energy, and it is essential to know how this energy will affect buildings. Response of earthquake in the region and damages and losses in the region to be hit by an earthquake is the subject of seismic analysis. Seismic hazard is defined as probability that the value of parameter related to ground motion or earthquake magnitude at the construction site exceeds a certain level within projected time [Askan and Yucemen, 2010]. Probability of exceedance within investigation year or annual rate of exceedance are called as seismic hazard if time is taken as year.

Seismic hazard analysis aims to determine the parameters (acceleration, velocity, displacement) related with ground motion which will be required in computing seismic loads that the structure will be exposed within its service life.

Calculating the return period of a certain magnitude of earthquake and determining the probability of exceedance of response of the region for certain intensity measure level are the subjects of seismic hazard analysis.

Seismic hazard results are expressed as quantitative values as a result of some engineering analysis. Thus, outputs of seismic hazard enable making a rational decision to structural engineers for calculation of seismic loads to which structure will be exposed.

Hazard curve, hazard map and response spectrum are the outcomes of seismic hazard analysis. Response spectrums are expressed responses of different kind of structure with different periods. These responses of the region can be expressed as different intensity measure level types. These intensity measure types can be spectral acceleration (Sa), spectral displacement (Sd), peak ground acceleration (PGA) etc. Hazard curve gives the relationship between annual probability of exceeding and intensity measure levels. Thanks to these graphs, the response of the region can be obtained, and it is expressed as annual probability of exceeding or probability of occurrence in the graph.

Seismic hazard analysis can be categorized as probabilistic and deterministic hazard analysis.

2.1.1. Deterministic Hazard Assessment

In this approach, it is necessary to determine the past earthquakes with high magnitudes having occurred in the region. A worst-case scenario earthquake is designed which is most likely to occur, and appropriate attenuation relationship is selected which is changeable from characteristics of the region.

Responses (such as acceleration, displacement velocity) due to earthquake are calculated with the help of suitable attenuation relationships.

Besides, being very practical of this approach, the biggest disadvantage is not to take into account of some uncertainties adequately which have important role in determining of the maximum ground acceleration [Porter, 2015].

2.1.2. Probabilistic Hazard Assessment

Probabilistic approach is more preferred, and it gives more reliable results when compared to the deterministic approach. It considers the uncertainties related with seismic characteristics of target region and it gives more reliable and realistic outputs. However, calculation part is more tedious and detailed because of having more uncertainty in this approach. The advantages of this approach can be listed as follows [Porter, 2015]:

- It examines past earthquakes in the region and takes into account in the analysis.

- Considers uncertainties related with sources.
- Calculates seismicity as return period.
- Allows analysist to use their foresight and experience.
- Enables to express seismic hazard in terms of spectral acceleration, spectral velocity, spectral displacement and intensity.

Probabilistic seismic hazard analysis consists of the following stages [Porter, 2015]:

i) Defining all the sources of region and determining the geometry of earthquake sources and its seismicity qualification. This process needs attention while determining sources which have possibility to generate an earthquake in the region. Also, it is essential since the other steps of this approach are related to this step.

ii) Correlating the magnitude-frequency relationship of each earthquake source. Gutenberg-Richter formula is generally used to obtain this correlation.

$$\text{Log } \lambda(m) = a - bm \tag{2.1}$$

ƛm gives the rates of magnitude greater than M. a and b values are statistical values which are obtained from the analysis of past earthquakes.

Every earthquake in the region does not consider in structural hazard. Thus, certain levels of magnitudes can be ignored by engineering. Probability of reoccurrence of certain magnitude can be expressed with the following formula:

$$F_M(m) = \frac{1 - 10^{-b(m - m_{\min})}}{1 - 10^{-b(m_{\max} - m_{\min})}}, \quad m_{min} < m < m_{max} \tag{2.2}$$

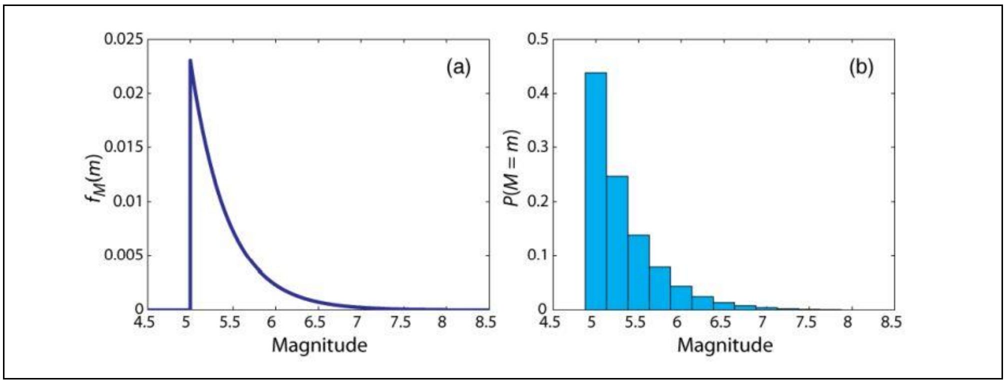


Figure 2.2: Illustration of discretization of a continuous magnitude distribution for a source with a truncated Gutenberg-Richter distribution.

iii) Identifying earthquake distances

At this part, distances between the site of interest and epicenter of earthquakes are calculated. Identifying distances has an importance widely on the hazard results in addition to magnitude characteristics.

For instance, an earthquake that is far away from the target area and has a higher magnitude can affect the region more than an earthquake with a lower magnitude and much closer to the area. Therefore, magnitude and distance parameters should be examined separately.

$$F_R\,(r) = \begin{cases} 0 & if\; r < 0 \\ \dfrac{r^2}{10\;000} & if\; 0 \leq r < 100 \\ 1 & if\; r \geq 100 \end{cases} \qquad (2.3)$$

iv) Ground motion prediction equation:

At this stage, the most suitable ground motion prediction equation model should be selected according to the characteristics of the region. This model gives the probability distribution for a certain intensity measure level based on certain magnitude and distance.

General formula of these attenuation relationship model is given in the formula below. These models give the probability distribution of ground motion intensity. Probability distribution of ground motion intensity can be obtained as a function of variables such as earthquake’s magnitude, distance, faulting mechanism, site conditions, etc.

This formula can be expressed with mean and standard deviation of that intensity measure level [Porter, 2015].

$$P(PGA > x|m,r) \ = 1 - \phi\ (\frac{lnx - \overline{lnPGA}}{\sigma_{lnPGA}} \tag{2.4}$$

As can be understood from the formula, the curves are cumulative distribution functions. But in some cases, probability density function can also be used.

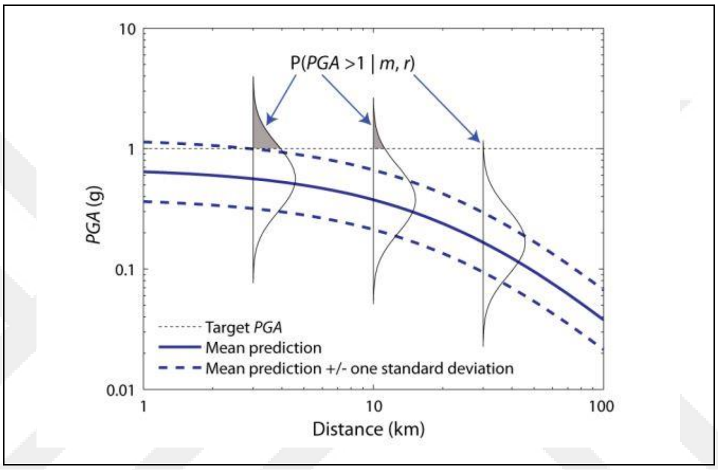


Figure 2.3: Graphical depiction of the example ground motion prediction model.

Constant values can be used in some approaches for mean and standard deviation values in the formula in some ground motion prediction equations [Cornell et al., 2003]. However, better results can be achieved by more iterations in analyzing of magnitude and distances pairs since there are many uncertainties related to region and other parameters.

v) Combining all the Information

Magnitude and distance probabilities with the probability of exceeding at certain intensity level x is combined at the final step.

In step 4, probability of ground motion is determined for a certain intensity measure type under given m and r parameters. At this step, the annual rate of exceedance is calculated by multiplying the probabilities of the magnitude, distance and probability of ground motion intensity which are mentioned at the previous steps.

$$\lambda(IM > x) = \sum_{i=1}^{n_{sources}} \lambda(M_i > m_{min}) \sum_{j=1}^{n_M} \sum_{k=1}^{n_R} P(IM > x|m_j, r_k) P(M_i = m_j) P(R_i = r_k) \qquad (2.5)$$

λ: the rate at which a ground motion IM exceeds a threshold x.

All the values achieved in the previous steps are taken into account in this section as seen in the formula above. Then, hazard curves are plotted after determining the rate of exceedance for each PGA value [Porter, 2015].

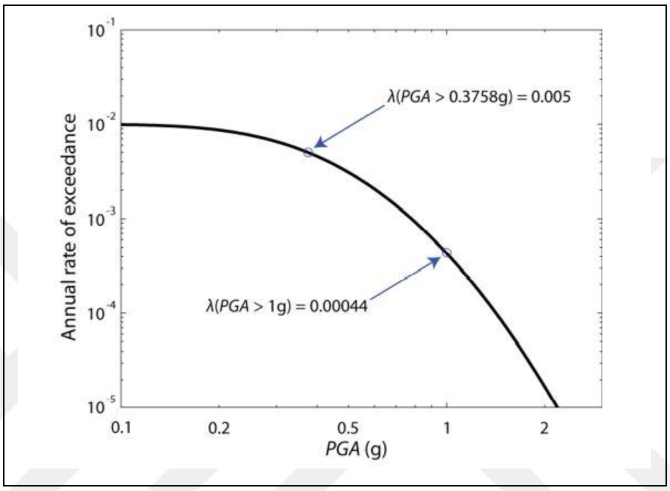


Figure 2.4: PGA Hazard Curve.

Contribution of each source on the total curve vary depending on intensity levels. The point here is the fact that even if there is a low-magnitude earthquake, it can affect the region. Because low-magnitude earthquakes with a higher probability of occurrence which refer Fault A at the graph have an importance for low PGA values. The effect and contribution of small earthquakes, which have higher probability of occurrence, at the given time span is less for higher intensity levels. However, high-magnitude earthquakes with lower probability of exceedance, Fault B, make great contribute for higher intensity levels [Porter, 2015].

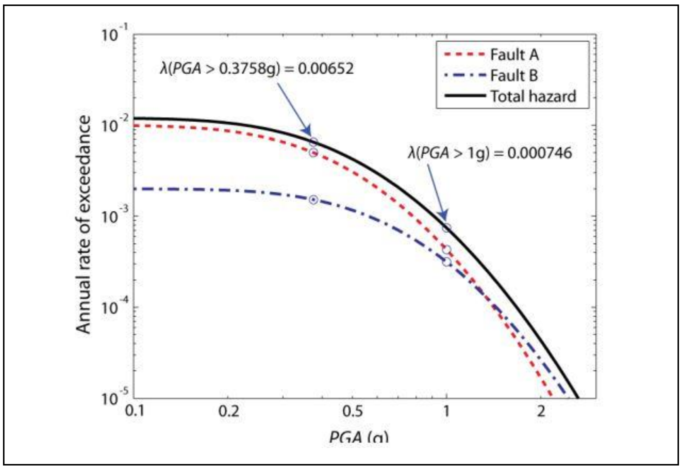


Figure 2.5: Hazard Curve-PGA.

Disaggregation analysis can be performed to observe the contribution of each fault to intensity level examined in detail afterwards of PSHA analysis. Thanks to the disaggregation analysis, contribution of source to site distances and magnitudes pairs on the hazard curve can be computed separately.

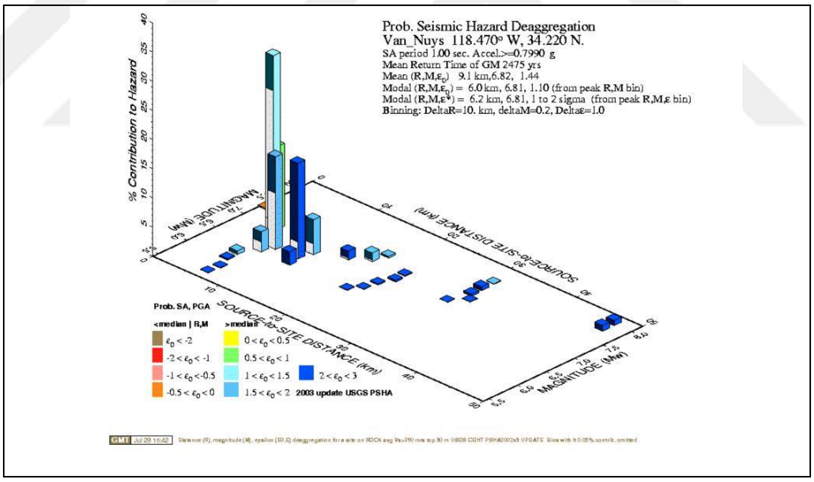


Figure 2.6: Example disaggregation for SA(1.0s) at a site in Los Angeles.

2.2. Uncertainties in Risk Assessment

There is always uncertainty because of the nature of earthquake. It is the relevant randomness and probabilistic ground motion. We can mention 2 types of uncertainties. These are aleatory and epistemic uncertainties. Uncertainties occur due to lack of knowledge or randomness of the nature of earthquake. Uncertainties can be mentioned in each step of the risk assessment. For instance, it is not possible to state a certain boundary in the limit states; and exact structural behavior of all building subjected cannot be known.

Uncertainties arising from the hazard contribute the most in risk assessment [Erdik, 2017]. In some studies, it is pointed out that the uncertainty coming from the hazard is more than the capacity of structural system. [Erberik and Elnashai, 2003], [Kwon and Elnashai, 2004], [Mostafa, 2003].

Aleatory uncertainty is a type of uncertainty that is observed due to the randomness of earthquake and its occurrence [Erdik, 2017].

Earthquake is a random and random ground movement as it is known. Thus, outputs of hazard assessment can be expressed as probabilistic. Fragility function and vulnerability function are expressed with probabilistic terms due to probabilistic hazard approach result. This uncertainty type will affect outputs such as loss distribution, exceedance curve.

There are some other parameters which can be associated with aleatory uncertainties. These are seismic input, frequency content of seismic records, and the variability in the materials and design of the building stock. Some correlations can be made to calculate these uncertainty types. These are intra- and inter-spatial correlations.

Epistemic Uncertainties is the type of uncertainty that arises from lack of knowledge [Erdik, 2017]. For instance, it might not always be known exactly which attenuation relationship should be used for the target region. In this case, logic trees are used to incorporate this uncertainty type and to minimize lack of knowledge. MONTE CARLO simulation which appears as a method to assess hazard assessment, also it helps to take epistemic uncertainty into account in the analysis.

Lack of knowledge of some aspects of the problem, limitation of the numerical modelling methodology, the estimation of the damage states, the repair cost estimation, and other analytical parameters used in the assessment can be examined in this uncertainty type.

2.3. Exposure Model

Exposure model contains information about target region. It can be called a kind of inventory of target region. Buildings which are exposed to seismic excitation are classified at this section. One of the most important principles for a proper risk assessment is to analyze the characteristics of area and the characteristics of building type in target region.

More accurate and realistic results can be achieved with more information about the region in the exposure model. There are many countries having these types of data. Providing and using of these data properly will directly affect results of risk and damage analysis.

Tuzla region in Istanbul province of Turkey will be examined in this study. Residential reinforced building types in the region are subject in this thesis.

Information about Tuzla region was received from the database of the relevant municipality.

Material type of buildings, location of buildings, load resistant type, construction year, rise type, all these information should be arranged in this section. Buildings should be classified according to these parameters. Because all these characteristics have an effect on the behavior of buildings in parallel with damage and risk results.

As known, the materials that are used in the construction can vary widely and show different characteristics and structural behaviors on the structure (reinforced concrete, steel, masonry, wood etc.) For this reason, it is important to define type of structures correctly.

Structural parameters that can affect the behavior of the structure are taken into account while classifying the buildings. These structural parameters may be related with lateral load resisting system (shear wall exist or not), ductility of system, material type and properties, irregularities etc. [Crowley et al., 2020]. Analysist may classify their structure according to these parameters. At this point more and proper information about structures will make analysis easier and lead to more accurate analysis results.

The date of construction of buildings is a guide to determine which code is taken into account. More detailed analyzes are made with development of technology and in parallel with codes. There may be some differences between seismic building codes of countries by years. For this reason, some updates on structural coefficients and structural parameters may have been developed that affected performance analysis or vulnerability analysis of buildings. Also, these updates may have been for defining damage states of structures. Global Exposure map is shown below [Crowley et al., 2018].

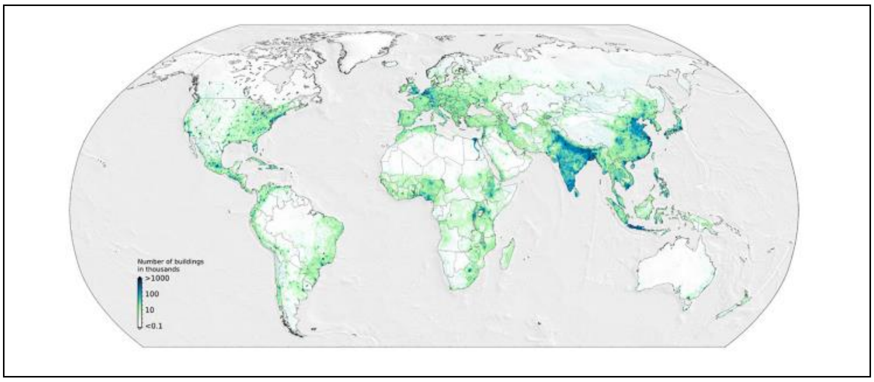


Figure 2.7: Global Exposure Map.

As it is known, buildings have different structural characteristics according to their height and they show different behaviors under a seismic excitation. There will be difference between their structural period, and this will affect their spectral response and their earthquake loads. When examining Performance analysis and fragility analysis results, it can be seen that result will be different according to structure’s height.

If it is desired to find economic loss in the region, buildings replacement cost on average should be defined in exposure model. Replacement cost can be defined as structural, nonstructural or business interruption within risk assessment frame in Openquake.

Also, if occupancy information of the region is defined in both exposure and vulnerability model, casualties and fatalities number can be calculated. Occupancy information can be defined both day and night occupancy. These 2 different occupancy types will give different risk results. Night population censuses of the buildings will be higher due to the working population.

All the features that will facilitate the user in examining, visualizing, classification the outputs are defined in this section. These parameters can be changeable from analysist to analysist. For example, if the analysist wants to examine the region quarter by quarter, the information about this parameter should be defined in the exposure model. In this way analysis results can be interpreted from various perspectives.

At this stage, the region is divided into assets by using Excel and Python Software. Also, Geographical Information System can be used. Grid size of the assets might vary depending on the size of region.

In this study, the region was divided into grids by 500 m by 500 m both in longitude and latitude. According to structure types and qualifications mentioned above, the buildings within the cells on the region are categorized with these parameters. This method provides a more organized metadata and a great convenience to the user in analysis.

Some abbreviations can be made to define taxonomy classes mentioned above. E.g; Definitions such as CR for reinforced concrete building, S for steel structures, LWAL with shear wall systems, HBET to express the number stories above ground [Silva et al., 2013]. These parameters help the user in modelling the region and evaluating the analysis results.

2.3.1. Uncertainties in Exposure Model

Some Risk and Hazard projects are conducted by many countries. The analyses are conducted. Global or country-based studies can be carried out. In such cases, it might not be possible to access the databases of each region because current census or information related to building stock in that region might not be available in database of every municipality.

There can be some difficulties in reaching these data, especially in rural areas in developing counties [Crowley et al., 2020]. Missing data or non-matching data with current census causes some uncertainties for the exposure model.

These uncertainties might arise from geographical location, built-up area, replacement cost, building class, and number of occupants. Consequently, it is possible to make several assumptions to provide these parameters in the region of interest.

As it is mentioned before, there are 2 types of uncertainties. These are aleatory and epistemic uncertainties. Epistemic uncertainties are caused by the lack of knowledge about the characteristics of the region. Collected data might not always have exactly the right information. Sometimes there might not be an inventory for the region of interest. For example, lack of knowledge for building classes in the region can be considered as epistemic uncertainty. This uncertainty can be minimized by observing the analyzes of experts who have previously worked on the region. This approach is similar to logic trees approach to consider different source models or GMPEs made by different experts in hazard assessment.

Another uncertainty type facing in the Exposure model is aleatory uncertainty. This type of uncertainty can be associated with average area per dwelling, average replacement cost per square meter, and the number of dwellings per building classes in the exposure model [Crowley et al., 2020]. Some distributions about these parameters can be made based on some existing data.

There are some equations that we cannot directly obtain from databases. So, some values can be generated from the parameter that the analysist have. These are [Crowley et al., 2020]:

$$A_{res\_building\_class} = N_{dwellings/building\_class}\ x\ A_{dwelling/building\_class} \tag{2.6}$$

A_(res_building_class) is the total area of that building class within the area.
N_(dwellings/building_class) is the number of buildings for building class
A_(dwelling/building_class) is the average floor area per dwelling within that building class

$$N_{res\_buildings} = \frac{N_{dwellings}}{N_{dwellings/story}\ x\ N_{stories/building\_class}} \tag{2.7}$$

$$P_{res\_buildings} = \frac{N_{dwellings/building\_class}}{N_{dwellings/admin}}\ x\ P_{admin} \tag{2.8}$$

As it is shown in the formula above, it can be obtained total population per that building class.

Pres_building_class; total population per within that building class.

Ndwellings/admin= total number of buildings

Padmin= total population

In Openquake engine, loss type can be defined as structural, non-structural, contents and business interrupt by regarding user’s requirements. Each of parameter that user wants to reach should be defined in exposure model.

It is possible to state that Openquake engine should know cost type of models to analyze. Cost type can be aggregated, per asset or per area.

Aggregated cost type refers to aggregated replacement cost for each asset. Per asset refers to replacement cost per building for each asset. Per area refers to replacement cost per area for each asset. If user defines cost type as per area, area type should be defined. Because Openquake engine should know total area to reach total loss of assets. Area type could be aggregated or per building. Aggregated indicates the aggregated area for each asset.

2.4. Fragility Model

Fragility curves are expressed as the probability of exceeding of damage states corresponding to the intensity measure types.

In general, probability of damages of related damage states can be obtained with help of this curve. It is the expression of the probability of damages which caused by a strong ground motion in the area. However, this excitation can be hurricane or extreme loading condition, but earthquake will be considered at this study.

Generating this curve is a process of computing the damages of structures. Damage analysis can be accomplished with help of these curves. Graphs are drawn based on intensity measure parameters since damages are caused by a certain strong ground motion. (Sa, Sd, PGA etc.)

These curves are expressed with cumulative lognormal functions which are shown below. For example, as it is shown in the graph, a building in moderate, extensive or complete damage state will also have reached slight damage. Because building reaches slight damage state at first, and after, other following damage states. If a structure reaches moderate damage, it will be also considered in slight damage state. And then it reaches moderate damage, so a slight damage covers them all.

The difference between probability of exceeding of damage states gives damage ratio which corresponds to those damage states for given intensity measure level.

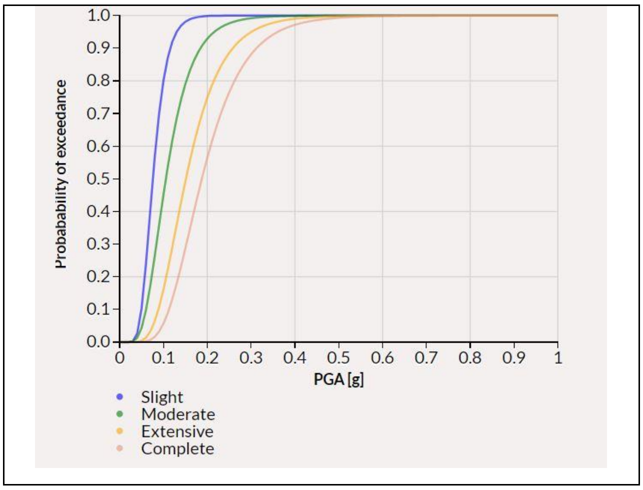


Figure 2.8: Fragility Curve, OQ Database.

In this study, 4 damage levels were considered. Fragility and vulnerability functions are also plotted based on these damage states. There are also 4 damage states in TSBC 2018 (Turkish Seismic Building Code, 2018). These damage states are also similar to HAZUS, and these are [FEMA, 2003]:

SLIGHT: This performance level corresponds to the situation in which structural damage to the structural elements of the building does not occur or the damage remains negligible. Small plaster cracks at corners of door and window openings and wall ceiling intersections can be incorporated with this damage state.

MODERATE: This performance level corresponds to the damage level where limited damage occurs in the structural elements of the building, in other words, the non-linear behavior is limited. Small diagonal cracks across shear wall panels exhibited by small cracks in stucco and gypsum wall panels; large cracks in brick chimneys; toppling of tall masonry chimneys can be incorporated with this damage state.

EXTENSIVE: This level of performance corresponds to the level of damage that is not too heavy and is mostly possible to repair in the structural elements of the building in order to ensure life safety. Large diagonal cracks across shear wall panels or large cracks at plywood joints; permanent lateral movement of floors and roof; toppling of most brick chimneys; cracks in foundations; splitting of wood sill plates and/or slippage of structure over foundations can be incorporated with this damage state.

COMPLETE: This level of performance corresponds to the pre-failure situation where severe damage to the structural elements of the building occurs.

Partial or complete collapse of the building is prevented. Structure may have large permanent lateral displacement due to wall failure or failure of the lateral load resisting system, large foundation cracks. Three percent of the total area of buildings with Complete damage is expected to be collapsed, on average.

It can be mentioned in 3 methods to achieve fragility curves. These are empirical, analytical and expert opinion methods [Porter, 2015].

In the empirical method: it is created by fitting a function with approximate observational data from the laboratory environment or the site. Buildings which are getting damage are observed. Buildings are classified according to damage states by considering their structural and architectural damages. Some statistical values can be generated based on building's damages. Several fragility functions can be derived according to these statistical data for different building type.

Analytical method: this method is based on the structural analysis of the buildings. Performance-based design analysis method is applied. Capacity spectrum of the structure can be determined with help of performance-based design method and then performance point of the building can be computed with the intersection of demand spectrum of earthquake and capacity spectrum. Seismic fragility curve is plotted by means of fragility functions depending on type and structural properties of the building with different methods and analyzes.

Buildings are classified according to their specific structural design parameters during the process of evaluation since many structural parameters will affect the results of fragility functions. Maybe hundreds of buildings are analyzed, and their results are examined statistically and assessed cumulative distribution in order to obtain fragility curve of a particular asset class.

With development of technology, analytical method is mostly preferred, considering that some difficult mathematical and statistical operations can be performed with help of computers.

Czarnecki first pointed out in her doctoral thesis that fragility curves can be derived with help of structural analysis. [Czarnecki, 1973]

In expert opinion or judgment-based opinion, many scientists who are experts in their field come together and estimate damage probability as a function of seismic excitations based on their experience and observations. For example, ATC-13 (Applied Technology Council 1985) compiles many judgment-based fragility functions for California buildings.

The lognormal cumulative distribution function is usually the best fit for fragility curves. The advantages of using lognormal cumulative distribution can be listed below [Porter, 2015]:

- With lognormal cumulative distribution function fits for using median and standard deviation parameter. The median and standard deviation are the main parameters for generating the curve.
- Most of engineers used this method. This is more traditional in earthquake engineering area.
- There are so many parameters that affect fragility curve. So, there could be a great deal of lack of knowledge and uncertainty. This distribution method allows generating fragility function with less information.

Building fragility curves are lognormal functions that describe the probability of reaching or exceeding of damage states, at given spectral response. Spectral response can be spectral displacement, spectral acceleration, PGA. These curves take into account the variability and uncertainty associated with capacity curve properties, damage states and ground shaking [Kircher et al., 1997].

2 parameters are essential for fragility functions. These are median value of demand parameter of each fragility function that can be expressed as mathematically a measure of central tendency and standard deviation that can be expressed measure of uncertainty. Lognormal cumulative distributions of fragility functions can be plotted with these 2 parameters.

There are 2 steps to obtain damages according to FEMA. These methods are based on the analytical fragility model.

i) Calculating Capacity curves
ii) Calculating Fragility curves

Structures show nonlinear behavior under the seismic excitation. It is utilized from Pushover method for calculating capacity of the building under an earthquake. Pushover curves show behavior of structure under lateral seismic loads. It gives seismic lateral forces in the vertical axis and lateral displacements of the building in horizontal axis. Displacement capacity under an earthquake can be obtained from curve. This curve contains displacements of structures corresponding to the yield and ultimate shear forces of the building. When curve is plotted, it can be seen that structure shows linear behavior to the yield point, after structure shows nonlinear behavior from the yield point to the ultimate point.

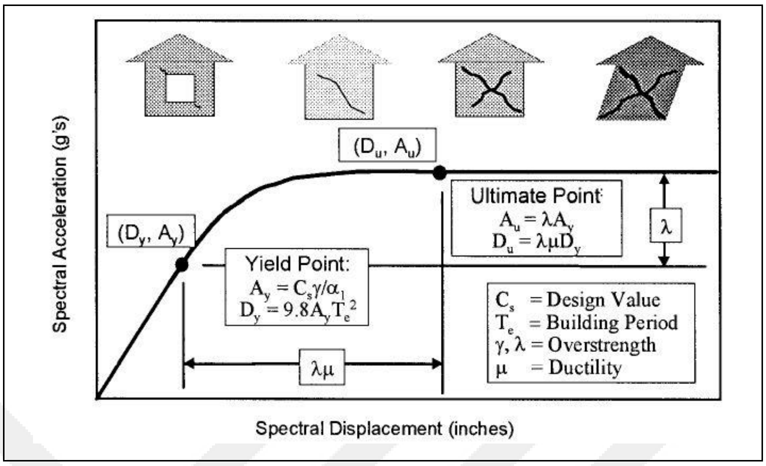


Figure 2.9: Example building capacity curve and control points.

Once the building's pushover curve is found, this curve is converted to a Sa-Sd graph which is called capacity spectrum with some modal participation factor, and amplitudes which exist in relevant design codes. The building's top displacement and shear force which are calculated in pushover analysis method are converted respectively spectral displacement and spectral acceleration. Capacity curve allows to compare capacity of building with the earthquake's demand by drawn in the same plane.

After obtaining capacity curve of building, the performance point of building can be determined by intersecting between capacity spectrum and demand spectrum. Performance point represents maximum inelastic capacity of building. This response can be called performance point. Earthquake’s demand and the building capacity should be on same plane for the comparison [Kircher et al., 1997].

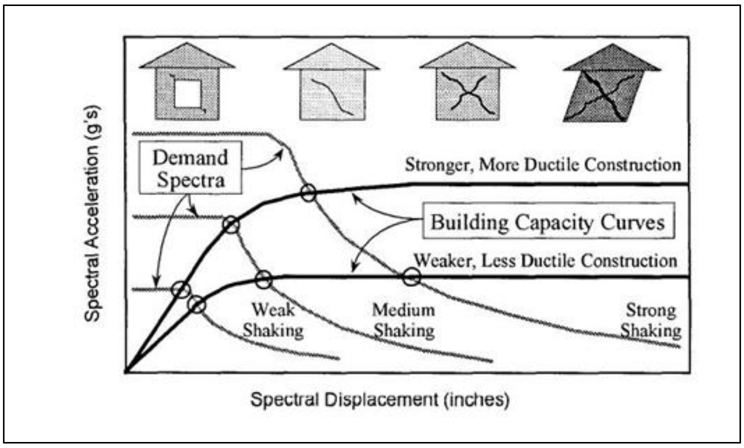


Figure 2.10: Intersection of demand spectra and building capacity curve.

There are some methods to calculate performance point in ELER Manual (Earthquake Loss Estimation Routine). Response spectrums are based on 5% damping ratios assumption in TBSC 2018 and usually in other Seismic code of countries. But damping ratio is not equal to 5% in reality. So, demand spectrum that derived from response spectrum should be arranged to real damping ratios. It gives more accurate results to calculate the demand of the earthquake according to their hysterical behavior. Thus, modification of demand spectrum is possible. The method explained below are based on ELER methodology. In these methods, demand spectrum is changed with some coefficients [ELER Manual, 2010].

- Capacity Spectrum Method
- MADRS (Modified Acceleration-Displacement Response Spectrum)
- Reduction Factor
- Coefficient method

The demand spectrum is modified with new damping ratio through different method mentioned above. Later, new performance point is determined.

Fragility curve parameters must be mentioned as well. According to Kircher, Development of Building Damage Functions for Earthquake Loss Estimation, median of spectral displacement ($\bar{S}_{d,ds}$) can be obtained by formula below [Kircher et al., 1997].

$$\bar{S}_{d,ds} = \delta_{ds}\ \alpha_2\ H \tag{2.9}$$

H is the typical roof height of the model building type of interest

δ_{ds} is drift ratio at threshold of structural damage state ds

α_2 is the fraction of the building (roof) height at the elevation where pushover mode displacement equals spectral displacement

Standard deviation which expresses the variability of these curves can be obtained with the formula below.

Lognormal standard deviation expresses the total variability of fragility-curve damage state. There are 3 components of total variability. All variabilities of demand, capacity, damage state standard are important to estimate the total variability. Standard deviation is expressed in terms of randomness and uncertainty components of variability.

$$\beta_{ds} = \sqrt{(CONV[\beta_{C,}\beta_D])^2 + (\beta_{T,ds})^2} \tag{2.10}$$

β_{ds} is the total lognormal standard deviation

$\beta_{C,}$ is standard deviation due to variability of capacity curve

β_D is standard deviation due to variability of demand spectrum

$(\beta_{T,ds}$ is standard deviation due to variability of threshold of damage state

And here is the main equation of fragility function which depends on damage state variability and damage state medians. These values can be applied on the structural and nonstructural damage states. The conditional probability of being in or exceeding a particular damage state given the spectral displacement is defined by Equation below [Kircher et al., 1997].

$$P[ds|S_d] = \phi[\frac{1}{\beta_{ds}}\ln\left(\frac{S_d}{\bar{S}_{d,ds}}\right)] \tag{2.11}$$

where Φ is the standard normal (Gaussian) complementary cumulative function

Sd is the inelastic spectral displacement demand (performance point)

Sd,ds is the median spectral displacement at which the structure reaches the threshold of the damage state

βds is the standard deviation of the natural logarithm of the Sd,ds.

After fragility curve is plotted as lognormal cumulative distribution with help of this formula which is shown at the above.

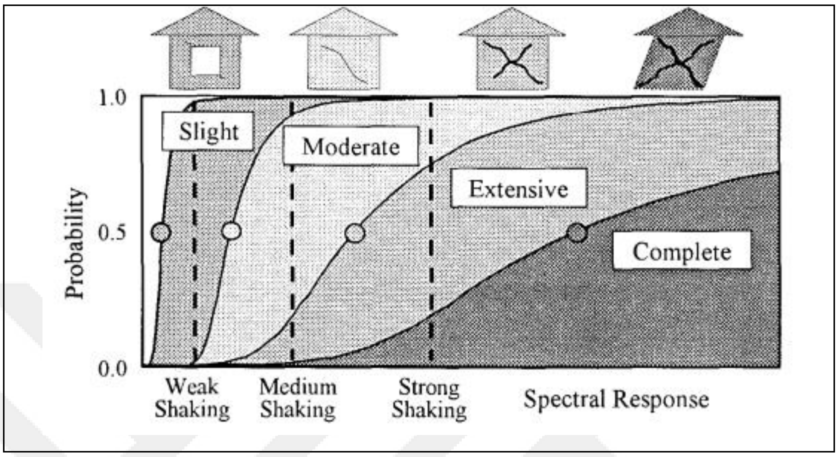


Figure 2.11: Example fragility curves for Slight, Moderate, Extensive and Complete damage.

Openquake considers mean value instead of median value in fragility functions. Appropriate transformation should be applied for median to mean parameter and plotting fragility curve. In this study, mean and standart deviation parameters of fragility functions are considered for damage analysis.

2.5. Consequence Model

A Consequence model establishes the relation between a physical damage state and the corresponding loss ratio [Openquake Manual, 2019].

Vulnerabilities that are required for risk analysis can derive with Consequence model.

Consequence model gives us the answer to the question of 'What percentage of the value does the structure lose at that damage state?' This loss value can vary depending on different country. If we assume total economic value of the building as replacement cost, direct economical factor can be calculated by dividing economic loss value by replacement cost for relevant damage states. Thanks to consequence models, this economical damage ratios can be known.

As mentioned in previous section, the probability of exceeding corresponding those damage states can be achieved by calculating fragility curves. The difference between probability of exceeding of the damage states gives the damage ratio corresponding to those damage states.

Vulnerability curves can be calculated by combining damage ratios obtained from fragility curve with consequence model for a particular damage state. Also, Openquake engine software is using this logic to generate vulnerability curves.

Consequence model values vary from country to country, taxonomies, and structure classes. These graphs can be varied to economical and seismicity factors of countries.

2.6. Vulnerability Model

Damageability is also measured in terms of degree of undesirable outcome, called loss here in terms of repair costs, and loss of functionality [Openquake Manual, 2019].

When loss is expressed as a function of environmental excitation, the function can be called a vulnerability function.

A seismic vulnerability function relates uncertain loss to a measure of seismic excitation, such as spectral acceleration response at some damping ratio and period. A seismic vulnerability function usually applies to a particular asset class.

Fragility curves are expressed as the probability of exceeding of the damage states based on the intensity measure types. Fragility curves are used in damage analysis of buildings since the damage ratios are obtained from this curve. Vulnerability curves are related to losses. Loss ratios for given asset class can be generated by using vulnerability curves.

These losses can be categorized as structural, nonstructural, contents, business interruption or occupants. Relevant loss ratios and parameters must be defined for each desired loss category.

There are several vulnerability functions methods. For instance, Intensity-based vulnerability function is based on the data which are obtained from field observation by researchers after earthquake occurred. There are several intensity-based vulnerabilities-class [Erdik et al., 2003]:

Intensity VI: A few buildings of vulnerability class C sustain D1 damage.

Intensity VII: A few buildings of vulnerability class C sustain D2 damage.

Intensity VIII: Many buildings of vulnerability class C suffer D2 damage, a few D3.

Analytical methods use engineering first principles to estimate the vulnerability function. In general, analytical methods employ the four analytical stages: slight, moderate, extensive and collapse damage states.

Analytical method provides insight where the empirical method does not. It can be used to estimate vulnerability of building types which have not yet experienced strong motion.

Earthquakes caused damages on the structure. These damages can be expressed as repair cost in economic terms and the values of structure can be expressed as replacement cost. Direct economic factor is obtained by dividing damage cost by replacement cost. Damage ratios can be calculated by the difference between each damage states at the given intensity measure level from the fragility curves. Then the loss ratios can be generated by multiplying the parameters coming from fragility and consequence model for the given intensity measure level [Openquake Webinar, 2020].

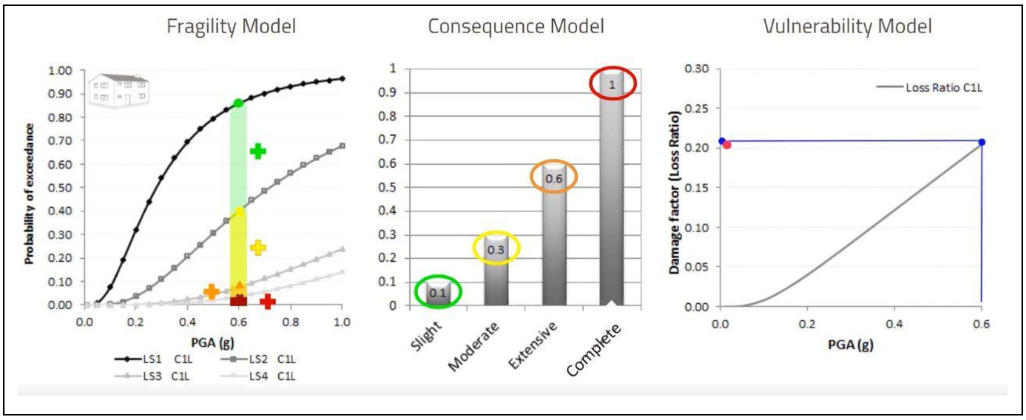


Figure 2.12: Generating of vulnerability curve.

There are also some uncertainties due to variability in replacement cost ratios. These uncertainties can be taken to account with coefficient of variation parameters. Margin of error can be minimized with the help of coV parameter.

Lognormal (LN), beta (BT) or a discrete probability mass (PM) are used in OpenQuake for taking to account the uncertainties in the vulnerability model [OpenQuake Manual, 2019].

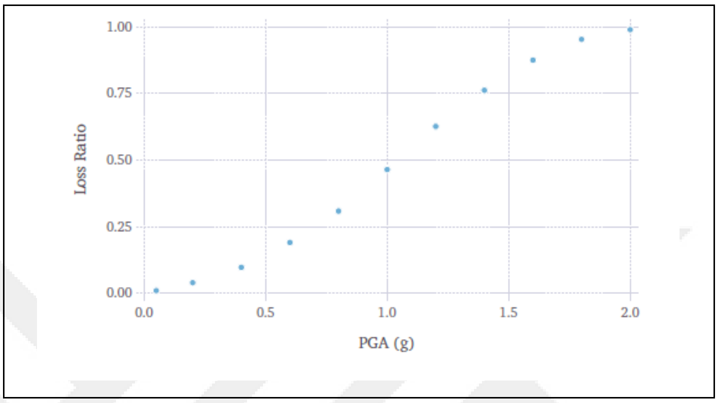


Figure 2.13: Vulnerability Curve.

2.7. Loss Curves

Vulnerability curves were employed while generating loss exceedance curves. Vulnerability curve gives the loss ratios at the given intensity measure level and loss ratios can be related with their standard deviation and mean parameters as it has been explained in the previous section. Probability of exceeding of each loss ratio can be calculated with the formula given below with the help of vulnerability curve parameters [Porter, 2015].

$$P[L \geq l|E_e] = 1 - P[L < l|E_e] = 1 - \phi(\frac{\ln(l/\theta_e}{\beta_e}) \tag{2.12}$$

Also, probability of occurrence of events should be taken into consideration. Loss ratios depend on these occurrences of events. So, the exceedance rate of each loss ratio can be calculated by multiplying probability of occurrence and the probability of exceeding of each loss ratio [Porter, 2015].

$$G[L \geq l] = \sum_{e}^{N_e} P[L \geq l|E_e].G[E_e] \tag{2.13}$$

P[L≥l |Ee] denotes the conditional probability that loss exceeds l given that event Ee occurs.

G[Ee] denotes the rate at which event Ee occurs

Then probability of exceeding is summed for each event at the related loss ratio level. Because each event contributes to each loss ratio level. This process is done at each loss ratio level for generating loss curves. A plot of G[L≥l] versus loss is sometimes called a loss exceedance curve, sometimes a risk curve [Porter, 2015].

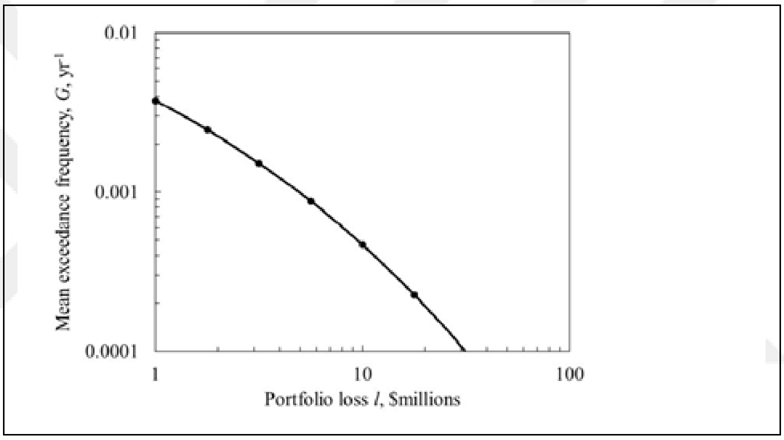


Figure 2.14: Loss exceedance curve.

3. INFORMATION ABOUT TARGET REGION

3.1. Fault Type, Seismic Activity of the Region, Seismotectonic Features

Istanbul has a high seismicity potential in terms of both hazard and risk because of its seismicity and the population living on the region. It is also important for economy of the country.

Turkey is one of the most seismically active regions of the world, considering its location. The country locates on the Alpine-Himalayan orogenic system that extends from Archipelago of the Azores to Southeast Asia. North Anatolian Fault Zone (NAFZ), Aegean Graben System (AGS), East Anatolian Fault (EAF) and Southeast Anatolian Thrust (SAT) are the most important faults in Turkey but the main seismicity events are caused by the NAFZ. NAFZ begins to lose its single fault line characteristic and splays into a complex fault system. So many researchers have studied on Marmara Sea and many tectonic models have been developed for this area. The main Marmara fault can be considered as young, and it is thought to be 200.000 years old. And the fault type is strike-slip fault.

Tuzla area is the one of the main regions in Istanbul metropolitan area. It is important for economy of the country in terms of shipyards, factories in the area.

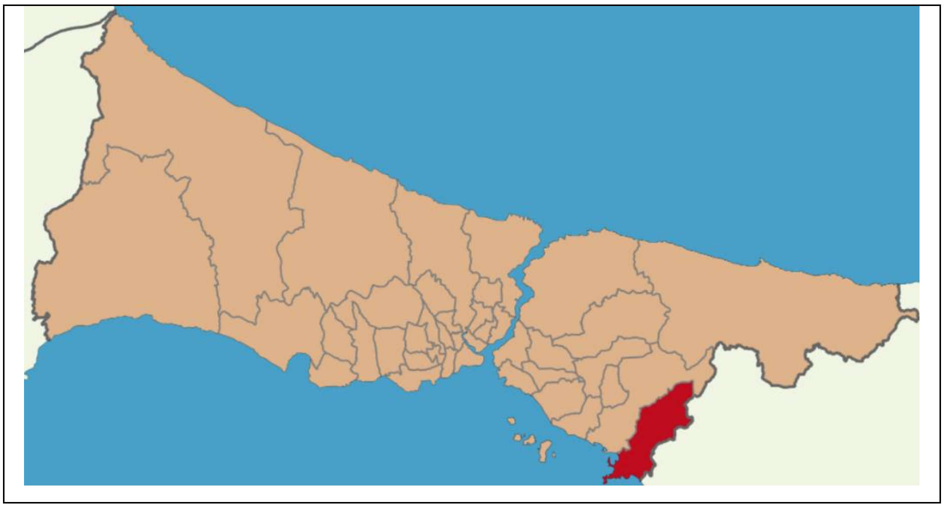


Figure 3.1: Map of Istanbul and location of Tuzla district.

Figure 3.2: Tuzla district map.

There are so many earthquakes occurred in this region. Thanks to records, it is possible to reach major events in the past and nowadays. But the expression of past earthquakes can be different from current data. Therefore, in general, very old earthquakes of the past are expressed in terms of Mercalli intensity measure type [Erdik et al., 2003].

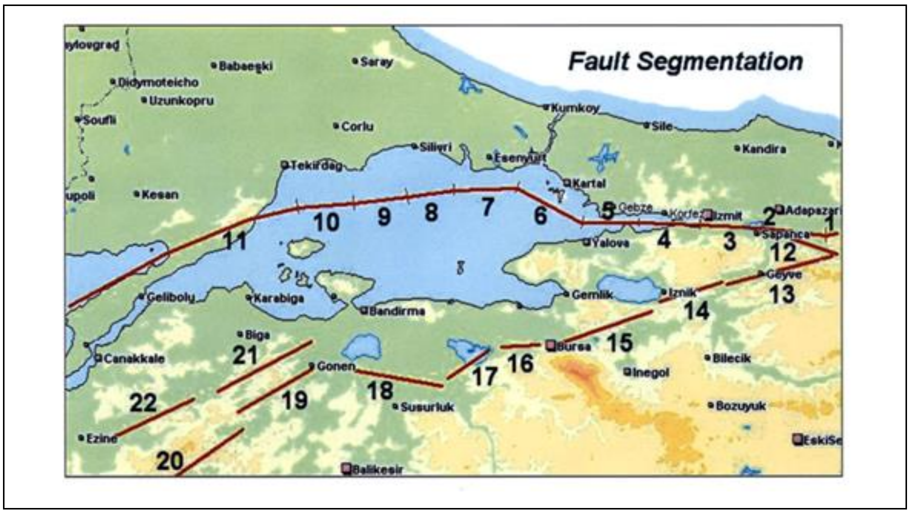


Figure 3.3: Main Marmara Fault.

For probabilistic analysis, there are so many sources designed and the characteristic of sources are defined like its geometry, a and b values, magnitude range, rake etc. Active shallow crusts regime is dominant in the region and Vs30 parameters are changing between 200 and 600 km/h. The Vs30 parameters is mapped at below.

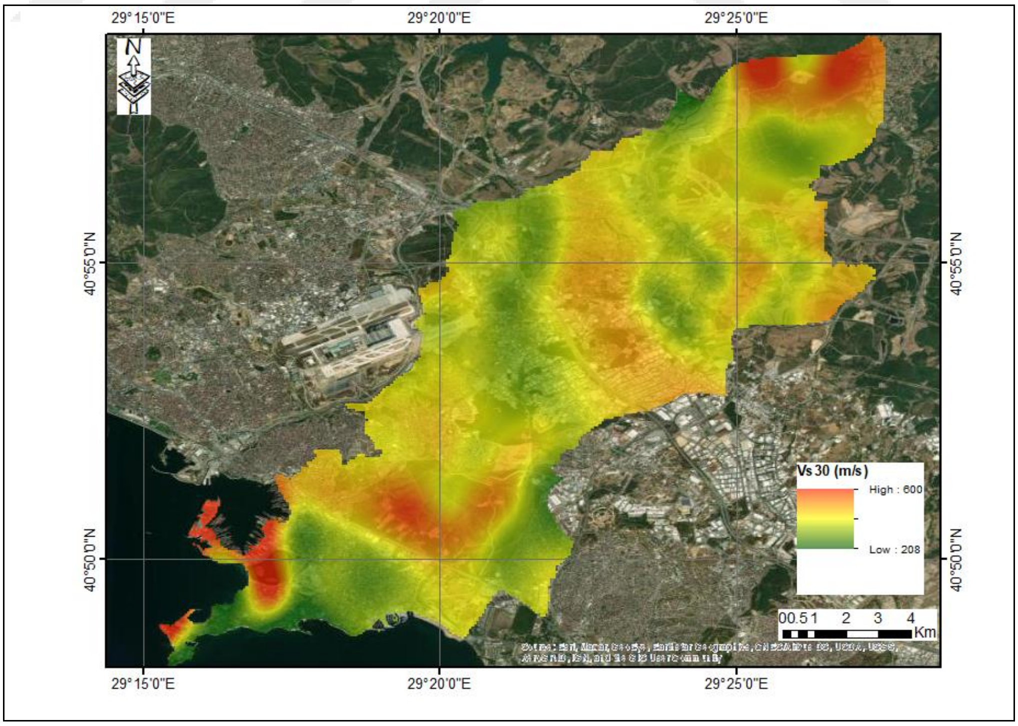


Figure 3.4: Vs 30 values.

Methiye Gündoğdu Gök Master Thesis which is about Seismic hazard assessment for Kocaeli region parameter has been used as hazard input in this study. Thank to this study, hazard results have been obtained [Gök, 2020].

Classical Probabilistic Hazard calculation mode has been executed for hazard assessment. AkkarBommer2010, CauzziFaccioli2008, ChiouYoungs2008, ZhaoEtAl2006Asc ground motion prediction models are adopted for creating Ground Motion Prediction Equation Model uncertainty model. Results of Probabilistic Hazard Analysis are as follows [Akkar et al.,2010], [Cauzzi and Faccioli, 2008], [Chiou and Youngs, 2008].

3.2. Exposure Model

In this study, Tuzla region in Istanbul has been selected as target region. It is located east side of Istanbul. To give brief perspective and basic information on the region, area of Tuzla is approximately 123 km^2 and 48 m above the sea level. The population of Tuzla is 273,608 according to 2020 census data. The population is composed of 139,481 males and 134,127 females. There are 237.833 people at the residential buildings in the night based on this study. It corresponds to 86.9% of the total population.

Tuzla has high seismicity; it has a high seismic risk because of the population living on the region. It is one of the regions which North Anatolian Fault (NAF) passes through. The past earthquakes in the region also prove this case. Tuzla region is located on commercial highways which have great importance for the country's economy. Also, Turkey's largest shipyards are in Tuzla and there are so many factories, workplaces here.

The region has so many types of structures. However, residence buildings or buildings with small workplace at entry level are subjects of this study. Most of the buildings were built before 2007. Total number of buildings is 18,675.

For classification of the exposure model, there are main parameters which are important for structural behavior of the structure. In this study, one of these categorization parameters is construction year of building. When the construction year of building is considered, the years have been spanned into 3 categories. These are 1980-2000, 2000-2007 and 2007-present. The Turkish Building Seismic Codes were revised in 1999 and 2007. Construction years are categorized based on these revision years.

The region has been divided by 500 m/500 m cells in both longitude and latitude. Assets have been specified according to these cells and the buildings; population has been arranged within the assets. If an exposure model is organized on a provincial, country or global basis, the region should be divided into larger cells (km to km cell).

Table 3.1: List of Taxonomies.

Building Types	Taxonomies	Low Rise	Mid Rise	High Rise	Code Type	Number of buildings	Ratio of buildings(%)
Type_1	CR/HBET:1,3/YPRE:2000/RES	X			Low	794	4.25
Type_2	CR/HBET:4,7/YPRE:2000/RES		X		Low	537	2.88
Type_3	CR/HBET:8,20/YPRE:2000/RES			X	Low	17	0.09
Type_4	CR/HBET:1,3/YBET:2000,2007/RES	X			Moderate	4454	23.85
Type_5	CR/HBET:4,7/YBET:2000,2007/RES		X		Moderate	3893	20.85
Type_6	CR/HBET:8,20/YBET:2000,2007/RES			X	Moderate	66	0.35
Type_7	CR/HBET:1,3/YBET:2007,2021/RES	X			High	3503	18.76
Type_8	CR/LWAL/HBET:4,7/YBET:2007,2021/RES		X		High	2505	13.41
Type_9	CR/LWAL/HBET:8,20/YBET:2007,2021/RES			X	High	99	0.53
Type_10	CR+CIP/HBET:8,20/YBET:2007,2021			X	High	206	1.10
Type_11	MUR/HBET:1,3/YPRE:2000/RES	X			Low	727	3.89
Type_12	MUR/HBET:1,3/YBET:2000,2007/RES	X			Moderate	889	4.76
Type_13	MUR/HBET:1,3/YBET:2007,2021/RES	X			High	617	3.30
Type_14	MUR/HBET:4,7/YPRE:2000/RES		X		Low	11	0.06
Type_15	MUR/HBET:4,7/YBET:2000,2007/RES		X		Moderate	17	0.09
Type_16	PC/HBET:1,3/YBET:2000,2007/RES	X			Moderate	6	0.03
Type_17	PC/HBET:1,3/YBET:2007,2021/RES	X			High	44	0.24
Type_18	PC/HBET:4,7/YBET:2007,2021/RES		X		High	3	0.02
Type_19	S/HBET:1,3/YBET:2000,2007/RES	X			Moderate	1	0.01
Type_20	S/HBET:1,3/YBET:2007,2021/RES	X			High	187	1.00
Type_21	S/HBET:4,7/YBET:2007,2021/RES		X		High	3	0.02
Type_22	W/HBET:1,3/YPRE:2000/RES	X			Low	6	0.03
Type_23	W/HBET:1,3/YBET:2000,2007/RES	X			Moderate	35	0.19
Type_24	W/HBET:1,3/YBET:2007,2021/RES	X			High	47	0.25
Type_25	W/HBET:4,7/YBET:2000,2007/RES		X		Moderate	1	0.01
Type_26	W/HBET:4,7/YBET:2007,2021/RES		X		High	7	0.04

2092 of the buildings in the region were built before 2000, 9.362 of them were built between 2000-2007 and 7221 of them were built in 2007 and later. It corresponds to 11% of residential buildings that were built between 1980-2000, 50% between 2000-2007, and 39% in 2007 and later.

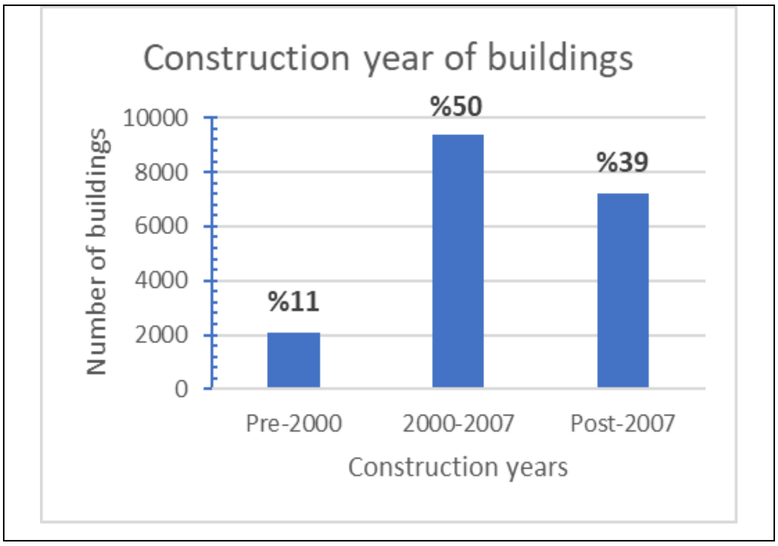


Figure 3.5: Construction year of buildings.

In general, building stock of the region consists of reinforced concrete and masonry structures. Reinforcement is not used in most of the masonry structures. Thus, the masonry structures have been assumed as unreinforced.

It is known that reinforcement was used in most of reinforced concrete structures, however the exact information about the reinforcement, irregularities and lateral load system information of the reinforced concrete structures could not be reached with the available data. Therefore, such uncertain information has been considered as arranging the exposure model.

Observing the number of buildings according to their material type, it can be obtained that more than 84.96% of building was constructed as reinforced concrete. There are 6 different types of building which can be categorized as reinforced concrete, masonry, steel, prefabricated, tunnel formwork and wood. 15868 (84.97%) of buildings are reinforced concrete structure. 2261 (12.11%) of them are masonry, 191 (1.02%) of them are steel, 96 (0.51%) of them are wood. 53 (0.28%) prefabricated and 206 related with tunnel formwork.

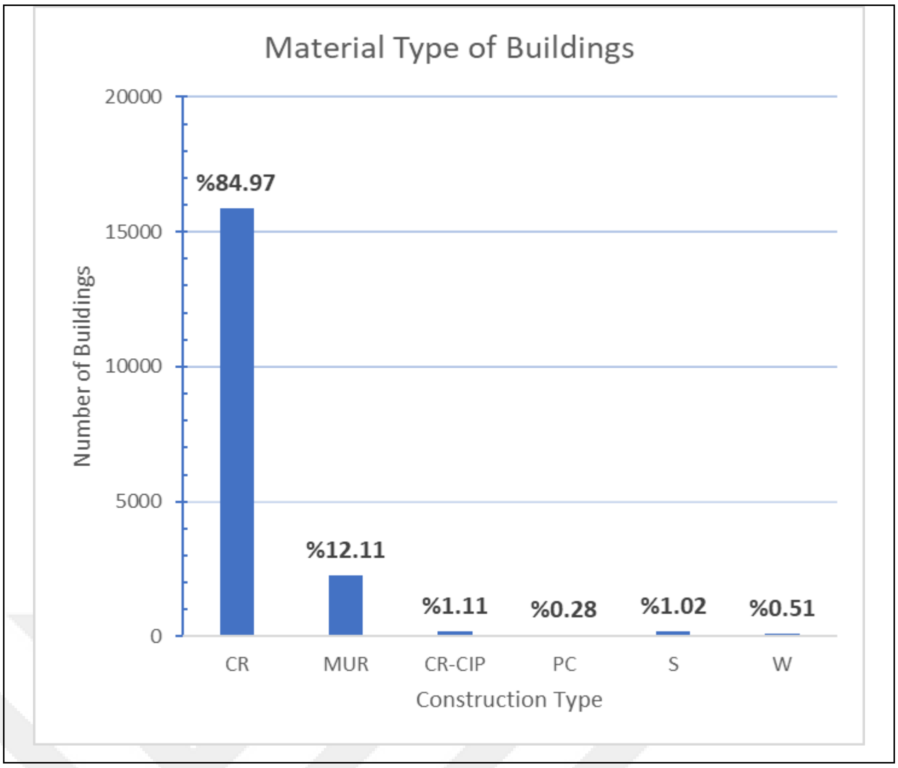


Figure 3.6: Material Type of Buildings.

Also, it is important to determine the rise type of building. Rise types can be computed based on number of storeys. There are 3 rise types. These are low rise, mid-rise and high-rise buildings. Building with 1-3 storeys are called as low-rise. 4-7 storeys are Mid-rise, and 8-20 storeys are high rise. It is one of the parameters affecting structural behavior of structure under seismic excitation. So, when rise type of buildings is examined, it can be concluded that there are 11.310 (60.56%) of them in 1-3 storeys which are categorized as low rise, 6977 (37.36%) of them are between 4 and 7 storey, and 388 (2.08%) of them are between 8 and 20 storeys.

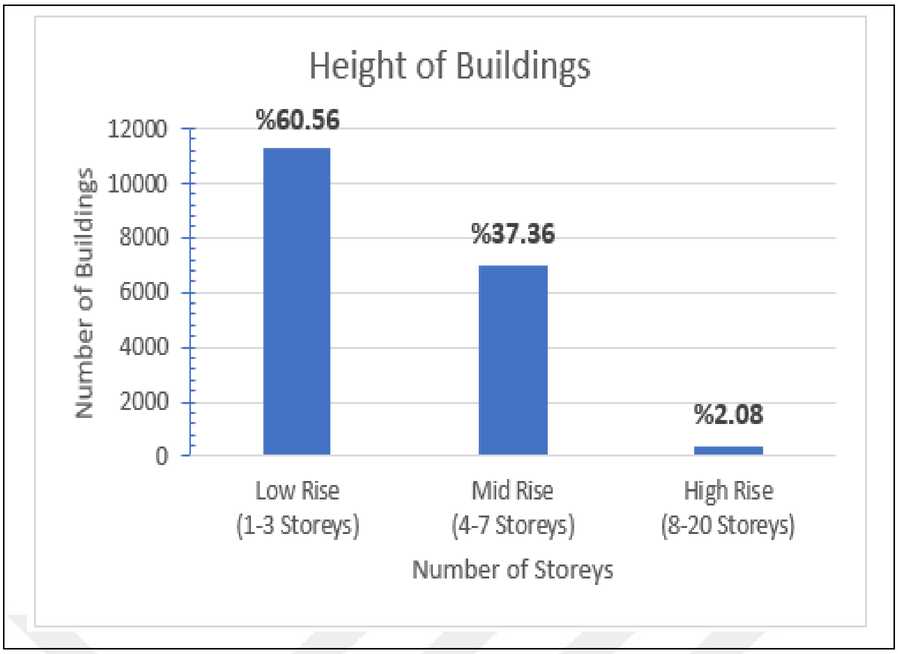


Figure 3.7: Height of Buildings.

In this study damage and loss analysis for reinforced concrete buildings have been performed because they cover most of building in inventory (approximately 85%). Reinforced concrete buildings constructed after 2007 with mid and high rise have been assumed as reinforced concrete with shear walls due to the stiff rules in the Turkish earthquake code.

Some assumptions have been made to determine replacement cost of buildings. Replacement cost of building has been obtained from statistica.com website and society expert opinion. Replacement costs are taken as 780 $, 689 $ and 598 $ per m2 respectively high-rise, mid-rise and low-rise reinforced concrete buildings. Areas for each building have been assumed 100 m2.

There are 9 types of reinforced concrete structure types in this study. Reinforced concrete structures have been categorized according to their rise type and their code type. These taxonomies have been classified based on the OpenQuake taxonomy Glossary [Silva et al., 2013]. So, these taxonomies have been categorized as shown in the below.

CR/HBET:1,3/YPRE:2000/RES: Residential Reinforced Concrete buildings - Low rise – Low code

CR/HBET:4,7/YPRE:2000/RES: Residential Reinforced Concrete buildings, Mid-rise, Low code

CR/HBET:8,20/YPRE:2000/RES: Residential Reinforced Concrete buildings, High-rise, Low code

CR/HBET:1,3/YBET:2000,2007/RES: Residential Reinforced Concrete buildings, Low-rise, Moderate code

CR/HBET:4,7/YBET:2000,2007/RES: Residential Reinforced Concrete buildings, Mid-rise, Moderate code

CR/HBET:8,20/YBET:2000,2007/RES: Residential Reinforced Concrete buildings, High-rise, Moderate code

CR/HBET:1,3/YBET:2007,2018/RES: Residential Reinforced Concrete buildings, Low-rise, High code

CR/LWAL/HBET:4,7/YBET:2007,2018/RES: Residential Reinforced Concrete buildings with shear walls, Mid-rise, High code

CR/LWAL/HBET:8,20/YBET:2007,2018/RES: Residential Reinforced Concrete buildings with shear walls, High-rise, High code

The number of buildings for these taxonomies has been shown in the graphic below. As it can be seen in the graph, the number of buildings of low-rise and moderate code and mid-rise and moderate code are the 2 taxonomies in majority. Low-rise, moderate code and mid-rise, moderate code are in the majority for reinforced concrete buildings in the region. Also, it can be seen that high-rise buildings are less in comparison to low-rise and mid-rise taxonomy classes.

1348 (8.5%) of reinforced concrete buildings were constructed before 2000 which have been considered as low code in this study. 8413 (53%) of reinforced concrete buildings were constructed between 2000-2007 and 6107 (38.50%) of reinforced concrete buildings were constructed between 2007-2021. When rise-type of buildings are examined, there are 8751 (55%) of RC buildings examined under low-rise, 6935 (43.70%) of RC buildings are in mid-rise category and 182 (1.30%) of RC buildings are in high-rise buildings.

Table 3.2: Reinforced concrete building features.

Building Types	Taxonomies	Moment Frame	Shear Wall	Height type	Code Type	Number of buildings	Ratio (%)
Type_1	CR/HBET:1,3/YPRE:2000/RES	X		Low	Low	794	4.25
Type_2	CR/HBET:4,7/YPRE:2000/RES	X		Mid	Low	537	2.88
Type_3	CR/HBET:8,20/YPRE:2000/RES	X		High	Low	17	0.09
Type_4	CR/HBET:1,3/YBET:2000,2007/RES	X		Low	Moderate	4454	23.85
Type_5	CR/HBET:4,7/YBET:2000,2007/RES	X		Mid	Moderate	3893	20.85
Type_6	CR/HBET:8,20/YBET:2000,2007/RES	X		High	Moderate	66	0.35
Type_7	CR/HBET:1,3/YBET:2007,2018/RES	X		Low	High	3503	18.76
Type_8	CR/LWAL/HBET:4,7/YBET:2007,2018/RES		X	Mid	High	2505	13.41
Type_9	CR/LWAL/HBET:8,20/YBET:2007,2018/RES		X	High	High	99	0.53

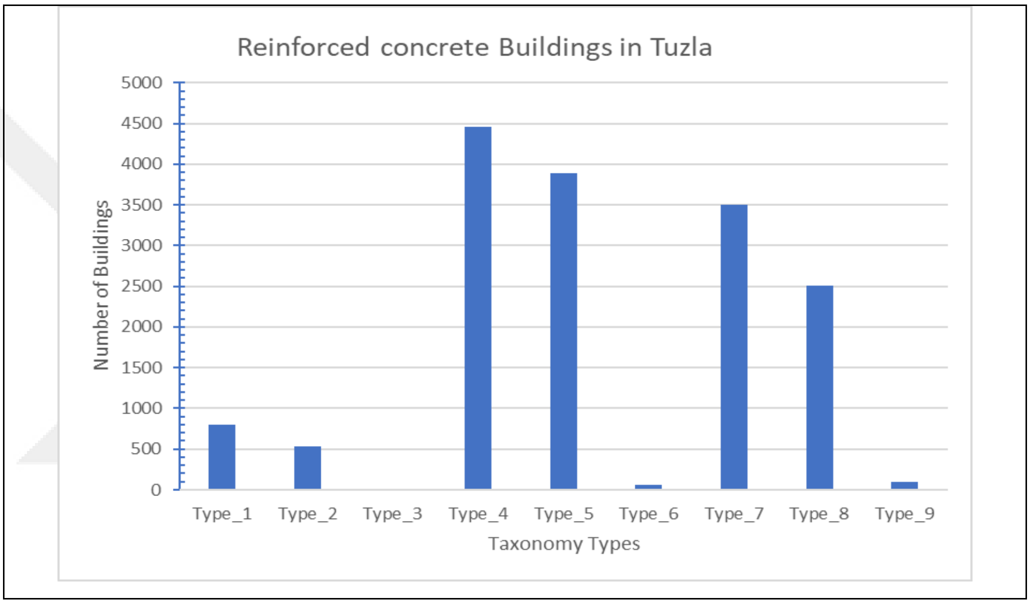


Figure 3.8: Number of Buildings of Reinforced Concrete Buildings.

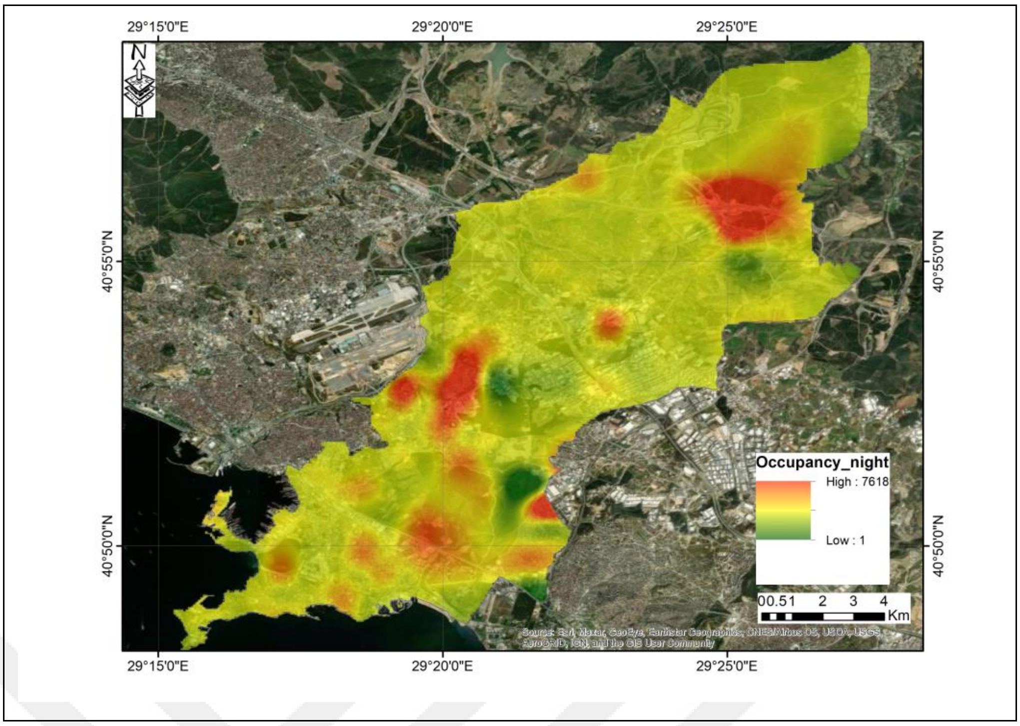


Figure 3.9: Occupancy at night of Tuzla.

3.3. Fragility Model

As mentioned in previous sections, Turkey has a high seismicity because of active fault which passes through the country. Therefore, there have been so many studies carried out about fragility analysis. Studies have especially focused more on reinforced concrete structure since this type of structures is the majority in building stock in Tuzla in Istanbul.

In addition to reinforced concrete buildings, there are so many building types in the region like masonry, steel, tunnel framework etc. So, more studies should be focused and carried out for other structure type.

Ahmed et al. focused more reinforced concrete structure for Turkey. They separated the buildings according to their ductility rise type and irregularity status. It was based on analytical approach.

Erberik generated a fragility model for reinforced concrete structures and masonry. They classified their models according to their number of stories, urban or rural type buildings [Erberik, 2008].

These fragility models consist of 3 damage states for reinforced concrete and 2 damage states for masonry buildings.

Kirçil and Polat developed many fragility models for reinforced concrete buildings and these models are based on 2 damage states [Kirçil and Polat, 2006].

LESSLOSS (2005) study is more comprehensive. There are so many buildings type varying from reinforced concrete to masonry buildings and its rise type. This study separates codes as pre-1979 and post 1980 since Turkish Building Seismic Code is renewed in 1980 [Syner-G, 2011].

The continuous fragility curve has been taken into account in the analysis because of the current data are continuous cumulative as well. Mean and standard deviation parameter has been defined as it is necessary for generating fragility curves.

The fragilities which are mentioned above mostly regard 2 or 3 damage states, so they were not used. But in this study 4 damage states have been considered. These are slight, moderate, extensive and collapse. In this study HAZUS99 [FEMA, 1999] fragility models are used. Their parameters have been modified based on Turkey. While doing this modification process, the models which are generated for Turkey have been taking into consideration.

There is an important point on what the fragility function parameters are. HAZUS considers median and standard deviation for fragility functions, but OpenQuake considers fragility parameters as mean and standard deviation. For this reason, a suitable conversion should be applied while convert median value to mean value [HAZUS, 2003].

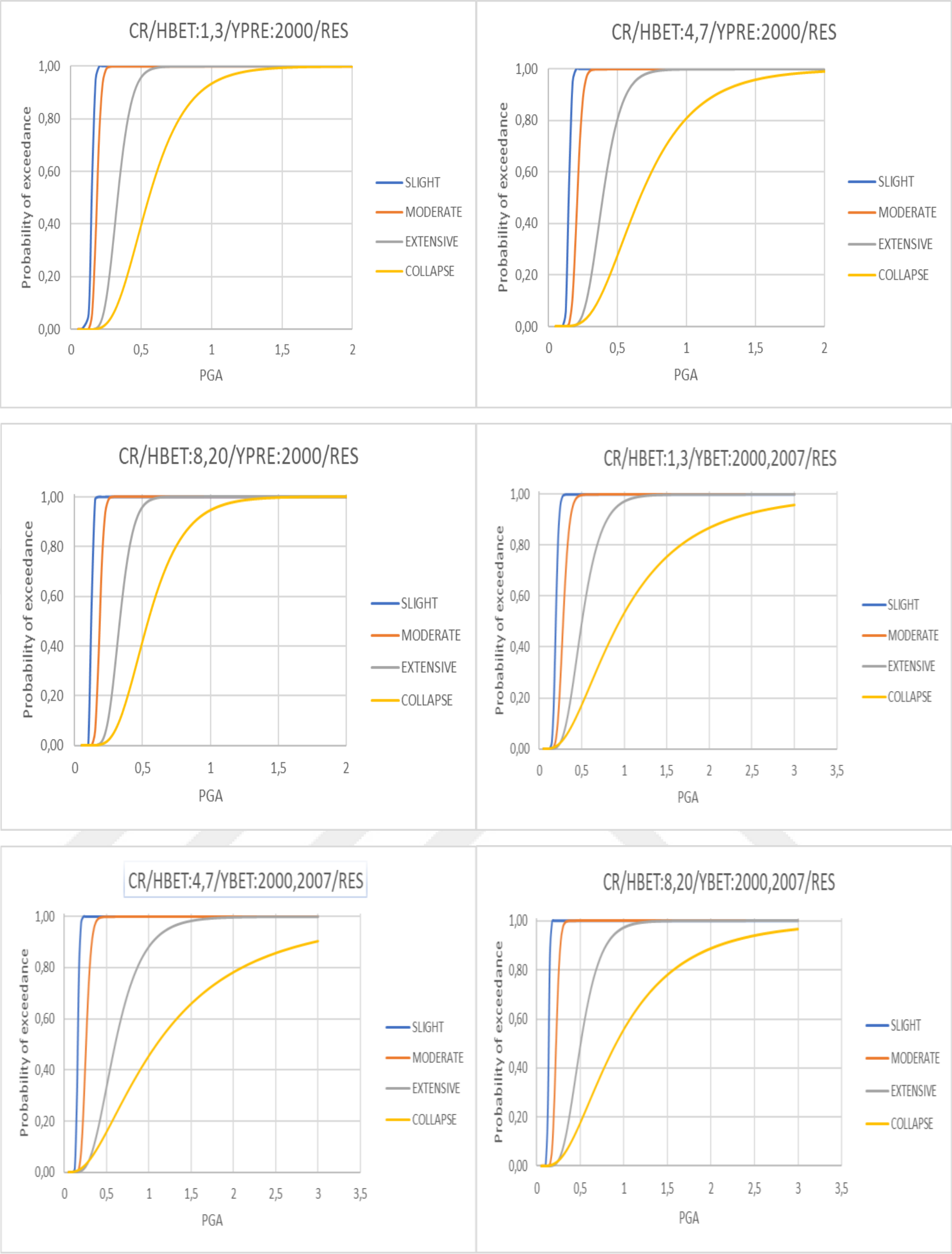


Figure 3.10: Fragility Curves for reinforced concrete buildings.

3.4. Consequence Model

Consequence models are related with direct economic and social losses. In this study 2 types of consequence models have been used [Bal et al, 2008]. Consequence model has been used for computing structural economic losses and HAZUS99 casualty rates for reinforced concrete buildings have been used for computing casualty and injury numbers at the target region [FEMA, 1999].

HAZUS99 casualty rates are separated into 4 levels:

- Level 1 is for injuries requiring basic medical aid without requiring
- Hospitalization
- Level 2 is for injuries requiring medical care and hospitalization, but not
- expected to progress into a life-threatening status
- Level 3 is for injuries that pose an immediate life-threatening condition if not
- treated adequately and expeditiously. The majority of these
- injuries result because of structural collapse and subsequent
- collapse or impairment of the occupants.
- Level4 is for instantaneously killed or mortally injured [FEMA, 1999].

3.5. Vulnerability Model

Vulnerability model is essential for obtaining the losses. Different loss types can be reached depending on the defined vulnerability model. These losses can be economical, casualties, etc. In this study, 2 types of losses have been examined. These are economic losses and occupant losses such as casualties and injuries. Vulnerability curves has been generated by combining the fragility curve and consequence model for region. Vulnerability models have been computed for all levels and number of people for all levels have been obtained.

The fragility curves have been used for damage analysis. And Bal et al. consequence model has been used for generating economical losses, and HAZUS99 casualty rates for reinforced concrete have been used for generating casualties and injury numbers [FEMA, 1999]. Firstly, damage ratios are calculated for each damage states by calculating the difference of probability of exceedance for certain intensity measure level from fragility models. Then, these damage ratios are multiplied with direct economic factor which might be generated by consequence model. The loss ratios can be calculated for certain intensity measure level (PGA for this study) and can be plotted with loss ratios at the y axis and PGA in the x axis. Structural vulnerability models that are used for economic losses in the risk analysis are as follows.

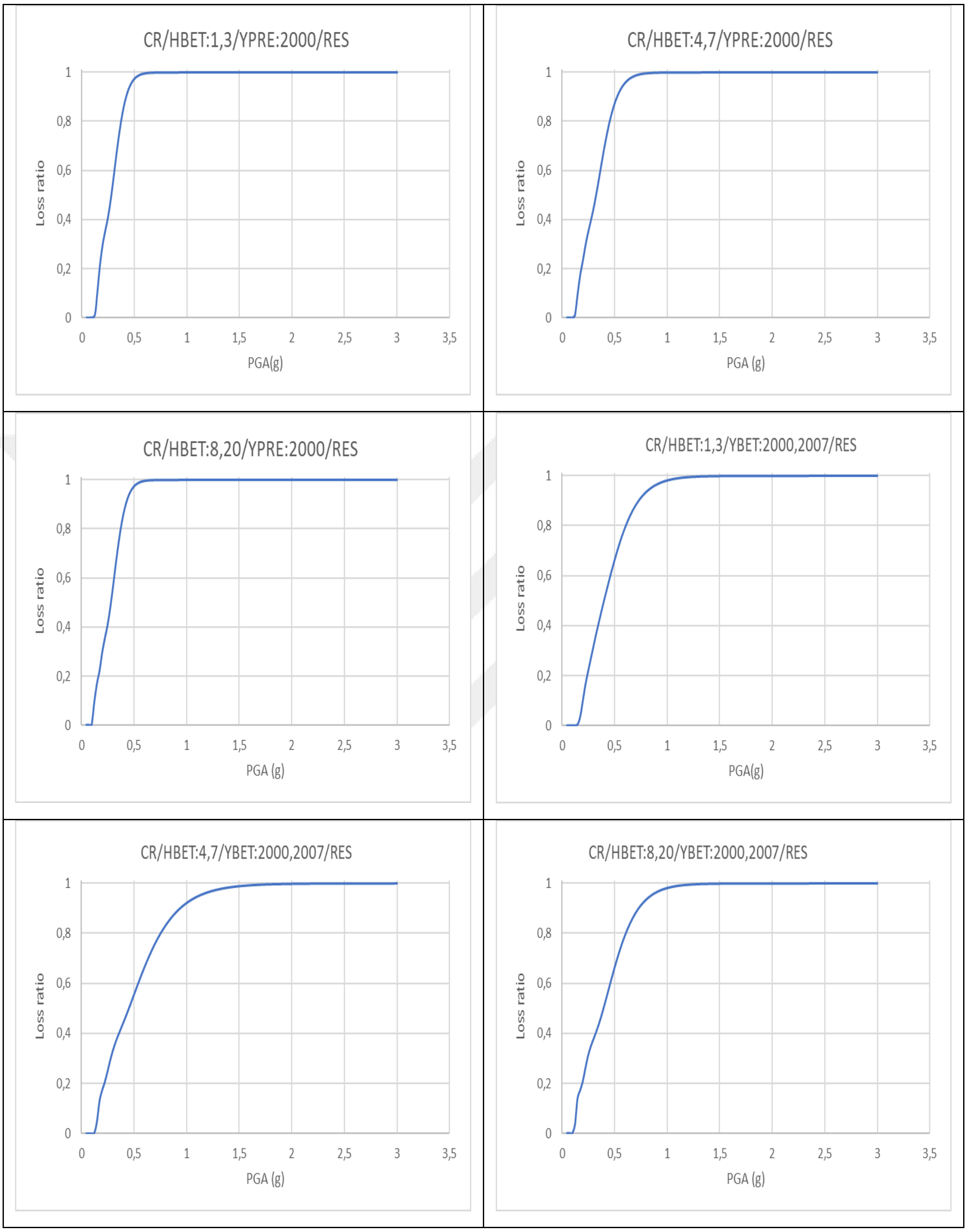


Figure 3.11: Structural Vulnerability Curve for Reinforced Concrete.

Occupant vulnerability models have been used for injury and casualty numbers in the risk analysis. There are 4 levels in HAZUS99 [FEMA, 1999] casualty and injury rates for reinforced concrete buildings. Each level has different casualty rates. Thus, different vulnerability models have been generated for each level and each taxonomy class. Vulnerability models for Level 4 which involve instantaneously killed or mortally injured people are shown below.

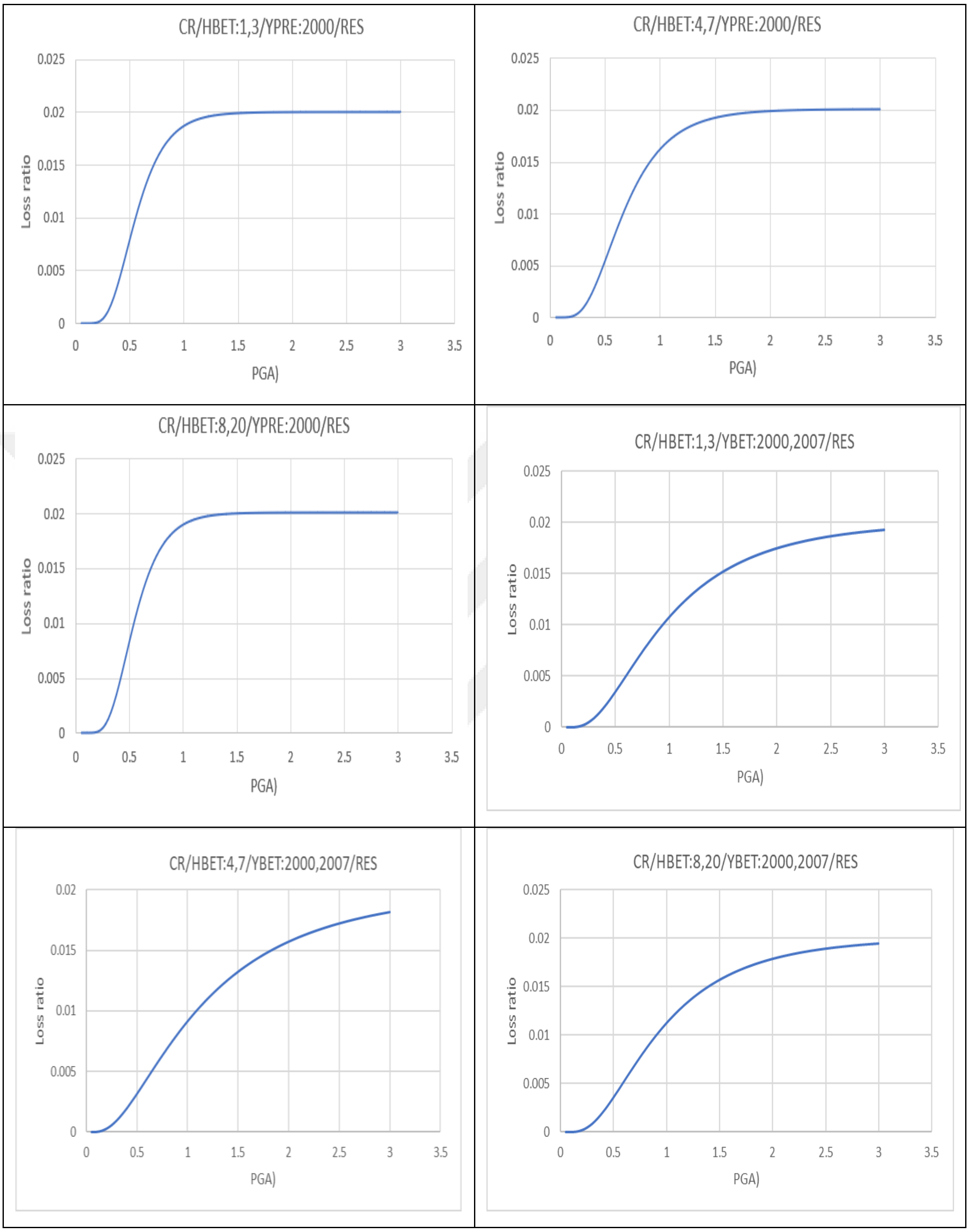


Figure 3.12: Occupants Vulnerability Curve for Reinforced Concrete – LEVEL 4.

4. APPLICATION OF PROPOSED METHODOLOGY FOR THE TARGET REGION

4.1. Classical Probabilistic Hazard Analysis

4.1.1. Methodology

Classical PSHA Calculator uses the ERF and Ground Motion model to compute hazard. It considers all the sources which effect the site unlike scenario analysis. It also considers all the uncertainties which user define at the hazard model preparation stage. Hazard curves values are computed site by site. It also enables to generate hazard maps for different probability of exceedance within given time span by using hazard curves.

4.1.2. Hazard Maps

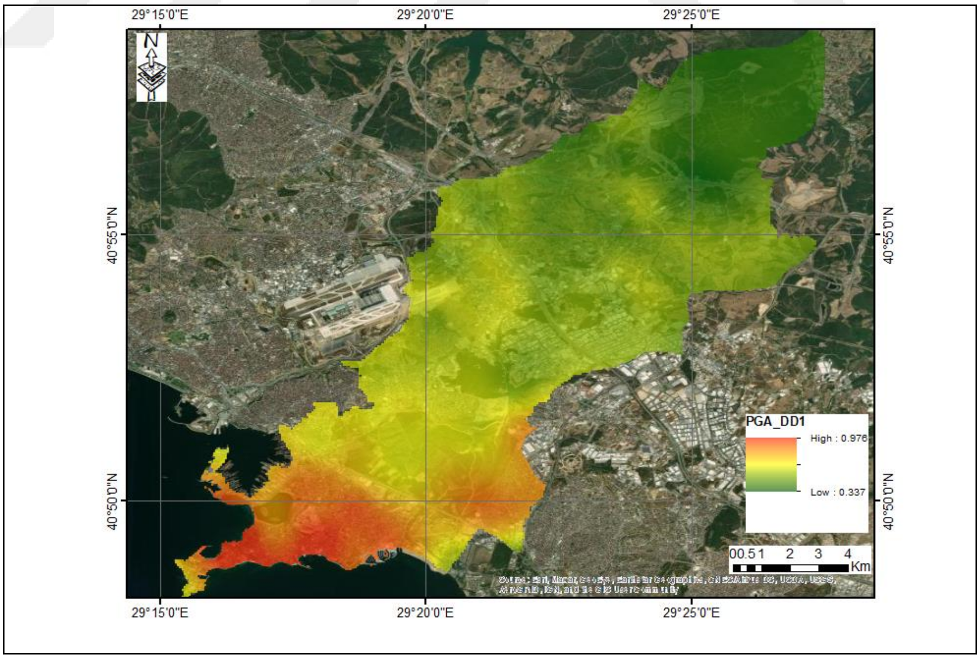


Figure 4.1: PGA Distribution map DD1 2475 years return period.

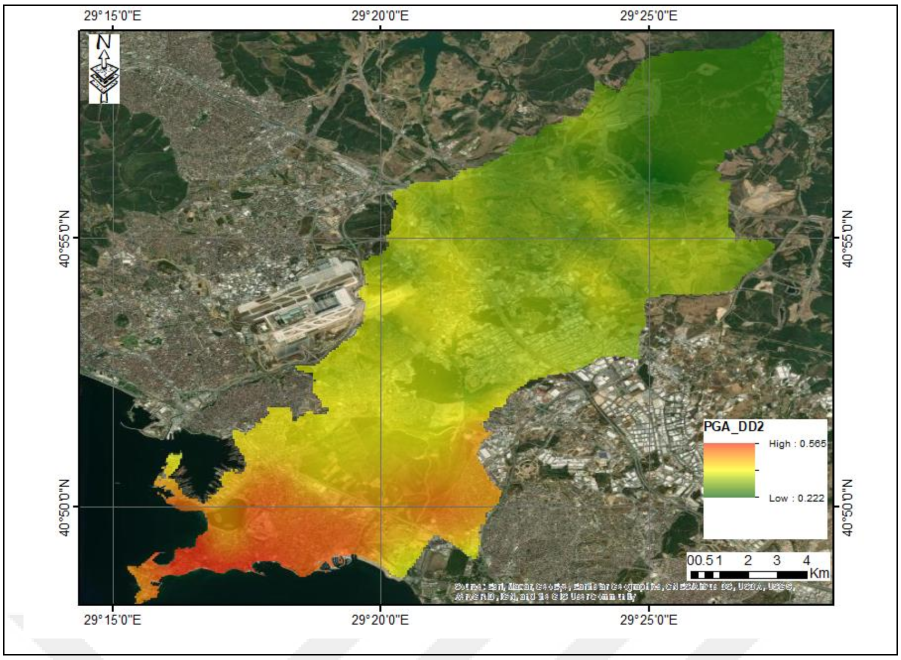


Figure 4.2: PGA Distribution map DD2 475 years return period.

Hazard results for each intensity measure level are calculated based on %2 probability of exceedance in 50 years which refers to DD1 and %10 probability of exceedance in 50 years which refers to DD2 in Turkish Seismic Building Code [TSBC, 2018].

It can be understood that especially coastal part of the region has more seismic hazard in both DD1 (2% probability of exceedance within 50 years, return period 2475 years and DD2 (10% probability of exceedance within 50 years, return period 475 years ground shaking) level from the Fig.4. (a) and Fig.4. (b). PGA reaches to 0.976g for DD1 earthquake level and 0.565g for DD2 level.

4.1.3. Hazard Maps

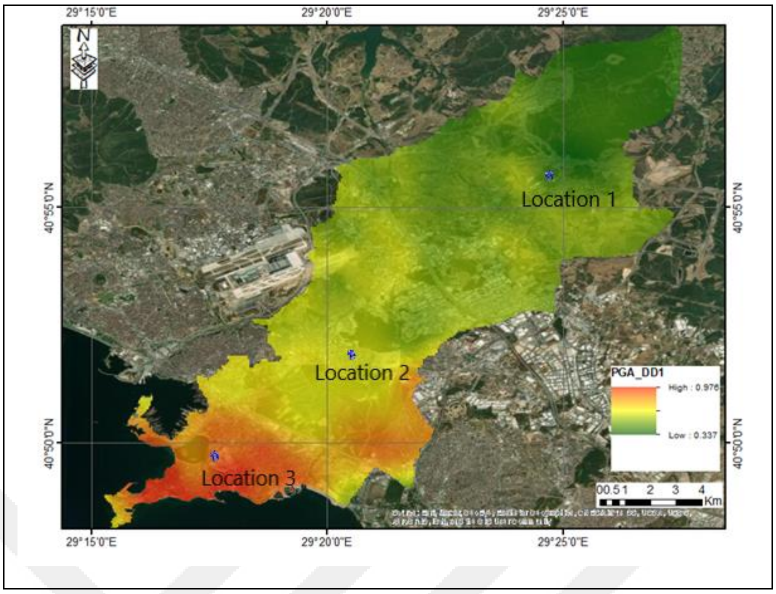


Figure 4.3: 3 Location in Tuzla.

It has been selected 3 locations in Tuzla region to show hazard curves for different asset. Locations are selected based on their hazard level. Location 1 is in low-hazard risk area, Location 2 is in mid-risk area and Location 3 is in high seismic hazard risk area. The hazard curves are plotted of these locations at below. It can be understood from the graph accelerations in T= 0.2 sec are higher than PGA and T=0.1 sec.

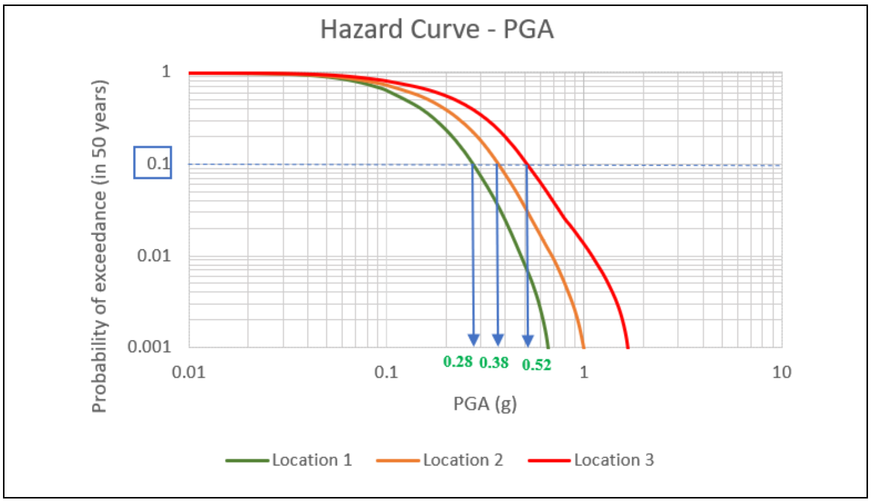


Figure 4.4: PGA Hazard Curve for %10 in 50 years.

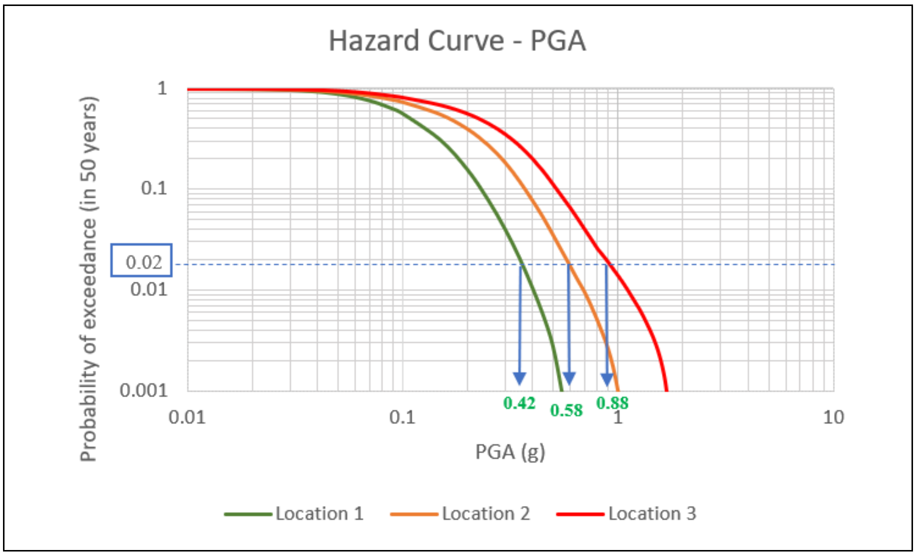


Figure 4.5: PGA Hazard Curve for %2 in 50 years.

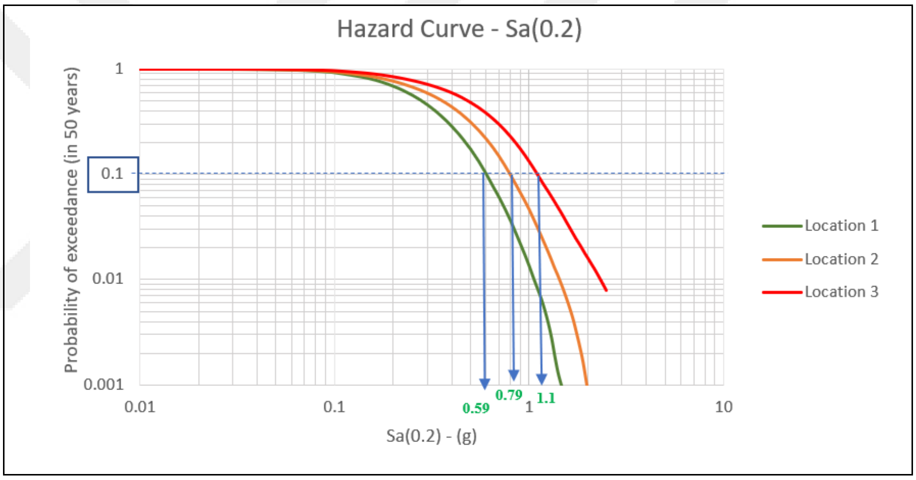


Figure 4.6: Sa (0.2) Hazard Curve for %10 in 50 years.

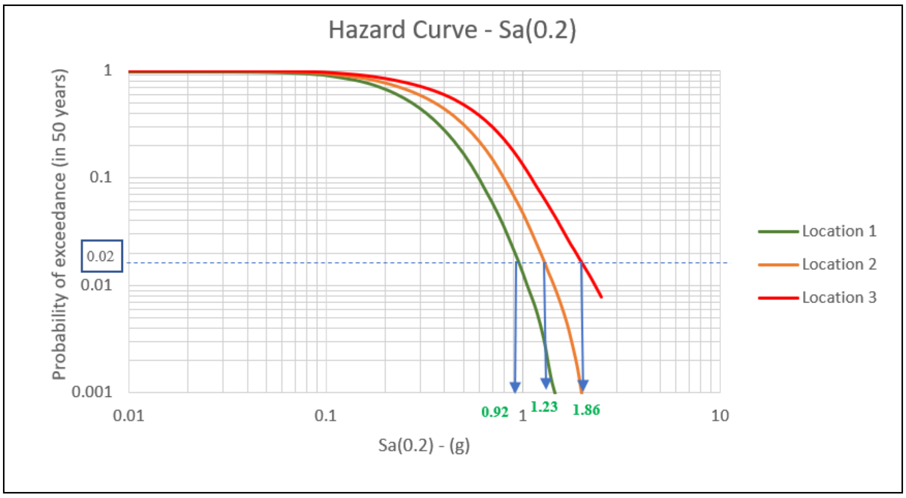


Figure 4.7: Sa (0.2) Hazard Curve for %2 in 50 years.

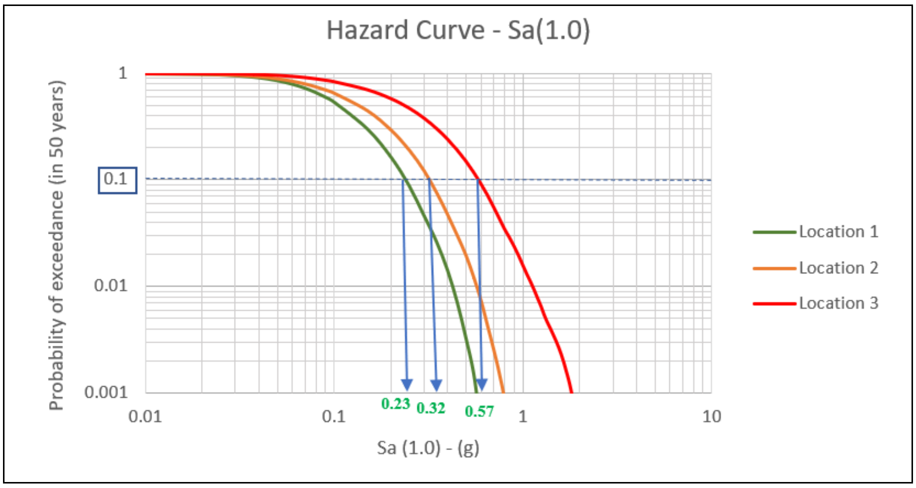


Figure 4.8: Sa (1.0) Hazard Curve for 10% in 50 years.

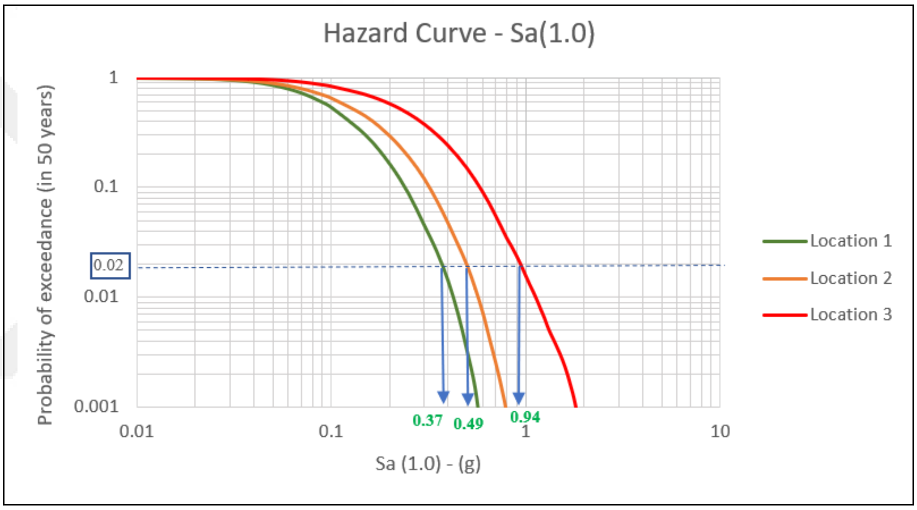


Figure 4.9: Sa (1.0) Hazard Curve for 2% in 50 years.

4.1.4. Uniform Hazard Spectra

Openquake engine enables to compute Uniform Hazard Spectra. The Uniform Hazard Spectras of the locations are plotted, and Response spectrums based on Turkish Building Seismic Code (TSBC 2018) are obtained (for %5 damping) from https://tdth.afad.gov.tr/ database. These two curves are plotted at the same plane at below.

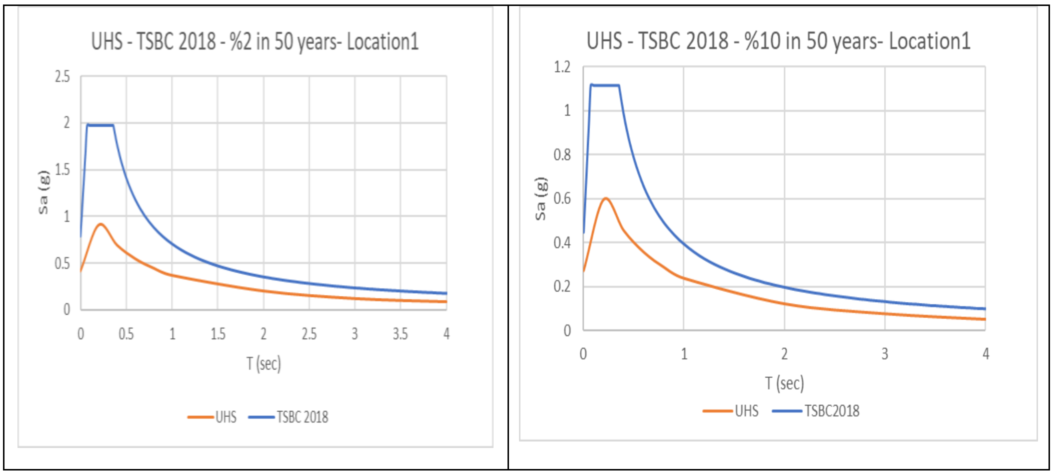


Figure 4.10: Unform Hazard Spectra and TSBC2018 Response Spectrum for Location 1.

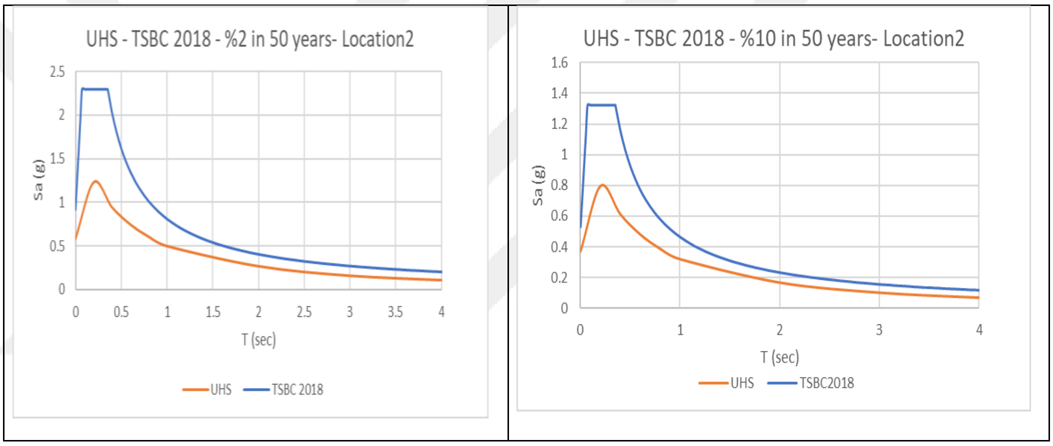


Figure 4.11: Unform Hazard Spectra and TSBC2018 Response Spectrum for Location 2.

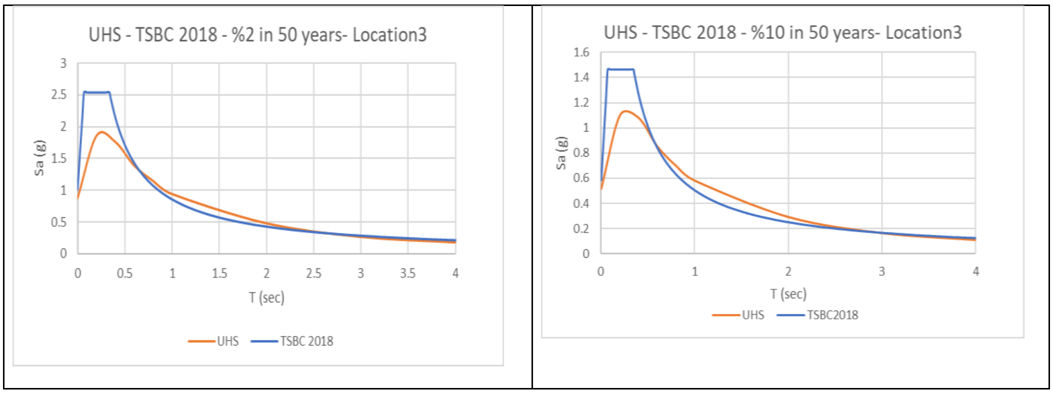


Figure 4.12: Unform Hazard Spectra and TSBC2018 Response Spectrum for Location 3.

4.2. Classical Probabilistic Damage Analysis

4.2.1. Methodology

This calculation mode is used for obtaining damages based on damage state levels such as slight, moderate, extensive and collapse damage states. Hazard Model, Exposure Model and Fragility Models are used for achieving this calculation as it is shown in the Figure 4.1. Outputs are damage distribution for asset, damage distribution for taxonomies and collapse maps.

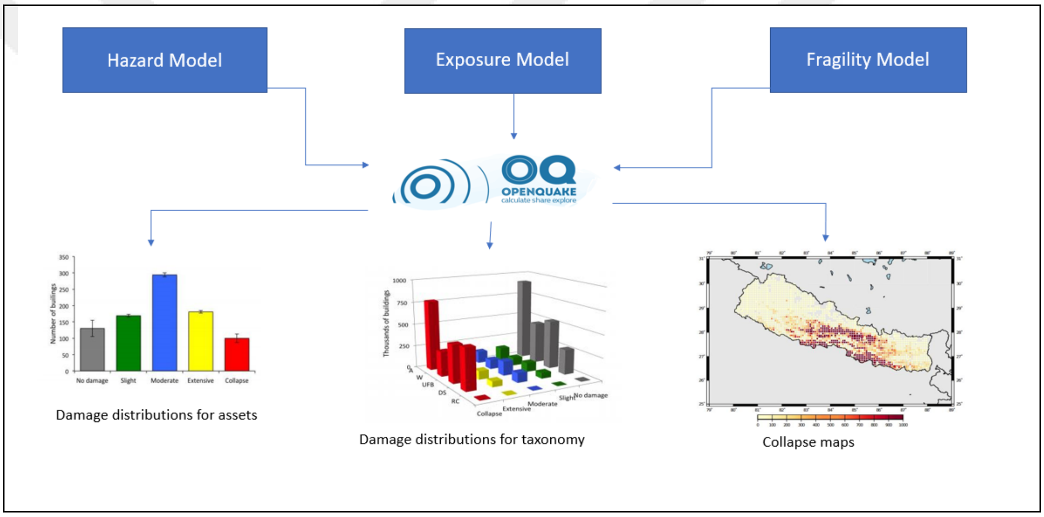


Figure 4.13: Flowchart of Classical Probabilistic Damage Analysis.

Fragility curve is essential for damage calculation because it is the expression of damages based on damage state levels. The distance between each pair of consecutive limit states is calculated corresponding to intensity measure level which is obtained from hazard calculation. In this calculation risk and hazard investigation time are taken as 50 years and results are shown below.

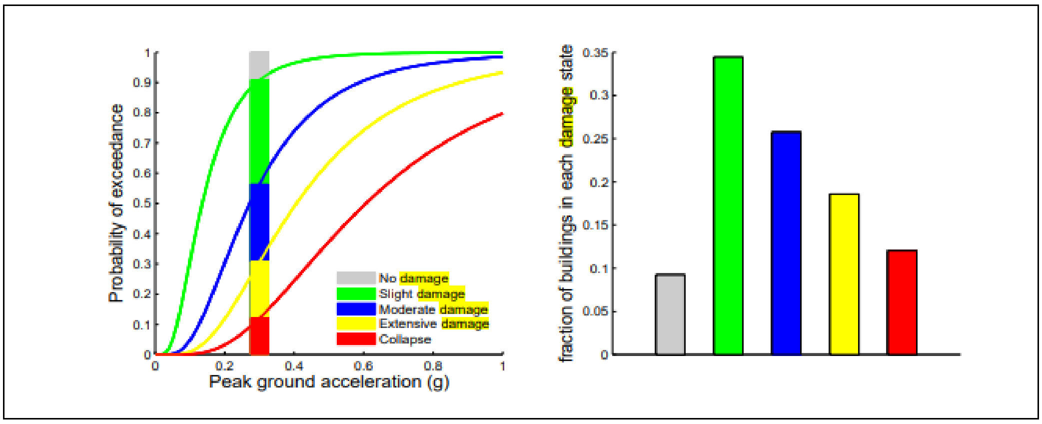
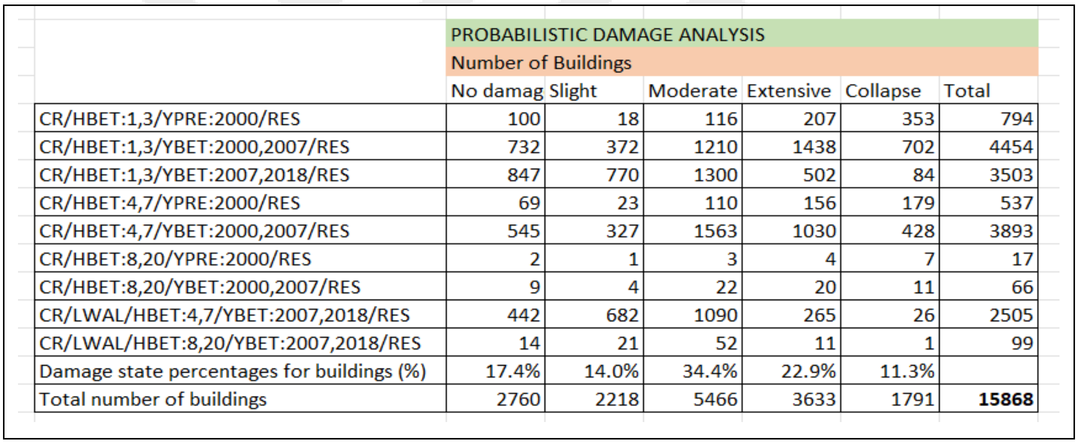


Figure 4.14: Representation of the fractions of building in each damage states, for a given intensity measure level (0.3 g), OQ Engine Book: Risk.

4.2.2. Results of Probabilistic Damage Analysis

Table 4.1: Number of buildings at damage states.



	PROBABILISTIC DAMAGE ANALYSIS					
	Number of Buildings					
	No damag	Slight	Moderate	Extensive	Collapse	Total
CR/HBET:1,3/YPRE:2000/RES	100	18	116	207	353	794
CR/HBET:1,3/YBET:2000,2007/RES	732	372	1210	1438	702	4454
CR/HBET:1,3/YBET:2007,2018/RES	847	770	1300	502	84	3503
CR/HBET:4,7/YPRE:2000/RES	69	23	110	156	179	537
CR/HBET:4,7/YBET:2000,2007/RES	545	327	1563	1030	428	3893
CR/HBET:8,20/YPRE:2000/RES	2	1	3	4	7	17
CR/HBET:8,20/YBET:2000,2007/RES	9	4	22	20	11	66
CR/LWAL/HBET:4,7/YBET:2007,2018/RES	442	682	1090	265	26	2505
CR/LWAL/HBET:8,20/YBET:2007,2018/RES	14	21	52	11	1	99
Damage state percentages for buildings (%)	17.4%	14.0%	34.4%	22.9%	11.3%	
Total number of buildings	2760	2218	5466	3633	1791	**15868**

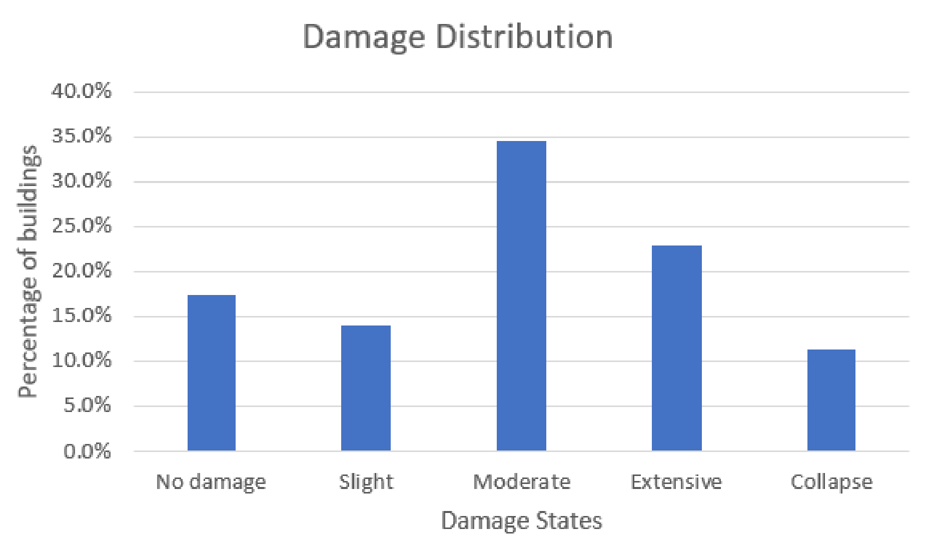


Figure 4.15: Damage distribution.

As it can be understood from the Table 4.1 and Figure 4.15., most damages occur in buildings with low code and mid code. Most of buildings are in moderate and extensive damage states. So many buildings are affected by consequences of earthquake.

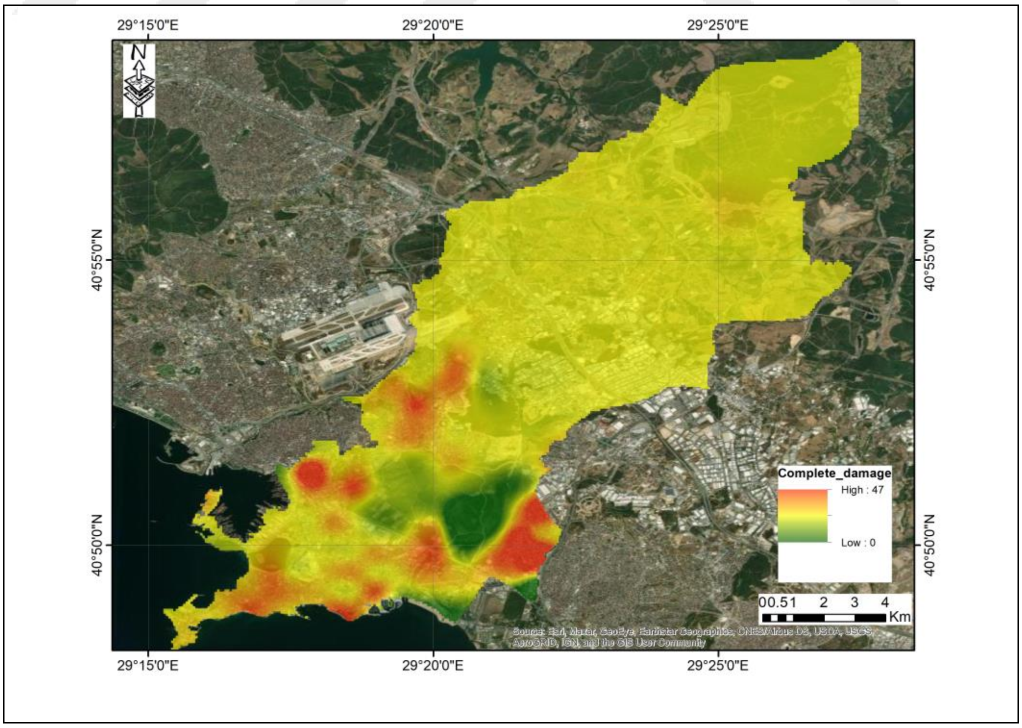


Figure 4.16: Complete damage state map.

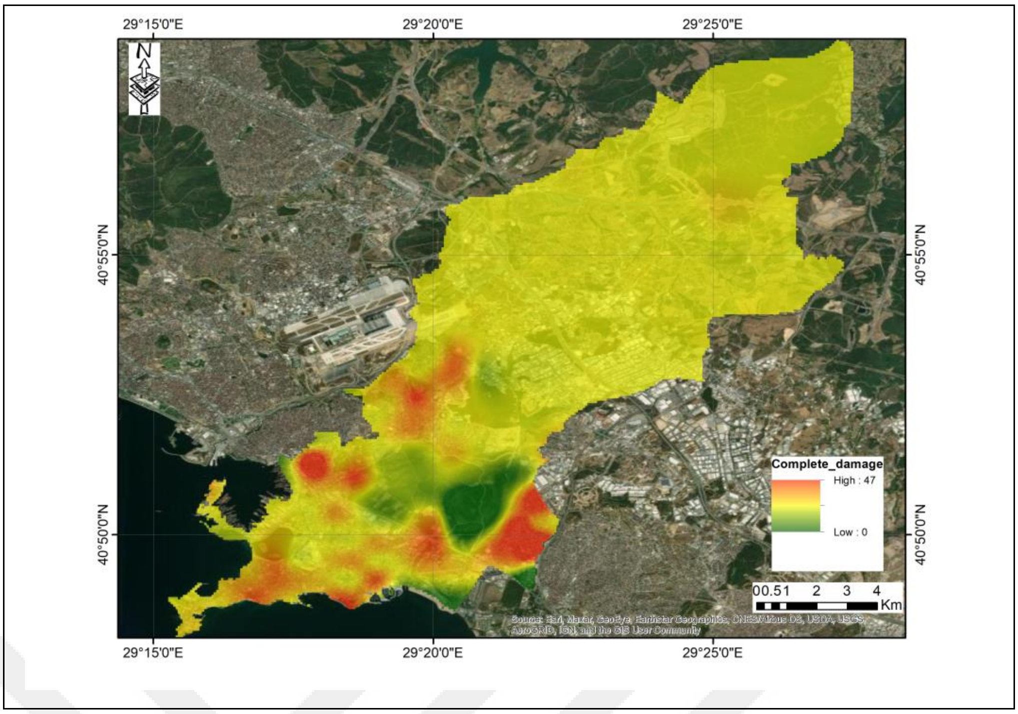


Figure 4.17: Extensive damage state map.

Structural damages are focused on the southern part of Tuzla. These areas are also densely populated areas, it is an important parameter which affects the risk results. Southern part of Tuzla has high seismicity in terms of seismic hazard as it can be understood from the hazard map. Maximum number of buildings for complete damage states reaches 47 within an asset and maximum number of buildings for extensive damage state reaches 90 within an asset. Hazard and risk investigation time are taken 50 years in damage calculation in Openquake. Postane, Aydıntepe, Şifa districts are among the areas with the most severe damages. When the number of buildings is examined, most of buildings are in moderate and extensive damage state.

4.3. Classical Probabilistic Seismic Risk Analysis

4.3.1. Methodology

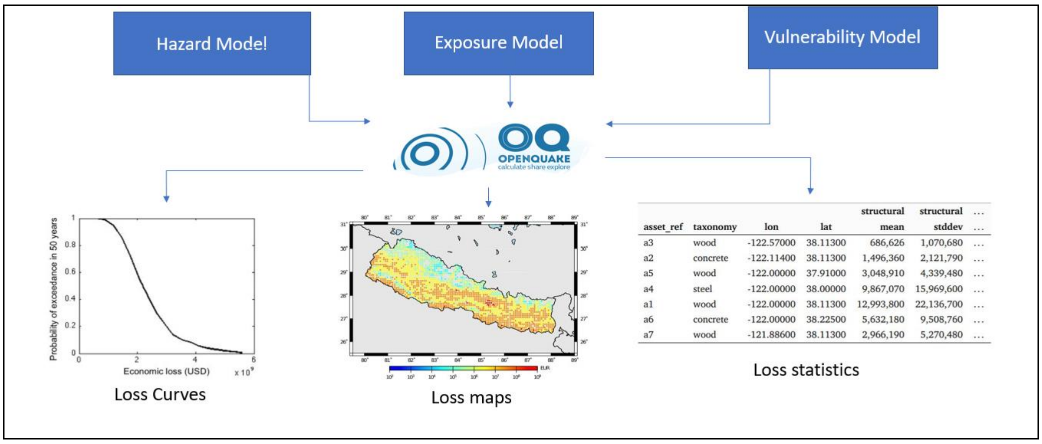
Hazard curves have been used as hazard data in this calculation mode since it’s based on probabilistic approach. Hazard curve considers all the sources which have potential to generate an earthquake. These curves are expressed probability of exceedance of excitation under intensity measure level.

Hazard curves are placed under vulnerability curve. Intensity measure level in both curves is placed on X axis. For the subjected loss ratio, the IML (intensity measure level) is read and the probability of exceedance corresponding to that value is found on the hazard curve. The midpoint of each loss interval is considered for doing this process. Upper and lower bound of each interval is specified and the probability of occurrence is calculated with the formula shown at below.

$$PO = PE[lowerbound] - PE[upperbound] \tag{4.1}$$

The loss exceedance matrixes have been generated as secondary step. The columns of this matrix consist of number of intensity measure level, and the rows have been referred to loss ratios defined in the vulnerability function [Crowley and Silva, 2013]. The probability of exceedance has been generated for each number of intensity measure level and loss ratio pairs. Calculating probability of exceedance for intermediate loss ratio’s function will lead to more accurate results. This will be better to not just calculate consecutive loss ratios defined in the discrete vulnerability. The loss exceedance matrix has been obtained after multiplying probability of exceedance with probability of occurrence for each loss ratio.

Probability of exceedance of each loss has been summed and loss ratios have been multiplied by the related asset values defined in the exposure model to generate loss exceedance curve.



asset_ref	taxonomy	lon	lat	structural mean	structural stddev	…
a3	wood	-122.57000	38.11300	686,626	1,070,680	…
a2	concrete	-122.11400	38.11300	1,496,360	2,121,790	…
a5	wood	-122.00000	37.91000	3,048,910	4,339,480	…
a4	steel	-122.00000	38.00000	9,867,070	15,969,600	…
a1	wood	-122.00000	38.11300	12,993,800	22,136,700	…
a6	concrete	-122.00000	38.22500	5,632,180	9,508,760	…
a7	wood	-121.88600	38.11300	2,966,190	5,270,480	…

Figure 4.18: Flowchart of Classical Probabilistic Analysis.

In this study, there are 2 type of losses obtained. These are structural, economical losses and casualties, and injuries. 2 different vulnerability curves are generated for structural economical losses and casualties and injuries. Losses are calculated based on %2 probability of exceedance in 50 years which refers to DD1 and %10 probability of exceedance in 50 years which refers to DD2 in Turkish Seismic Building Code (TSBC 2018).

4.3.2. Results of Structural Economic Losses

4.3.2.1. Loss Maps

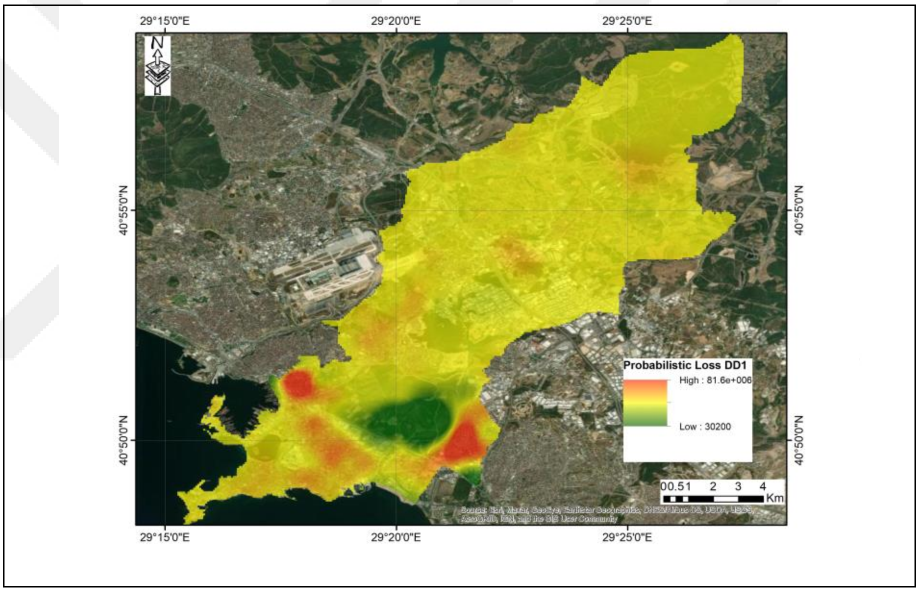


Figure 4.19: Structural Loss Map for DD1 Level of Ground Shaking.

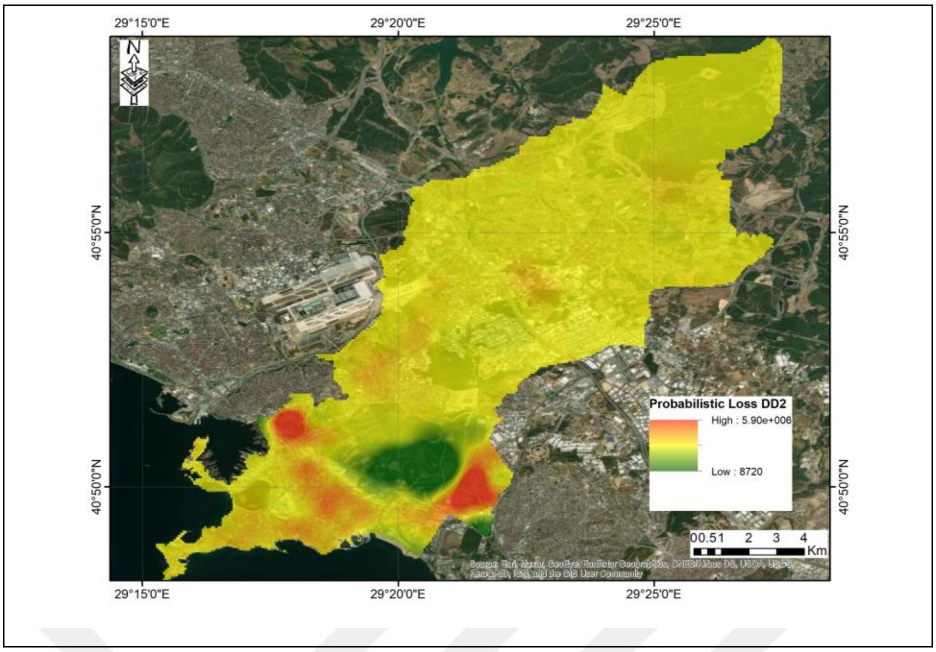


Figure 4.20: Structural Loss Map for DD2 Level of Ground Shaking.

Maximum loss is about 81.6 million USD and minimum loss is 30200 USD within given assets DD1 level of earthquake which refers to earthquakes with 2475 occurrence period. For DD2 earthquake level, maximum loss is approximately 5.90 million USD and minimum loss is about 8720 USD. If these losses were considered as quarter by quarter, loss value would be higher. Postane, Aydıntepe and Şifa districts are among areas with the most economic losses.

4.3.2.2. Loss Curves

3 assets have been selected both CR/HBET:4,7/YBET:2000,2007/RES class which refer to mid-rise and mid-code Reinforced Concrete buildings and CR/HBET:4,7/YBET:2007,2018/RES class which refer to mid-rise and high-code Reinforced Concrete buildings to show loss curves. Assets have been selected from different locations based on their structural loss level. The assets which are selected for CR/HBET:4,7/YBET:2007,2018/RES class have been showed in Figure 4.21 and Figure 4.24 and loss curves which belong to these assets are shown at below.

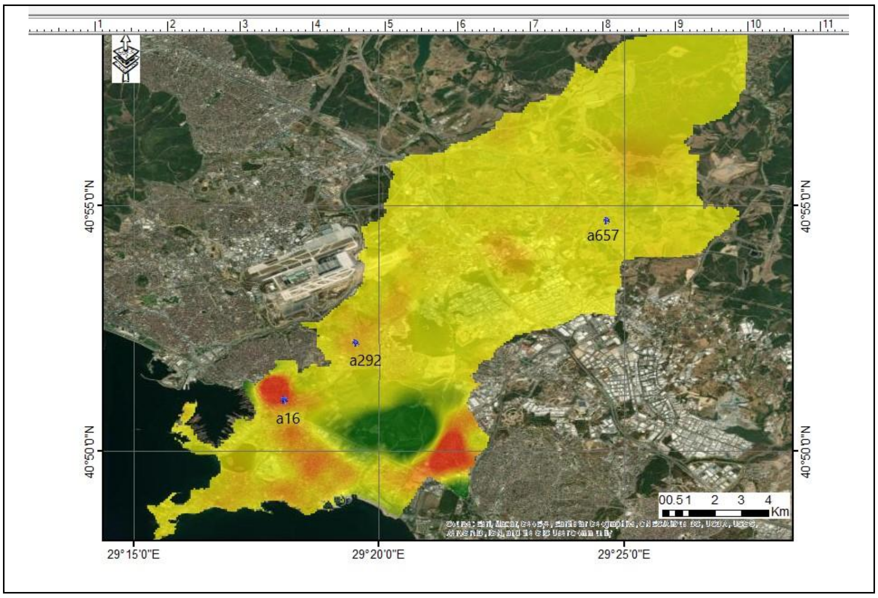


Figure 4.21: Location of a16, a292, a657 assets.

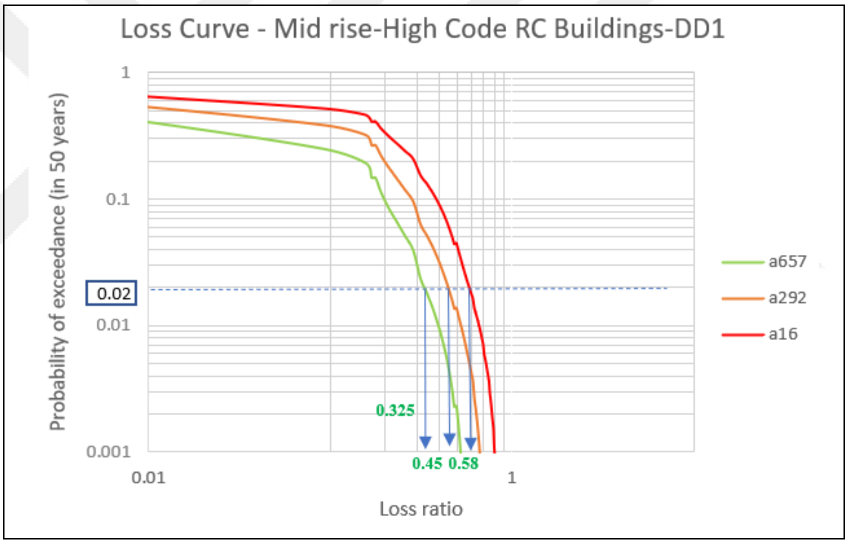


Figure 4.22: Loss curve for a16, a292, a657
(2% prob. In 50 years).

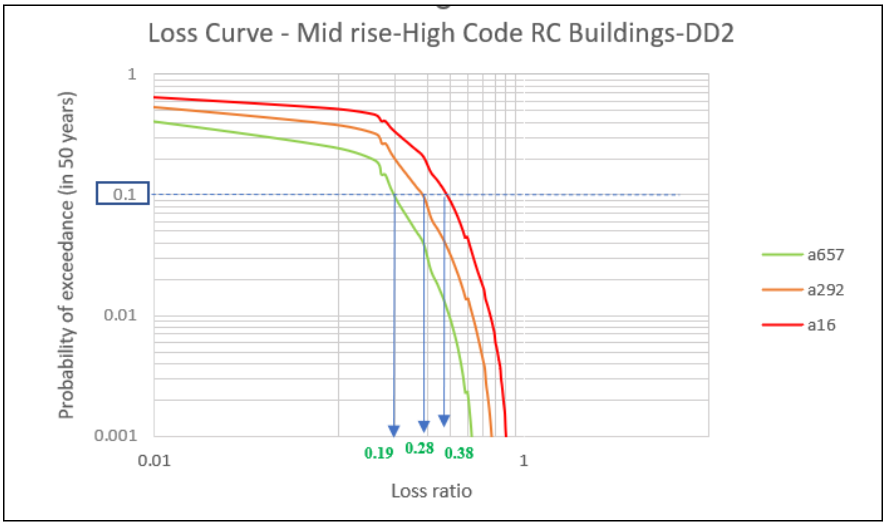


Figure 4.23: Loss curve for a16, a292, a657
(10% prob. In 50 years).

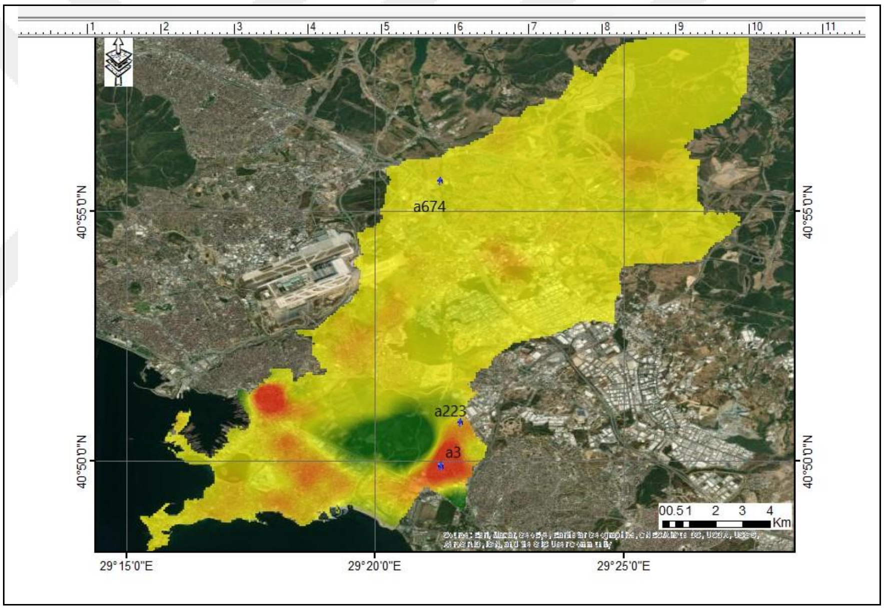


Figure 4.24: Location of a3, a223, a674.

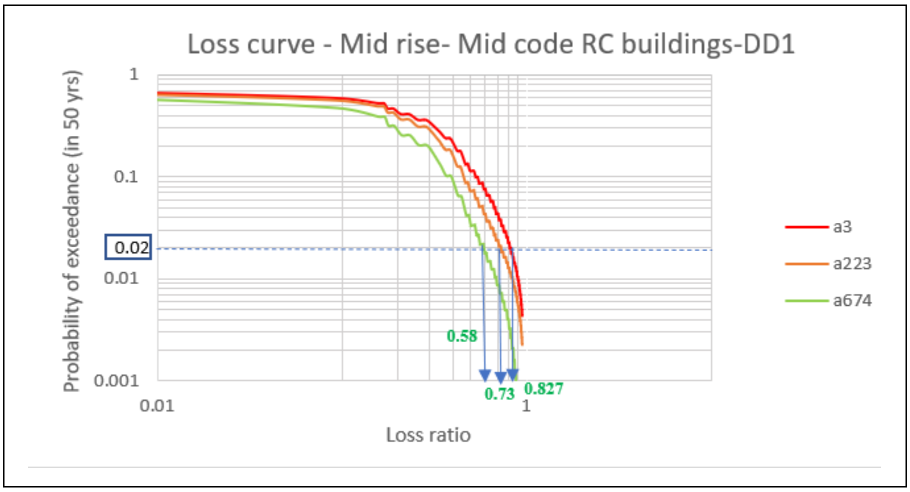


Figure 4.25: Loss curve for a3, a223, a674
(2% prob. In 50 years).

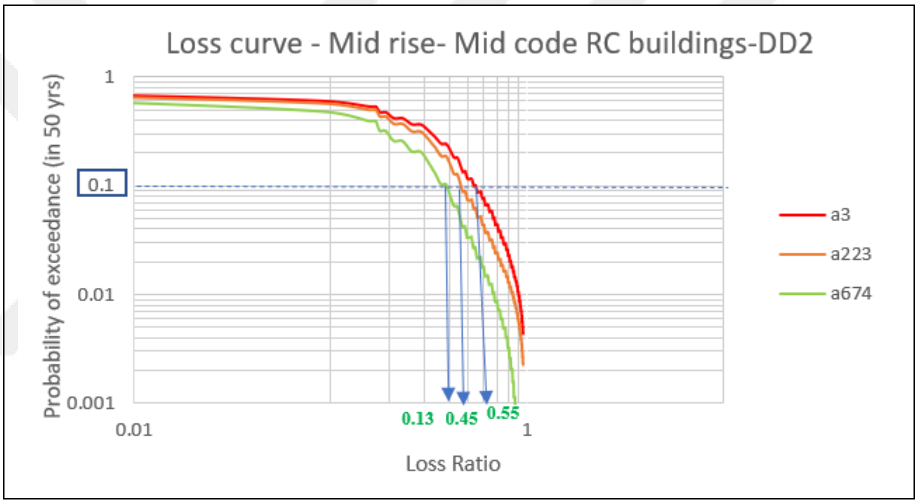


Figure 4.26: Loss curve for a3, a223, a674
(10% prob. In 50 years).

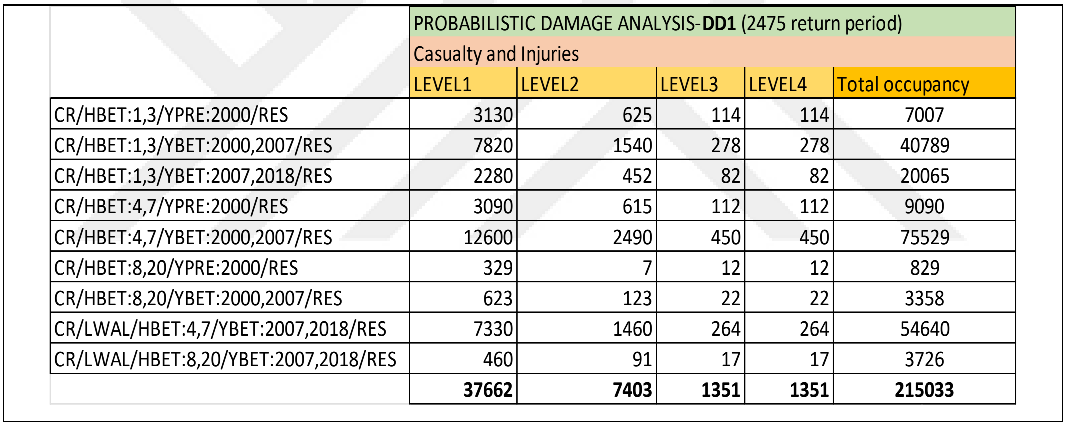
The loss curves which are shown above are from different asset and areas of the region. These assets are taken according to their structural losses level. If loss ratios are examined for 2% of exceedance in 50 years in two graph Figure 4.22 and Figure 4.25, loss ratios are higher a3 and a16 assets. Also, the structural losses are higher at these locations. It reaches 81.5 million USD. These results are shown that south part of the region subjected with the most losses. Losses decrease as it goes north.

When the structural losses and loss ratios are compared, values are decreased of high-code taxonomy class. This prove that how the codes effect structural losses.

4.3.3. Result of Casualties and Injuries

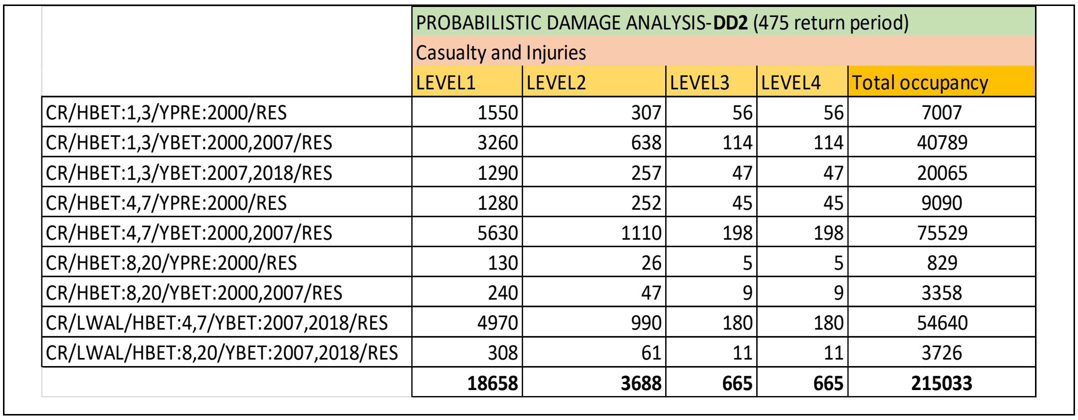
Occupant vulnerability curves are generated with the combination of fragility curves and HAZUS99 [FEMA, 1999] Casualty Rates. Number of people for each level of injury is generated as shown below. Level 1 is for injuries requiring basic medical aid without requiring hospitalization. Thus, the number of people in this level are higher than the other levels. Whereas number of people in Level 4 which is for instantaneously killed or mortally injured is less. However, it is worth to consider. Consequently, so many people will be affected of consequences of earthquake.

Table 4.2: Number of Injury and casualty for DD1 (2475 yrs. Return period).



	PROBABILISTIC DAMAGE ANALYSIS-**DD1** (2475 return period)				
	Casualty and Injuries				
	LEVEL1	LEVEL2	LEVEL3	LEVEL4	Total occupancy
CR/HBET:1,3/YPRE:2000/RES	3130	625	114	114	7007
CR/HBET:1,3/YBET:2000,2007/RES	7820	1540	278	278	40789
CR/HBET:1,3/YBET:2007,2018/RES	2280	452	82	82	20065
CR/HBET:4,7/YPRE:2000/RES	3090	615	112	112	9090
CR/HBET:4,7/YBET:2000,2007/RES	12600	2490	450	450	75529
CR/HBET:8,20/YPRE:2000/RES	329	7	12	12	829
CR/HBET:8,20/YBET:2000,2007/RES	623	123	22	22	3358
CR/LWAL/HBET:4,7/YBET:2007,2018/RES	7330	1460	264	264	54640
CR/LWAL/HBET:8,20/YBET:2007,2018/RES	460	91	17	17	3726
	37662	**7403**	**1351**	**1351**	**215033**

Table 4.3: Number of Injury and casualty for DD2 (475 yrs. Return period).



	PROBABILISTIC DAMAGE ANALYSIS-**DD2** (475 return period)				
	Casualty and Injuries				
	LEVEL1	LEVEL2	LEVEL3	LEVEL4	Total occupancy
CR/HBET:1,3/YPRE:2000/RES	1550	307	56	56	7007
CR/HBET:1,3/YBET:2000,2007/RES	3260	638	114	114	40789
CR/HBET:1,3/YBET:2007,2018/RES	1290	257	47	47	20065
CR/HBET:4,7/YPRE:2000/RES	1280	252	45	45	9090
CR/HBET:4,7/YBET:2000,2007/RES	5630	1110	198	198	75529
CR/HBET:8,20/YPRE:2000/RES	130	26	5	5	829
CR/HBET:8,20/YBET:2000,2007/RES	240	47	9	9	3358
CR/LWAL/HBET:4,7/YBET:2007,2018/RES	4970	990	180	180	54640
CR/LWAL/HBET:8,20/YBET:2007,2018/RES	308	61	11	11	3726
	18658	**3688**	**665**	**665**	**215033**

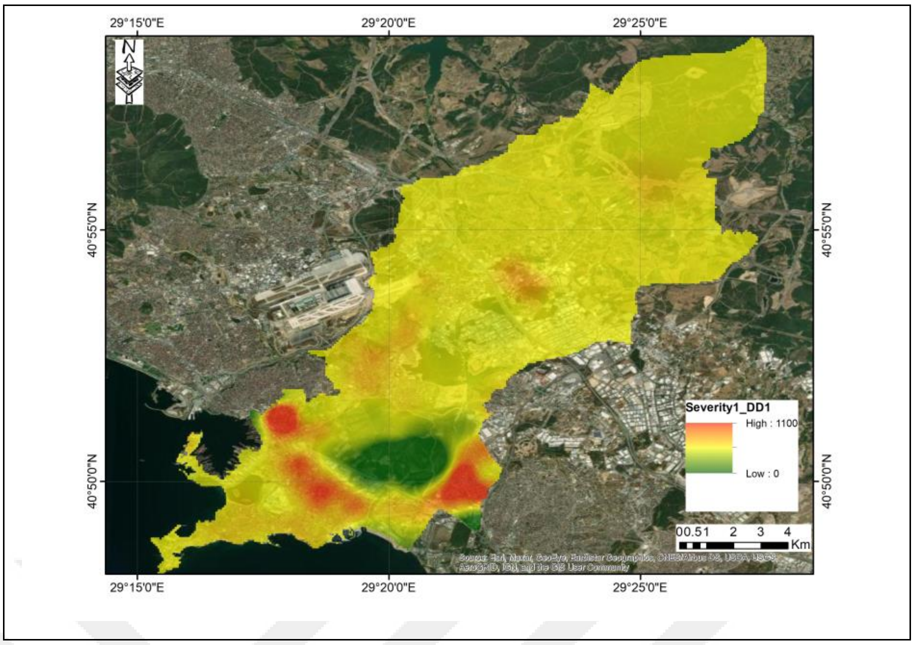


Figure 4.27: Occupancy Loss Map for Level 1 -DD1.

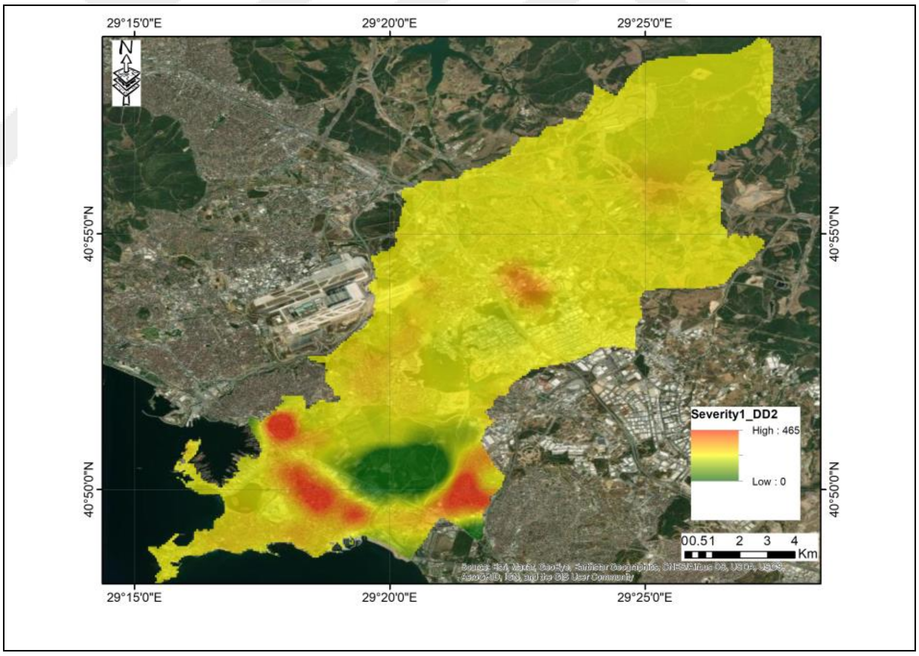


Figure 4.28: Occupancy Loss Map for Level 1 -DD2.

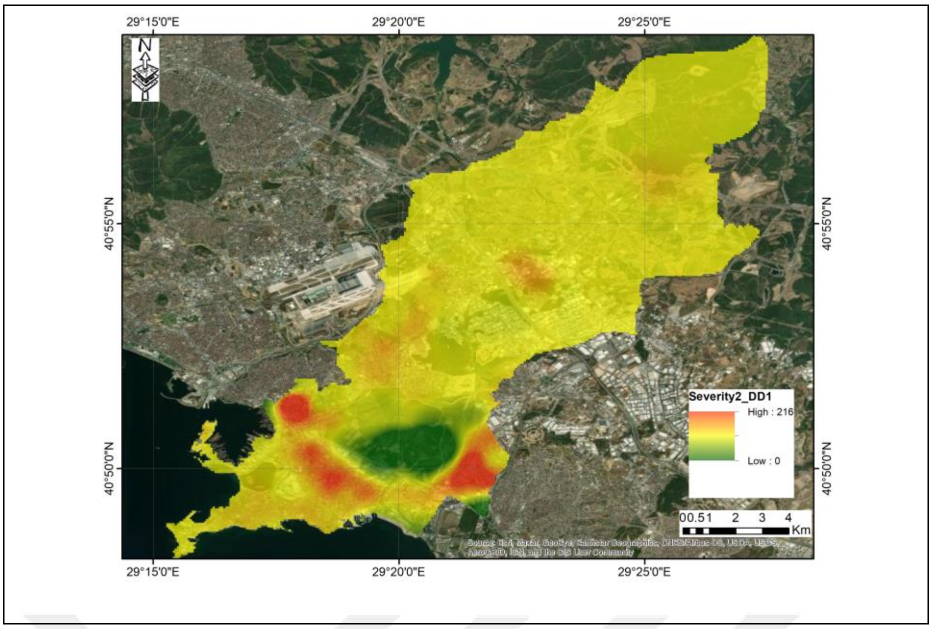


Figure 4.29: Occupancy Loss Map for Level 2 -DD1.

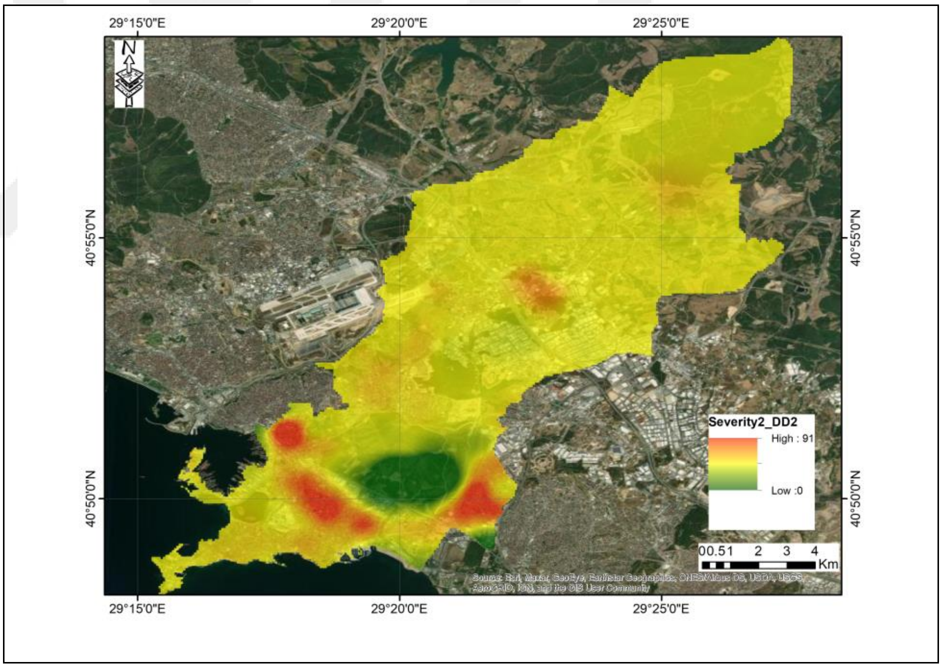


Figure 4.30: Occupancy Loss Map for Level 2 -DD2.

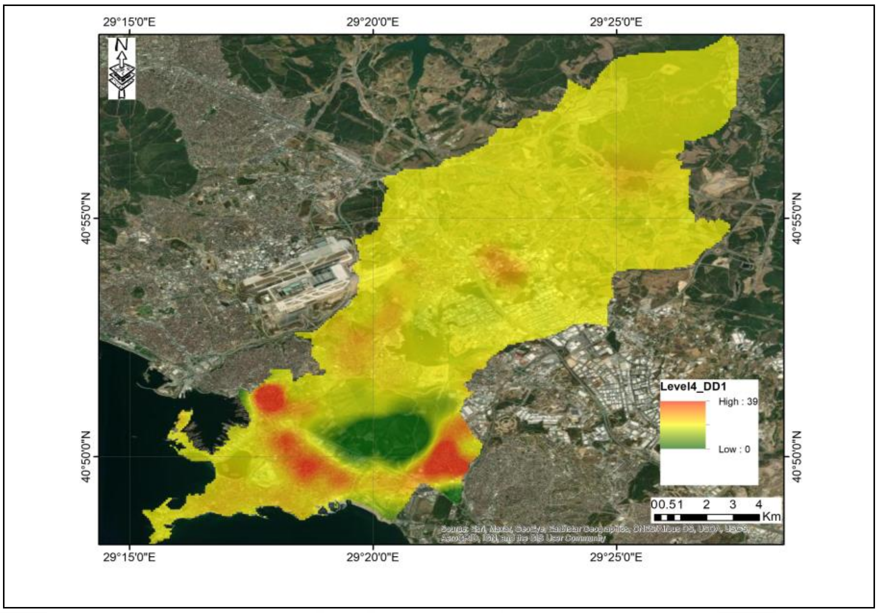


Figure 4.31: Occupancy Loss Map for Level 4 -DD1.

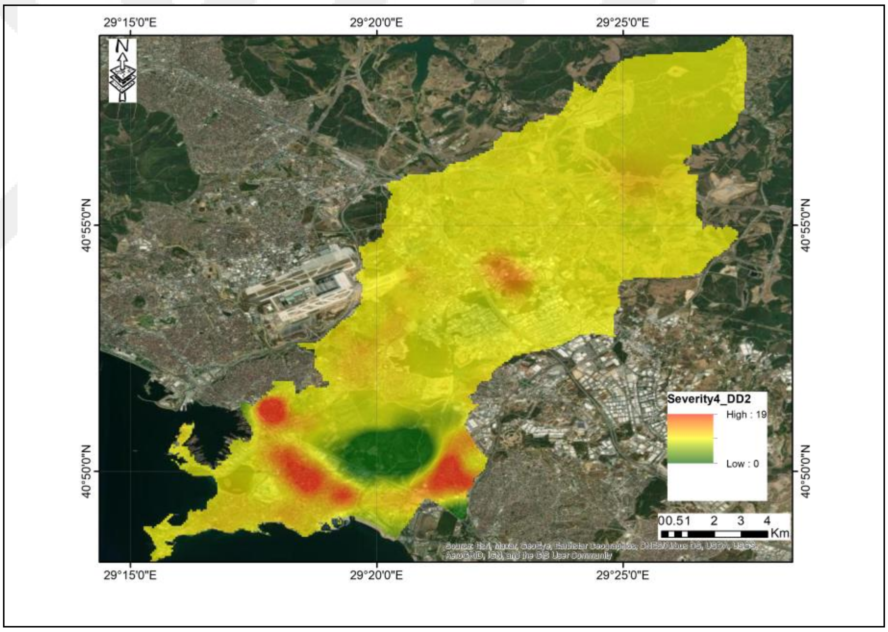


Figure 4.32: Occupancy Loss Map for Level 4 -DD2.

5. CONCLUSIONS

When collapse building in damage states is examined, the most vulnerable building class is CR/HBET:1,3/YPRE:2000/RES which refers to reinforced concrete, low-rise and constructed before 2000 and CR/HBET:4,7/YPRE:2000/RES which refers reinforced concrete mid-rise and constructed before 2000. These buildings are considered as pre-code buildings. These results prove the importance of developing building codes. With the development of technology, new techniques are applied in designing structures. These buildings should be examined and retrofit, or reconstruction studies should be performed for making ready these buildings to the earthquakes. Also, the economic losses are about 81.6 million USD for DD1 and 5.9 million USD for DD2 level of shaking. These losses indicate that the economic loss will be high during a potential extreme seismic event. Also, the south area of Tuzla region has higher seismic hazard, and this area is important in terms of its economic value. Region will face with difficulties both economic and social way.

Some precautions should be taken by relevant departments and organizations for minimizing the potential losses. The results of this study will contribute the studies for reducing results of seismic risk and rehabilitation of buildings that are vulnerable to an earthquake.

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BIOGRAPHY

Melis Erdogan was raised in Istanbul and completed her high school degree in in Istanbul. After graduated from high school, she studied in Sakarya University in Civil Engineering Department. She graduated from here in 2015. She started her professional career with the jobs. She continued her professional life with master's degree in Gebze Technical University in 2018.