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SEISMIC RISK ASSESSMENT OF SCHOOL BUILDINGS IN KOCAELI REGION

SİNAN YAZICI

A THESIS OF MASTER OF SCIENCE
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EARTHQUAKE AND STRUCTURAL ENGINEERING PROGRAM

ADVISOR: ASSOC. PROF. DR. ABDULLAH CAN ZÜLFİKAR

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GEBZE TEKNİK ÜNİVERSİTESİ

LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

KOCAELİ BÖLGESİNDEKİ OKUL YAPILARININ SİSMİK RİSK DEĞERLENDİRMESİ

SİNAN YAZICI

YÜKSEK LİSANS TEZİ

İNŞAAT MÜHENDİSLİĞİ ANABİLİM DALI

DEPREM VE YAPI MÜHENDİSLİĞİ PROGRAMI

DANIŞMAN: DOÇ. DR. ABDULLAH CAN ZÜLFİKAR

EKİM 2024

MASTER of SCIENCE JURY APPROVAL FORM

A thesis submitted by Sinan Yazıcı, defended on 18/10/2024 before the jury formed with the 04/07/2024 date and 2024/34 numbered decision of the GTU Graduate Administration Board, has been accepted as a MASTER of SCIENCE thesis in the Department of Civil Engineering, Earthquake and Structural Engineering Program.

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Gebze Technical University Graduate Administration Board
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ABSTRACT

Türkiye, due to its geographical location, is situated at the intersection of dangerous fault lines, making it a region with a high risk of earthquakes. Especially in densely populated areas, potential earthquakes pose a significant threat to life and property. In this context, Kocaeli, like many other provinces in Türkiye, is a region with a high population density and consequently high seismic risk. This heightened risk in Kocaeli necessitates a comprehensive seismic assessment of structures used as gathering and protection areas during disasters, such as educational buildings.During and after natural disasters, ensuring the resilience of public service structures (e.g., schools, hospitals) is crucial for community safety. Schools, in particular, are of utmost importance due to the high density of students and staff they accommodate. The safety of these structures, which can become crowded in times of emergency, is vital for preventing potential casualties and injuries during earthquakes.This study focuses on determining the seismic risks of school buildings in Kocaeli province. The first step of this risk assessment involves conducting a hazard analysis for the region. Hazard analysis is concerned with possible earthquakes in a specific area and the impact they may have. In this analysis process, parameters such as the region's soil characteristics, historical earthquake records, fault line depths, and other fault features are examined in detail. Based on this data, probabilistic ground motion values (ground accelerations) are calculated to understand the magnitude and intensity of potential seismic movements in the area. Using this information, a hazard map for Kocaeli province has been created.

Following the hazard analysis, existing school buildings in the region were examined. These structures were analyzed and categorized according to their structural characteristics and resilience levels. After the classification of these buildings, vulnerability curves specific to these structures were generated. Vulnerability curves are graphical tools used to estimate the potential damage to structures in response to specific seismic activity. Thus, projections regarding the potential damage to school buildings during and after an earthquake were made.

By incorporating building stock analysis and vulnerability curves, the expected levels of damage in the assessed school buildings can be calculated. Based on these damage estimates, recommendations have been provided on necessary safety measures to ensure the security of these school buildings. Additionally, to verify the accuracy and validity of the study, a performance-based risk assessment was conducted on a typical structure from the school buildings in Kocaeli. This assessment provides more detailed insights into how these school buildings might perform under real earthquake conditions.

In conclusion, this study aims to highlight the earthquake risk of high-importance school buildings in Kocaeli province. Through the conducted risk assessment, valuable information has been obtained regarding necessary precautions to enhance the safety of these buildings, and recommendations have been developed for implementing these measures.

Keywords: Seismic Hazard Analysis, Seismic Risk Assessment, Hazard Curve, Hazard Map, Fragility Curve

ÖZET

Türkiye, coğrafi yapısı itibarıyla tehlikeli fay hatlarının kesişim noktalarından biri üzerinde yer almakta olup, bu durum ülkeyi yüksek deprem riski taşıyan bir bölge haline getirmektedir. Özellikle yoğun nüfuslu bölgelerde meydana gelebilecek depremler, geniş çaplı can ve mal kayıplarına yol açma potansiyeline sahiptir. Bu çerçevede, Türkiye'deki pek çok il gibi Kocaeli de nüfus yoğunluğu yüksek ve dolayısıyla yüksek sismik risk taşıyan bir bölgedir. Kocaeli'nin bu riskli durumu, özellikle eğitim yapıları gibi afet durumlarında insanların toplanma ve korunma alanı olarak kullanılan yapılar üzerinde kapsamlı bir sismik değerlendirme yapılmasını gerektirir.Doğal afetler sırasında ve sonrasında toplumun güvenliğini sağlamak için, kamu hizmeti sunan yapıların (okullar, hastaneler vb.) dayanıklı olması kritik öneme sahiptir. Bu yapılardan okullar, öğrenci ve personel yoğunluğu nedeniyle özellikle önemli bir konumdadır. Afet anında kalabalık ve yoğun bir şekilde kullanılabilen bu tür yapıların güvenliğinin sağlanması, olası can kayıplarını ve yaralanmaları önleyebilmek adına hayati önemdedir.Bu çalışma, Kocaeli ilindeki okul binalarının sismik risklerini belirlemeye odaklanmıştır. Bu risk değerlendirmesinin temelini oluşturan ilk adım, bölgenin tehlike analizinin yapılmasıdır. Tehlike analizi, belirli bir bölgede meydana gelebilecek depremler ve bu depremlerin yaratacağı etkilerle ilgilidir. Bu analiz sürecinde, bölgenin zemin özellikleri, geçmiş deprem kayıtları, fay hatlarının derinlikleri ve özellikleri gibi parametreler detaylı bir şekilde incelenir.

Bu veriler doğrultusunda, bölgeye özgü olası depremlerin yaratacağı ivme değerleri (yer ivmeleri) hesaplanarak, bölgedeki potansiyel sismik hareketlerin büyüklüğü ve şiddeti hakkında bilgi elde edilir. Bu bilgiler ışığında, Kocaeli ili için bir tehlike haritası oluşturulmuştur.Tehlike analizinin ardından, bölgede var olan mevcut okul binaları incelenmiştir. Bu yapılar, yapısal özellikleri ve dayanıklılık seviyelerine göre analiz edilerek belirli kategorilere ayrılmıştır. Yapıların sınıflandırılmasının ardından, bu yapılara özgü kırılganlık eğrileri oluşturulmuştur. Kırılganlık eğrileri, yapıların belirli bir sismik hareket karşısında ne düzeyde hasar görebileceğini tahmin etmek için kullanılan grafiksel temsil araçlarıdır. Böylece, okul binalarının deprem sırasında ve sonrasında maruz kalabileceği potansiyel hasarlar hakkında öngörülerde bulunulmuştur.

Yapı stoğu analizi ve kırılganlık eğrilerinin oluşturulmasıyla, değerlendirilen okul binalarında meydana gelmesi beklenen hasar seviyeleri hesaplanabilir hale gelmiştir. Bu hasar tahminleri doğrultusunda, okul binalarının güvenliğini sağlamak amacıyla alınması gereken önlemler hakkında öneriler sunulmuştur. Bunun yanı sıra, çalışmanın doğruluğunu ve geçerliliğini test etmek amacıyla, Kocaeli'deki okul binalarından tipik bir örneğe dayalı olarak performansa dayalı bir risk değerlendirmesi yapılmıştır. Bu değerlendirme, okul binalarının gerçek deprem koşulları altında nasıl bir performans sergileyebileceği konusunda daha ayrıntılı bilgiler sağlamaktadır.Sonuç olarak, bu çalışma Kocaeli ilindeki yüksek öneme sahip okul binalarının deprem riskini ortaya koymayı amaçlamaktadır. Yapılan risk değerlendirmesi sayesinde, söz konusu binaların güvenliğini artırmaya yönelik gerekli tedbirler hakkında bilgiler elde edilmiş ve bu tedbirlerin hayata geçirilmesi için öneriler geliştirilmiştir.

Anahtar Kelimeler: Sismik Tehlike Analizi, Sismik Risk Değerlendirmesi, Tehlike Eğrisi, Tehlike Haritası, Kırılganlık Eğrisi

ACKNOWLEDGEMENTS

I would like to express my heartfelt gratitude to the many individuals who supported and guided me in completing this thesis. First and foremost, I am deeply indebted to my thesis advisor, Assoc. Prof. Dr. A. Can ZÜLFİKAR, who supported me patiently at every stage of this study, motivated me with his understanding, and guided me with his valuable knowledge and expertise. His mentorship played a pivotal role in shaping and refining this work.I would also like to extend my sincere thanks to Dr. Ali YEŞİYURT, who, despite his demanding academic responsibilities, took the time to provide both scientific and moral support for my work. His guidance and encouragement were invaluable throughout this process.Furthermore, I am profoundly grateful to Dr. Öğr. Üyesi Ülgen MERT TUĞSAL and Dr. Öğr. Üyesi Ebru HARMANDAR for their valuable feedback and suggestions during the evaluation of my thesis. Their meticulous reviews and constructive comments significantly contributed to the final version of this study.Lastly, I would like to thank everyone who stood by me during this journey, offering their unwavering support and dedication. I firmly believe that this thesis has become a more meaningful and higher-quality work thanks to the contributions of these exceptional individuals.

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LIST OF SYMBOLS AND ABBREVIATIONS

a	: Acceleration
a,b	: Constants for Gutenberg-Richter Recurrence Law
g	: Gravity
m_{min}	: Minimum magnitude
m_{max}	: Maximum magnitude
T	: Period
Vs_{30}	: The time-averaged shear-wave velocity to 30m depth
S_a	: Spectral accerelation
S_d	: Spectral displacement
S_{dy}	: Dispşacement of yield
S_{du}	: Ultimate displacement capacity
CR	: Reinforced concrete
DD-1	: The earthquake ground motion level with a 2% probability of exceedance in 50 years (recurrence period of 2475 years)
DD-2	: The earthquake ground motion level with a 10% probability of exceedance in 50 years (recurrence period of 475 years)
ESHM20	: Europen seismic hazard model 2020
GMPE	: Ground motion prediction equations
GEM	: Global earthquake model
HBET	: Number of floors
LFM	: Moment frame
NAF	: North anatolian fault
PGA	: Peak ground accelereation
PGV	: Peak ground velocity
poes	: Probability of exceeding seismicity
sec	: second
TBDY-2018	: Turkish Building Seismic Code
UHS	: Uniform hazard spectrum

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1. INTRODUCTION

1.1. General

Türkiye, due to its geographical location, lies within active tectonic zones and has faced destructive earthquakes throughout its history. Major fault lines such as the North Anatolian Fault, the East Anatolian Fault, and the Western Anatolian Graben System are among the primary factors increasing Türkiye's seismic risk. This natural reality makes earthquake preparedness a critical necessity in all aspects of society and construction processes. However, historical data and recent events reveal that the significant loss of life and property following earthquakes often stems from a lack of adequate preparedness.

The resilience of structures in regions with high seismic risk is one of the most critical factors in minimizing the impacts of earthquakes. Ensuring structural safety not only protects individuals' physical well-being but also preserves the economic and social fabric of society. In **Figure 1.1**, we see the remains of a collapsed school building in Malatya. In this type of collapse, the likelihood of significant loss of life is extremely high.In this context, the earthquake preparedness of educational buildings holds particular significance. Schools are not merely places where educational activities take place; they also serve as gathering centers during emergencies and play a vital role in fostering societal cohesion. Therefore, constructing earthquake-resistant school buildings and ensuring the safety of existing ones is an indispensable part of a community's overall disaster preparedness.

This study aims to examine the current state of preparedness of structures in Türkiye against earthquakes, with a specific focus on the seismic safety of school buildings. The research will include regional hazard analysis, risk assessments, evaluation of the building stock, and the development of tailored, practical solutions for schools. Furthermore, raising public awareness about earthquakes and determining necessary measures to enhance the resilience of structures are key focal points of this study.

Figure 1.1: Malatya Şehit Yarbay Songül Yakut primary school building.

In conclusion, this study seeks to highlight the critical role of school buildings in fostering an earthquake-prepared society and to develop sustainable and effective measures for these structures. The findings obtained are expected to contribute not only to the scientific literature but also to guide disaster management and building safety policies.

1.2. Literatur Survey

The rapid urbanization has led to the uncontrolled development of the physical environment, which has become the primary source of current earthquake (EQ) risks. Reinforced concrete (RC) structures constitute a large portion of the existing building stock, especially in developing countries. Due to their poor performance during major earthquakes in recent years, significant research has been initiated to assess the seismic vulnerability of the existing building stock and to improve the expected seismic performance of these structures **[Yakut and Erduran, 2005]**.

Studies on the seismic vulnerability of school buildings in Türkiye have been limited and generally focused on specific regions or building types. However, several significant studies conducted both in Türkiye and worldwide provide important insights into the earthquake safety of school buildings and the assessment of their seismic performance. Below is a detailed summary of some noteworthy studies:

Yakut and Erduran (2005)'s study examined the seismic safety of RC (reinforced concrete) school buildings in Türkiye. The research highlighted that school buildings generally have low strength capacity and are often inadequately designed. It also emphasized that these buildings pose a high risk during earthquakes**[Yakut and Erduran, 2005]**.

Gülkan and Sözen (1999)'s study analyzed the seismic resilience of school buildings in Türkiye. It stated that most schools lacked adequate seismic measures, which could lead to significant damage following major earthquakes. The research suggested that stricter inspections should be conducted during the design and construction of school buildings **[Gülkan and Sözen, 1999]**.

In studies based on the Bingöl Earthquake (2003) data, it was found that school buildings with short walls and weak structural elements in Bingöl suffered more damage. It was recommended that strengthening techniques be applied to improve the seismic safety of such buildings. Gülkan and Utkutuğ (2003) discussed the Field Law of California and examined the damage to school buildings in Bingöl after the 2003 earthquake. They concluded that shear walls in both orthogonal directions are the most critical requirement for the earthquake safety of RC school buildings. This requirement should be made mandatory through a code similar to the Field Law **[Gülkan and Utkutuğ, 2005]**.

Dilmaç et al. (2018) examined the factors affecting the seismic performance of existing reinforced concrete buildings in Türkiye and concluded that the compressive strength of concrete and the transverse reinforcement are the most critical parameters for earthquake safety **[Dilmaç et al., 2018]**.

Ulutaş et al. (2019) found that school buildings would struggle to meet performance requirements without at least two separate shear walls in both directions. Ulutaş et al. (2019-2) examined the shear wall ratio in school buildings and concluded that for earthquake-safe school buildings, the shear wall area should be 1.12%, 1.51%, 1.79%, and 2% of the floor area for 2, 3, 4, and 5-story buildings, respectively. **[Ulutaş et al., 2019]**.

Levent Mazlıgüney's 2020 study focused on the seismic vulnerability of reinforced concrete (RC) school buildings in Türkiye. The study aimed to develop more accurate fragility curves (F.C.s) for earthquake risk assessment and to evaluate the seismic performance of these buildings based on several seismic codes.Mazlıgüney's research analyzed a database of 321 school buildings, conducting both walk-down and detailed seismic evaluations, including nonlinear static analysis. He created fragility curves specific to RC school buildings, taking into account different seismic parameters and building conditions. His study compared these curves with existing models and found that the fragility curves developed in the thesis could be a valuable tool for estimating earthquake damage in Türkiye **[Mazlıgüney L., 2020]**.

The results of his thesis highlighted the importance of updated seismic assessments and retrofitting strategies, suggesting that the proposed fragility curves could be effectively used in Türkiye's building stock to enhance earthquake resilience and support risk mitigation efforts. The study also examined the effectiveness of Türkiye's Building Earthquake Code (TBEC-2018) in assessing the performance of RC school buildings.

The studies in FEMA 154 (1998) and ATC-21 (2009) focus on rapid evaluation methods for assessing the seismic safety of school buildings in the United States. These methods were found to be effective in quickly determining the performance of school buildings, particularly in emergency situations, helping decision-makers make informed choices during earthquakes or other disasters. The rapid assessment tools aim to streamline the evaluation process, enabling prompt safety decisions to protect occupants and guide necessary interventions.

In the reports by UNESCO and WHO, the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the World Health Organization (WHO) have published reports addressing the seismic resilience of school buildings worldwide. These reports highlight that the majority of school buildings in developing countries are at high risk in the event of major earthquakes, emphasizing the importance of strengthening measures and identifying seismic risks in schools.

Studies on School Buildings in Japan: Japan is a leading country in terms of seismic resilience of school buildings. Research conducted in the country examines innovative design and strengthening methods aimed at enhancing the seismic safety of schools. These studies highlight that, considering Japan's high seismic activity, school buildings are continuously reinforced and innovative structural solutions are employed.

1.3. Structural and Life Safety

In the context of earthquake preparedness, there are essential priorities and criteria that must be addressed to ensure structural and life safety. Schools play a pivotal role in this regard because they are spaces where the young population the country's future spends a significant part of their day. Protecting these environments is not only a moral obligation but also a strategic necessity for national development and resilience.

Determining the hazard and risk levels of school buildings before an earthquake occurs is of paramount importance. Governments and local authorities must prioritize this issue and implement targeted measures to mitigate risks and protect lives.

1.4. Seismic Hazard and Risk Analysis

The significance of earthquake preparedness becomes clearer when regions are subjected to probability-based hazard and risk analyses, with results providing critical insights. This thesis focuses on conducting a seismic risk assessment for school buildings in Kocaeli, one of Türkiye's most densely populated and economically significant cities.

The seismic risk assessment process includes the following steps:

- **Hazard Analysis:** Identifying and evaluating potential earthquake hazards specific to the region.
- **Building Stock Survey:** Researching and documenting the structural inventory of school buildings.
- **Fragility Curves:** Using fragility curves tailored to the characteristics of the existing building stock to estimate the probability of damage at varying earthquake intensities.
- **Loss Estimation:** Combining hazard data, building stock information, and fragility curves to calculate potential losses.

This study integrates these elements to create maps and detailed reports that focus on the concepts of earthquake hazard, risk, and vulnerability. The outcomes are expected to contribute significantly to disaster management practices and efforts to improve the earthquake resilience of school buildings.

1.5. Historical Earthquake and Damage

Türkiye's history provides valuable lessons through the documented impacts of past earthquakes on schools. This section highlights notable incidents:

Kahramanmaraş Earthquake (February 6, 2023)

- **Kahramanmaraş:** 19 schools were completely destroyed, and 64 schools sustained severe damage.
- **Malatya:** 2 schools collapsed, 46 schools were heavily damaged, and 18 schools suffered moderate damage.
- **Elazığ:** 23 schools were heavily damaged, while 42 schools experienced moderate to light damage, requiring structural reinforcement.

Erzincan Earthquake (March 13,1992)

- One school was destroyed.

Marmara Earthquake (Agust 17,1999)

- **Istanbul:** 20 schools were severely damaged.
- **İzmit:** 27 schools were destroyed.
- **Gölcük:** 2 schools collapsed.
- **Yalova:** 13 schools were completely destroyed.

Bolu Earthquake (November 12,1999)

- **Bolu:** 27 schools were destroyed.
- **Düzce:** 11 schools were severely damaged.

Afyon Earthquake (February 3, 2002)

14 schools were damaged.

1.6. Implications and Future Directions

The recurring damage to schools in these historical earthquakes demonstrates the urgent need for proactive measures. Implementing seismic risk assessments, strengthening vulnerable buildings, and constructing earthquake-resilient schools are essential steps to mitigate future disasters.

This study not only evaluates past incidents but also aims to create a roadmap for reducing risks in the education sector. By focusing on a densely populated city like Kocaeli, the research will provide actionable insights for policymakers and disaster management authorities.

2. SEISMIC RISK ASSESSMENT

Seismic risk analysis is a process used to assess how structures in a region respond to seismic hazards, such as earthquakes, and predict potential damages. This analysis not only evaluates the physical structure of buildings but also takes into account environmental factors, local ground conditions, historical earthquake data, and potential damages. Seismic risk analysis plays a crucial role in developing strategies to minimize the effects of hazards before, during, and after an earthquake. Therefore, seismic risk analysis is particularly important in earthquake-prone regions.

Seismic risk analysis typically involves three main stages: **hazard analysis**, **vulnerability analysis**, and **risk assessment**. Each stage provides critical insights about earthquake risks and helps in taking necessary measures to ensure the safety of structures.

Seismic risk analysis is a crucial tool for understanding earthquake risks and implementing measures to reduce those risks. The stages of hazard analysis, vulnerability analysis, and risk assessment provide comprehensive insights into seismic safety and help develop resilient solutions for both existing and future buildings. Therefore, seismic risk analysis is critical for ensuring earthquake safety and enhancing a community's resilience against disasters

2.1. Seicmic Risk Assessment Process

2.1.1. Risk Assessment Formula

Risk=Hazard×Exposure×Vulnerability (Erdik,2017)

Hazard: Refers to the probability of an earthquake occurring in a specific region and its potential severity. This includes determining the ground motion parameters (e.g., peak ground acceleration) and creating probabilistic hazard maps and spectra based on seismic activity.

Exposure: Represents the inventory of assets at risk, such as buildings, infrastructure, and population. This includes detailed information about the location, type, and value of the structures.

Vulnerability: Assesses the susceptibility of the exposed assets to damage when subjected to seismic hazards. Vulnerability is quantified through curves and models that relate structural properties to expected damage or losses.

2.1.2. Components of Risk Assessment

Hazard Analysis: This step involves determining the probability and intensity of seismic events.Outpust include:

Hazard Curves: These describe the probability of exceeding specific ground motion levels.

Response Spectra: Used to assess the response of structures to ground shaking.

Hazard Maps: Geospatial representation of seismic hazards in a region.

Exposure Model: An inventory of physical assets, including the types, locations, and characteristics of buildings and infrastructure. Helps estimate the potential scale of impact.

Fragility Curves: Represent the probability of a structure reaching or exceeding a particular damage state, given a level of seismic intensity. These curves link exposure to potential damage levels probabilistically.

Vulnerability Curves: Extend fragility curves to estimate economic losses or downtime. Provide a connection between structural damage and financial or functional consequences.

2.1.3. Outcome

The combined analysis of hazard, exposure, and vulnerability enables the quantification of earthquake risk, expressed in terms of expected damage, economic losses, or other impacts. This is critical for disaster mitigation, urban planning, and resilience building.

2.2. Fault Characteritics of Kocaeli Region

Kocaeli, one of Türkiye’s most populous cities, is located on the right-lateral North Anatolian Fault Zone (NAF). This region, situated in an active and shallow continental crust, is highly susceptible to seismic activity, making it crucial to conduct probabilistic seismic hazard analyses. Kocaeli’s location on this fault zone increases the risk of significant seismic events,emphasizing the need for a better understanding of the area’s seismic threats.

2.2.1. North Anatolian Fault(NAF)

The North Anatolian Fault is approximately 1,100 kilometers long, running across the entire northern part of Türkiye, from the Lake Van region in the east to the Gulf of Saros in the west. The fault does not consist of a single linear feature but is a fault zone made up of multiple segments. This fault zone has a number of active segments, which complicates its behavior and the overall seismic hazard posed by it. NAF is a right-lateral strike-slip fault, meaning the motion along the fault displaces the earth's crust horizontally to the right, creating potential for large earthquakes and ground displacement. In **Figure 2.1,** the map of major fault lines across Türkiye is shown.

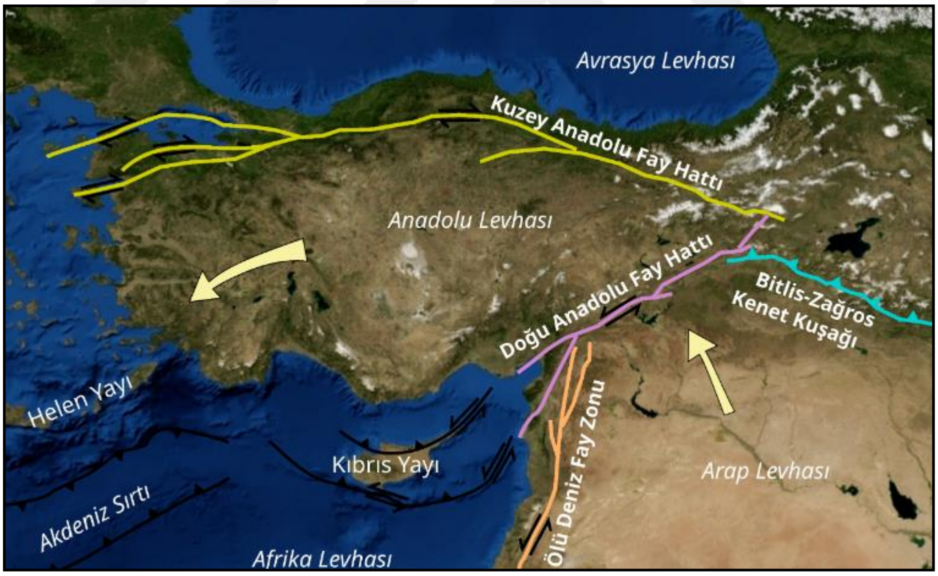


Figure 2.1: North anatolian fault line.

One of the key characteristics of the NAF is its rapid movement. The fault slips at a rate of approximately 2-3 cm per year. This high rate of slip increases the fault’s seismic potential and makes it a significant source of earthquakes. When the map in **Figure 2.2** is examined, it is understood that the slip on the fault is directed from east to West. The frequent and powerful earthquakes produced by the NAF represent a substantial risk to the region, especially in densely populated areas like Kocaeli.

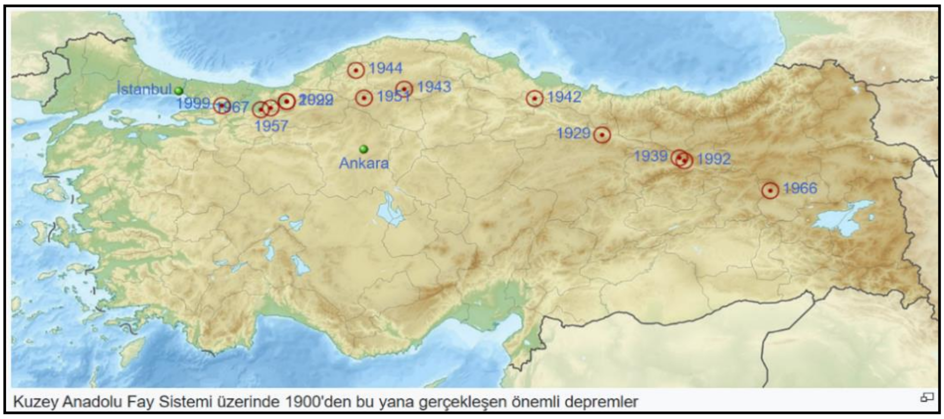


Figure 2.2: Significant earthquakes that have occurred in NAFTA since 1900.

The North Anatolian Fault extends all the way to Western Anatolia, passing through the Sea of Marmara. The Sea of Marmara is an important structural feature, as it contains an extensional basin. This characteristic is similar to the Salton Trough in California, another extensional basin located along the San Andreas Fault. The Salton Trough is known for its seismic activity, and the Sea of Marmara, with its similar structural features, poses a comparable seismic risk. Both regions are prone to large-scale earthquakes due to the tectonic environments they are situated in.

2.2.2. Importance of Kocaeli Fault

Kocaeli’s location along the North Anatolian Fault makes it highly susceptible to large seismic events. Earthquakes in this region could significantly impact human life and infrastructure. The cities in the Marmara region, especially Kocaeli, must be prepared for the effects of the fault’s seismic activity. Probabilistic seismic hazard analyses can help quantify the likelihood and potential impacts of large earthquakes, aiding in the implementation of mitigation strategies to reduce risks. Therefore, the seismic characteristics of Kocaeli are critical for both scientific research and local government planning. This region remains a focal point for seismic monitoring and risk management efforts.

2.3. Seismic Hazard Analysis

Seismic hazard refers to the likelihood of ground motion resulting from an earthquake that may cause damage and losses. Seismic risk assessment evaluates the potential impact of this hazard on human settlements and infrastructure. This assessment is crucial for urban planning, civil engineering, and disaster management. The process of seismic hazard and risk assessment is as follows:

2.3.1. Hazard Analysis Process

Identifying Regional Characteristics:

Coordinates and Ground Properties: The geographical coordinates and ground properties (such as soil type, local seismic activity) of the area are determined as the first step. The type of soil is a critical factor that influences how seismic waves are transmitted.

Earthquake Magnitudes: Past earthquakes in the region are analyzed to determine the potential maximum and minimum earthquake magnitudes.

Seismic Depths: The depths at which earthquakes occur (such as surface or deeper fault zones) are also crucial in this analysis.

Analysis and Software:

Openquake Software: This software is used to model the seismic characteristics of the region, including local building resilience, ground properties, and potential ground motions. Openquake can integrate global seismic data and simulate various ground motion scenarios. It is particularly effective in defining parameters and visualizing results.

Logic Trees: Combinations of different parameters (such as soil type and earthquake magnitude) are modeled using logic trees. This approach enables the analysis of multiple seismic scenarios

2.3.2. Seismic Source Model and ESHM20

A seismic source model involves defining the sources of earthquakes (faults, regional seismic activities) and modeling the resulting ground motions. The main parameters in this model are:

Source Model Definitions:

Regional Seismic Activity: Previous significant earthquakes in the region are considered to calculate the probabilities of future seismic events. In **Figure 2.3**, the EMEC regions of the ESHM20 model are shown, and in **Figure 2.4**, the distributions of earthquakes in these regions are shown based on their depths.

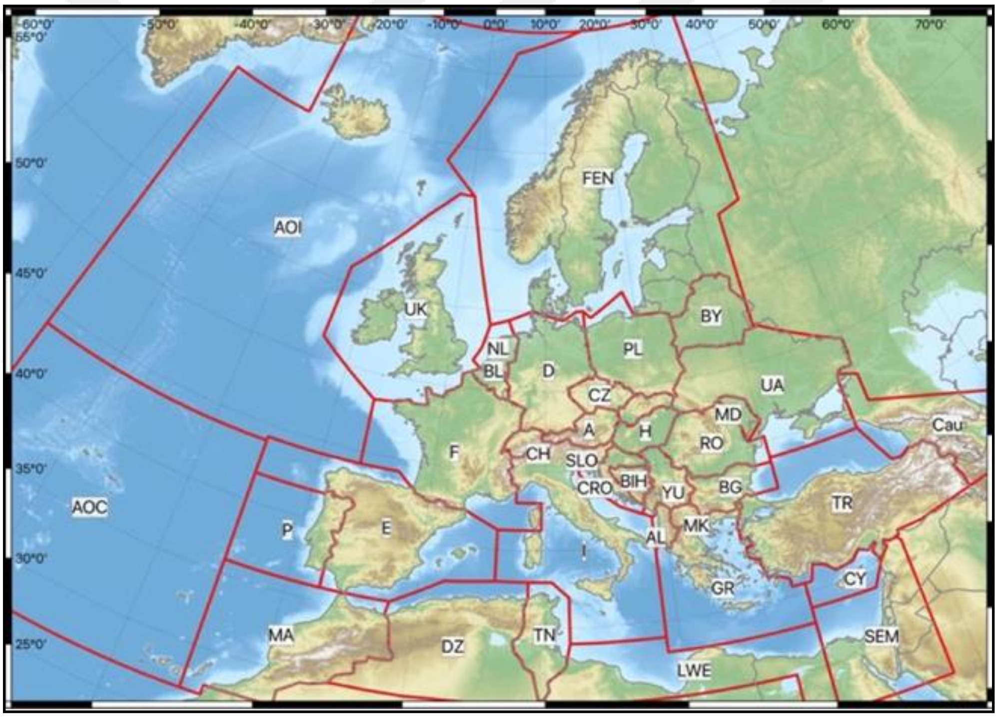


Figure 2.3: EMEC regions for data compilation in the ESHM20 model.

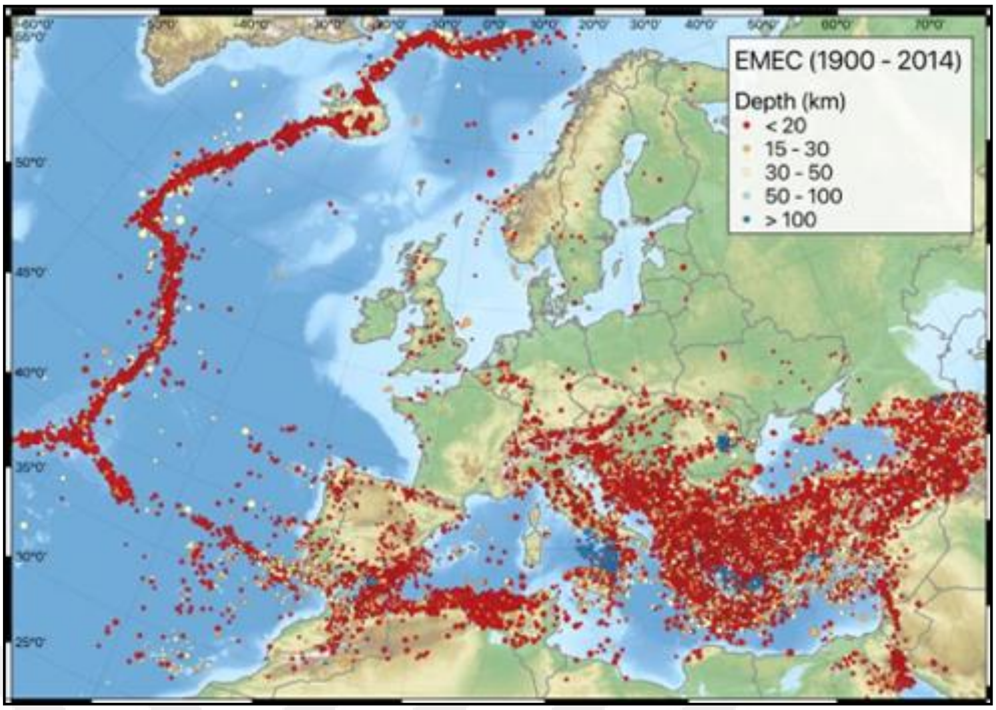


Figure 2.4: The EMEC earthquake data catalog covering the years 1900-2014.

Faults and Seismic Depths: Active faults in the region, their seismic depths, and characteristics are defined. These faults are important factors influencing regional seismic risk. In **Figure 2.5**, the faults included in the study area are shown along with their names. In **Table 2.1**, the earthquakes that occurred on these faults are presented, including their time, maximum and minimum magnitudes, and Gutenberg-Richter values.

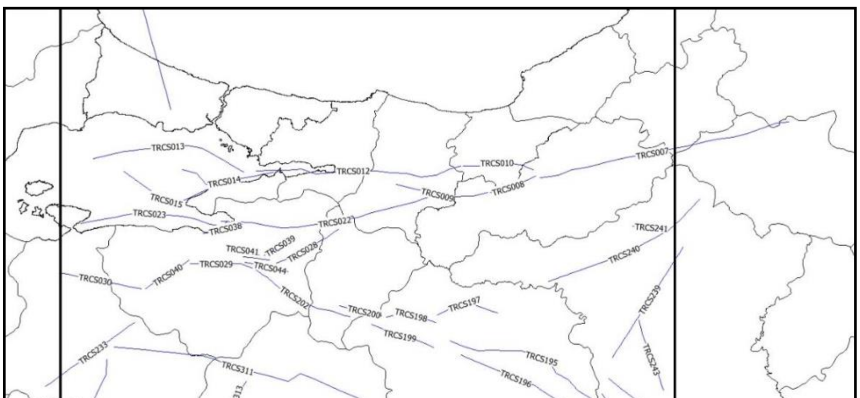


Figure 2.5: The active faults within the study area of and used in the analysis.

Gutenberg-Richter Relationship: A statistical model that defines the frequency and magnitude distribution of earthquakes. This model calculates the probability of earthquakes of specific magnitudes occurring.

Table 2.1: Source information in selected area.

Source Code	Source Name	Fault Type	a	b	Mmin	Mmax
TRCS007	NAF-1944 Bolu Gerede	Right-Lateral Strike-Slip	3,60061	0,750384	5,5	7,6
TRCS008	NAF-1957 Bolu Abant Earthquake Rupture	Right-Lateral Strike-Slip	3,37894	0,750384	5,5	6,9
TRCS009	NAF-1967 Mudurnu Valley Earthquake	Right-Lateral Strike-Slip	3,28058	0,750384	5,5	7,1
TRCS010	NAF-1999 Duzce Earthquake	Right-Lateral Strike-Slip	3,44966	0,750384	5,5	6,9
TRCS012	NAF-1999 Izmit Earthquake	Right-Lateral Strike-Slip	2,93401	0,750384	5,5	7,5
TRCS013	Marmara NAF - Eastern	Right-Lateral Strike-Slip	3,51543	0,750384	5,5	73
TRCS014	NAF -1894 Cinarcik) (South Earthquake	Right-Lateral Strike-Slip	2,20907	0,750384	5,5	71
TRCS015	NAF - South Imrali Basin	Right-Lateral Strike-Slip	2,20194	0,750384	5,5	71
TRCS022	Gemlik NAF - Geyve	Right-Lateral Strike-Slip	3,02299	0,750384	5,5	75
TRCS023	NAF Gemlik Bandirma	Right-Lateral Strike-Slip	2,93138	0,750384	55	7,3
TRCS028	NAF - Yenisehir1	Right-Lateral Strike-Slip	3,82033	0,944468	5,5	7,0

Table 2.2: Continue.

TRCS029	NAF - Bursa 1855B Earthquake	Normal	12,8132 5	0,750384	55	68
TRCS030	NAF -1964 Manyas Earthquake	Normal	2,95319	0,750384	5,5	7,1
TRCS038	NAF - Gencali Fault	Right-Lateral Strike-Slip	2,85827	0,750384	5,5	6,6
TRCS039	NAF - Yenisehir2	Right-Lateral Strike-Slip	2,65592	0,750384	5,5	6,5
TRCS040	NAF - Bursa Earthquake 1855A	Right-Lateral Strike-Slip	2,66906	0,750384	5,5	6,8
TRCS041	NAF-Turankoy	Normal	2,82781	0,750384	5,5	6,4
TRCS042	NAF - Barakfaki	Normal	3,97584	0,944468	5,5	6,4
TRCS044	NAF - Burhani e	Right-Lateral Strike-Slip	3,6977	0,944468	5,5	6,7
TRCS191	Cihanbeyli Fault Zone 1	Right-Lateral Strike-Slip	1,86265	0,944468	5,5	6,9
TRCS192	Cihanbeyli Fault Zone2	Right-Lateral Strike-Slip	1,32675	0,944468	5,5	6,5
TRCS193	Yeniceoba Fault Zone	Right-Lateral Strike-Slip	1,82963	0,944468	5,5	7
TRCS194	llica Fault Zone	Right-Lateral Strike-Slip	1,84955	0,944468	5,5	6,9
TRCS195	Sivrihisar North	Right-Lateral Strike-Slip	1,91616	0,944468	5,5	6,9
TRCS196	Sivrihisar South	Right-Lateral Strike-Slip	1 75375	0,944468	5,5	6,9
TRCS197	Alpu North	Right-Lateral Strike-Slip	1,55974	0,944468	5,5	6,8

Table 2.3: Continue.

TRCS198	1956 Eskisehir Earthquake	Right-Lateral Strike-Slip	1,49762	0,944468	5,5	6,8
TRCS199	Eskisehir South	Right-Lateral Strike-Slip	1,53286	0,944468	5,5	6,9
TRCS200	Inonu North	Right-Lateral Strike-Slip	1,42239	0,944468	5,5	6,7
TRCS202	Bursa Inonu	Right-Lateral Strike-Slip	1,74469	0,944468	5,5	6,8
TRCS207	Murat Dagi South 2	Right-Lateral Strike-Slip	3,91382	0,944468	5,5	6,7
TRCS208	1970 Gediz Earthquake	Normal	4,11476	0,944468	5,5	7
TRCS209	1969 Demirci Earthquake	Normal	3,92771	0,944468	5,5	6,9
TRCS210	Sindirgi	Normal	3,90741	0,944468	5,5	6,7
TRCS217	Bolvadin Graben West	Normal	1,19743	0,944468	5,5	6,8
TRCS226	Murattagi North 2	Normal	1,21295	0,944468	5,5	6,6
TRCS231	Uludagı Fault 2	Normal	1,25211	0,944468	5,5	6,6
TRCS232	Akhisar Fault Zone	Right-Lateral Strike-Slip	1,8464	0,944468	5,5	6,9
TRCS233	Balikesir Fault Zone 1	Right-Lateral Strike-Slip	3,47586	0,905855	5,5	6,9
TRCS239	Murted Fault Zone	Right-Lateral Strike-Slip	1,54631	0,944468	5,5	6,9
TRCS240	Celticki Fault Zone 1	Right-Lateral Strike-Slip	1,68915	0,944468	5,5	6,9
TRCS241	Celtikci Fault Zone 2	Right-Lateral Strike-Slip	1,17932	0,944468	5,5	6,4
TRCS243	Haymana Fault Zone 2	Right-Lateral Strike-Slip	3,35948	0,944468	5,5	6,7
TRCS310	Kutahya Fault Zone 1	Normal	1,74283	0,944468	5,5	6,9

Table 2.4: Continue.

TRCS311	Kutahya Fault Zone 2	Right-Lateral Strike-Slip	2,0532	0,944468	5,5	6,9
TRCS313	Emet Graben - Western Boundary	Normal	1,27506	0,944468	5,5	6,8

ESHM20(European Seismic Hazard Model 2020):

ESHM20 is a model used to determine seismic hazard levels across Europe. The 2020 version provides an updated dataset for seismic risk calculation in various European regions. With the data provided by ESHM20, seismic sources in the investigated region are identified, and the seismic hazard is quantified. For example, in regions like Kocaeli, the model helps calculate the likelihood of different ground motion intensities and frequencies. An area source model was created by obtaining all area source information from ESHM20 within a circular area of 150 km from the Kocaeli city center. In **Figure 2.6**, the area sources of ESHM20 are shown on the map.

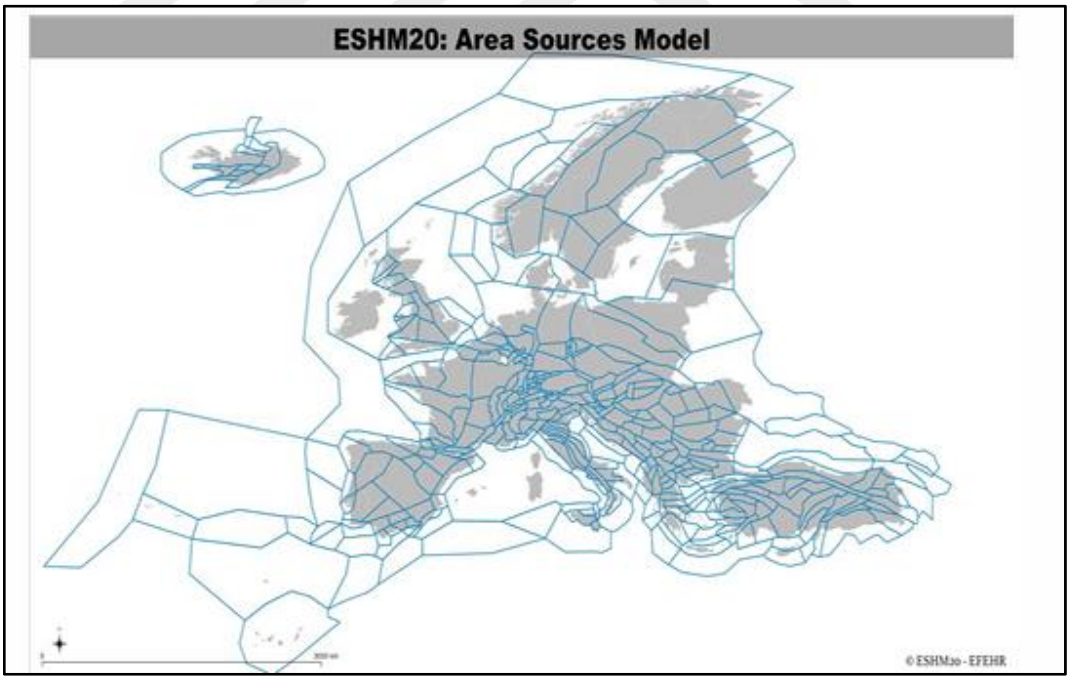


Figure 2.1: ESHM20 area sources model.

All of the examined, investigated, and created area source model has been defined in OpenQuake as an Area Source model file for seismic hazard and seismic risk analysis, as shown in **Figure 2.7**.

```xml
<?xml version='1.0' encoding='UTF-8'?>
<nrml xmlns:gml="http://www.opengis.net/gml" xmlns="http://openquake.org/xmlns/nrml/0.4">
  <sourceModel name="SHARE ASC Area Source Model">
      <simpleFaultSource tectonicRegion="Active Shallow Crust" id="440" name="TRCS007">
      <simpleFaultGeometry>
        <gml:LineString>
          <gml:posList>33.260211 40.958435 33.161175 40.946835 33.047776 40.925548 32.932094 40.913271 32.817286 40.897083 32.704469 40.874345
        </gml:LineString>
        <dip>70.0</dip>
        <upperSeismoDepth>0.0</upperSeismoDepth>
        <lowerSeismoDepth>16.0</lowerSeismoDepth>
      </simpleFaultGeometry>
      <magScaleRel>WC1994</magScaleRel>
      <ruptAspectRatio>1.0</ruptAspectRatio>
      <truncGutenbergRichterMFD maxMag="7.8" bValue="0.8" aValue="3.51755" minMag="6.4"/>
      <rake>-177.0</rake>
    </simpleFaultSource>
    <simpleFaultSource tectonicRegion="Active Shallow Crust" id="441" name="TRCS008">
      <simpleFaultGeometry>
        <gml:LineString>
          <gml:posList>31.509552 40.694574 31.463199 40.678224 31.416846 40.661874 31.368303 40.644751 31.31976 40.627628 31.268702 40.615481 3
        </gml:LineString>
        <dip>78.0</dip>
        <upperSeismoDepth>0.0</upperSeismoDepth>
        <lowerSeismoDepth>18.0</lowerSeismoDepth>
      </simpleFaultGeometry>
      <magScaleRel>WC1994</magScaleRel>
      <ruptAspectRatio>1.0</ruptAspectRatio>
      <truncGutenbergRichterMFD maxMag="7.2" bValue="0.8" aValue="3.11316" minMag="6.4"/>
      <rake>180.0</rake>
    </simpleFaultSource>
    <simpleFaultSource tectonicRegion="Active Shallow Crust" id="442" name="TRCS009">
      <simpleFaultGeometry>
        <gml:LineString>
          <gml:posList>31.134696 40.595308 31.075674 40.585074 31.016651 40.57484 30.955598 40.573192 30.894545 40.571544 30.833562 40.574299 3
        </gml:LineString>
        <dip>89.0</dip>
        <upperSeismoDepth>0.0</upperSeismoDepth>
        <lowerSeismoDepth>18.0</lowerSeismoDepth>
      </simpleFaultGeometry>
      <magScaleRel>WC1994</magScaleRel>
      <ruptAspectRatio>1.0</ruptAspectRatio>
      <truncGutenbergRichterMFD maxMag="7.4" bValue="0.8" aValue="3.16699" minMag="6.4"/>
      <rake>-171.5</rake>
    </simpleFaultSource>
    <simpleFaultSource tectonicRegion="Active Shallow Crust" id="443" name="TRCS010">
      <simpleFaultGeometry>
```


Figure 2.7: Area source model created specifically for the region.

2.3.3. Ground and Structural Parameters

Ground and structural parameters play a critical role in seismic risk assessment. These parameters define how ground motion intensity affects buildings and infrastructures.

Vs30 Values: Vs30 is a parameter related to ground properties that indicates the average shear wave velocity in the top 30 meters of soil. This value helps determine how seismic waves are transmitted through the ground and the likely effects on buildings. In the study, **Vs30** values are calculated for school buildings based on their coordinates. Vs30 values were obtained from the mapelse internet-based application **(Figure 2.8)** using USGS (U.S. Geological Survey) data. A total of 977 school structures and Vs30 values were determined according to the locations of these structures.

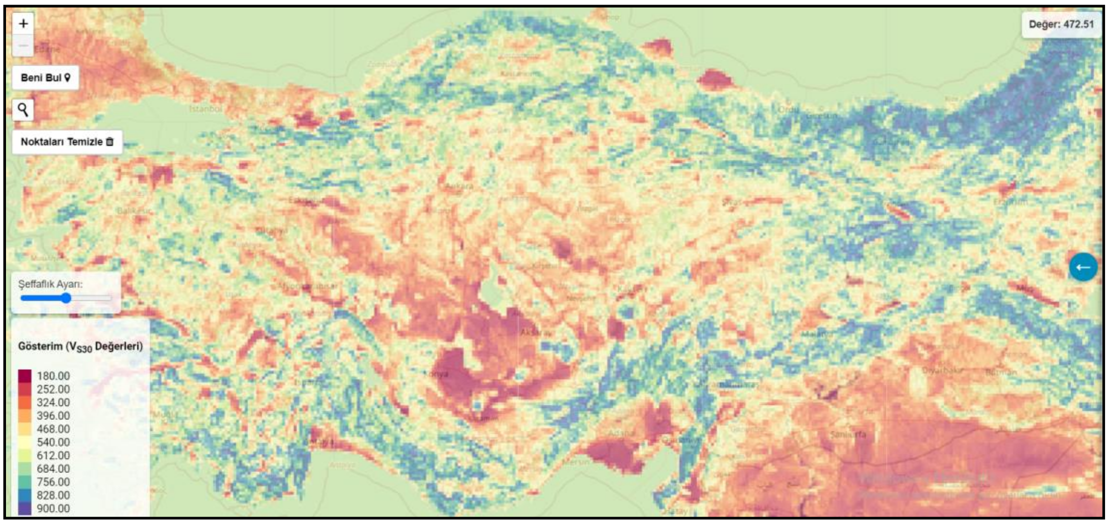


Figure 2.8: Vs30 distrubition map of Türkiye.

Ground Motion Prediction Equations (GMPE): GMPEs are mathematical models used to predict ground motions based on factors such as earthquake magnitude, source depth, and distance from the source. In Openquake software, these equations are used to simulate various ground motion scenarios and assess their impact.

In this study, a ground motion prediction equation logic tree has been created using the ground motion prediction equations obtained by Abrahamson et al. (2014), Boore et al. (2014), Campbell and Bozorgnia (2014), and Chiou and Youngs (2014), each contributing 25% to the equation. These equations and their usage rates have been defined in OpenQuake as a GMPE logic tree file, as shown in **Figure 2.9** **[Abrahamson et al, 2014]**, **[Boore at al., 2014]**, **[Campbell and Bozorgnia, 2014]**, **[Chiou and Youngs, 2014]**.


```xml
<?xml version="1.0" encoding="UTF-8"?>
<nrml xmlns:gml="http://www.opengis.net/gml" xmlns="http://openquake.org/xmlns/nrml/0.4">
    <logicTree logicTreeID='lt1'>
<!-- 1.0 Logic Tree for Active Shallow Crust -->
        <logicTreeBranchingLevel branchingLevelID="bl1">
            <logicTreeBranchSet uncertaintyType="gmpeModel" branchSetID="bs1" applyToTectonicRegionType="Active Shallow Crust">

                <logicTreeBranch branchID="b1"> <uncertaintyModel>AbrahamsonEtAl2014</uncertaintyModel>
                    <uncertaintyWeight>0.25</uncertaintyWeight>
                </logicTreeBranch>

                <logicTreeBranch branchID="b2"> <uncertaintyModel>BooreEtAl2014</uncertaintyModel>
                    <uncertaintyWeight>0.25</uncertaintyWeight>
                </logicTreeBranch>

                <logicTreeBranch branchID="b3"> <uncertaintyModel>CampbellBozorgnia2014</uncertaintyModel>
                    <uncertaintyWeight>0.25</uncertaintyWeight>
                </logicTreeBranch>

                <logicTreeBranch branchID="b4"> <uncertaintyModel>ChiouYoungs2014</uncertaintyModel>
                    <uncertaintyWeight>0.25</uncertaintyWeight>
                </logicTreeBranch>

            </logicTreeBranchSet>
        </logicTreeBranchingLevel>

    </logicTree>
</nrml>
```

Figure 2.9: GMPE logic tree file in defined OpenQuake.

Analysis: In a study of the Kocaeli region, Openquake software was used to generate seismic hazard maps, hazard spectra, and hazard curves. In this analysis, earthquakes with a 10% and 2% exceedance probability within 50 years were examined. The results of this analysis can be used to assess the earthquake resilience of school buildings in the region. Additionally, the results inform engineering and infrastructure planning for the area.

```
[general]

description = Classical PSHA – Area Source (KOCAELI)
calculation_mode = classical
random_seed = 23

[geometry]

sites_geometry = geometry_site.csv
region_grid_spacing = 2

[logic_tree]

number_of_logic_tree_samples = 0

[erf]

rupture_mesh_spacing = 2
width_of_mfd_bin = 0.2
area_source_discretization = 10

[site_params]

site_model_file = site_model.csv
reference_depth_to_2pt5km_per_sec = 5.0
reference_depth_to_1pt0km_per_sec = 100.0

[calculation]

source_model_logic_tree_file = source_model_logic_tree.xml
gsim_logic_tree_file = gmpe_logic_tree.xml
investigation_time = 50.0
intensity_measure_types_and_levels = {
  "PGA": logscale(0.005, 5.00, 105),
  "SA(0.025)": logscale(0.005, 5.00, 105),
  "SA(0.05)": logscale(0.005, 5.00, 105),
  "SA(0.1)": logscale(0.005, 5.00, 105),
  "SA(0.2)": logscale(0.005, 5.00, 105),
  "SA(0.3)": logscale(0.005, 5.00, 105),
  "SA(0.4)": logscale(0.005, 5.00, 105),
  "SA(0.5)": logscale(0.005, 5.00, 105),
  "SA(0.6)": logscale(0.005, 5.00, 105),
  "SA(0.7)": logscale(0.005, 5.00, 105),
  "SA(1.0)": logscale(0.005, 5.00, 105),
  "SA(2.0)": logscale(0.005, 5.00, 105),
  "SA(3.0)": logscale(0.005, 5.00, 105),
  "SA(4.0)": logscale(0.005, 5.00, 105),
  "SA(5.0)": logscale(0.005, 5.00, 105),
  "SA(6.0)": logscale(0.005, 5.00, 105)}
truncation_level = 3
maximum_distance = 200
pointsource_distance = 2

[output]

export_dir = /tmp
hazard_maps = true
uniform_hazard_spectra = true
poes = 0.1 0.02
```

Figure 2.10: Hazard analysis job file in defined OpenQuake.

Conclusion and Evaluation: Seismic hazard analyses are crucial for reducing earthquake risks and ensuring the safety of buildings. Specifically, risk assessments for sensitive structures (such as schools and hospitals) and densely populated areas play a vital role in disaster preparedness and emergency planning. The results from these analyses will guide urban planning, engineering solutions, and help improve the overall resilience of cities to earthquakes.

To perform a hazard analysis, the job file shown in **Figure 2.10** was defined in the OpenQuake program. In the job file, hazard maps and hazard spectra were requested as analysis outputs.

2.3.4. Hazard Curve

The hazard curve is a critical tool used to represent the likelihood of an earthquake of a specific magnitude occurring within a given region over a particular time frame. This graph is constructed based on the statistical analysis of ground motion parameters, such as frequency, amplitude, and intensity.

It provides insight into the relationship between the severity of potential ground shaking and its corresponding probability, allowing for a quantitative assessment of seismic risk. The hazard curve is typically derived from historical seismic data, geological surveys, and predictive models that consider factors like fault line activity, tectonic plate interactions, and local soil conditions.

This curve plays an essential role in seismic hazard assessments, enabling engineers, urban planners, and policymakers to design infrastructure, establish building codes, and implement mitigation strategies that align with the level of seismic risk in a region. By evaluating the probabilities of different levels of ground motion, it ensures that resources are allocated effectively to enhance public safety and reduce potential damages caused by earthquakes.

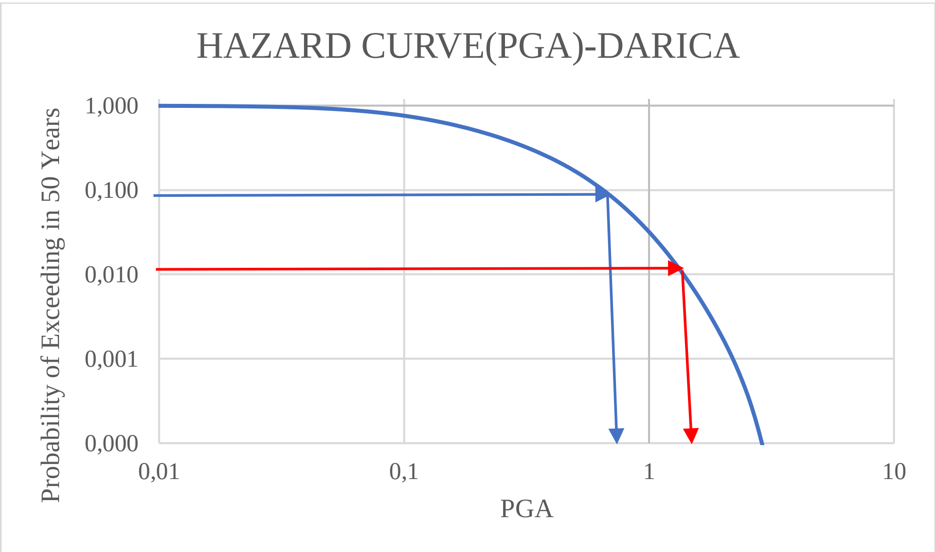


Figure 2.11: Darıca hazard curve.

When the hazard curve for Darıca in **Figure 2.11** is examined;

- PGA is 0,642g for Probability of Exceeding in 50 Years is equal to %10
- PGA is 1,160g for Probability of Exceeding in 50 Years is equal to %2

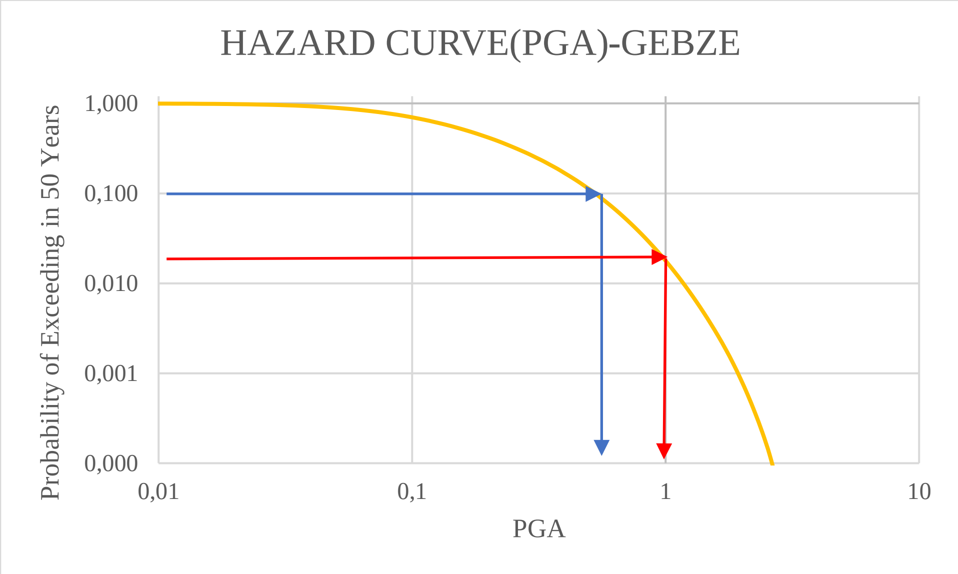


Figure 2.12: Gebze hazard curve.

When the hazard curve for Gebze in **Figure 2.12** is examined;

- PGA is 0,522g for Probability of Exceeding in 50 Years is equal to %10
- PGA is 0,950g for Probability of Exceeding in 50 Years is equal to %2

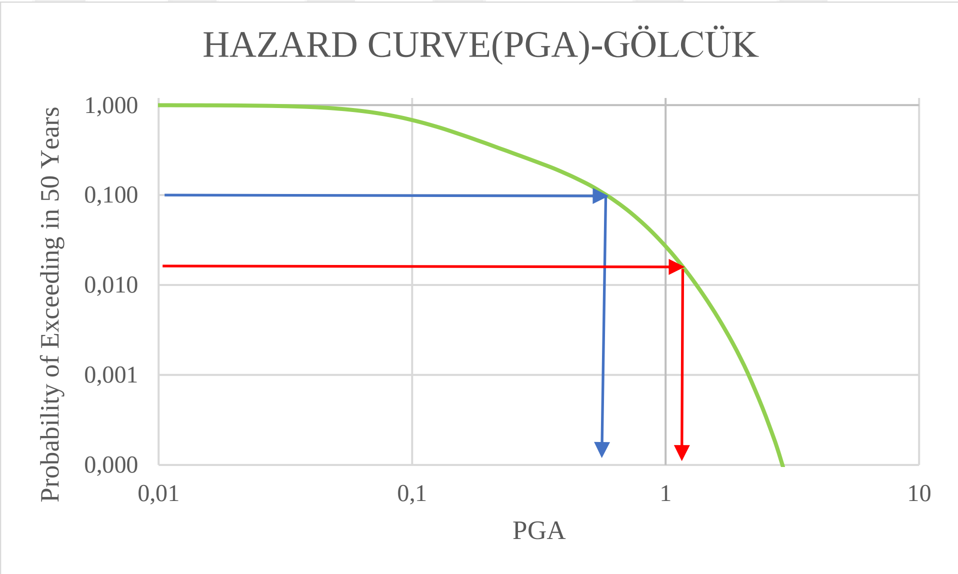


Figure 2.13: Gölcük hazard curve.

When the hazard curve for Gölcük in **Figure 2.13** is examined;

- PGA is 0,583g for Probability of Exceeding in 50 Years is equal to %10
- PGA is 1,108g for Probability of Exceeding in 50 Years is equal to %2

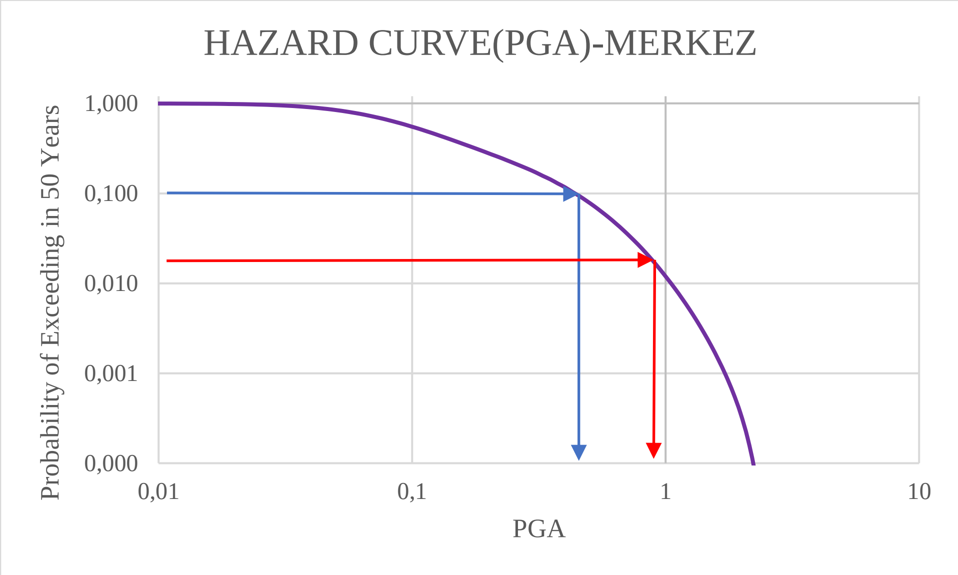


Figure 2.14: İzmit hazard curve.

When the hazard curve for İzmit in **Figure 2.14** is examined;

- PGA is 0,439g for Probability of Exceeding in 50 Years is equal to %10
- PGA is 0,861g for Probability of Exceeding in 50 Years is equal to %2

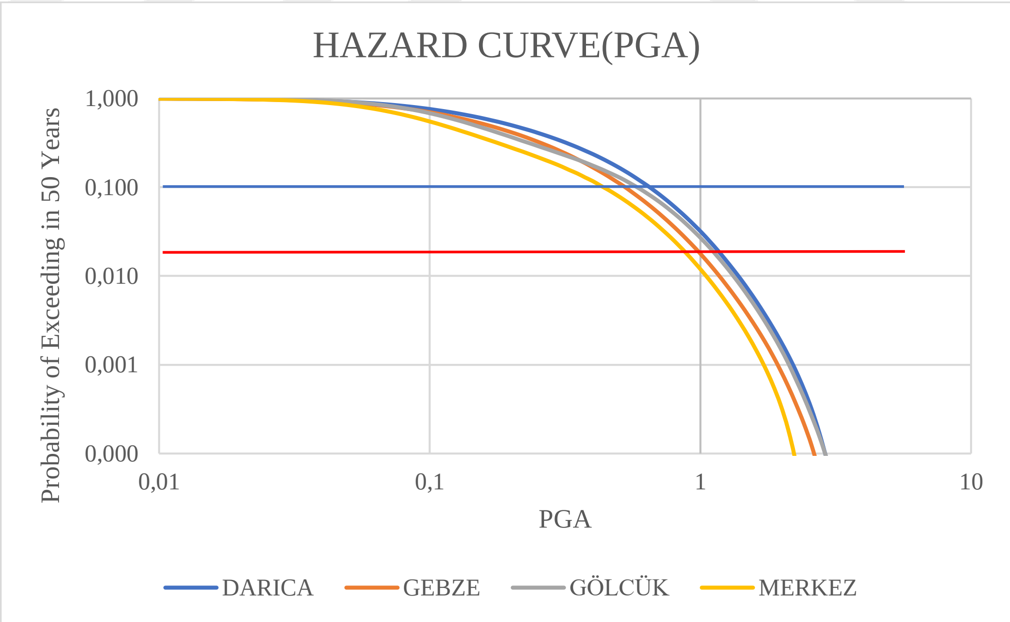


Figure 2.15: Compare to hazard curve.

When the compared hazard curves in **Figure 2.15** are examined;

The Vs30 values of the examined regions are as follows;

Lower parts of Darıca (29.37091,40.76031) Vs30 = 478 m/sec.

Center of Gebze (29.41845,4079628) Vs30 = 448 m/sec.

Upper parts of Gölcük (29.8928,407234) Vs30 = 238 m/sec.

Upper parts of İzmit (29.94098,4077830) Vs30 = 604 m/sec.

When the hazard curves of four points are compared and analyzed, the ranking from the most dangerous is Darıca, Gölcük, Gebze, and İzmit. It is observed that Darıca and Gölcük, which are very close to the North Anatolian Fault (NAF), have similar acceleration values. From Gebze's acceleration values, we understand that acceleration decreases as we move northward, away from the NAF. The difference between İzmit and Gebze can be explained by the fact that İzmit has a better soil classification compared to Gebze.

2.3.5. Uniform Hazard Spectra

The hazard spectra, generated using the outputs from the OpenQuake software, allow for a detailed examination of period-dependent probabilistic acceleration values of ground motions. These spectra are a critical tool for understanding the seismic behavior of different structures by showing the expected acceleration values for various periods in a specific region. Since periods directly affect the flexibility of structures, the seismic performance of each structure can vary based on its period. Therefore, the hazard spectra provide important information for evaluating a structure's resilience.

In this section, the generated hazard spectra will be compared with the standard spectrum defined in TBDY2018 (Turkish Building Earthquake Code 2018). TBDY provides a base spectrum used in building design, which takes into account the probabilistic seismic effects in a given region. The comparison with this spectrum will help determine whether there are any differences based on local conditions and the characteristics of the building stock. In particular, the TBDY2018 spectrum is designed to ensure the safety of buildings by providing acceleration values corresponding to a specific probability of occurrence for an earthquake.

Based on the findings, similarities and differences between the TBDY2018 spectrum and the site-specific hazard spectra will be evaluated. For example, in some regions, the acceleration values from the TBDY2018 spectrum may not align with those from the local hazard spectrum in a particular period range. This could require different seismic design strategies for buildings. The impact of these differences on structural safety is particularly significant in high-risk areas, as changes in design to improve resilience could have major consequences.

Furthermore, analyzing period-dependent accelerations will help better understand the seismic design needs and retrofitting requirements of structures. For instance, if significant differences are observed in a particular period range, additional strengthening measures may be required for some buildings. Such analyses play a crucial role in improving the seismic resilience of the building stock and ensuring better performance during earthquakes. In conclusion, these analyses provide an important reference for enhancing the seismic durability of existing buildings while minimizing potential risks.

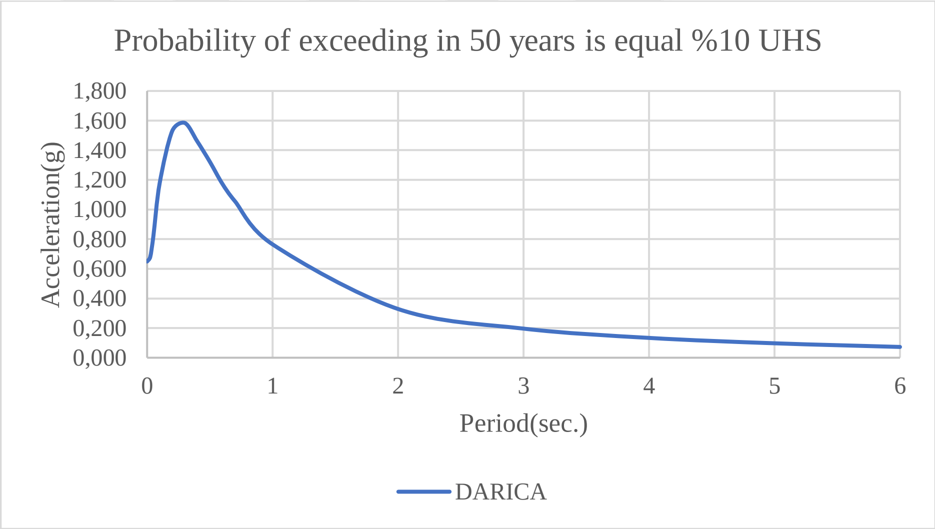


Figure 2.16: Poes in 50 years is equal %10 UHS Darıca.

When the hazard spectrum for Darıca in **Figure 2.16** is examined;

- When probability of exceeding in 50 years is equal %10 ;

  T (period) = 0.2 sec → a (acceleration) = 1,529g

  T (period) = 0,3 sec → a (acceleration) = 1,584g

  T (period) = 0,4 sec → a (acceleration) = 1,460g

  T (period) = 0,5 sec → a (acceleration) = 1,322g

  T (period) = 1.0 sec → a (acceleration) = 0,765g

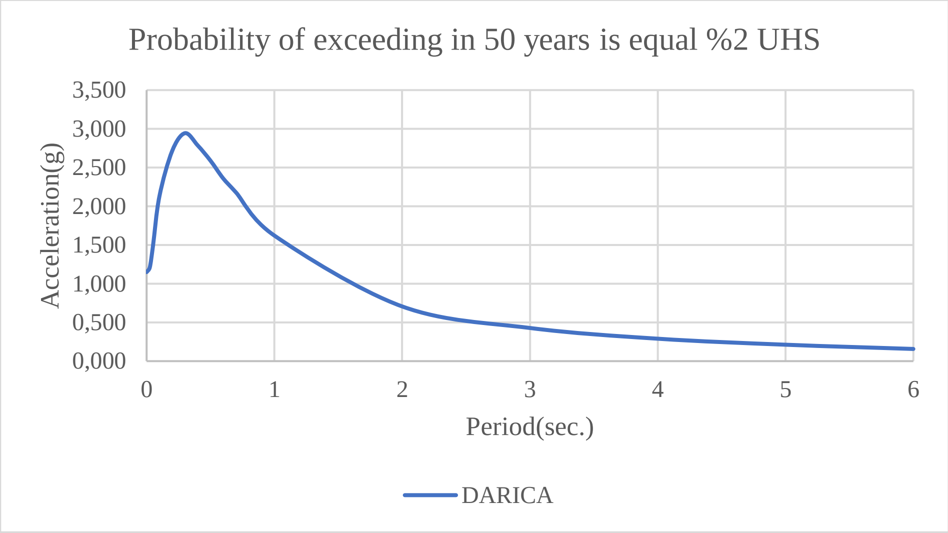


Figure 2.17: Poes in 50 years is equal %2 UHS Darıca.

When the hazard spectrum for Darıca in **Figure 2.17** is examined;

- When probability of exceeding in 50 years is equal %2 ;

T (period) = 0.2 sec → a (acceleration) = 2,714g

T (period) = 0,3 sec → a (acceleration) = 2,944g

T (period) = 0,4 sec → a (acceleration) = 2,786g

T (period) = 0,5 sec → a (acceleration) = 2,589g

T (period) = 1.0 sec → a (acceleration) = 1,621g

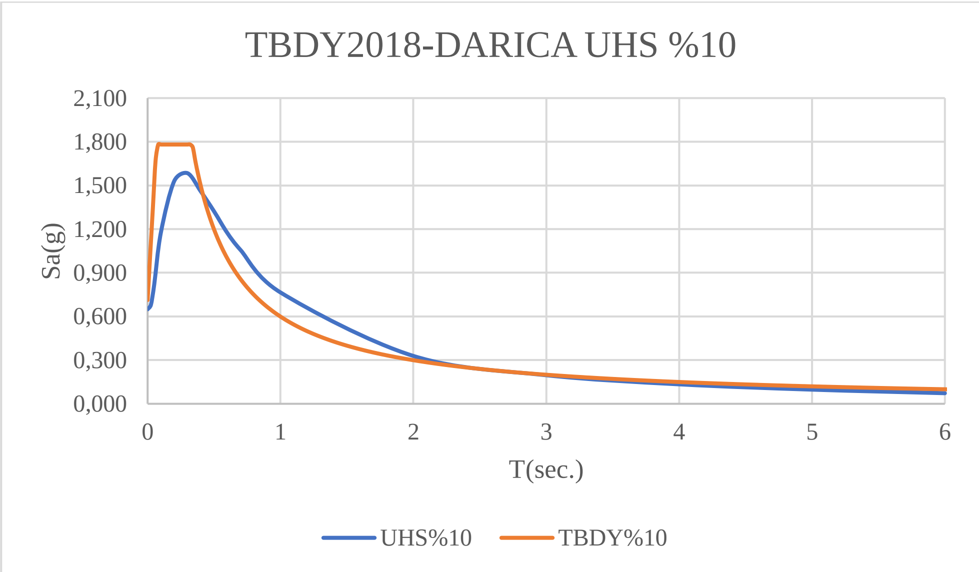


Figure 2.18: Poes in 50 years is equal %10 UHS-TBDY2018 Darıca.

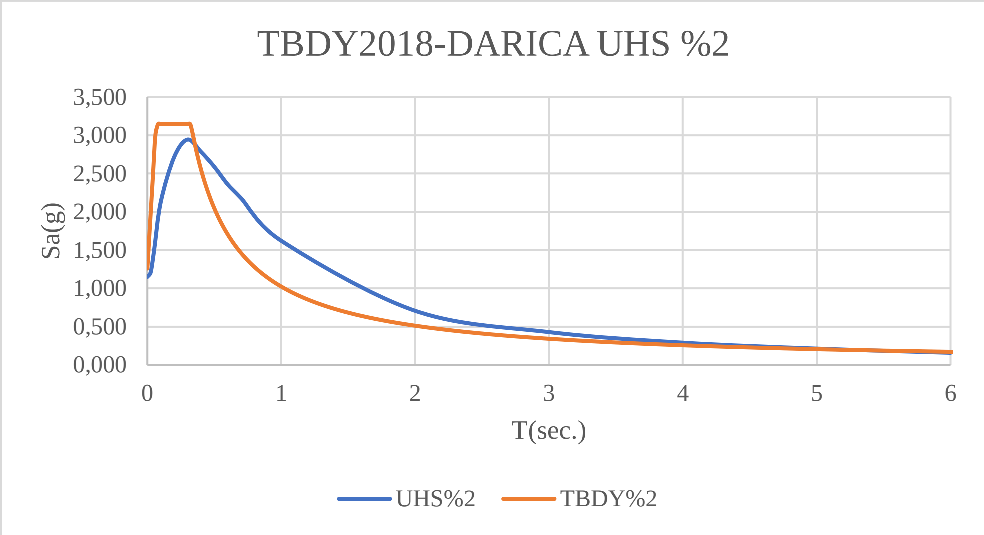


Figure 2.19: Poes in 50 years is equal %2 UHS-TBDY2018 Darıca.

When the site-specific hazard spectrum for Darıca is compared with the TBDY2018 (Turkish Building Earthquake Code 2018) spectrum **(Figure 2.18 and Figure 2.19)**, it is evident that structures with a period range of 0.44 - 2.4 seconds are likely to experience higher accelerations. This indicates a potential vulnerability for structures within this period range, which may negatively impact their seismic performance. Therefore, it is critically important to conduct performance analyses for these structures and implement necessary engineering measures to enhance their seismic safety.

Considering the typology of buildings in the Darıca region, it is estimated that 4-5-6 story school buildings have approximate periods falling within the 0.44 - 2.4 second range. Such school buildings, due to their height and the fact that they house a dense population of students and staff while providing essential public services, require more detailed investigations. The potential hazards these buildings may face during an earthquake could lead to severe consequences in terms of safety for the occupants.

In this context, detailed performance analyses should be carried out for 4-5-6 story school buildings in Darıca, risks should be identified, and necessary retrofitting measures should be implemented. During retrofitting, factors such as the soil characteristics of the area, the current condition of the structural system, and the site-specific hazard spectrum should be considered to develop strategies that enhance seismic resilience. These approaches will play a vital role in minimizing earthquake risks for critical public buildings in the region and ensuring the overall safety of the community.

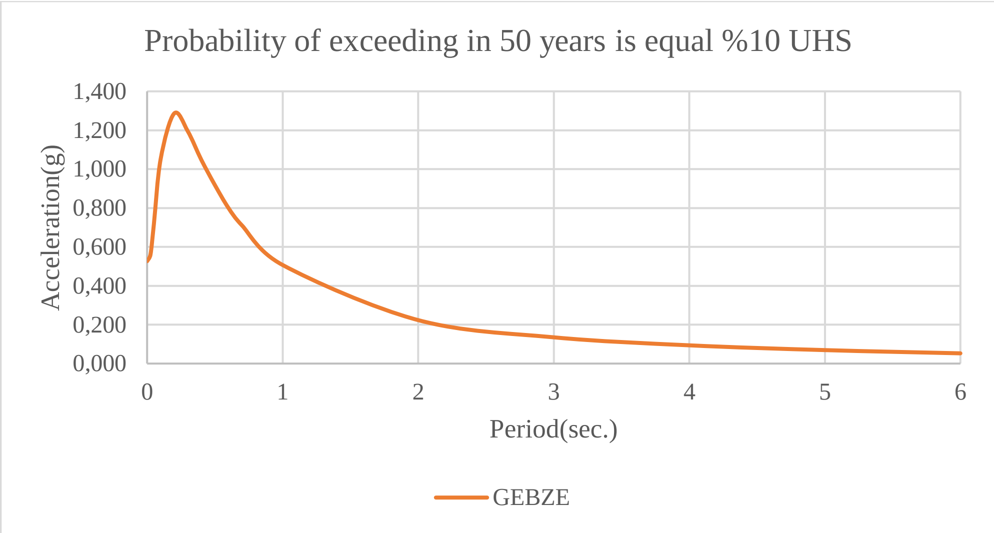


Figure 2.20: Poes in 50 years is equal %10 UHS Gebze.

When the hazard spectrum for Gebze in **Figure 2.20** is examined;

- When probability of exceeding in 50 years is equal %10 ;

  T (period) = 0.2 sec → a (acceleration) = 1,286g

  T (period) = 0,3 sec → a (acceleration) = 1,195g

  T (period) = 0,4 sec → a (acceleration) = 1,048g

  T (period) = 0,5 sec → a (acceleration) = 0,918g

  T (period) = 1.0 sec → a (acceleration) = 0,507g

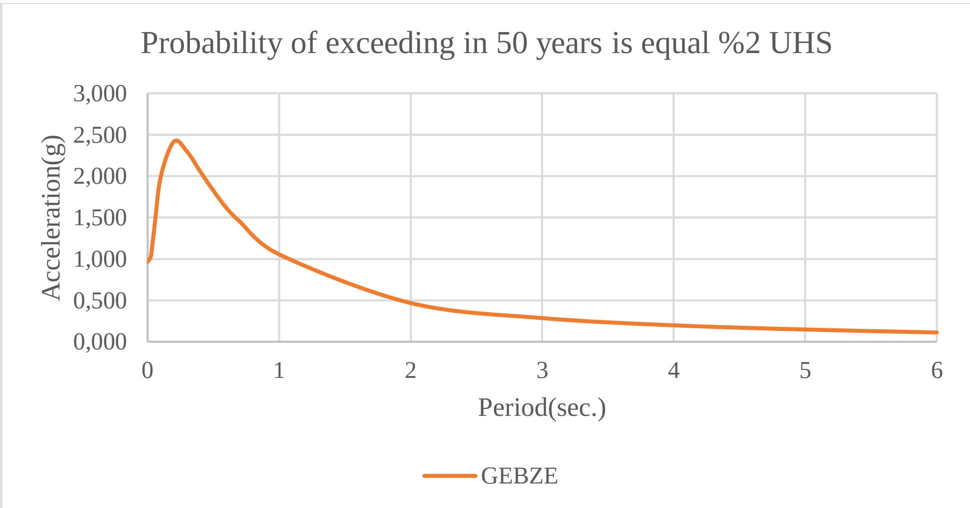


Figure 2.21: Poes in 50 years is equal %2 UHS Gebze.

When the hazard spectrum for Gebze in **Figure 2.21** is examined;

- When probability of exceeding in 50 years is equal %2 ;

  T (period) = 0.2 sec → a (acceleration) = 2,417g

  T (period) = 0,3 sec → a (acceleration) = 2,296g

  T (period) = 0,4 sec → a (acceleration) = 2,056g

  T (period) = 0,5 sec → a (acceleration) = 1,825g

  T (period) = 1.0 sec → a (acceleration) = 1,621g

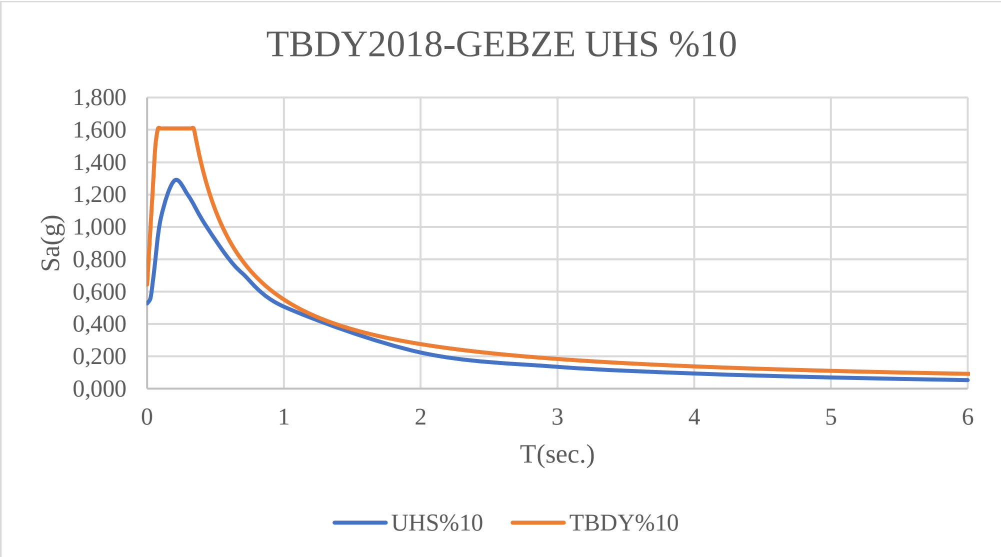


Figure 2.22: Poes in 50 years is equal %10 UHS-TBDY2018 Gebze.

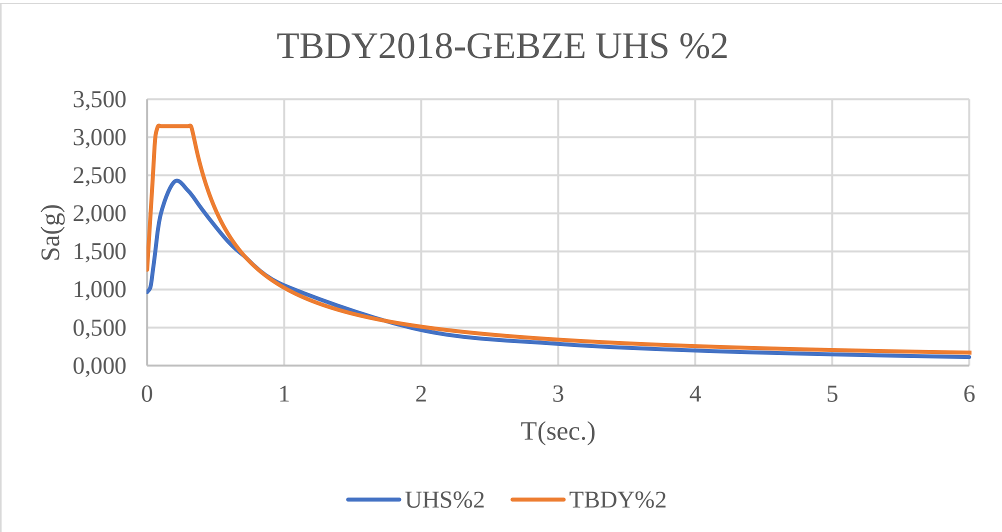


Figure 2.23: Poes in 50 years is equal %2 UHS-TBDY2018 Gebze.

When the site-specific hazard spectrum for Gebze is compared with the TBDY2018 spectra **(Figure 2.22 and Figure 2.23)**, it has been observed that the spectrum comparisons for both earthquake levels overlap or are safer.

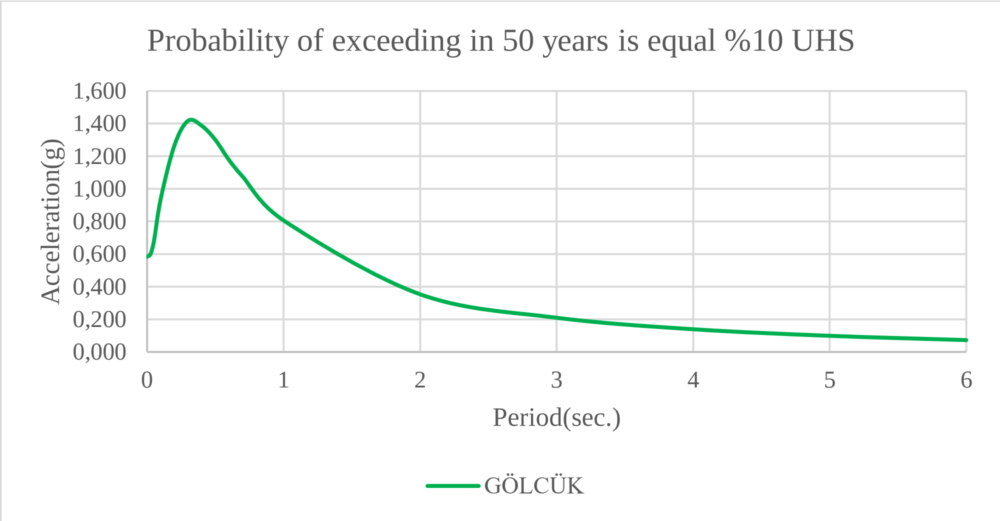


Figure 2.24: Poes in 50 years is equal %10 UHS Gölcük.

When the hazard spectrum for Gölcük in **Figure 2.24** is examined;

- When probability of exceeding in 50 years is equal %10 ;

T (period) = 0.2 sec → a (acceleration) = 1,529g

T (period) = 0,3 sec → a (acceleration) = 1,584g

T (period) = 0,4 sec → a (acceleration) = 1,460g

T (period) = 0,5 sec → a (acceleration) = 1,322g

T (period) = 1.0 sec → a (acceleration) = 0,765g

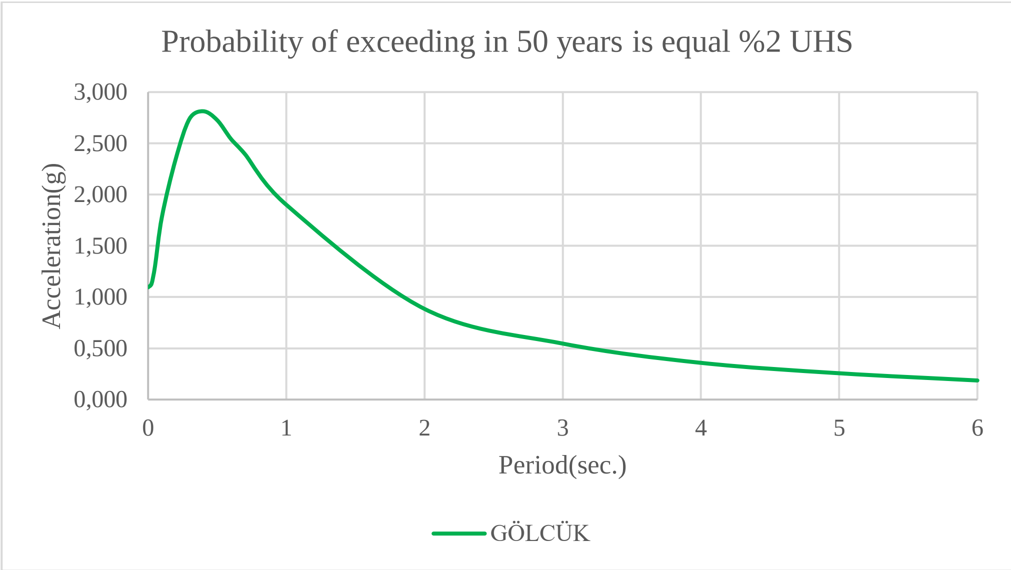


Figure 2.25: Poes in 50 years is equal %2 UHS Gölcük.

When the hazard spectrum for Gölcük in **Figure 2.25** is examined;

- When probability of exceeding in 50 years is equal %2 ;

T (period) = 0.2 sec → a (acceleration) = 2,714g

T (period) = 0,3 sec → a (acceleration) = 2,944g

T (period) = 0,4 sec → a (acceleration) = 2,786g

T (period) = 0,5 sec → a (acceleration) = 2,589g

T (period) = 1.0 sec → a (acceleration) = 1,621g

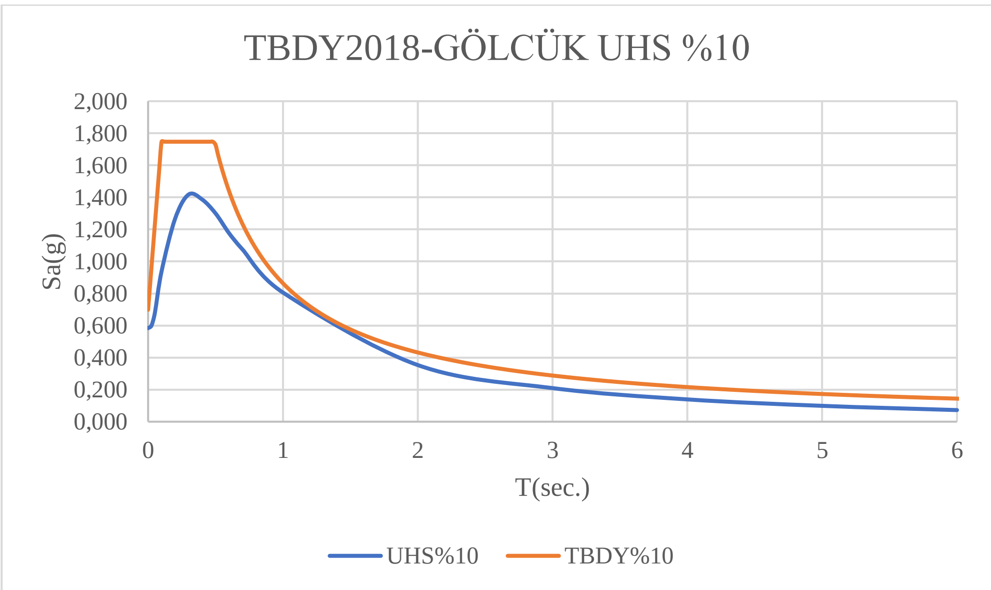


Figure 2.26: Poes in 50 years is equal %10 UHS-TBDY2018 Gölcük.

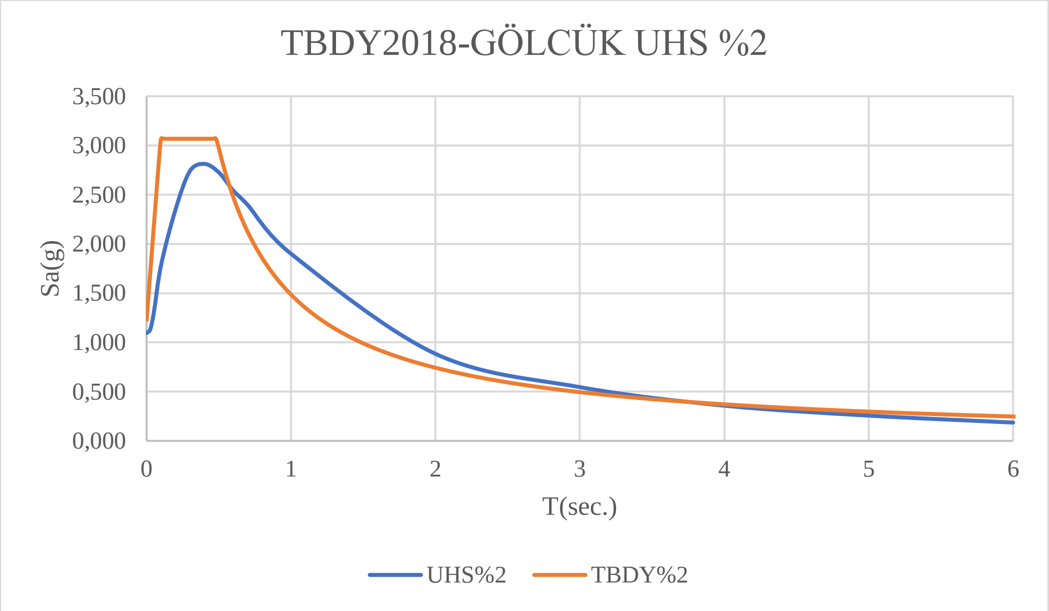


Figure 2.27: Poes in 50 years is equal %2 UHS-TBDY2018 Gölcük.

It has been observed that the spectrum comparisons for the earthquake level with a 10% probability of exceedance in 50 years either overlap or are safer. This means that when comparing the seismic hazard spectrum calculated for this probability level with other design or reference spectra (such as those outlined in building codes like TBDY), the resulting values of seismic accelerations or forces are either within similar ranges or lower than those predicted by the other spectra.

This suggests that, for this seismic hazard level, the design spectra (or the spectra derived from local seismic hazard models) are sufficiently conservative or align well with the expected seismic demands. In practical terms, this could mean that structures designed based on these spectra may experience lower-than-expected seismic forces or are sufficiently protected against the calculated levels of seismic activity.

Such observations can lead to more confidence in the safety and reliability of designs, reducing the need for additional safety measures or adjustments to building codes in regions with a 10% probability of exceedance in 50 years. In summary, these spectra not only align but may also offer a higher level of safety compared to the original design parameters, ensuring better protection against seismic risks.

When the spectra generated for Gölcük are compared with the TBDY for an earthquake with a 2% probability of exceedance in 50 years (**Figure 2.26 and Figure 2.27**), accelerations above the design are expected for structures with periods between

T=0.58 seconds and T=3.3 seconds. In this context, structures within this period range should be examined, and precautions should be taken if necessary.

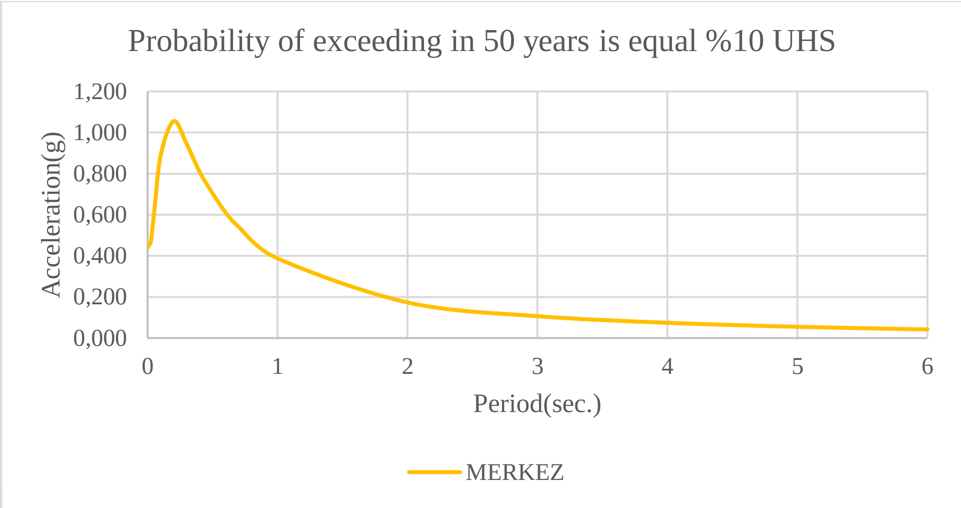


Figure 2.28: Poes in 50 years is equal %10 UHS İzmit.

When the hazard spectrum for İzmit in **Figure 2.28** is examined;

- When probability of exceeding in 50 years is equal %10 ;

  T (period) = 0.2 sec → a (acceleration) = 1,055g

  T (period) = 0,3 sec → a (acceleration) = 0,945g

  T (period) = 0,4 sec → a (acceleration) = 0,809g

  T (period) = 0,5 sec → a (acceleration) = 0,704g

  T (period) = 1.0 sec → a (acceleration) = 0,387g

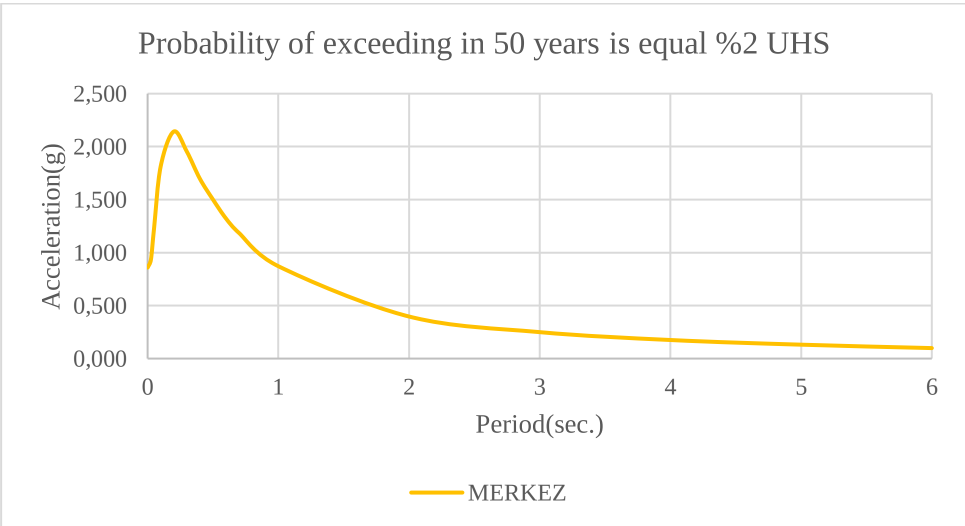


Figure 2.29: Poes in 50 years is equal %2 UHS İzmit.

When the hazard spectrum for İzmit in **Figure 2.29** is examined;

- When probability of exceeding in 50 years is equal %2 ;

  T (period) = 0.2 sec → a (acceleration) = 2,143g

  T (period) = 0,3 sec → a (acceleration) = 1,954g

  T (period) = 0,4 sec → a (acceleration) = 1,697g

  T (period) = 0,5 sec → a (acceleration) = 1,507g

  T (period) = 1,0 sec → a (acceleration) = 0,872g

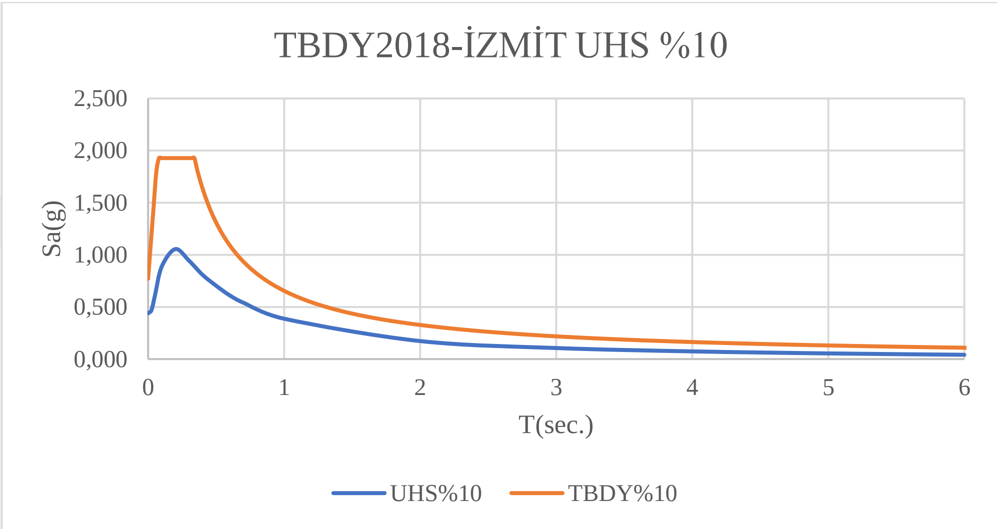


Figure 2.30: Poes in 50 years is equal %10 UHS-TBDY2018 İzmit.

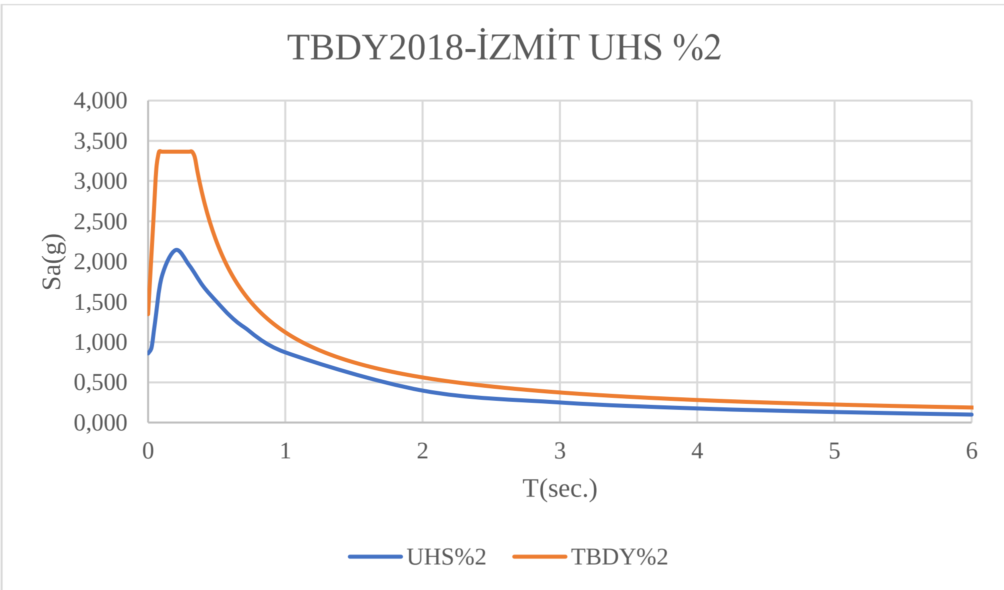


Figure 2.30: Poes in 50 years is equal %2 UHS-TBDY2018 İzmit.

When the site-specific hazard spectrum for İzmit is compared with the TBDY2018 spectra**(Figure 2.29 and Figure 2.30)**, it has been observed that the spectrum comparisons for both earthquake levels overlap or are safer.

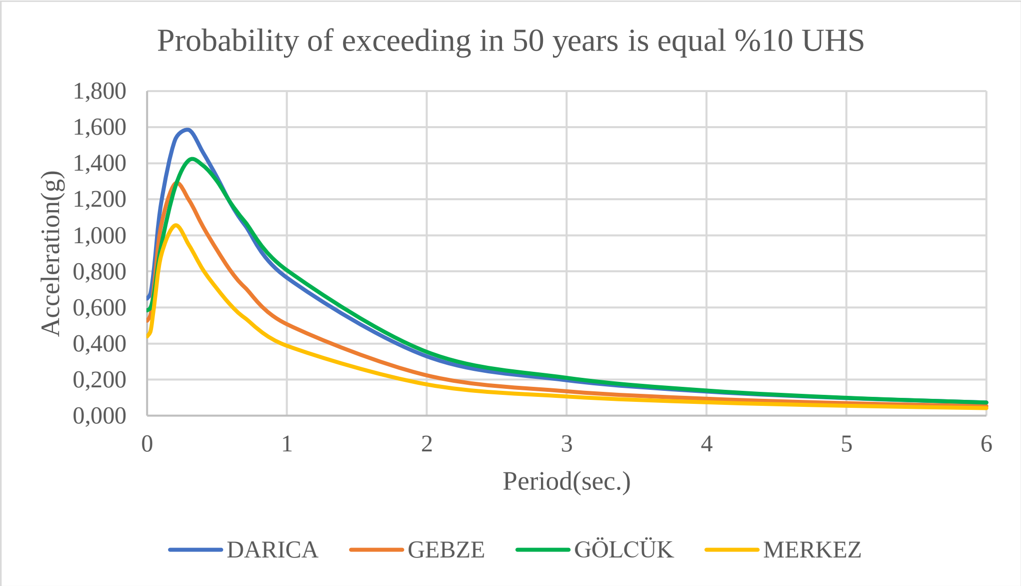


Figure 2.31: Poes in 50 years is equal %10 UHS-Compare.

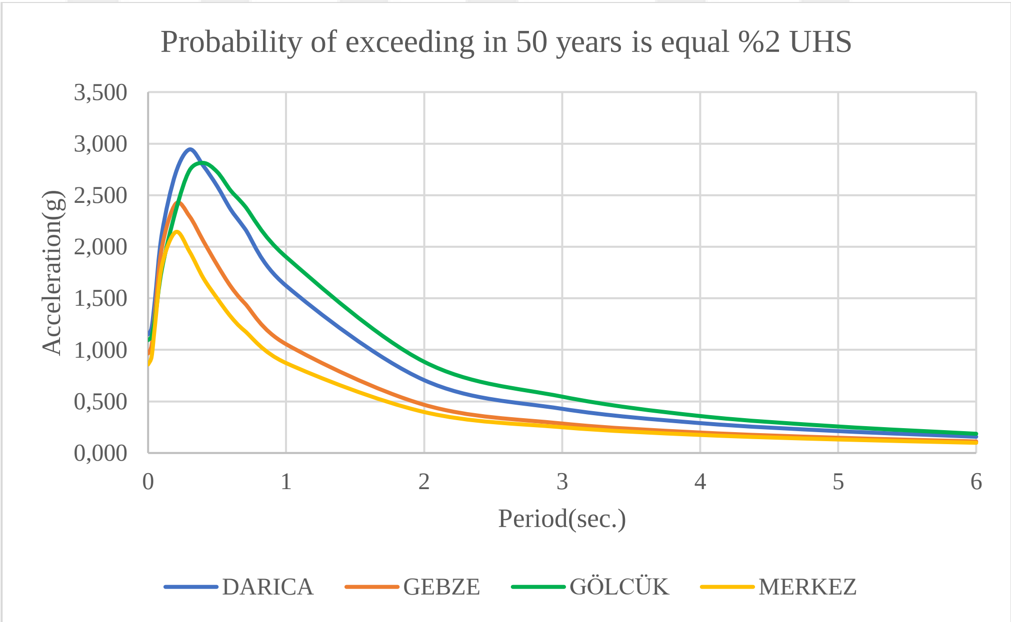


Figure 2.32: Poes in 50 years is equal %2 UHS-Compare.

When the hazard spectra are compared**(Figure 2.31 and Figure 2.32)**, it is observed that Darıca and Gölcük, which are close to the North Anatolian Fault (NAF), have similar acceleration values. In these areas, the local seismic activity and the proximity to the fault lead to similar seismic hazard levels, so the hazard spectra for these two locations show parallel trends.

On the other hand, since the selected location of Izmit has a better soil class compared to Gebze, a slight difference in acceleration values is observed. Soil class is an important factor affecting the propagation of seismic waves. In Izmit, the better soil class leads to less amplification of seismic waves, resulting in lower acceleration values for the same earthquake level. This suggests that the seismic risk in Izmit is slightly lower.

In conclusion, these observations show how factors such as soil conditions and proximity to fault lines affect seismic hazard and acceleration values. These differences indicate important considerations for the design of structures, as different engineering solutions may be required for different locations.

2.3.6. Hazard Maps

Hazard maps visually present the distribution and magnitude of potential seismic effects in a region, providing an important reference for structural durability and safety. These maps determine the hazard levels for structures in a specific area based on factors such as local soil characteristics, regional fault lines, and the likelihood of major earthquakes occurring.

Since most school buildings in the current building stock are typically 2, 3, and 5-story buildings, their periods generally fall within the range of 0.2-0.3-0.5 seconds. These periods vary according to the rigidity and flexibility characteristics of the buildings and determine how they interact with seismic effects. Therefore, hazard maps have been specifically created for structures within this period range, and the acceleration values these buildings may experience during an earthquake have been identified.

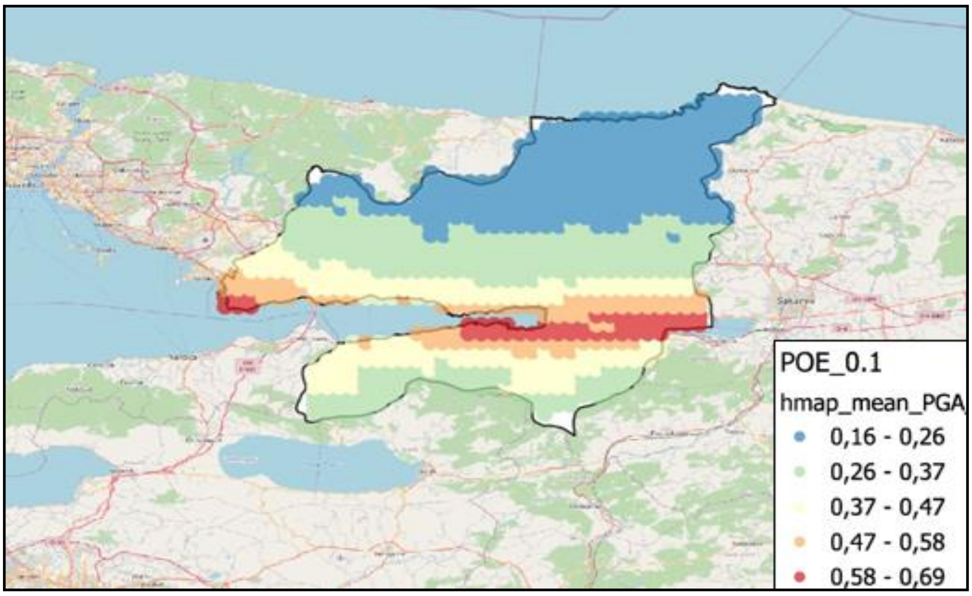


Figure 2.33: Hazard map of poes in 50 years is equal %10 for PGA.

When **Figure 2.33** is examined, it can be seen that the PGA distribution for an earthquake with a 10% probability of exceedance in 50 years ranges from 0.16g to 0.69g. When **Figure 2.34** is examined, it can be seen that the PGA distribution for an earthquake with a 2% probability of exceedance in 50 years also ranges from 0.16g to 0.69g.

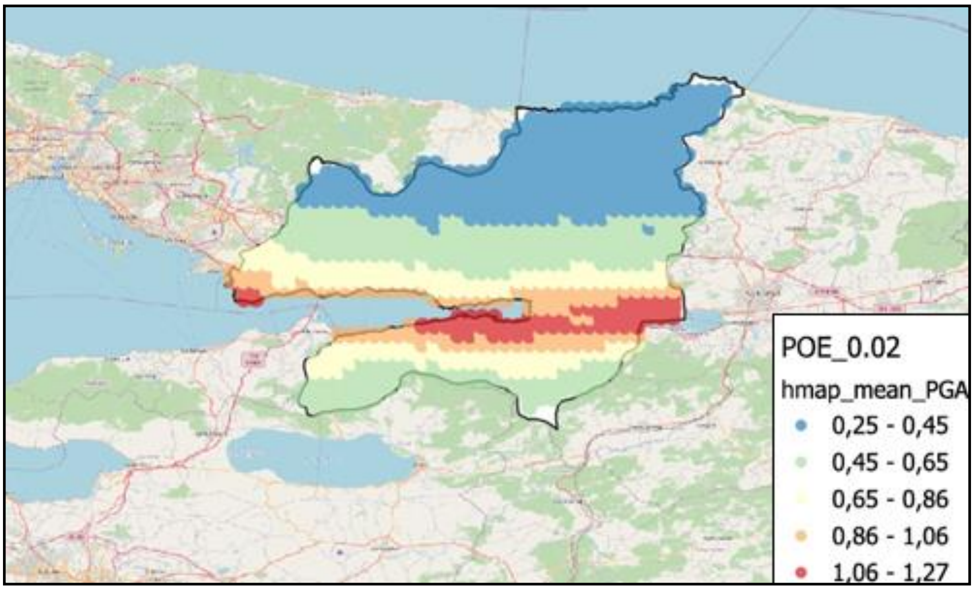


Figure 2.34: Hazard hap of poes in 50 years is equal %2 for PGA.

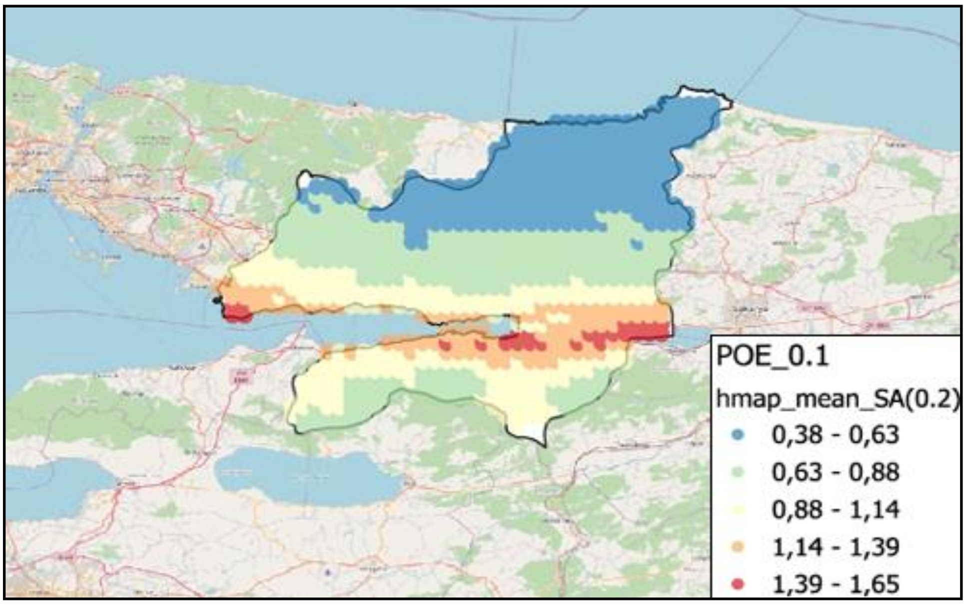


Figure 2.35: Hazard map of poes in 50 years is equal %10 for Sa(T=0,2sec.).

In the earthquake with a 10% probability of exceedance in 50 years, the acceleration distribution for structures with a period of 0.2 seconds ranges from 0.38g to 1.65g, as shown in **Figure 2.35**. Structures with a period of 0.2 seconds can be considered as approximately 2-story buildings.

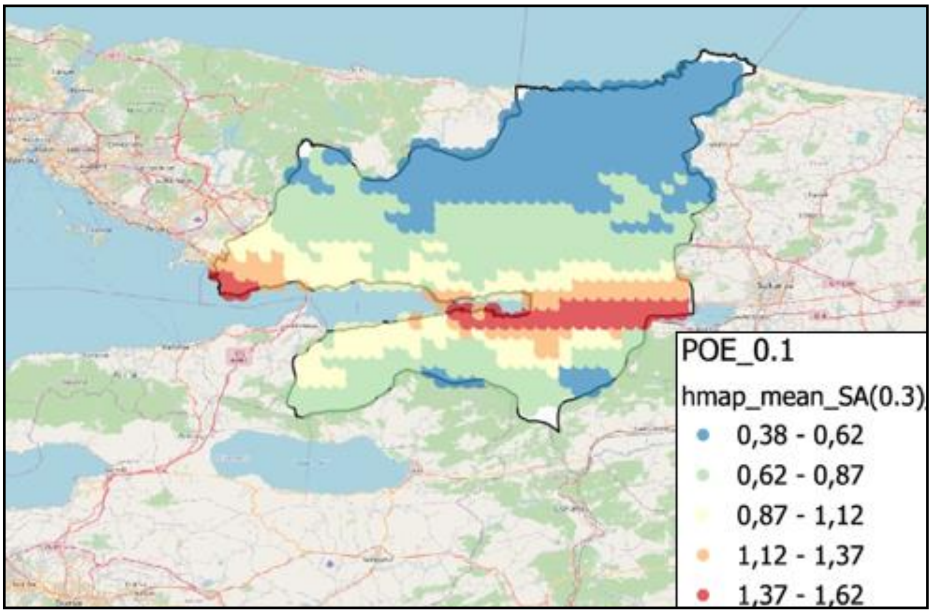


Figure 2.36: Hazard map of poes in 50 years is equal %10 for Sa(T=0,3sec.).

In the earthquake with a 10% probability of exceedance in 50 years, the acceleration distribution for structures with a period of 0.3 seconds ranges from 0.38g to 1.62g, as shown in **Figure 2.36**. Structures with a period of 0.3 seconds can be considered as approximately 3-story buildings.

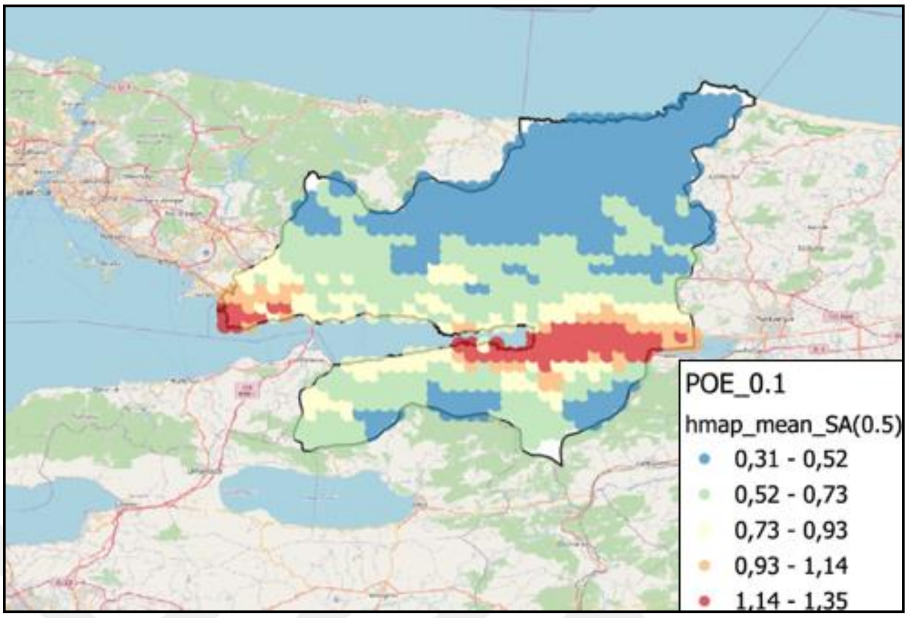


Figure 2.37: Hazard map of poes in 50 years is equal %10 for Sa(T=0,5).

In the earthquake with a 10% probability of exceedance in 50 years, the acceleration distribution for structures with a period of 0.5 seconds ranges from 0.31g to 1.35g, as shown in **Figure 2.37**. Structures with a period of 0.5 seconds can be considered as approximately 5-story buildings.

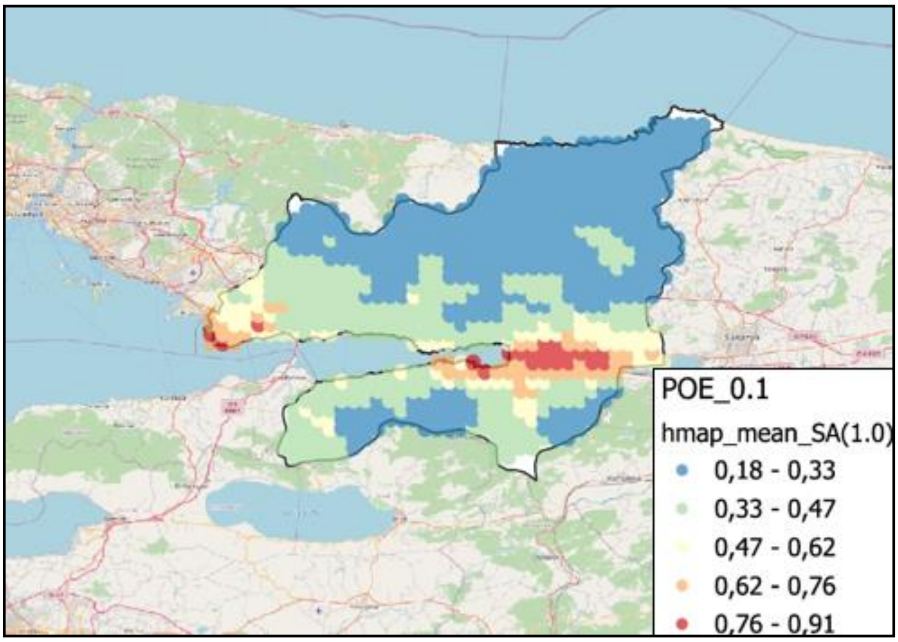


Figure 2.38: Hazard map of poes in 50 years is equal %10 for Sa(T=1,0).

In the earthquake with a 10% probability of exceedance in 50 years, the acceleration distribution for structures with a period of 1.0 seconds ranges from 0.18g to 0.91g, as shown in **Figure 2.38**. Structures with a period of 1.0 seconds can be considered as approximately 10-story buildings.

When all these maps and spectra are examined, it can be concluded that the Marmara Sea coast is less hazardous compared to the northern and southern regions of the city. Within the scope of this study, hazard maps have been specifically created for the periods typically associated with school buildings. As a result of these examinations, it has been observed that the most hazardous districts are Darıca, Gölcük, Başiskele, and Kartepe. These districts have a medium-level population in Kocaeli. The most populous districts, İzmit and Gebze, have been found to be less hazardous compared to these districts. This situation can be explained by the effects of factors such as the ground conditions, building density, and seismic hazard levels in these areas.

2.4. Risk Analysis

Seismic risk analysis typically involves three main stages: **hazard analysis**, **vulnerability analysis**, and **risk assessment**. The risk formula is obtained by combining these three analyses**(Figure 2.39)**.Each stage provides critical insights about earthquake risks and helps in taking necessary measures to ensure the safety of structures.

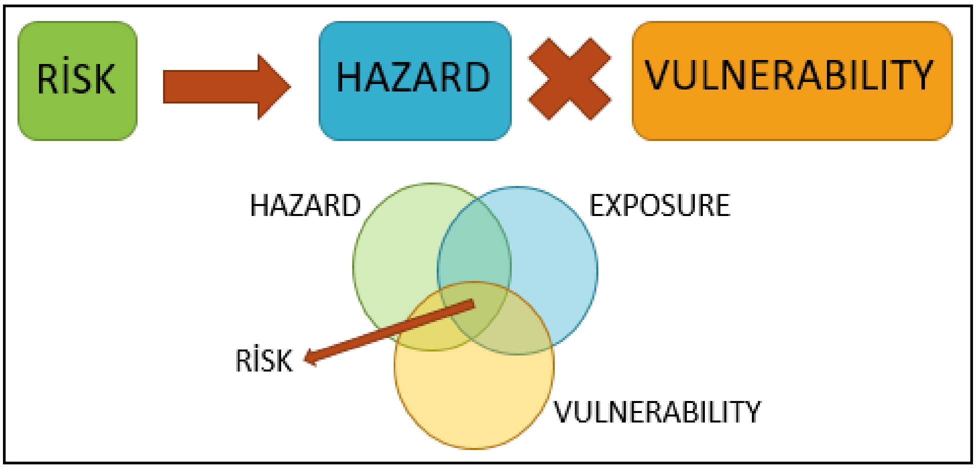


Figure 2.39: Formula of risk.

2.4.1. Importance and Applications of Seismic Risk Analysis

Seismic risk analysis not only helps assess current hazards but also provides the necessary steps to prepare for future seismic events. This analysis facilitates the development of safer structures by identifying weaknesses in existing buildings and guiding design solutions for new constructions. Seismic risk analysis is a fundamental tool for the following applications:

- **Disaster Response Planning**: It helps in preparing emergency response strategies for potential earthquakes.
- **Strengthening and Retrofitting**: Engineering solutions can be developed to enhance the resilience of buildings at high risk.
- **Land Use Planning**: In areas with high seismic risk, construction can be limited or designed to be more earthquake-resistant.

2.4.2. Hazard Analysis Within Risk Analysis

Hazard analysis is the first step in seismic risk analysis. This stage determines the potential magnitude, frequency, and effects of earthquakes in a region. The factors considered during hazard analysis include:

- **Seismic Activity**: Historical earthquake data helps to predict the potential magnitude and frequency of future earthquakes.
- **Ground Conditions**: The type of soil and local ground structure can influence the intensity and distribution of seismic waves.
- **Regional Hazards**: Active fault lines and their proximity to structures are significant factors in seismic hazard assessment.

Once the hazard analysis is completed, a seismic risk map for the region can be created, which serves as an essential reference for the subsequent stages.

2.4.3. Vulnerability Analysis

Vulnerability analysis assesses the susceptibility of structures to seismic hazards. The vulnerability of buildings varies depending on factors such as construction materials, building types, design standards, age, and ground conditions. Factors considered in vulnerability analysis include:

- **Building Type**: Different construction types, such as reinforced concrete, masonry, or steel, have varying seismic resistance.
- **Age and Condition of the Structure**: Older buildings may not comply with modern seismic codes, making them more vulnerable.
- **Ground Conditions**: Poor soil conditions can amplify seismic waves and result in more severe impacts on buildings.
- **Structural Elements**: The condition of the building's load-bearing systems, walls, columns, and beams also plays a role in its vulnerability.

Vulnerability analysis is usually performed using **fragility curves** or **performance tables** that describe how buildings respond to different levels of seismic intensity and the expected damage.

2.4.4. Risk Assessment

Risk assessment combines seismic hazard data and vulnerability information to determine the overall risk. This stage estimates the potential damage to structures in the event of an earthquake and evaluates their overall risk exposure. During this stage, the following factors are considered:

- **Damage Probability**: The likelihood that a structure will sustain damage at various levels of seismic intensity is calculated.
- **Damage Assessment**: The potential economic, structural, and health impacts of the damage are evaluated.
- **Risk Mapping**: The data from hazard and vulnerability analyses are combined to create a risk map that identifies areas and buildings at high risk.

The risk assessment results can be used to plan mitigation measures, such as strengthening buildings, upgrading engineering designs, or implementing emergency response strategies for high-risk structures.

2.4.5. Building Inventory and Exposure Model

A building inventory and exposure model is a comprehensive framework used to assess and analyze the physical characteristics and vulnerabilities of buildings in a specific area, typically in relation to risk management, disaster preparedness, or environmental impacts.

The building inventory refers to the collection of data regarding the structures within a specific geographical area. This inventory typically includes essential information about each building, such as:

- **Location:** Geographic coordinates or address.
- **Size and Structure:** Dimensions, number of floors, type of construction (e.g., residential, commercial, industrial), and material used.
- **Age and Condition:** Year of construction, renovations, and overall structural integrity.
- **Usage:** Primary function of the building (e.g., residential, office, school, hospital).
- **Vulnerabilities:** Identifying factors that may increase the risk of damage or destruction, such as proximity to flood zones, earthquake-prone areas, or fire hazards.

The building stock used in this study has been evaluated by examining the local government records of the region. As a result of this evaluation, it was determined that 29.59% of the public buildings in the area are school buildings**(Figure 2.40)**. This percentage represents the highest proportion among public buildings. The proportions of other building categories are presented in the table below.

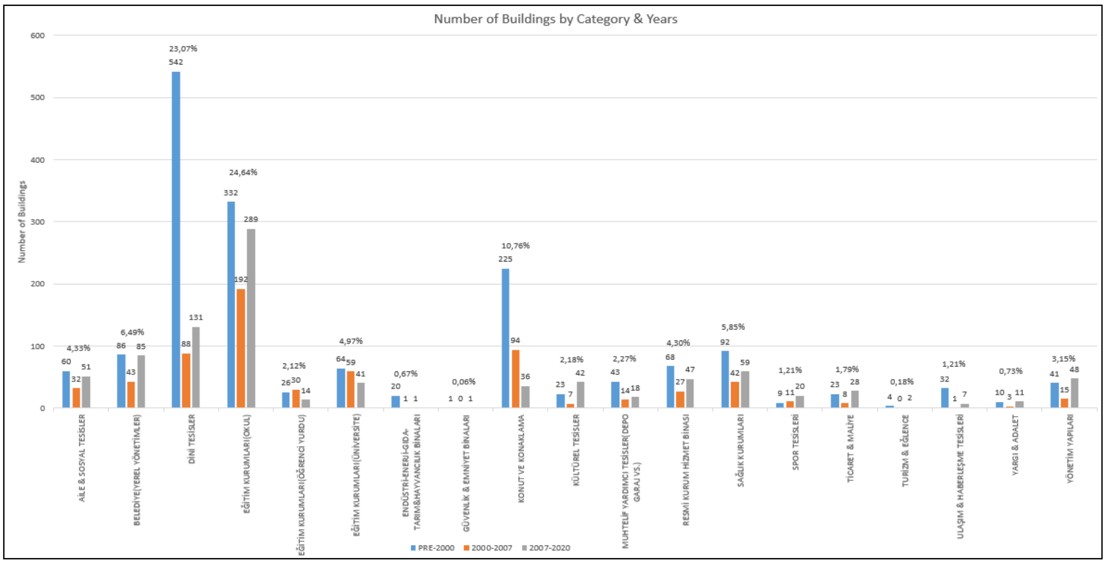


Figure 2.40: Number of buildings by category and year.

When this stock is examined, it was found that 83.30% of the public buildings have 1 to 3 normal floors, 16.13% have 4 to 7 floors, and 0.58% have 8 or more normal floors**(Figure 2.41)**. As for school buildings, it was determined that they have 1, 2, 3, 4, 5, or 6 normal floors, and no school buildings were found with more than 6 normal floors.

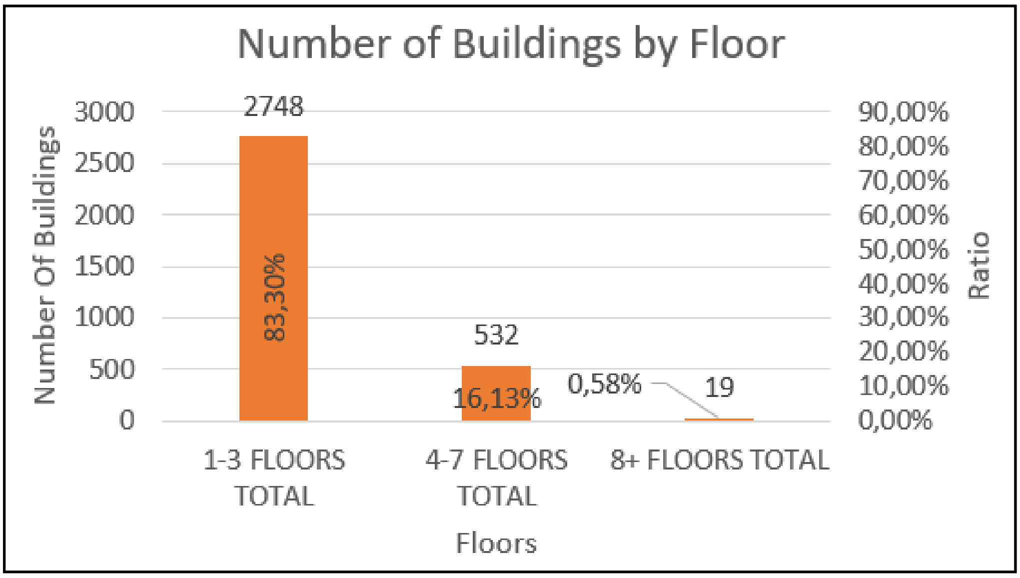


Figure 2.41: Number of buildings by floor for all public building.

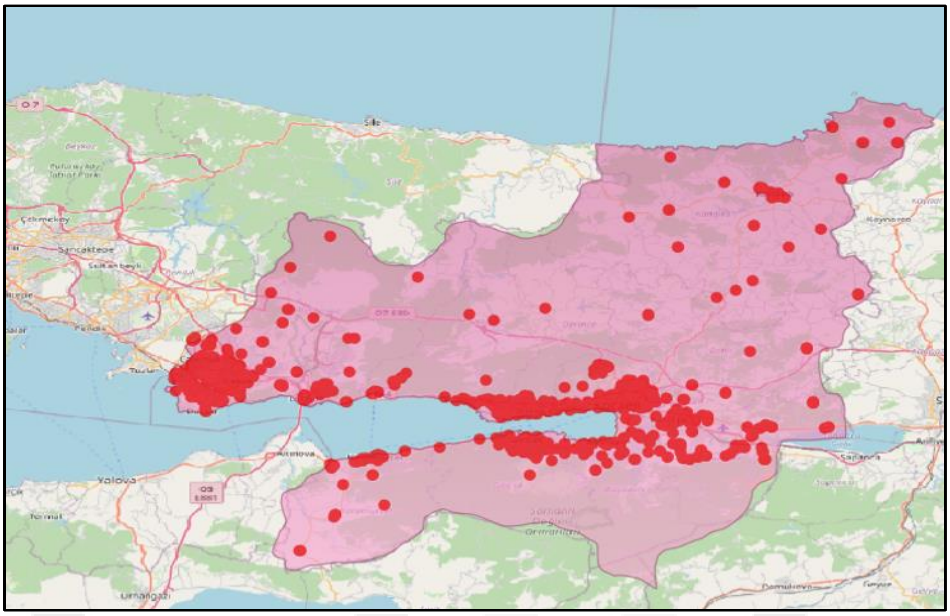


Figure 2.42: School building inventory map in Kocaeli.

As a result of these evaluations, school buildings have been classified according to height, construction year, and structural system type. These classifications are detailed in the tables below. The distribution of school buildings on the Kocaeli map is shown in **(Figure 2.42)**. The inventory of school buildings across Kocaeli, organized into groups, is shown in **Table 2.2**.

Table 2.2: Kocaeli region school buildings inventory.

CATEGORY	HEIGHT	CONSTRUCTION YEAR	NUMBER OF BUILDINGS
RC KOCAELİ REGION	Low-Rise (1-3 Floors)	Pre-2000	330
		2000-2007	210
		2007-2020	163
	Mid-Rise (4-7 Floors)	Pre-2000	66
		2000-2007	41
		2007-2020	167
		TOPLAM	977

Table 2.3: Başiskele school buildings inventory.

CATEGORY	HEIGHT	CONSTRUCTION YEAR	NUMBER OF BUILDINGS
RC BAŞİSKELE 40.745248 29.956344	Low-Rise (1-3 Floors)	Pre-2000	22
		2000-2007	13
		2007-2020	6
	Mid-Rise (4-7 Floors)	Pre-2000	1
		2000-2007	5
		2007-2020	10
		TOPLAM	57

The inventory of school buildings in Başiskele district, organized into groups, is shown in **Table 2.3**.

Table 2.4: Çayırova school buildings inventory.

CATEGORY	HEIGHT	CONSTRUCTION YEAR	NUMBER OF BUILDINGS
RC CAYIROVA 40.824215 29.372233	Low-Rise (1-3 Floors)	Pre-2000	2
		2000-2007	11
		2007-2020	15
	Mid-Rise (4-7 Floors)	Pre-2000	2
		2000-2007	1
		2007-2020	17
		TOPLAM	48

The inventory of school buildings in Çayırova district, organized into groups, is shown in **Table 2.4**.

Table 2.5: Darıca school buildings inventory.

CATEGORY	HEIGHT	CONSTRUCTION YEAR	NUMBER OF BUILDINGS
RC DARICA 40.762176 29.384333	Low-Rise (1-3 Floors)	Pre-2000	12
		2000-2007	7
		2007-2020	3
	Mid-Rise (4-7 Floors)	Pre-2000	6
		2000-2007	3
		2007-2020	16
		TOPLAM	47

The inventory of school buildings in Darıca district, organized into groups, is shown in **Table 2.5**.

Table 2.6: Derince school buildings inventory.

CATEGORY	HEIGHT	CONSTRUCTION YEAR	NUMBER OF BUILDINGS
RC DERİNCE 40.756186 29.830913	Low-Rise (1-3 Floors)	Pre-2000	11
		2000-2007	8
		2007-2020	12
	Mid-Rise (4-7 Floors)	Pre-2000	4
		2000-2007	3
		2007-2020	14
		TOPLAM	52

The inventory of school buildings in Derince district, organized into groups, is shown in **Table 2.6**.

Table 2.7: Dilovası school buildings inventory.

CATEGORY	HEIGHT	CONSTRUCTION YEAR	NUMBER OF BUILDINGS
RC DİLOVASI 40.787621 29.544152	Low-Rise (1-3 Floors)	Pre-2000	10
		2000-2007	3
		2007-2020	5
	Mid-Rise (4-7 Floors)	Pre-2000	1
		2000-2007	0
		2007-2020	6
		TOPLAM	25

The inventory of school buildings in Dilovası district, organized into groups, is shown in **Table 2.7**.

Table 2.8: Gebze school buildings inventory.

CATEGORY	HEIGHT	CONSTRUCTION YEAR	NUMBER OF BUILDINGS
RC GEBZE 40.79875 29.434477	Low-Rise (1-3 Floors)	Pre-2000	67
		2000-2007	36
		2007-2020	41
	Mid-Rise (4-7 Floors)	Pre-2000	16
		2000-2007	7
		2007-2020	26
		TOPLAM	193

The inventory of school buildings in Gebze district, organized into groups, is shown in **Table 2.8**.

Table 2.9: Gölcük school buildings inventory.

CATEGORY	HEIGHT	CONSTRUCTION YEAR	NUMBER OF BUILDINGS
RC GÖLCÜK 40.716848 29.819531	Low-Rise (1-3 Floors)	Pre-2000	15
		2000-2007	15
		2007-2020	14
	Mid-Rise (4-7 Floors)	Pre-2000	5
		2000-2007	3
		2007-2020	17
		TOPLAM	69

The inventory of school buildings in Gölcük district, organized into groups, is shown in **Table 2.9**.

Table 2.10: İzmit school buildings inventory.

CATEGORY	HEIGHT	CONSTRUCTION YEAR	NUMBER OF BUILDINGS
RC İZMİT 40.763891 29.93041	Low-Rise (1-3 Floors)	Pre-2000	67
		2000-2007	49
		2007-2020	31
	Mid-Rise (4-7 Floors)	Pre-2000	20
		2000-2007	13
		2007-2020	31
		TOPLAM	211

The inventory of school buildings in İzmit district, organized into groups, is shown in **Table 2.10**.

Table 2.11: Kandıra school buildings inventory.

CATEGORY	HEIGHT	CONSTRUCTION YEAR	NUMBER OF BUILDINGS
RC KANDIRA 41.070357 30.152393	Low-Rise (1-3 Floors)	Pre-2000	24
		2000-2007	12
		2007-2020	0
	Mid-Rise (4-7 Floors)	Pre-2000	0
		2000-2007	3
		2007-2020	2
		TOPLAM	41

The inventory of school buildings in Kandıra district, organized into groups, is shown in **Table 2.11**.

Table 2.12: Karamürsel school buildings inventory.

CATEGORY	HEIGHT	CONSTRUCTION YEAR	NUMBER OF BUILDINGS
RC KARAMÜRSEL 40.691273 29.616413	Low-Rise (1-3 Floors)	Pre-2000	17
		2000-2007	11
		2007-2020	2
	Mid-Rise (4-7 Floors)	Pre-2000	3
		2000-2007	1
		2007-2020	4
		TOPLAM	38

The inventory of school buildings in Karamürsel district, organized into groups, is shown in **Table 2.12**.

Table 2.13: Kartepe school buildings inventory.

CATEGORY	HEIGHT	CONSTRUCTION YEAR	NUMBER OF BUILDINGS
RC KARTEPE 40.753365 30.023215	Low-Rise (1-3 Floors)	Pre-2000	34
		2000-2007	27
		2007-2020	25
	Mid-Rise (4-7 Floors)	Pre-2000	2
		2000-2007	1
		2007-2020	11
		TOPLAM	100

The inventory of school buildings in Kartepe district, organized into groups, is shown in **Table 2.13**.

Table 2.14: Körfez school buildings inventory.

CATEGORY	HEIGHT	CONSTRUCTION YEAR	NUMBER OF BUILDINGS
RC KÖRFEZ 40.776382 29.737712	Low-Rise (1-3 Floors)	Pre-2000	49
		2000-2007	18
		2007-2020	9
	Mid-Rise (4-7 Floors)	Pre-2000	6
		2000-2007	1
		2007-2020	13
		TOPLAM	96

The inventory of school buildings in Körfez district, organized into groups, is shown in **Table 2.14**.

Exposure model; various data related to building stock are collected in this model for the analysis of buildings' risk exposure to specific events or hazards. These include:

Definition of Building Groups: Buildings are classified according to their type, use, construction style, or other characteristics. This classification is important for accurately assessing the risk associated with the buildings in the model. The building groups shown in the visual may illustrate this classification.

Recurrence Period of the Event: This refers to the frequency at which a specific event (such as an earthquake, flood, or fire) is expected to occur. The recurrence period is predicted based on historical data and helps in evaluating future risks.

Number of People at the Time: The number of people in the building at the time of the event is a crucial data point for risk analysis and impact assessment. This helps in calculating potential casualties and damages.

Coordinates: The physical location of the buildings is essential for accurately building the model. Coordinates help in analyzing building layouts, environmental factors, and the degree of impact in the event of a disaster.

This kind of data enhances the accuracy of the exposure model and allows for better prediction of the effects of potential hazards on buildings. Considering the entire building stock and classifications, it is defined in OpenQuake as an exposure model file, as shown in **Figure 2.42**.

```
<?xml version="1.0" encoding="UTF-8"?>
<nrml xmlns="http://openquake.org/xmlns/nrml/0.4">
    <exposureModel id="ex1" category="buildings" taxonomySource="GEM taxonomy">
        <description></description>
        <conversions>
            <costTypes>
                <costType name="structural" type="per_asset" unit="USD"/>
            </costTypes>
        </conversions>
                <occupancyPeriods>day</occupancyPeriods>
        <assets>
            <asset id="a1" number="22"  taxonomy="CR/LFM/HBET:3,1/Pre-2000" >
                <location lon="29.956344" lat="40.745248" />
                <costs>
                    <cost type="structural" value="100"/>
                </costs>
                <occupancies>
                    <occupancy occupants="11000" period="day"/>
                </occupancies>
            </asset>
            <asset id="a2" number="13"  taxonomy="CR/LFM/HBET:3,1/2000-2007" >
                <location lon="29.956344" lat="40.745248" />
                <costs>
                    <cost type="structural" value="100"/>
                </costs>
                <occupancies>
                    <occupancy occupants="6500" period="day"/>
                </occupancies>
            </asset>
            <asset id="a3" number="6"  taxonomy="CR/LFM/HBET:3,1/2007-2020" >
                <location lon="29.956344" lat="40.745248" />
                <costs>
                    <cost type="structural" value="100"/>
                </costs>
                <occupancies>
                    <occupancy occupants="3000" period="day"/>
```

Figure 2.42: Exposure model data file in OpenQuake.

2.4.6. Fragility Curves

Fragility curves used for estimating damage and loss in seismic risk assessments are typically created for structure types with similar characteristics in a specific country or region. However, creating these curves based on regional characteristics is difficult and time-consuming, so fragility curves from international studies are often used instead. However, using fragility curves that do not reflect the building stock of a country or region can lead to damage and loss estimates that are unrealistic.

One of the most common approaches to defining damage in academia is the use of a single damage model per building class. This approach was followed by GEM in its 2018 release of the global risk model, which is described in more detail in Martins and Silva (2020). While such a method is widely supported, it raises some issues when there is a need to estimate losses separately for structural, non-structural components, and contents.

In this method, a single damage model is used for each building class to estimate the overall damage due to seismic events. This approach is efficient and effective for general risk assessment and understanding the overall performance of buildings. However, when more detailed damage estimates are needed for specific components of a building (such as structural elements like foundations and load-bearing systems, non-structural elements like walls and interior features, and contents like furniture and equipment), this single model approach can be insufficient.

Structural components often sustain damage due to more significant seismic forces, while non-structural components and contents may suffer damage from lower levels of seismic intensity. As such, separate damage models may be required for different parts of the building to accurately estimate the losses. Therefore, while using a single damage model is effective for general performance assessment, more detailed modeling may be necessary for component-based loss estimation..

Damage to structural elements is proportional to the level of displacement with damage initiation stating at the yielding point. Before this the building is assumed to deform elastically, and thus with no significant damage is to be expected. The thresholds for moderate and extensive damage were placed evenly distributed between the onset of damage and the ultimate displacement capacity**(Figure 2.43)**.

Damage state	Damage threshold
Slight	Sd_y
Moderate	0.67Sd_y+0.33Sd_u
Extensive	0.33Sd_y+0.67Sd_u
Complete	Sd_u

Figure 2.43: Structural damage states threshold.

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 visually seen in **Figure 2.44.**

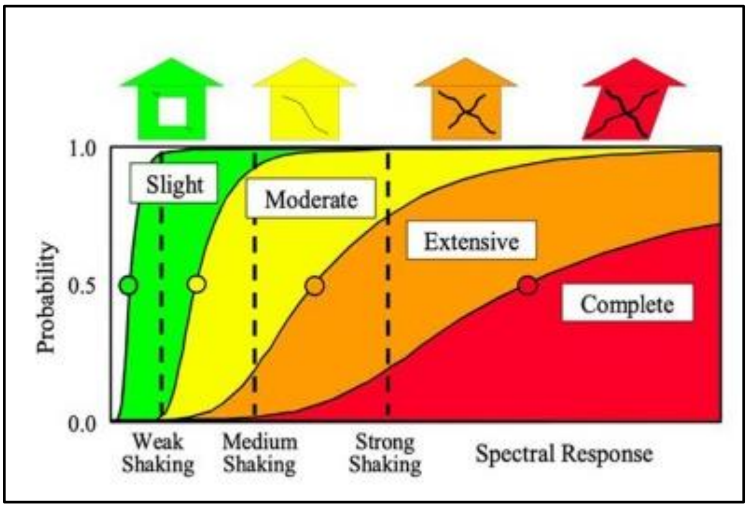


Figure 2.44: Fragility curve damage states.

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

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.

In line with all this information, a fragility model was created by selecting fragility curves appropriate to the structure types from OpenQuake data.

The Selected Structural Tyspes: When the school buildings in the area were examined, it was found that there are structures with 1-6 normal floors. No school building with more than 6 normal floors was identified. Buildings with 1-3 normal floors are classified as low-rise, while buildings with 4-7 floors are classified as mid-rise. All the examined buildings are reinforced concrete moment frame structures. It is assumed that the flexibility level of the structures is high. It is also assumed that there are plan irregularities in the buildings.

The Selected Frugility Functions for The Selected Structural Tyspes: Based on all the selected building types, appropriate fragility curves have been researched and selected. The fragility curves available in the OpenQuake library were filtered by Country: Türkiye, Region: Asia, Material: Reinforced Concrete, and Frame Type: Moment Frame. As a result of this filtering, the curves obtained for high ductility and irregular structures, specifically Ahmet et al. (CR/DUC/IRIR_Low-rise and CR/DUC/IRIR_Mid-rise), were selected**(Figure 2.45 and Figure 2.46)**.

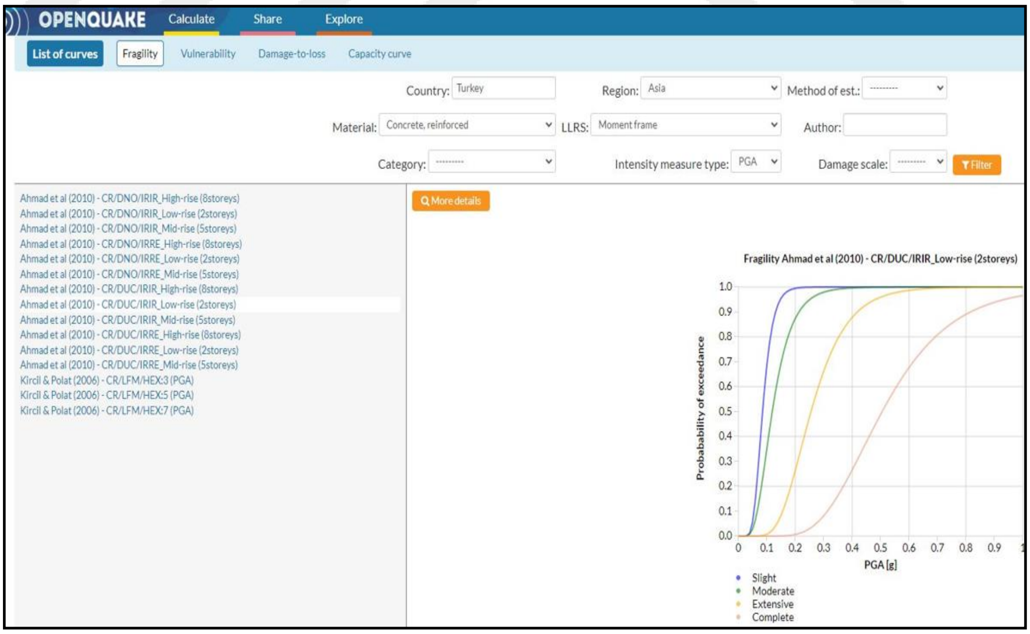


Figure 2.45: Selected fragility curve for low rise schools.

All selected fragility curves have been defined in OpenQuake as a structural fragility model file, as shown in **Figure 2.47.**

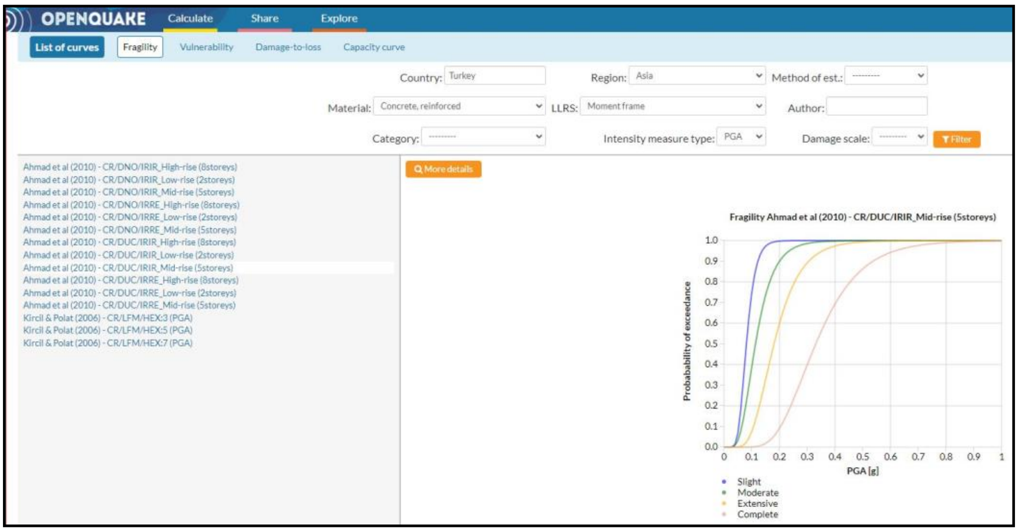


Figure 2.46: Selected fragility curve for mid rise schools.

```
<?xml version='1.0' encoding='UTF-8'?>
<nrml xmlns:gml="http://www.opengis.net/gml" xmlns="http://openquake.org/xmlns/nrml/0.4">
  <fragilityModel format="continuous">
    <description>Fragility Function for Kocaeli</description>
    <limitStates>slight moderate extensive complete</limitStates>

    <fragilityFunction noDamageLimit="0.05" type="lognormal">
      <taxonomy>CR/LFM/HBET:3,1/Pre-2000</taxonomy>
      <IML IMT="PGA" imlUnit="g" maxIML="3.0" minIML="0.0"/>

        <fragilityFunctionContinues ls="slight">
      <params mean="0.09" stddev="0.031"/>
      </fragilityFunctionContinues>

        <fragilityFunctionContinues ls="moderate">
      <params mean="0.132" stddev="0.063"/>
      </fragilityFunctionContinues>

        <fragilityFunctionContinues ls="extensive">
      <params mean="0.275" stddev="0.11"/>
      </fragilityFunctionContinues>

        <fragilityFunctionContinues ls="complete">
      <params mean="0.542" stddev="0.21"/>
      </fragilityFunctionContinues>
    </fragilityFunction>

    <fragilityFunction noDamageLimit="0.05" type="lognormal">
      <taxonomy>CR/LFM/HBET:3,1/2000-2007</taxonomy>

      <IML IMT="PGA" imlUnit="g" maxIML="3.0" minIML="0.0"/>

        <fragilityFunctionContinues ls="slight">
      <params mean="0.09" stddev="0.031"/>
      </fragilityFunctionContinues>

        <fragilityFunctionContinues ls="moderate">
      <params mean="0.132" stddev="0.063"/>
      </fragilityFunctionContinues>
```

Figure 2.47: Structural fragility model file in OpenQuake.

Taxonomy: CR/LFM/HBET:/Pre-2000,2000-2007,2007-2020

CR: Concrete

LFM: Moment Frame

HBET: Story Number

2.4.7. Risk Map

A risk map is a visual representation that displays the potential hazards, risks, and their impacts in a specific area. Risk maps, which assess various threats such as natural disasters (earthquakes, floods, fires, landslides) or human-made risks, are important tools in disaster management, planning, and preparedness processes. A risk map determines the level of risk in an area, showing which regions need prioritized actions and preventive measures.

In conclusion, risk maps are a vital source of information for both individuals and institutions. Identifying risks in advance is a critical step in minimizing loss of life and economic damages and in building a more resilient society.

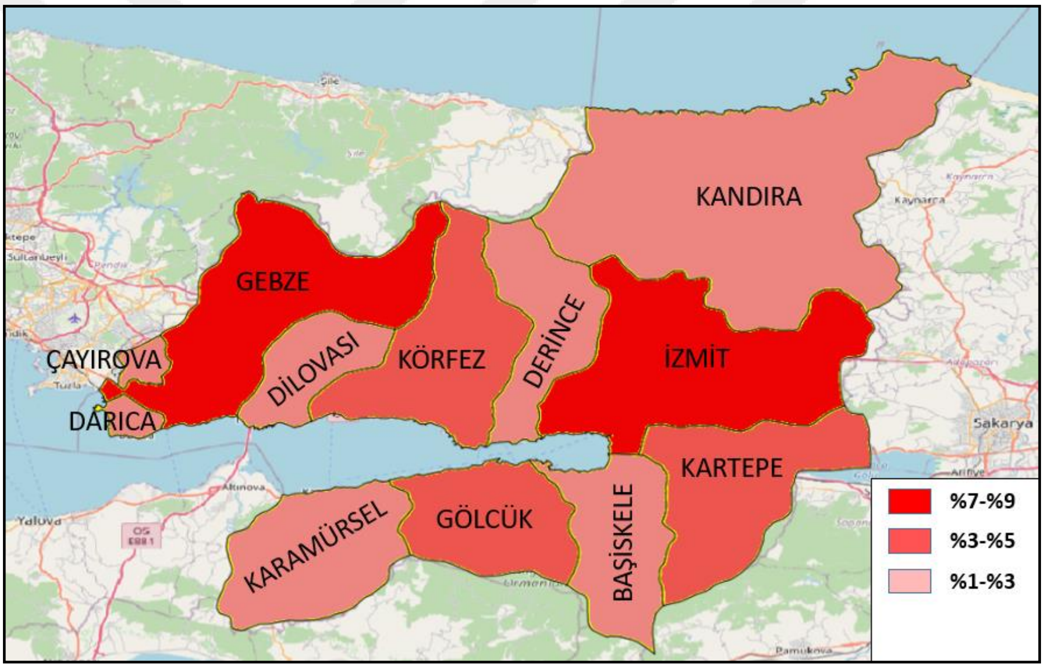
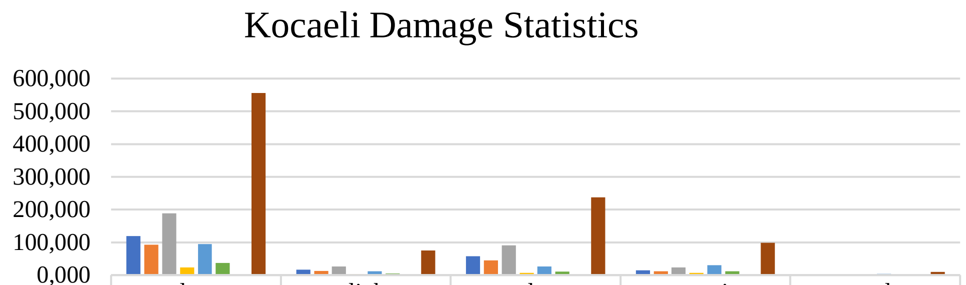


Figure 2.48: Seismic risk map for Kocaeli.

The seismic risk map of Kocaeli, as shown in **Figure 2.48**, provides a visual representation of the varying seismic risk levels across different regions within the province. The map helps identify high-risk areas with a higher likelihood of strong ground shaking and damage, enabling targeted mitigation measures and more efficient allocation of resources. Additionally, the map highlights densely populated or infrastructure-sensitive areas that may be more vulnerable to earthquake damage, assisting in determining which areas require more attention in terms of building safety, preparedness, and emergency response.

2.4.8. Damage Statistics

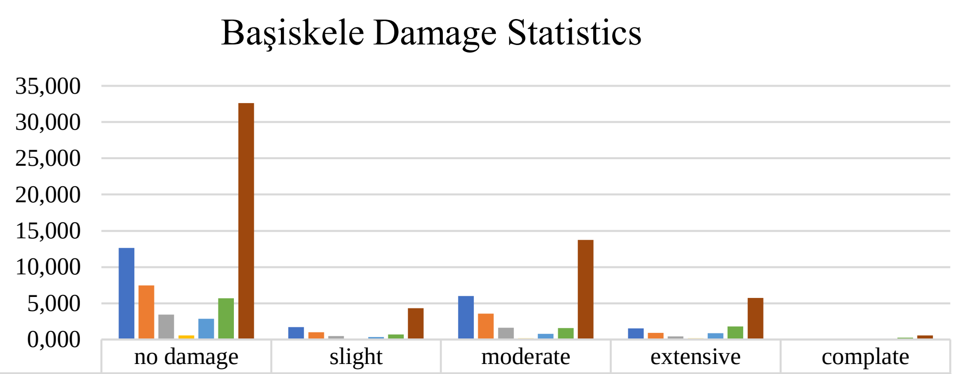
A total of 977 structures have been assessed for risk. As a result of this assessment, the following tables have been created statistically, and structural losses have been identified regionally.



	no damage	slight	moderate	extensive	complate
3,1/Pre2000	120	17	58	15	1
3,1/2000-2007	93	13	45	11	1
3,1/2007-2020	188	26	91	23	1
7,4/Pre-2000	23	3	6	7	1
7,4/2000-2007	95	12	26	30	4
7,4/2007-2020	38	5	10	12	2
Total Ratio	56,94%	7,67%	24,33%	10,06%	1,00%
Total Number	556	75	238	98	10

Figure 2.49: Kocaeli region structural loss statistics.

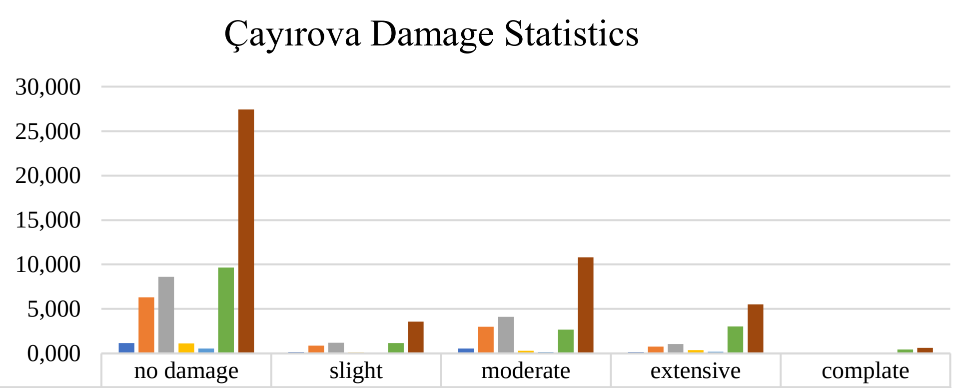
Upon examining the image in **Figure 2.49**, it is projected that, across Kocaeli, 56.94% of school buildings will remain no damaged, 7.67% will sustain slight damage, 24.33% will sustain moderate damage, 10.06% will sustain extensive damage, and 1.00% will collapse. If the evaluation is made based on numerical figures, it is projected that, across Kocaeli, 556 school buildings will remain no damaged, 75 will sustain slight damage, 238 will sustain moderate damage, 98 will sustain extensive damage, and 10 will collapse.



	no damage	slight	moderate	extensive	complate
3,1/Pre2000	13	2	6	2	0
3,1/2000-2007	7	1	4	1	0
3,1/2007-2020	3	0	2	0	0
7,4/Pre-2000	1	0	0	0	0
7,4/2000-2007	3	0	1	1	0
7,4/2007-2020	6	1	2	2	0
Total Number	33	4	14	6	1

Figure 2.50: Başiskele structural loss statistics.

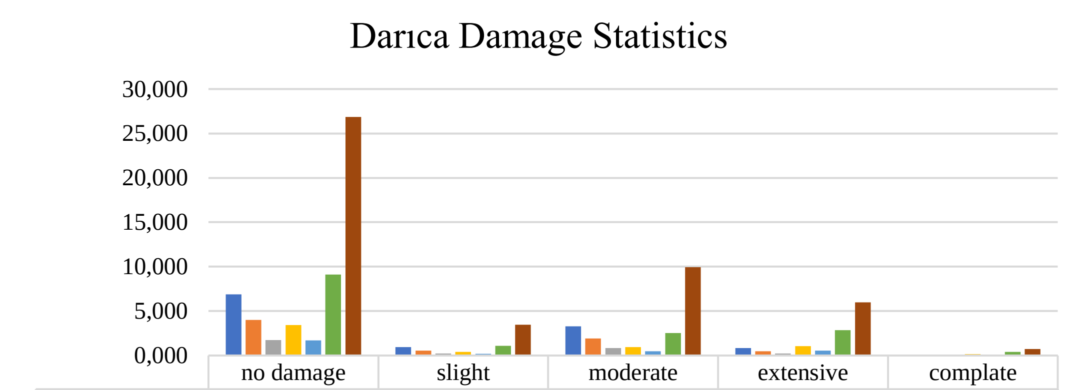
When **Figure 2.50** is examined for the Başiskele district, it is predicted that 33 schools will not sustain damage, 4 schools will slight damage, 14 schools will moderate damage, 6 schools will extensive damage, and 1 school will collapse.



	no damage	slight	moderate	extensive	complate
3,1/Pre2000	1	0	1	0	0
3,1/2000-2007	6	1	3	1	0
3,1/2007-2020	9	1	4	1	0
7,4/Pre-2000	1	0	0	0	0
7,4/2000-2007	1	0	0	0	0
7,4/2007-2020	10	1	3	3	0
Total Number	27	4	11	6	1

Figure 2.51: Çayırova structural loss statistics.

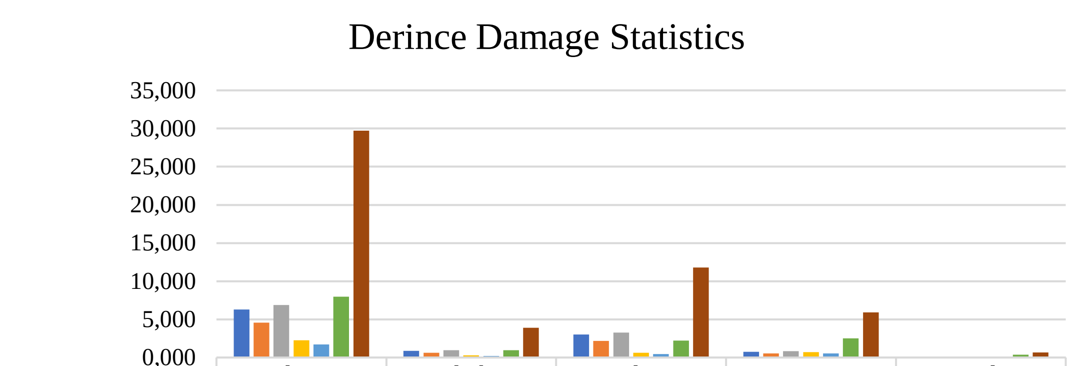
When **Figure 2.51** is examined for the Çayırova district, it is predicted that 27 schools will not sustain damage, 4 schools will slight damage, 11 schools will moderate damage, 6 schools will extensive damage, and 1 school will collapse.



	no damage	slight	moderate	extensive	complate
3,1/Pre2000	7	1	3	1	0
3,1/2000-2007	4	1	2	0	0
3,1/2007-2020	2	0	1	0	0
7,4/Pre-2000	3	0	1	1	0
7,4/2000-2007	2	0	0	1	0
7,4/2007-2020	9	1	3	3	0
Total Number	27	3	10	6	1

Figure 2.52: Darıca structural loss statistics.

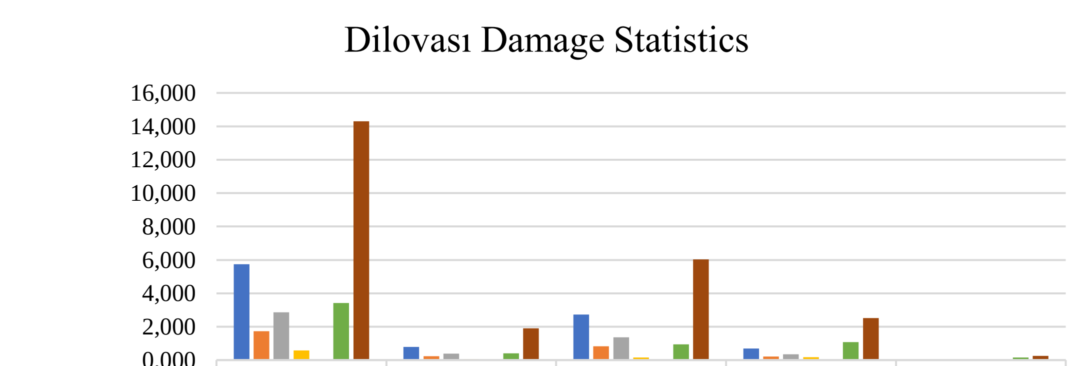
When **Figure 2.52** is examined for the Darıca district, it is predicted that 27 schools will not sustain damage, 3 schools will slight damage, 10 schools will moderate damage, 6 schools will extensive damage, and 1 school will collapse.



	no damage	slight	moderate	extensive	complate
3,1/Pre2000	6	1	3	1	0
3,1/2000-2007	5	1	2	1	0
3,1/2007-2020	7	1	3	1	0
7,4/Pre-2000	2	0	1	1	0
7,4/2000-2007	2	0	0	1	0
7,4/2007-2020	8	1	2	2	0
Total Number	30	4	12	6	1

Figure 2.53: Derince structural loss statistics.

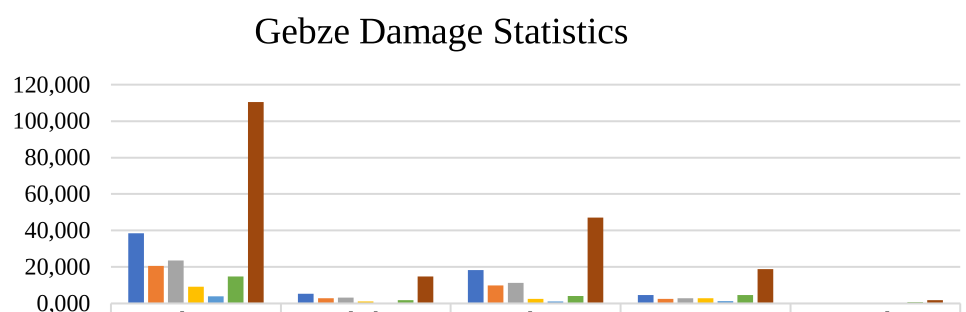
When **Figure 2.53** is examined for the Derince district, it is predicted that 30 schools will not sustain damage, 4 schools will slight damage, 12 schools will moderate damage, 6 schools will extensive damage, and 1 school will collapse.



	no damage	slight	moderate	extensive	complate
3,1/Pre2000	6	1	3	1	0
3,1/2000-2007	2	0	1	0	0
3,1/2007-2020	3	0	1	0	0
7,4/Pre-2000	1	0	0	0	0
7,4/2000-2007	0	0	0	0	0
7,4/2007-2020	3	0	1	1	0
Total Number	14	2	6	3	0

Figure 2.54: Dilovası structural loss statistics.

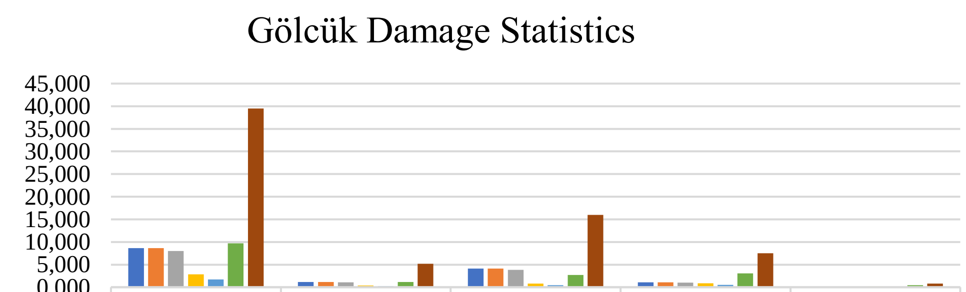
When **Figure 2.54** is examined for the Dilovası district, it is predicted that 14 schools will not sustain damage, 2 schools will slight damage, 6 schools will moderate damage, 3 schools will extensive damage, and 0 school will collapse.



	no damage	slight	moderate	extensive	complate
3,1/Pre2000	38	5	18	5	0
3,1/2000-2007	21	3	10	3	0
3,1/2007-2020	24	3	11	3	0
7,4/Pre-2000	9	1	3	3	0
7,4/2000-2007	4	0	1	1	0
7,4/2007-2020	15	2	4	5	1
Total Number	110	15	47	19	2

Figure 2.55: Gebze structural loss statistics.

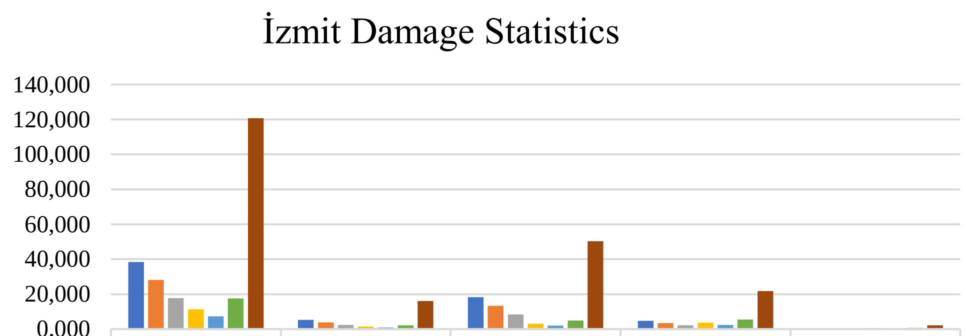
When **Figure 2.55** is examined for the Gebze district, it is predicted that 110 schools will not sustain damage, 15 schools will slight damage, 47 schools will moderate damage, 19 schools will extensive damage, and 2 school will collapse.



	no damage	slight	moderate	extensive	complate
3,1/Pre2000	9	1	4	1	0
3,1/2000-2007	9	1	4	1	0
3,1/2007-2020	8	1	4	1	0
7,4/Pre-2000	3	0	1	1	0
7,4/2000-2007	2	0	0	1	0
7,4/2007-2020	10	1	3	3	0
Total Number	39	5	16	8	1

Figure 2.56: Gölcük structural loss statistics.

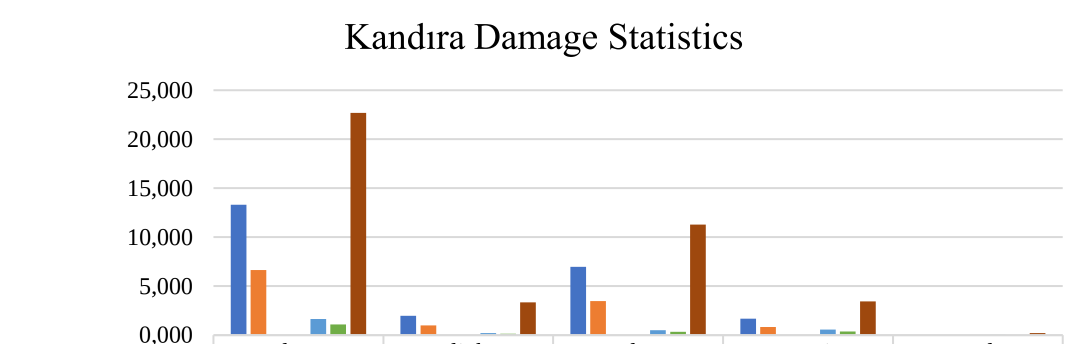
When **Figure 2.56** is examined for the Gölcük district, it is predicted that 39 schools will not sustain damage, 5 schools will slight damage, 16 schools will moderate damage, 8 schools will extensive damage, and 1 school will collapse.



	no damage	slight	moderate	extensive	complate
3,1/Pre2000	38	5	18	5	0
3,1/2000-2007	28	4	13	3	0
3,1/2007-2020	18	2	8	2	0
7,4/Pre-2000	11	1	3	4	1
7,4/2000-2007	7	1	2	2	0
7,4/2007-2020	18	2	5	6	1
Total Number	121	16	50	22	2

Figure 2.57: İzmit structural loss statistics.

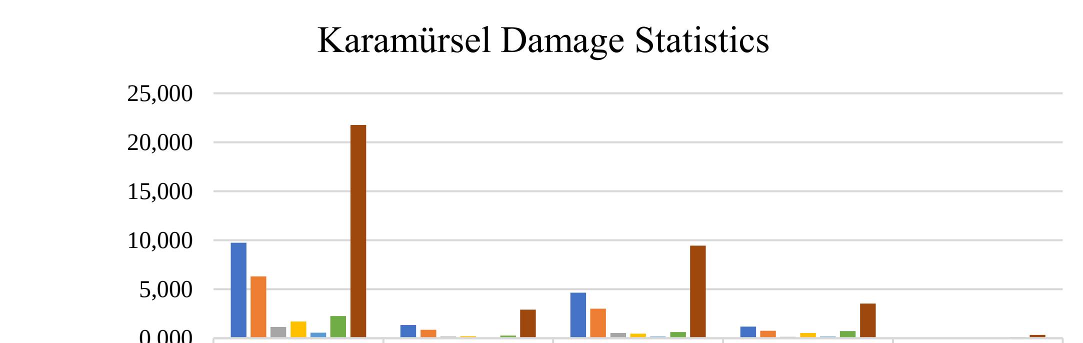
When **Figure 2.57** is examined for the İzmit district, it is predicted that 121 schools will not sustain damage, 16 schools will slight damage, 50 schools will moderate damage, 22 schools will extensive damage, and 2 school will collapse.



	no damage	slight	moderate	extensive	complate
3,1/Pre2000	13	2	7	2	0
3,1/2000-2007	7	1	3	1	0
3,1/2007-2020	0	0	0	0	0
7,4/Pre-2000	0	0	0	0	0
7,4/2000-2007	2	0	1	1	0
7,4/2007-2020	1	0	0	0	0
Total Number	23	3	11	3	0

Figure 2.58: Kandıra structural loss statistics.

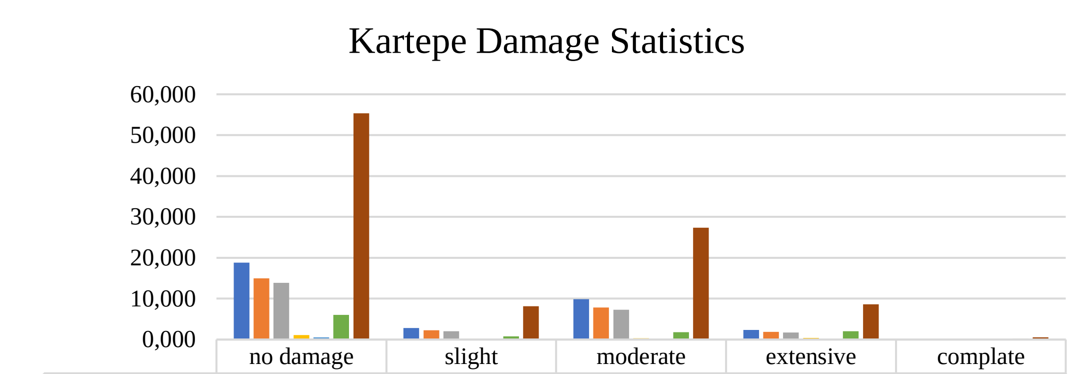
When **Figure 2.58** is examined for the Kandıra district, it is predicted that 23 schools will not sustain damage, 3 schools will slight damage, 11 schools will moderate damage, 3 schools will extensive damage, and 0 school will collapse.



	no damage	slight	moderate	extensive	complate
3,1/Pre2000	10	1	5	1	0
3,1/2000-2007	6	1	3	1	0
3,1/2007-2020	1	0	1	0	0
7,4/Pre-2000	2	0	0	1	0
7,4/2000-2007	1	0	0	0	0
7,4/2007-2020	2	0	1	1	0
Total Number	22	3	9	4	0

Figure 2.59: Karamürsel structural loss statistics.

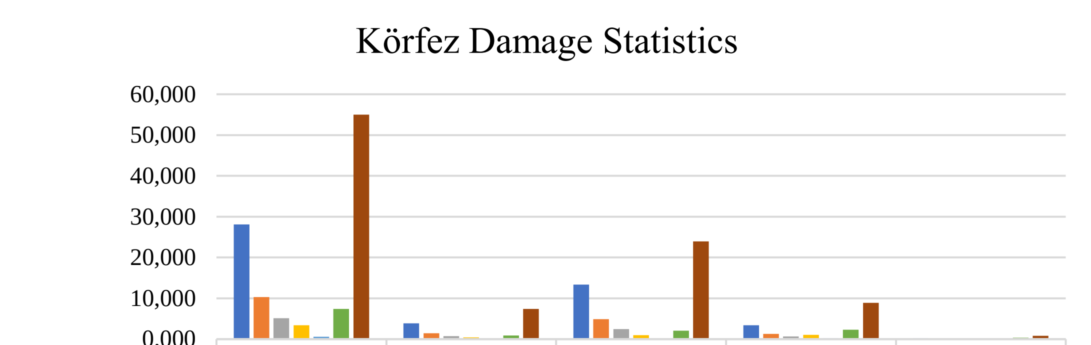
When **Figure 2.59** is examined for the Karamürsel district, it is predicted that 22 schools will not sustain damage, 3 schools will slight damage, 9 schools will moderate damage, 4 schools will extensive damage, and 1 school will collapse.



	no damage	slight	moderate	extensive	complate
3,1/Pre2000	19	3	10	2	0
3,1/2000-2007	15	2	8	2	0
3,1/2007-2020	14	2	7	2	0
7,4/Pre-2000	1	0	0	0	0
7,4/2000-2007	1	0	0	0	0
7,4/2007-2020	6	1	2	2	0
Total Number	55	8	27	9	1

Figure 2.60: Kartepe structural loss statistics.

When **Figure 2.60** is examined for the Kartepe district, it is predicted that 55 schools will not sustain damage, 8 schools will slight damage, 27 schools will moderate damage, 9 schools will extensive damage, and 1 school will collapse.



	no damage	slight	moderate	extensive	complate
3,1/Pre2000	28	4	13	3	0
3,1/2000-2007	10	1	5	1	0
3,1/2007-2020	5	1	2	1	0
7,4/Pre-2000	3	0	1	1	0
7,4/2000-2007	1	0	0	0	0
7,4/2007-2020	7	1	2	2	0
Total Number	55	7	24	9	1

Figure 2.61: Körfez structural loss statistics.

When **Figure 2.61** is examined for the Körfez district, it is predicted that 55 schools will not sustain damage, 7 schools will slight damage, 24 schools will moderate damage, 9 schools will extensive damage, and 1 school will collapse.

3. RESULTS

In this section, the results of all the studies and research will be examined. The current situation of the schools in the region and the results of the risk and hazard analysis will be evaluated. The risk map created as a result of all this work has been developed based on the percentage of damaged buildings among 977 structures. When this map is examined, the following results can be drawn.

The hazard assessments revealed that the districts of Darıca, Gölcük, Başiskele, and Kartepe have high hazard levels. These districts pose a significant hazard due to factors such as their proximity to major fault lines and soil characteristics, considering their geographical locations and settlement areas. However, during the risk assessment stage, it was found that the highest seismic risk is in the districts of Gebze and İzmit, which is different from these districts. This difference is not only due to geographical and structural hazard factors but also the population density and settlement characteristics.

Gebze and İzmit are the largest and most populous districts in Kocaeli and are important centers for industry and trade. This high population density increases the number of buildings in both districts, which in turn raises the number of structures that may potentially be damaged in natural disasters. Particularly in densely populated areas, the concentration of many buildings and people in the same region further exacerbates the risk. Additionally, most of the buildings in these districts are old, which is another important factor that reduces their durability. Therefore, it cannot always be said that where the seismic hazard is high, the seismic risk will also be high, as other factors such as population density and building quality should also be considered. This study not only allows us to understand where the seismic risk is concentrated but also emphasizes the importance of considering various factors during seicmic risk assessment.

Moreover, the majority of buildings in these districts are old, which further reduces their resilience. Thus, it is not always valid to assume that high seismic hazard areas will also have high seismic risks, as factors such as population density and building quality should also be taken into account. This study provides insights into where the risk is concentrated and helps understand the overall situation.

After Gebze and İzmit, the most risky areas are Gölcük, Kartepe, and Körfez. The least risky areas are Başiskele, Çayırova, Darıca, Derince, Kandıra, and Karamürsel. Kandıra is the area with the least hazard and risk. The low seismic hazard is due to its distance from the fault line, and the low seicmic risk is attributed to its low population. This map and study clearly show that high hazard areas do not necessarily mean high risk. While high seismic hazard levels indicate areas with a high probability of natural disasters (such as earthquakes), this does not always translate into high seismic risk. Risk is related not only to the presence of hazards but also to factors such as the durability of buildings in the area, population density, infrastructure conditions, and disaster preparedness.

For example, if buildings in a high seismic hazard area are modern and resilient, this area may not carry a high seismic risk. Similarly, a region with low population density and good disaster preparedness may have a lower risk than a high-hazard area. Therefore, the relationship between seismic hazard and seismic risk is not always linear, and when conducting regional seismic risk analysis, it is important to consider not only the seismic hazard level but also other critical factors. This study highlights these differences and shows that risk assessments must be more comprehensive and accurate.

In the damage statistics conducted within the scope of this study for the DD2 earthquake level defined in TBDY2018, it was found that a total of 977 buildings were evaluated, and the following results were obtained: 10 buildings will reach collapse damage level, 98 buildings will suffer severe damage, 238 buildings will sustain moderate damage, 75 buildings will have light damage, and 556 buildings will remain undamaged.

These above data provide significant information for earthquake disaster management. For instance, it can be concluded that the 346 school buildings (238 + 98 + 10 = 346) that are expected to experience moderate, high, and collapse damage levels need to be strengthened. Alternatively, controlled demolition could be carried out for these buildings, and new, more durable structures could be built in their place.
buildings, and new, more durable structures could be built in their place.

This above data can be used not only to make decisions about structural reinforcement or reconstruction but also to estimate the budget required for these efforts. By identifying which schools need reinforcement and calculating the costs for these reinforcements, it will be possible to provide a rapid and effective solution to be prepared for a potential earthquake disaster. Such analyses are critical in minimizing future earthquake risks and reducing potential damages.

In a general evaluation based on average casualties from collapsed buildings, assuming there are 500 students in each school building, if 10 school buildings collapse, approximately 5000 students would be at risk. This calculation highlights the potential impact of natural disasters, especially earthquakes, on a large student population. Based on this calculation, the urgent need to make schools more resilient, reinforced, or rebuilt becomes clear.

In terms of disaster management, it is clear that measures need to be taken in these school buildings. Considering this study, the high seismic risk in Gebze and İzmit necessitates prioritizing work in these two districts.

When the regional damage statistics tables are evaluated, it is possible to roughly see how many schools in each district require measures. This enables budget planning and identification. For example, in Gebze, 19 schools have suffered severe damage, and 2 schools are expected to collapse. Based on this finding, it can be concluded that a total of 21 schools need to be reinforced. A budget can be allocated by estimating the reinforcement costs for these 21 schools.

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BIOGRAPHY

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PUBLICATIONS AND PRESENTATIONS FROM THE THESIS

Yazıcı S., Zülfikat C., Yeşilyurt A., (2024), "Seismic Risk Assessment at Urban Scale with OpenQuake Software", Gebze Technical University Undergraduate Researchs Symposium , Gebze, Türkiye, 30-31 May.