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Araştırma Makalesi / Research Article

# The Evaluation of Earthquake Risk of Existing Buildings in Başakşehir District of Istanbul Province

Volkan ERGEN[1], Abdullah Can ZÜLFİKAR[2], Samet KILIÇ[3*]

## Abstract

In order to ensure public safety and sustainable urban growth, it is imperative that existing buildings in new residential districts have their seismic risk evaluated. Başakşehir district is a place where new settlements are significantly dense in Istanbul. In this study, two pilot regions were selected within the district and the entire district was subjected to scenario earthquake hazard and damage estimation analysis. Four historical earthquakes and one instrumental earthquake that affected the Marmara region were chosen as scenario earthquakes and predicted earthquake damage analyses were conducted as part of the study. The initial step involved compiling the structure inventory data in the Başakşehir pilot districts. Both the building inventory of the pilot regions and the building inventory of the Başakşehir district were updated through field research for this procedure and the acquisition of building licenses from pertinent institutions and organizations. The building inventory obtained in the second stage was transferred to the geographic information system program QGİS. After this procedure, the Earthquake Loss Estimation Routine (ELER) program, which carries out earthquake damage analysis, was used to compute the estimated earthquake damage analyses for the various regions. The distribution of damage that occurred in the research regions was transferred at the final stage as a consequence of the analysis that was conducted, and assessments were produced using comparisons between the regions. Consequently, it was shown that the new settlements performed better for earthquake scenarios. This study can contribute to additional scientific studies that will estimate post-earthquake damage to existing structures in other districts of Istanbul.

**Keywords:** Earthquake damage analysis, Earthquake loss estimation routine (ELER), HAZUS classification, Seismic risk assessment.

# İstanbul ili Başakşehir İlçesi Mevcut Yapıların Deprem Riskinin Değerlendirilmesi

## Öz

Kamu güvenliğinin ve sürdürülebilir kentsel büyümenin sağlanması için yeni yerleşim bölgelerindeki binaların sismik risk değerlendirmesinin yapılması çok önemlidir. Başakşehir ilçesi İstanbul'da yeni yerleşimlerin önemli bir yoğunlukta olduğu bir yerdir. Bu çalışmada ilçe içerisinde iki pilot bölge seçilerek ilçenin tamamı senaryo deprem tehlikesi ve hasar tahmin analizine tabi tutulmuştur. Çalışma kapsamında senaryo depremi olarak, Marmara bölgesini etkileyen 4 tarihi deprem ve 1 aletsel deprem seçilmiş ve öngörülen deprem hasar analizleri yapılmıştır. İlk adımda, Başakşehir pilot bölgelerindeki yapı envanteri verilerinin derlenmiştir. Bu işlem için saha araştırması yapılmış ve ilgili kurum ve kuruluşlardan yapı ruhsatı alınarak hem pilot bölgelerin bina envanteri hem de Başakşehir ilçesinin bina envanteri elde edilmiştir. İkinci aşamada elde edilen yapı envanteri coğrafi bilgi sistemi programı QGİS'e aktarılmıştır. Bu işlemin ardından deprem hasar analizini yapan Earthquake Loss Estimation Routine (ELER) programı kullanılarak çeşitli bölgeler için tahmini deprem hasar analizleri hesaplanmıştır. Yapılan analizler sonucunda son aşamada araştırma bölgelerinde meydana gelen hasarların dağılımı aktarılmış ve bölgeler arası karşılaştırmalar yapılarak değerlendirmeler üretilmiştir. Sonuç olarak, deprem senaryolarında yeni kentlerin daha iyi performans gösterdiği ortaya çıkmıştır. Bu çalışma ile İstanbul ilinin diğer ilçelerindeki yapıların deprem sonrası hasar tahminlerinin yapılacağı ilave bilimsel çalışmalara katkı sağlanabileceği düşünülmektedir.

**Anahtar Kelimeler:** Deprem hasar analizi, Earthquake loss estimation routine (ELER), HAZUS sınıflandırması, Sismik risk değerlendirmesi.

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## 1. Introduction

One of the most devastating natural disasters, earthquakes can cause major infrastructure damage, fatalities, and long-term economic effects (Kılıç, 2024; Kılıç et al., 2022). In many seismically active areas, residential districts have grown as a result of urbanization, which is fueled by rising economic development and population density. A combination of quickly built and older buildings, many of which might not adhere to current seismic codes, can be found in these new residential neighborhoods. One crucial step in minimizing vulnerabilities and guaranteeing urban resilience is evaluating the risk of earthquakes for such buildings (Erberik and Elnashai, 2004; Askan et al., 2011).

Numerous factors, such as building age, geotechnical conditions, construction materials, and structural design, affect the seismic risk of existing buildings in new residential districts. Rapid urbanization frequently results in construction methods that put time ahead of quality, producing structures with subpar seismic performance (Ambraseys and Jackson, 1998). Seismic susceptibility is further increased by the fact that urban growth frequently takes place in places with difficult geological characteristics, such as soft soils, reclaimed lands, or sites with a high propensity for liquefaction (Seed and Idriss, 1982). These elements highlight how crucial it is to evaluate existing structures in order to pinpoint hazards and put appropriate mitigation plans in place.

The region in which Türkiye is situated has a lengthy history of earthquakes. Large and destructive earthquakes have struck Türkiye ever since earthquake records were first documented. The 7.2 magnitude Erzincan earthquake in 1939, the 7.9 magnitude Samsun Ladik earthquake in 1943, the 7.2 magnitude Çanakkale earthquake in 1953, the 7.5 magnitude Van Muradiye earthquake in 1976, and the 7.8 magnitude Izmit Gölcük earthquake in 1999 had major impacts on the socio-economic development of Türkiye (Kılıç et al., 2021). Türkiye suffered significant losses in terms of life and property due to the devastating Van Muradiye earthquake in 2011, the Elazığ earthquake in 2020, which had a magnitude of 6.8, and the Kahramanmaraş earthquakes in 2023, which had a magnitude of 7.8. In 2009, the Istanbul Metropolitan Municipality released the Istanbul Possible Earthquake Damage Estimates report (İBB, 2009). The study provides guidance by calculating the number of fatalities, property losses, households in need of emergency shelter, and economic losses from potential earthquake-related damages, demonstrating how prepared Istanbul is for an earthquake. The study includes guiding research that demonstrates how prepared Istanbul is for an earthquake. On a regional level, Istanbul has become a settlement with a rise in new residential areas since 2009. Estimates of earthquake damage must be made for newly constructed residential areas that were created after 2009 and were not covered by the 2009 research. Therefore, the damage estimates that may result from potential earthquakes will be unclear due to the lack of seismic damage estimates for new residential zones. This shortcoming necessitates assessing earthquake damage estimation in newly constructed residential zones (Barış et al., 2023).

Structural engineering, geotechnical analysis, and urban planning are all integrated into the multidisciplinary process of modern earthquake risk assessment. Building integrity under seismic loads is the main objective of structural examinations, which examine aspects such as ductility, lateral load resistance, and seismic code compliance (Priestley et al., 2007). Given that some soil types intensify seismic waves and worsen structural damage, geotechnical analysis takes into account how soil characteristics influence building behavior during earthquakes (Boore et al., 1997). To reduce risk and improve post-disaster recovery efforts, urban design factors, including building density, road networks, and emergency service accessibility are also essential (Godschalk, 2003). Technological developments have greatly enhanced earthquake risk assessment techniques. Building vulnerabilities and seismic hazards may be thoroughly analyzed using spatial data such as Geographic Information Systems (GIS) (Schmidt et al., 2011). In a similar vein, engineers may simulate possible earthquake scenarios and forecast building performance under different earthquake conditions using simulation software (Yadollahi et al., 2012). These approaches are particularly valuable in newly developed residential areas characterized by diverse structural typologies and complex geological conditions.

With an emphasis on structural, geotechnical, and urban planning perspectives, the study's objective is to evaluate the earthquake risk of existing buildings in newly constructed residential areas. The study identifies high-risk buildings and suggests workable plans for risk reduction and retrofitting by integrating field surveys, numerical modeling, and geospatial analysis. This study advances the scientific understanding of urban seismic resilience and provides insightful information to engineers, urban planners, and legislators. The Istanbul Başakşehir Kayabaşı and Bahçeşehir regions were selected as the pilot regions for this reason. The building stock in the pilot region, the building design code, and other information were used as input data for the study.

This study evaluated the region's earthquake damage within the framework of newly developed residential area evaluation and looked at earlier earthquake damage estimation techniques. It benefited from the Turkish-made ELER program (ELER, 2010), which is comparable to the HAZUS program, and the HAZUS program, which is one of the internationally recognized tools for earthquake damage estimation for the study region (Hazus, 2012).

Proactive earthquake risk management is increasingly essential as urbanization accelerates in metropolitan regions. In order to promote safer and more sustainable urban development in seismically active areas, this project aims to close the gap between science and practice by thoroughly evaluating existing buildings in new residential districts. Additional scientific research that tries to estimate the post-earthquake damage to existing structures in other Istanbul districts can benefit from this study.

## 2. Materials and Methods

### 2.1. ELER Method

Following the Northridge earthquake in 1994 (California, USA) and the Kobe earthquake in 1995, damage assessment frameworks were developed with the support of insurance companies and local governments. The HAZUS program, which incorporates fragility curves based on four building code periods, was established by the Federal Emergency Management Agency (FEMA) to standardize the process of estimating earthquake damage nationwide (Hazus, 2012). In the USA, Geohazard International created the RADIUS technique. The International Decade for Natural Disaster Reduction (IDNDR) program of the United Nations developed the Risk Assessment Tools for Seismic Disaster Diagnosis of Urban Areas (RADIUS) in 1997. The Canadian emergency agency created the Natural Hazards Electronic Mapping and Assessment Tools Information System (NHEMATIS). Furthermore, studies on risk assessment and damage estimation evaluation issues have developed Extremum in Russia, TELES in Taiwan (Yeh et al., 2006), ELER, HAZTURK, and RED-AFAD in Türkiye. Additionally, there are the SELENA and FEMA-P58 approaches (NORSAR, 2015; FEMA, 2005). The Boğaziçi University Kandilli Observatory Earthquake Research Institute and the European Union collaborated to develop the earthquake loss estimating program Earthquake Loss estimating Routine (ELER) in order to calculate earthquake losses (ELER, 2010).

As construction technologies advance, the understanding of earthquakes continues to grow. A fresh idea emerges with every new earthquake. The information uncovered following earthquakes and the opportunities presented by new technology are used in actual trials to update earthquake and construction rules. The key elements of building design and the subtleties of the construction phase are also updated by changing the regulations. The trials that FEMA carried out for the HAZUS program revealed that the number of floors, carrier system type, and age of the structure all affect the building fragility curves (FEMA, 2012). Four code periods, ranging from old to new, are used to define the structure's age in the fragility curves that were produced by the studies. Fragility curves indicate increasing vulnerability with older code periods, with code 4 representing the newest standard. Because of this, the building's year has a crucial impact on both the structure's susceptibility and overall health.

In this study, ELER method was used. It begins by adding inputs related to earthquake ground motion. The system projects damage and indirect losses of life and property in the building inventory vulnerable to seismic ground motions. Four modules are ready for estimating earthquake damage in ELER. Based on the provided earthquake magnitude and epicenter information, the system receives the distribution of Peak Ground Acceleration (PGA) and Velocity (PGV), as well as design spectral acceleration ($S_a$) and displacement ($S_d$) ground motion values from the first earthquake hazard analysis module. The Level 0 module estimates loss of life and injuries using intensity-loss of life or magnitude-loss of life relationships according to population information based on geographical information systems. The Level 2 module estimates the number of damaged buildings and the corresponding casualties using a vulnerability assessment method based on spectral acceleration and displacement (ELER, 2010).

The ELER program was used to estimate the damage caused by earthquakes. Building fragility curves and capacity values were transferred to the application using HAZUS open-source data. The HAZUS method's first stage involves grouping structures based on their load-bearing system types and calculating fragility and capacity curves. During the study, extensive effort was made to determine the appropriate HAZUS classification for structures listed in building permits as framed, shear wall, or mixed load-bearing systems. HAZUS has categorized structures as either framed or shear wall, making classification of mixed structural systems challenging. Capacity values and fragility curves, as well as classification criteria, should be established for dual structural systems.

### 2.2. Field Study

Istanbul, with its dense population and economic activity, is crucial to Türkiye and is located near the northern Anatolian fault line. Preparedness for earthquakes is therefore crucial for Istanbul (Zülfikar et al., 2017). The Turkish Grand National Assembly passed the Urban Transformation Law in 2012, which mandates the reconstruction of disaster-prone areas or neighborhoods. In this way, buildings prone to seismic risk have been demolished and reconstructed, and new neighborhoods have been established.

An estimated 1 million inhabitants from two pilot zones within the coordinates between 41° 7'33.19"N - 41° 6'41.59"N and 28° 45'47.96"E - 28°46'55.62"E were used to assess the earthquake damage assessment of new residential areas.

This section contains details about the first pilot region in Kayabaşı neighborhood in Başakşehir district, Istanbul province, where the study is conducted, as well as the second pilot region in Istanbul province, Başakşehir district, the second part of Bahçeşehir neighborhood, including demographic density, structure distribution, and transportation network. Due to the recent urban transformation in Türkiye, existing old structures need to be renewed or retrofitted. New settlement zones that are resistant to earthquakes and situated distant from fault lines are likewise becoming more popular. Since the report was released, new neighborhoods have been created in Istanbul (İBB, 2009). Two pilot areas were selected from the new settlement regions according to the study criteria. Figure 1 displays the satellite view of the first pilot region Kayabaşı, Başakşehir district, İstanbul. In this study, change detection analyses were conducted in the construction areas using satellite images from remote sensing techniques. The results obtained with remote sensing techniques will constitute important baseline information for earthquake risk studies planned to be carried out in the region. These results also provide important information for reducing physical and socio-economic losses (Tekin et al., 2022). Figure 2 shows the building importance classification of pilot regions one and two.


(a) (b)

**Figure 1.** a) 1st pilot region of Kayabaşı district of Başakşehir district of İstanbul, located at the coordinates of 41° 7'33.19"N - 41° 6'41.59"N and 28°45'47.96"E - 28°46'55.62"E, b) 2nd pilot region of Bahçeşehir 2nd part district of Başakşehir district of İstanbul, located at the coordinates of 41° 5'47.64"N- 41° 4'57.20"N and 28°39'31.93"E- 28°38'29.22"E ((URL-2 , 2025).

The majority of the structures in the Kayabaşı region, the first pilot region of the study areas, are cast-in-place reinforced concrete structures, according to the general structural distribution. It has been noted that the average building height is over 25 meters, and the average number of stories is more than ten, in residential areas that use reinforced concrete framed systems, shear wall systems, and dual systems.

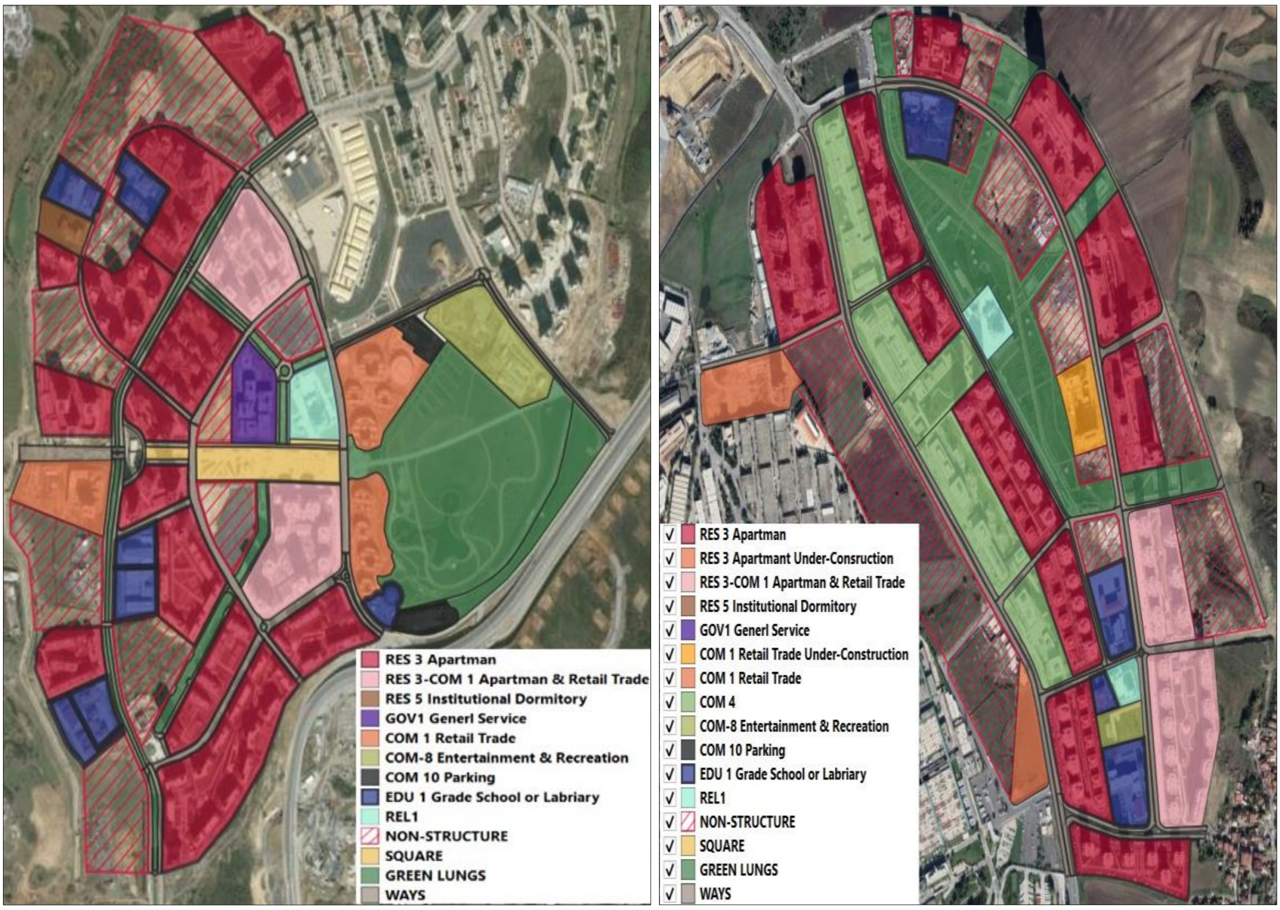


**Figure 2.** Building importance classification of pilot 1-2 regions according to the HAZUS method.

There are four educational buildings, one place of worship, one dormitory, one public library, one public garden, one public facility currently under construction, and one shopping mall in addition to the general stock and commercial units in the area. In the first pilot region, there are a total of 8664 independent units, including 7175 residences and 1489 business units. In addition, there is one residence for students, one sports facility that is now being built, and one building used by the local administration. The majority of the structures in the Bahçeşehir 2nd part region, the second pilot region of the research areas, are cast-in-situ reinforced concrete structures. It has been noted that there are no irregular building forms, no masonry structures, and that reinforced concrete framed systems, shear wall systems, and dual systems are employed. There are two religious buildings, additional outbuildings, two educational facilities, and a public garden in the area, in addition to the general building stock and commercial units. There are 8021 independent units in the second pilot region, including 960 commercial units (157 under construction) and 7061 residential units (1463 under construction). There are three schools, two of which are under construction, two places of worship, and one preschool (Ergen, 2017).

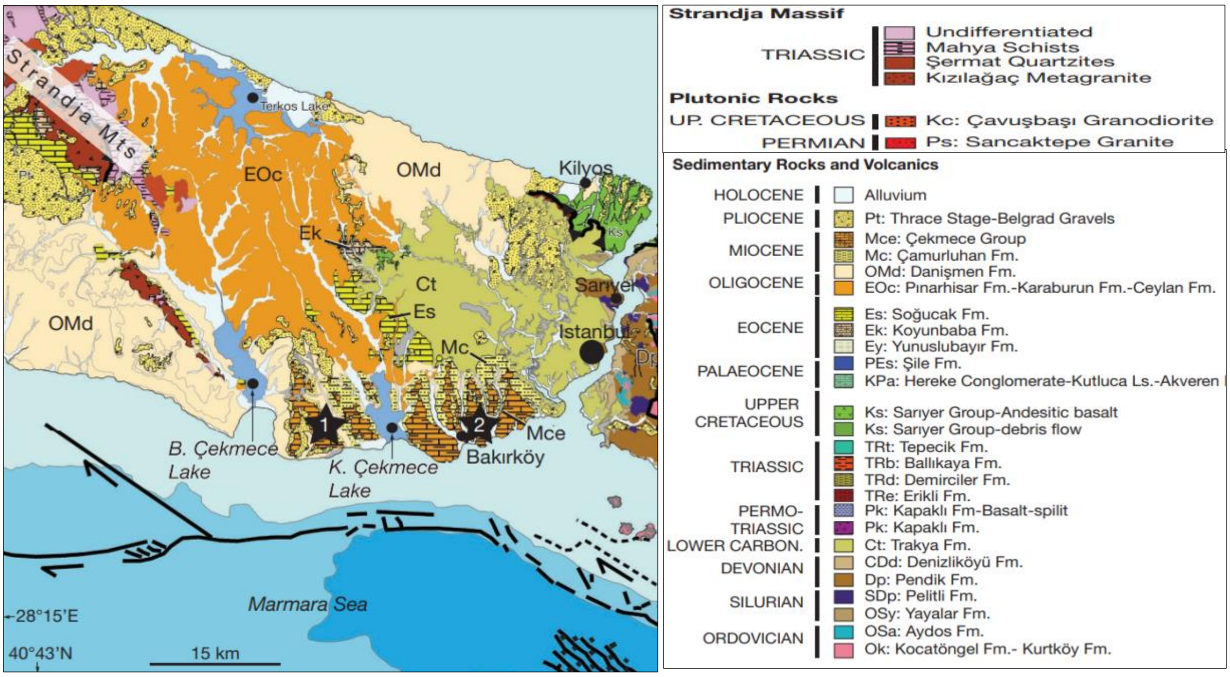


**Figure 3.** Geological formation of European side of İstanbul.

According to engineering geology, moderately weathered, fragmented claystone with weak to medium strength, as well as highly solid hard clay from the Çekmek and Çukurçeşme formations, are observed in the pilot regions as shown in Figure 3 (Lom et al., 2016). Building construction years of pilot zones are given in Figure 4 and Table 1 & Table 2 respectively.

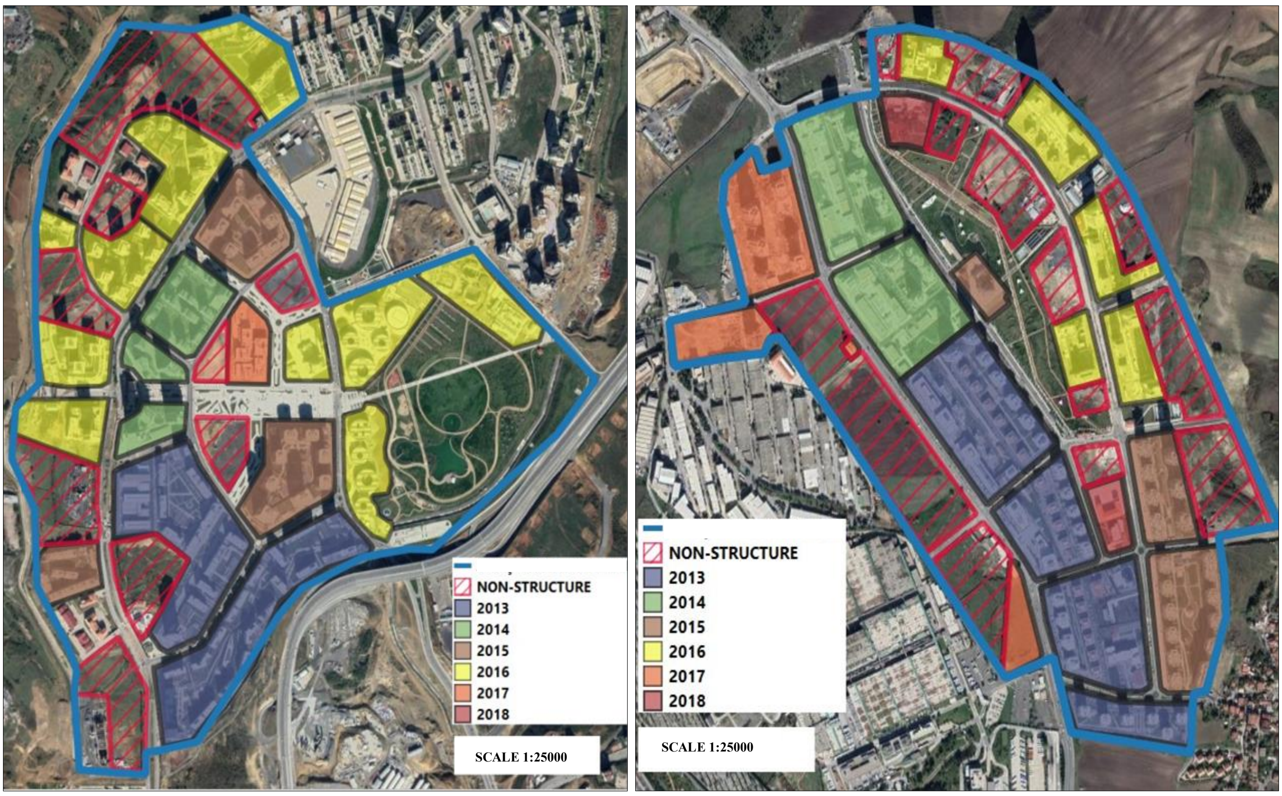


**Figure 4.** Building construction years of pilot zone 1 and 2.

**Table 1.** 1st Pilot zone building construction years.

| Construction Year | Number of Buildings | Percentage | Design Code | Design Code Classification |
|---|---|---|---|---|
| 2013 | 33 | 20.12 | TDY-2007 | High |
| 2014 | 23 | 14.02 | TDY-2007 | High |
| 2015 | 55 | 33.54 | TDY-2007 | High |
| 2016 | 52 | 31.71 | TDY-2007 | High |
| 2017 | 1 | 0.61 | TDY-2007 | High |
| Total | 164 | 100 | | |

**Table 2.** 2nd Pilot zone building construction years.

| Construction Year | Number of Buildings | Percentage | Design Code | Design Code Classification |
|---|---|---|---|---|
| 2013 | 51 | 31.68 | TDY-2007 | High |
| 2014 | 20 | 12.42 | TDY-2007 | High |
| 2015 | 35 | 21.74 | TDY-2007 | High |
| 2016 | 28 | 16.15 | TDY-2007 | High |
| 2017 | 26 | 16.15 | TDY-2007 | High |
| 2018 | 3 | 1.86 | TDY-2007 | High |
| Total | 163 | 100 | | |

### 2.3. Database Compilation

A set of data must be prepared for the analytic ELER program, which will be used to estimate earthquake damage in the areas where the study is conducted. This section describes how to get information about the structures at the core of this data, compile and parse it, and then modify it for the program.

When examining programs that analyze earthquake damage estimation, we see that HAZUS is the American damage loss estimation methodology. This procedure, which starts by first establishing the earthquake hazard, uses the building fragility curves obtained as a result of the building inventory information. The ELER program, which we employ for this study, is built on the same methodology as the HAZUS program. The HAZUS approach has been approved as a foundation for research as well as for gathering and compiling data. Data on the building inventory needed to estimate earthquake damage was gathered using the HAZUS program and modified for this study's usage of the ELER tool.

Field studies began with field surveys of the pilot locations, which are the focus of the study. Türkiye’s Ministry of Environment and Urbanization's dangerous building detection form for risky structures was used to construct a condensed preliminary building observation form. There are multiple sections on the form created for buildings that pose a risk. The first part contains general information about the building's location; the second part includes information about the current lateral load bearing system, the numbers of stories, and the average height of the building; the third part includes samples taken from the building; and the fourth and fifth parts contain the results of the performance analysis. The building location is listed in the first section of the condensed preliminary observation form created for this project, followed by the number of stories, building height, and the current lateral load bearing system.

Kayabaşı region, the initial pilot region of the research area, appears to have a dominant reinforced concrete structure type based on the early observation study. Construction typically takes place between 2016 and 2017. As lateral load bearing systems, traditional reinforced concrete frame systems and concrete shear wall systems have been predominantly used. It was observed that the streets and avenues were broad, and the regional park and plaza occupied a sizable area. Additionally, it has been noted that the development is ordered and planned rather than haphazard or overcrowded. It has been observed that the structures have an average height of about 35 meters and include 10 stories.

According to the preliminary observation study carried out for the second pilot zone, Bahçeşehir 2$^{nd}$ part, the region's new residential area was primarily composed of reinforced concrete buildings, mostly constructed between 2016 and 2017. The regional center has a huge green space when we look at it. Residential blocks are dispersed throughout the green area. Commercial office buildings can be found at various locations around the area. It has been observed that the average height of the structures is about 35 meters, and the average number of stories is about 10.

### 2.4. Examination of the Study Area

Programs for estimating and analyzing earthquake damage require a variety of data. A detailed overview of this data was prepared. First, the types of building lateral load-bearing systems are described. Next, necessary information such as the number of building stories and building heights was provided.

Knowing the year of construction is crucial for research estimating seismic damage. This importance relates to identifying the design codes used during the building's design phase before construction. As technology and information exchange have advanced, Türkiye's earthquake regulations have been updated seven times so far. Notable updates to the earthquake regulations include those implemented in 1975, 1998, and 2007. The most recent version is the Turkish Building Earthquake Regulation (TBDY, 2018) (Koçer et al., 2020).

Building design codes are classified into four levels by the HAZUS earthquake damage prediction methodology: high code, medium code, low code, and pre-code. These levels range from new design codes to older design codes. So, structures built according to the 2007 and 2018 seismic design codes are classified as high-code structures. Structures built between 2000 and 2007 are classified as medium-code structures. Structures built between 1980 and 2000 are classified as low-code structures. Structures built before 1980 are classified as pre-code structures.

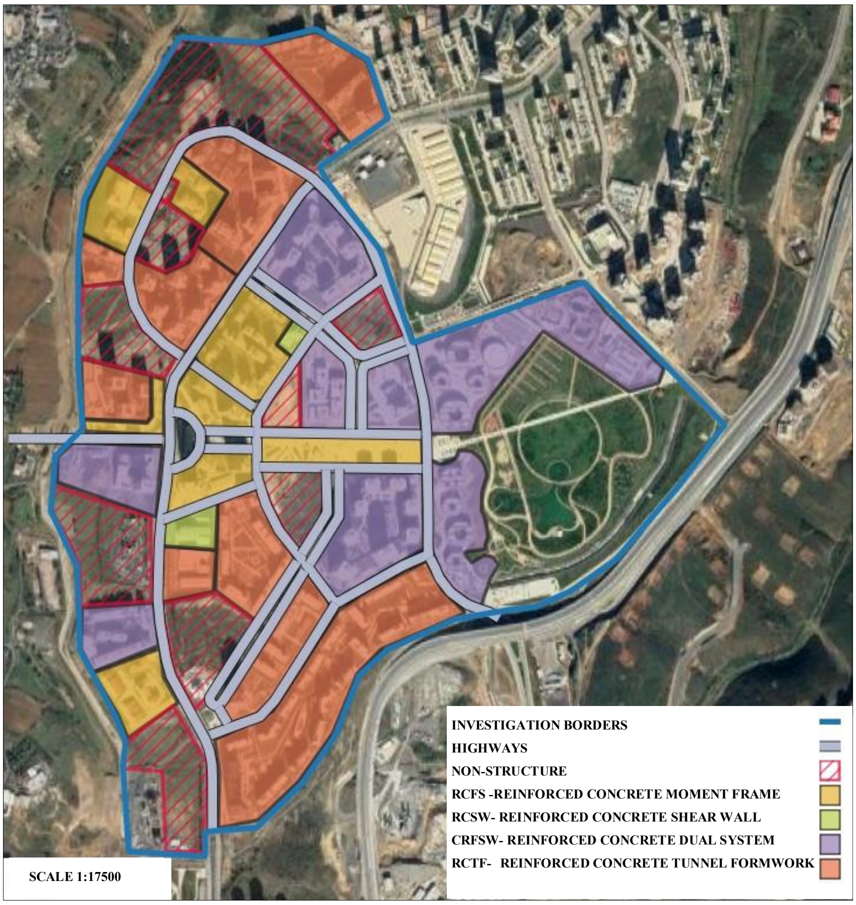


**Figure 5.** For 1st pilot area, lateral load bearing system distribution.

**Table 3.** For 1st Pilot zone, building lateral load bearing system numeric data.

| Lateral Load Bearing System | Number of Buildings | Percentage |
|---|---|---|
| Reinforced Concrete Moment Frame (RCFS) | 34 | 20.73 |
| Reinforced Concrete Shear Wall (RCSW) | 60 | 36.59 |
| Reinforced Concrete Dual System (CRFSW) | 5 | 3.05 |
| Reinforced Concrete Tunnel Formwork (RCTF) | 65 | 39.63 |
| Total | 164 | 100 |

**Table 4.** For 2nd Pilot zone, building lateral load bearing system numeric data.

| Lateral Load Bearing System | Number of Buildings | Percentage |
|---|---|---|
| Reinforced Concrete Moment Frame (RCFS) | 49 | 30.06 |
| Reinforced Concrete Shear Wall (RCSW) | 60 | 36.81 |
| Reinforced Concrete Dual System (CRFSW) | 32 | 19.63 |
| Reinforced Concrete Tunnel Formwork (RCTF) | 22 | 13.50 |
| Total | 163 | 100 |

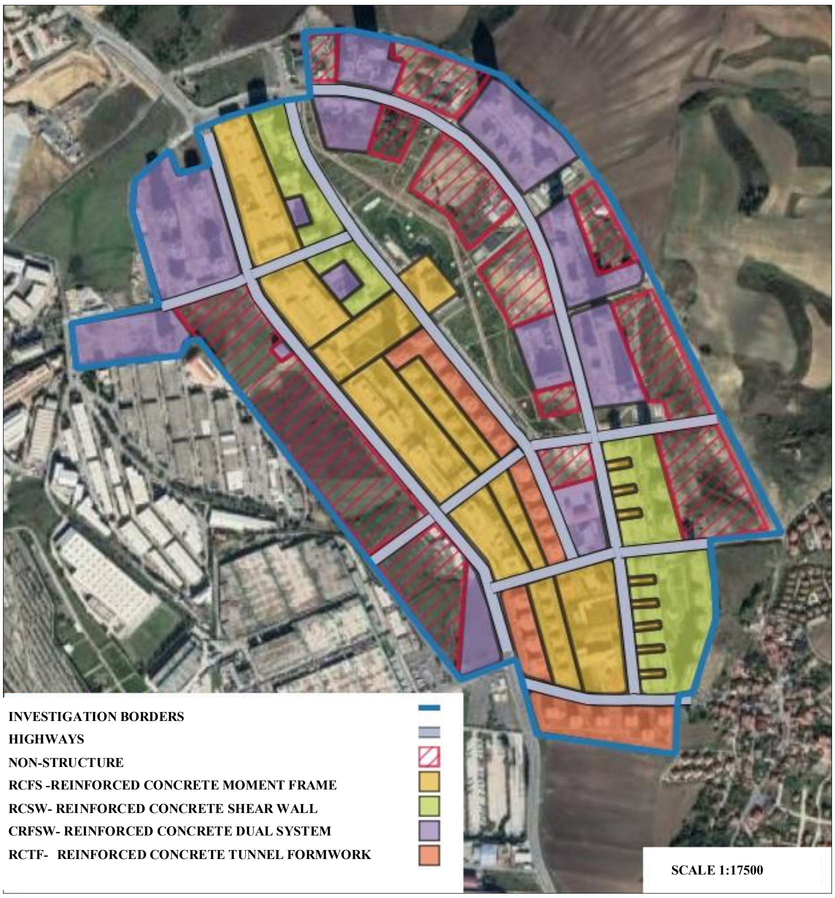


**Figure 6.** For 2nd pilot area, lateral load bearing system distribution.

Understanding the building's lateral load-bearing system is another essential piece of information required to generate fragility curves. HAZUS also classifies fragility curves based on building lateral load-bearing systems. The study areas are mostly composed of tunnel formwork lateral load-bearing systems, shear wall systems, and reinforced concrete frame systems. The four categories of load-bearing systems in the areas are: reinforced concrete tunnel formwork system (RCTF), reinforced concrete frame system (RCFS), reinforced concrete shear wall system (RCSW), and combined reinforced concrete frame and shear wall system (CRFSW).

The building load-bearing system in the Kayabaşı region, the first pilot area in the study, was classified using GIS software and is shown in Figure 5. The types of building load-bearing systems in the first pilot region are presented numerically and as percentages in Table 3. The building load-bearing system in the Bahçeşehir Second Part region, the second pilot area of the study, was classified using GIS software and is shown in Figure 6. The types of building load-bearing systems for the second pilot region are presented numerically and as percentages in Table 4.

Building height and the number of stories is additional factors to consider when estimating earthquake damage losses. According to HAZUS, building fragility values are grouped into three categories: 1-3 stories, 4-7 stories, 8 stories and above. Each building height group has its own set of values for the building fragility curve. Therefore, the study areas are organized based on building heights and the number of stories.

Figure 7 shows the distribution of building story numbers in Kayabaşı, the first pilot region, generated using a GIS application (Ergen, 2017). The story numbers for the first pilot region are distributed numerically and proportionately in Table 5. In the area, 59.76% of buildings have more than eight stories, 14.63% have between four and seven stories, and 25.61% have four stories or fewer.

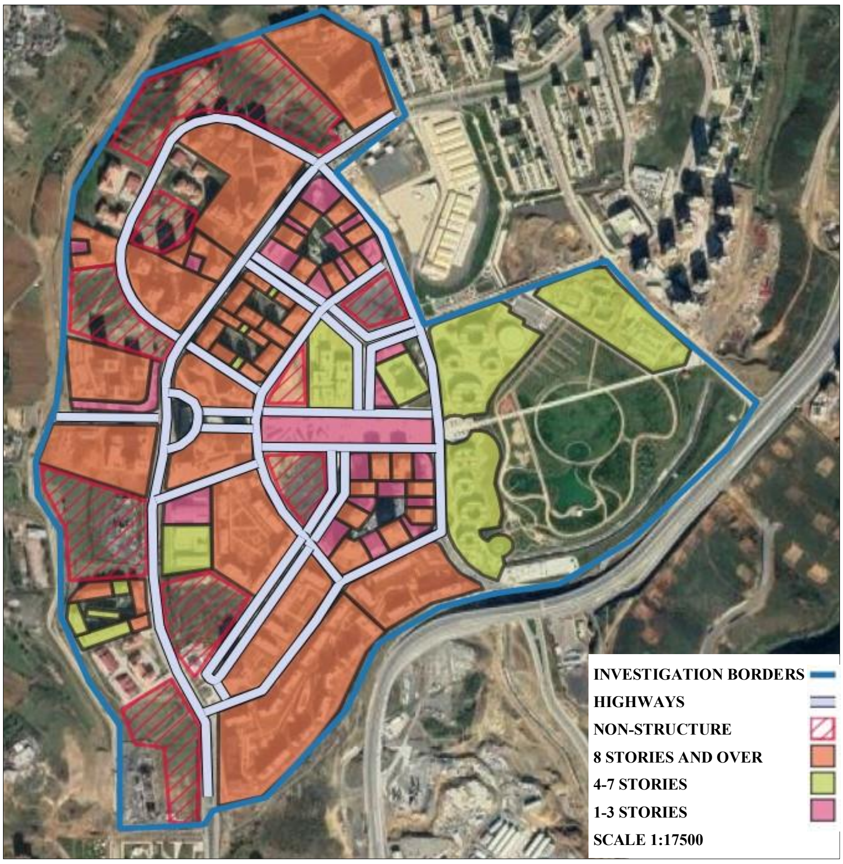


**Figure 7.** Distribution of story numbers in the 1st pilot region Kayabaşı.

**Table 5.** Distribution of story numbers in the pilot region Kayabaşı.

| Story Numbers | Number of Buildings | Percentage |
|---|---|---|
| 8 stories and over | 98 | 59.76 |
| 4-7 stories | 24 | 14.63 |
| 1-3 stories | 42 | 25.61 |
| Total | 164 | 100 |

Figure 8 displays the building story number distribution generated using a GIS application for second pilot region, which is the second part of Bahçeşehir. The number of stories for the second pilot region is presented numerically and as percentages in Table 6. In the area, 52.76% of the buildings have more than eight stories, 20.25% have four to seven stories, and 26.99% have four stories or less.

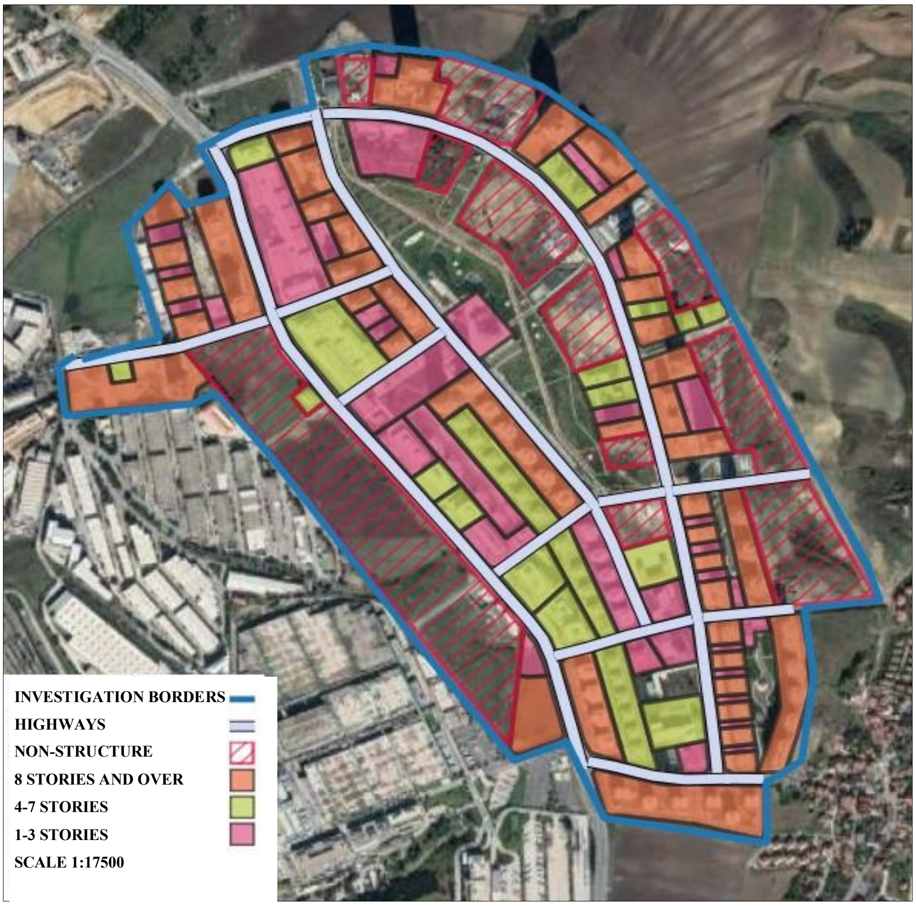


**Figure 8.** Distribution of story numbers in the 2nd pilot region Bahçeşehir.

**Table 6.** Distribution of story numbers in the pilot region Bahçeşehir.

| Story Numbers | Number of Buildings | Percentage |
|---|---|---|
| 8 stories and over | 86 | 52.76 |
| 4-7 stories | 33 | 20.25 |
| 1-3 stories | 44 | 26.99 |
| Total | 163 | 100 |

Türkiye's household numbers by province were revealed in the 2019 edition of TÜİK's Household Statistics (URL-1, 2020). Based on TÜİK data, the average number of households in Türkiye was found to be 3.35. The average number of households in Istanbul was found to be 3.33. The initial pilot zone of the study area consists of 7175 households. The second pilot region has 7061 households. By multiplying the average household size in Istanbul by the number of households in the study areas, the estimated population is approximately 23,890 in the first pilot region and 23,513 in the second pilot region.

## 3. Analysis And Evaluations

During the research, a number of computer applications were utilized. A free geographic information system application called QGIS was utilized to graphically represent the details of the study areas. The computer formats needed for evaluating earthquake damage have been converted with the help of QGIS. The QGIS application divides work areas into equal parts. In accordance with building groups, the number of buildings inside identical parts was recorded into the attribute tables. In order to use the population data for the regions in earthquake damage estimation systems, they were also entered into the QGIS program (QGIS, 2017).

Earthquake damage estimation was performed using the ELER tool. These applications provide estimates of earthquake damage in addition to facilitating the generation of data on earthquake hazards and modeling the earthquake's impact. The ELER program uses structural fragility curve values similar to those displayed in HAZUS. The damage conditions in the buildings were analyzed in light of these building fragility ratings.

The free LibreOffice application was used to create research documents and tables. This section presents observations made while on field trips. There are studies on the types of data required for evaluating earthquake damage, how they are gathered, compiled, and categorized.

Field research provided the building inventory needed for analysis. The data sets in the work titled Building damage analysis for updated building dataset of Istanbul, published as a scientific study by Betül Ergün Konukçu (Konukçu et al., 2016), were used for the comparisons between the research regions and other districts. Within the Başakşehir district, 617 building inventories were collected from areas within the district boundaries but outside the project areas; these were not included in the existing data sets.

This section provides a detailed road map for earthquake damage estimation and loss analysis. The ELER program was used to assist in the analysis. The analysis results were presented and interpreted using graphs.

### 3.1. Evaluation of Soil Class and Seismic Condition

Using historical and instrumental earthquakes that have affected the Marmara region, five different earthquake scenarios were developed. They are presented in Table 7. According to the sources, the earthquake in 1509 was one of the most severe natural disasters Istanbul has ever seen, which illustrates the magnitude of these quakes. Because of this, the incident was referred to as Doomsday (minor apocalypse) by Ottoman historians (Ürekli, 2010). Istanbul suffered significant damage and numerous fatalities as a result of this earthquake. Four to five thousand individuals died, and over a thousand homes were damaged. Approximately ten thousand people are thought to have been injured. In terms of magnitude and devastation, the 1766 earthquake is believed to have been quite similar to the 1509 one; approximately four thousand people lost their lives, and numerous others were injured (Sezer, 1968). Taking into account the 1999 7.4-magnitude earthquake that struck the Gölcük district of Kocaeli province, which had a devastating impact on the Marmara region and claimed over 17,000 lives, severely damaged over 66 thousand homes, and destroyed over 10,000 business centers, resulting in economic losses of roughly 9 to 13 billion US dollars. In order to assess the risk of earthquake damage, scenario-based earthquakes were developed based on historical data and previous studies (Konukcu et al., 2016; Utkucu, 2011; Yaltırak et al., 2003).

**Table 7.** Historical earthquake records.

| No | Date | Latitude | Longitude | $M_s$ | $M_w$ | Location |
|---|---|---|---|---|---|---|
| 1 | 10.09.1509 | 40.9 | 28.7 | 7.2 | - | İstanbul |
| 2 | 22.05.1766 | 40.8 | 29.0 | 7.1 | 7.35 | Marmara |
| 3 | 02.09.1754 | 40.8 | 29.2 | 6.8 | 7.16 | İzmit |
| 4 | 10.07.1894 | 40.7 | 29.6 | 7.3 | 7.32 | İzmit |
| 5 | 17.08.1999 | 40.7 | 29.9 | 7.4 | 7.43 | İzmit |

Ground movements resulting from ruptures of the faults nearest to the locations in the historical earthquake records shown in Table 7 were computed using the Earthquake Hazard Analysis (DTA) module in the ELER program to assess earthquake damage hazard. For the five historical earthquakes, the ELER DTA module defined the earthquake locations and depths. For the initial earthquake record, the scenario earthquake characteristics were chosen as follows: 1509 Earthquake; Magnitude $M_s$: 7.2; Fault depth: 16 km; Fault rupture length: 55 km; Fault type: strike-slip; Center latitude: 40.90° N; Center longitude: 28.7° E.". Using Turkish fault datasets, the ELER algorithm can automatically determine the fault rupture length closest to the given coordinates and locate the earthquake source. Figure 9 shows the fault rupture used as input in the ELER program's DTA and earthquake hazard analysis modules (ELER, 2010).

A damping ratio of 5% was considered for the structures. Shear wave velocity at 30 meters depth, fault source characteristics, and site effects related to ground motions are all included in the ELER program. The ELER program allows for direct modification of ground (site) conditions at the surface. Again, the default ELER program setting for Istanbul uses the shear wave velocity at 30 meters depth. In this study, ELER employed the ground motion attenuation relationship developed by Chiou and Young (2008), among various algorithms to calculate ground movements. Wald's (1999) methodology was utilized to estimate earthquake intensity measures (Chiou and Young, 2008).

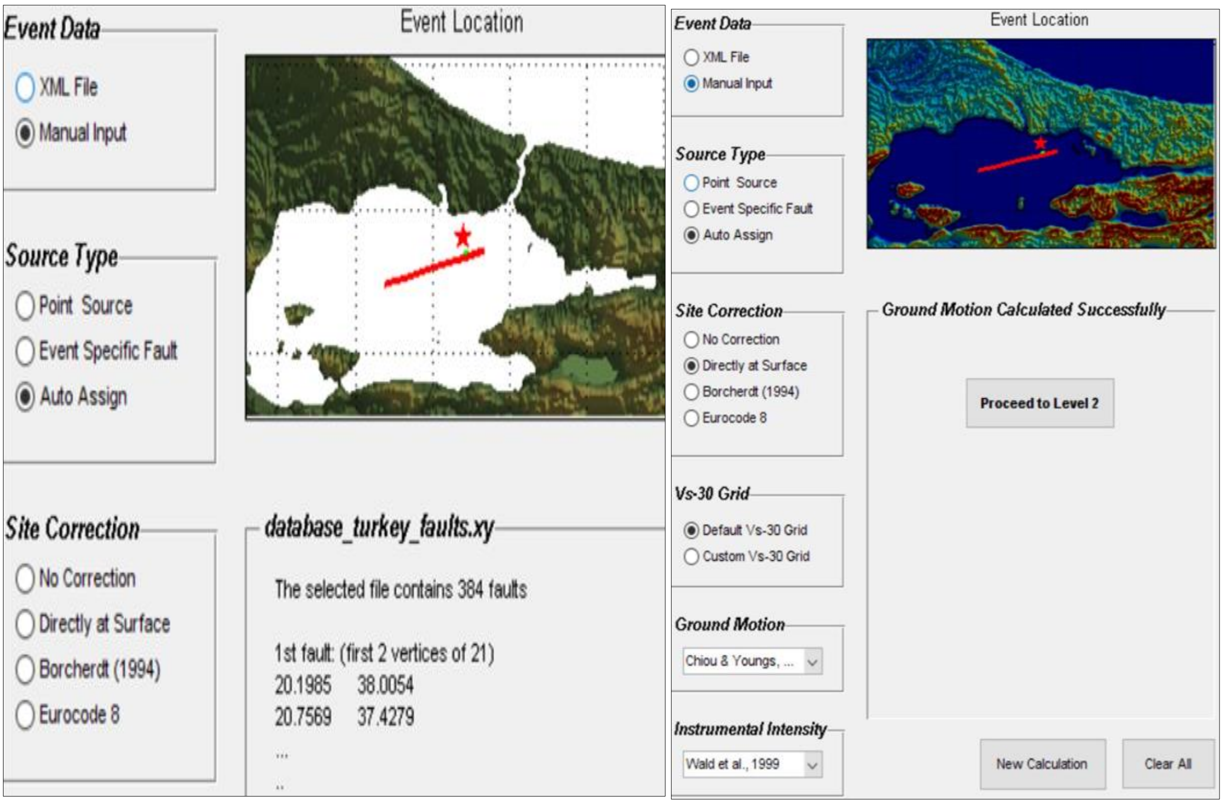


**Figure 9.** a) The center whose coordinates are entered and fault rupture, b) ELER program earthquake hazard analysis module.

After 0.2 and 1.0 seconds, ELER completes the calculation of earthquake hazard parameters and displays acceleration time histories and peak ground acceleration graphs. Figure 10 shows the Marmara peak ground acceleration distribution of the first scenario earthquake, the 1509 Istanbul earthquake. Using the DTA module of the ELER program, all earthquake scenarios were simulated similarly to generate earthquake hazard assessments. For each scenario, specific coordinates were provided, and the ELER program automatically calculated the distances between the earthquake fault ruptures and these coordinates. Other scenario earthquakes' peak acceleration distributions are displayed in Figure 10 for the Marmara earthquake in 1766, which had a fault rupture length of about 50 km; the Izmit earthquake in 1754, which had a fault rupture length of about 35 km; and the year 1894, which had a fault rupture length of about 70 km; the Izmit earthquake, followed by a fault rupture length of about 80 km in 1999 and the peak acceleration distributions for the Izmit, Gölcük earthquake (ELER, 2010).

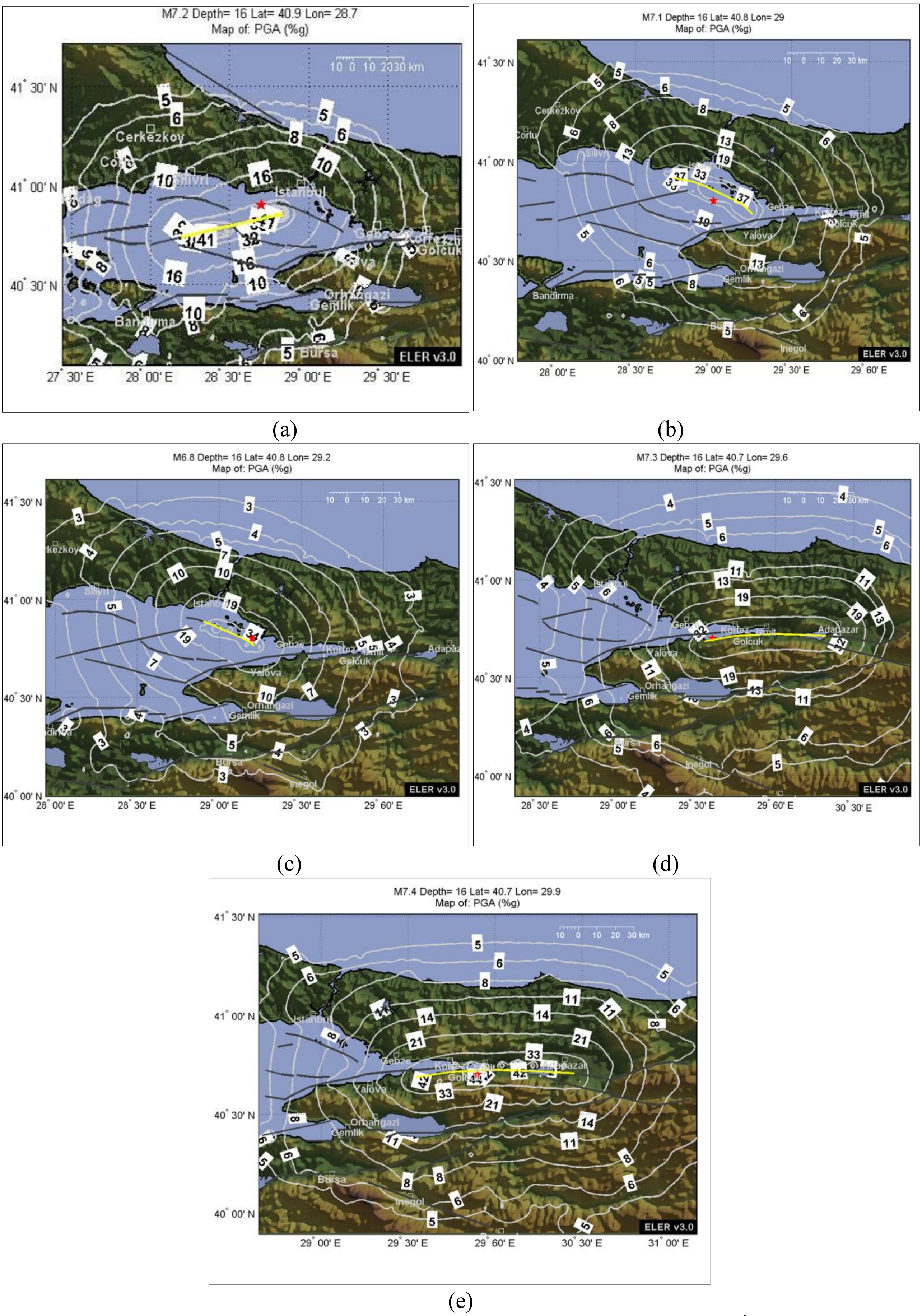


**Figure 10.** Peak acceleration distribution of earthquakes from ELER program a) 1509 İstanbul earthquake, b) 1766 Marmara earthquake, c) 1754 İzmit earthquake, d) 1894 İzmit earthquake, e) 1999 İzmit Gölcük earthquake.

### 3.2. Evaluation of Building Inventory

As indicated earlier, the HAZUS technique organizes buildings based on their importance, structural system type, and number of stories. The analysis was based on the HAZUS building classification because it provides open access to fragility curves, capacity curves, and other relevant coefficients categorized by building classes. According to HAZUS, the designations C1L, C1M, and C1H refer to reinforced concrete frame lateral load bearing systems with one to three stories, four to seven stories, and eight or more stories, respectively. (Ergen, 2017; Kılıç et al., 2022; Kılıç, 2025; Kılıç 2015). Table 8 is an example of a HAZUS building categorization.

**Table 8.** Type of building model (HAZUS).

| No | Label | Description | Height | | | |
|---|---|---|---|---|---|---|
| | | | Range | | Typical | |
| | | | Name | Stories | Stories | Meter |
| 16 | C1L | Concrete Moment Frame | Low-Rise | 1 – 3 | 2 | 6.09 |
| 17 | C1M | | Mid-Rise | 4 - 7 | 5 | 18.28 |
| 18 | C1H | | High-Rise | 8+ | 12 | 36.57 |
| 19 | C2L | Concrete Shear Walls | Low-Rise | 1 - 3 | 2 | 6.09 |
| 20 | C2M | | Mid-Rise | 4 - 7 | 5 | 18.28 |
| 21 | C2H | | High-Rise | 8+ | 12 | 36.57 |
| 22 | C3L | Concrete Frame with Concrete Shear Walls | Low-Rise | 1 - 3 | 2 | 6.09 |
| 23 | C3M | | Mid-Rise | 4 - 7 | 5 | 18.28 |
| 24 | C3H | | High-Rise | 8+ | 12 | 36.57 |

This section, which divides the program into four parts based on year and applicable regulatory codes, covers the HAZUS program in detail. Information about the building's construction year and the corresponding regulatory code was also necessary for analysis in the ELER program. As a result, the year of construction was used to categorize the regulation code, which is essential for analysis. Structures built prior to 1980 were classified as pre-code and assigned HAZUS category 1. Accordingly, structures built between 1980 and 2000 were assigned category 2 (low code), those built between 2000 and 2007 category 3 (medium code), and those constructed after 2007 category 4 (high code). For example, a 2-story reinforced concrete moment frame system built prior to 1980 is classified as C1L1; one built between 1980 and 2000 as C1M2; and a 5-story reinforced concrete moment frame system built between 2000 and 2007 as C1M3. Similarly, a ten-story reinforced concrete shear wall system constructed after 2007 is classified as C2H4. This classification system is referred to as Structure ELER Categorization (SEC). The complete code structure classification is presented in Table 9 (Ergen, 2017; Zülfikar et al., 2017).

**Table 9.** Type of building model (HAZUS).

| Label | Description | Number of Stories | Construction Year |
|---|---|---|---|
| C1L1 | Concrete Moment Frame | 1 – 3 | Pre 1980 |
| C1L2 | | 1 – 3 | 1980-2000 |
| C1L3 | | 1 – 3 | 2000-2007 |
| C1L4 | | 1 – 3 | After 2007 |
| C1M1 | Concrete Moment Frame | 4 - 7 | Pre 1980 |
| C1M2 | | 4 - 7 | 1980-2000 |
| C1M3 | | 4 - 7 | 2000-2007 |
| C1M4 | | 4 - 7 | After 2007 |
| C1H1 | Concrete Moment Frame | 8+ | Pre 1980 |
| C1H2 | | 8+ | 1980-2000 |
| C1H3 | | 8+ | 2000-2007 |
| C1H4 | | 8+ | After 2007 |
| C2L1 | Concrete Shear Walls | 1 – 3 | Pre 1980 |
| C2L2 | | 1 – 3 | 1980-2000 |
| C2L3 | | 1 – 3 | 2000-2007 |
| C2L4 | | 1 – 3 | After 2007 |
| C2M1 | Concrete Shear Walls | 4 - 7 | Pre 1980 |
| C2M2 | | 4 - 7 | 1980-2000 |
| C2M3 | | 4 - 7 | 2000-2007 |
| C2M4 | | 4 - 7 | After 2007 |
| C2H1 | Concrete Shear Walls | 8+ | Pre 1980 |
| C2H2 | | 8+ | 1980-2000 |
| C2H3 | | 8+ | 2000-2007 |
| C2H4 | | 8+ | After 2007 |
| C3L1 | Concrete Frame with Concrete Shear Walls | 1 – 3 | Pre 1980 |
| C3L2 | | 1 – 3 | 1980-2000 |
| C3L3 | | 1 – 3 | 2000-2007 |
| C3L4 | | 1 – 3 | After 2007 |
| C3M1 | Concrete Frame with Concrete Shear Walls | 4 - 7 | Pre 1980 |
| C3M2 | | 4 - 7 | 1980-2000 |
| C3M3 | | 4 - 7 | 2000-2007 |
| C3M4 | | 4 - 7 | After 2007 |
| C3H1 | Concrete Frame with Concrete Shear Walls | 8+ | Pre 1980 |
| C3H2 | | 8+ | 1980-2000 |
| C3H3 | | 8+ | 2000-2007 |
| C3H4 | | 8+ | After 2007 |

## 4. Findings and Discussion

Figure 11 shows capacity curves for a number of ELER classes of structures. Table 10 provides a few structural fragility curves as well. The ELER program's "exceltomat" module was used to transfer the building groups' capacity and fragility curves (ELER, 2010).

The building inventory was assessed and compared with those of other regions by focusing on the dominant building groups in the study areas. The distribution of Structure ELER Categorization in the first and second pilot regions is displayed in Table 11. With a percentage of 50%, C2M4 buildings make up the majority of the first pilot region. C2H4 buildings represent the second largest group at 29%. In the second pilot region, C2H4 buildings dominate, accounting for 49% of the structures. The C1L4 group is the second most common, comprising 25%. It is evident that the dominant building groups differ between the two regions. In this case, the analysis concentrated on evaluating the damage caused by earthquakes to the C2M4, C1L4, and C2H4 structures.

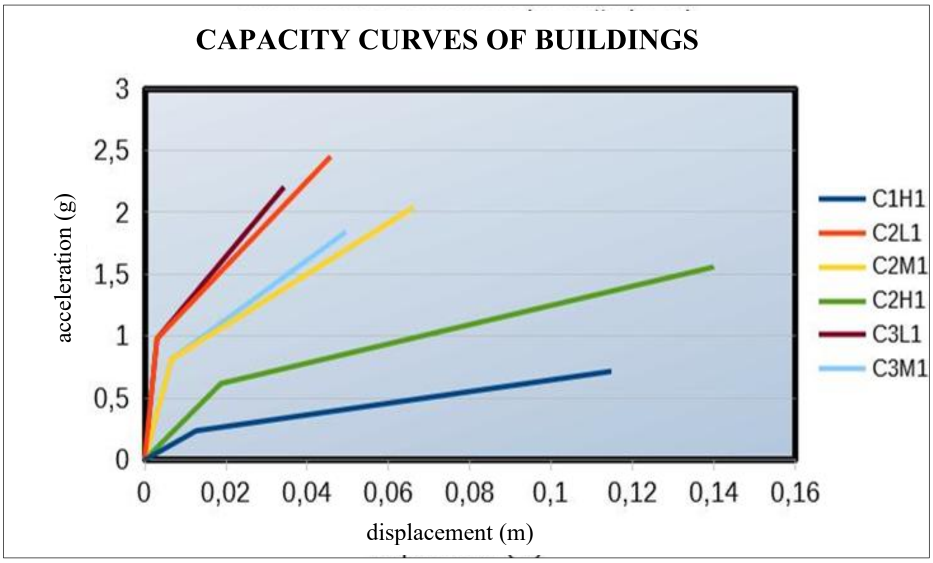


**Figure 11.** Capacity curves of building groups (Ergen, 2017).

**Table 10.** Structure fragility curves of structure types.

| | Slightly Damaged | | Medium Damaged | | Heavily Damaged | | Very Heavily Damaged | |
|---|---|---|---|---|---|---|---|---|
| Label | Median | Beta | Median | Beta | Median | Beta | Median | Beta |
| C1L4 | 0.02286 | 0.81 | 0.04572 | 0.84 | 0.13716 | 0.86 | 0.36576 | 0.81 |
| C1M4 | 0.0381 | 0.68 | 0.0762 | 0.67 | 0.2286 | 0.68 | 0.6096 | 0.81 |
| C1H4 | 0.05486 | 0.66 | 0.109728 | 0.64 | 0.329184 | 0.67 | 0.877824 | 0.78 |
| C2L4 | 0.01829 | 0.81 | 0.04572 | 0.84 | 0.13716 | 0.93 | 0.36576 | 0.92 |
| C2M4 | 0.03048 | 0.74 | 0.0762 | 0.77 | 0.2286 | 0.68 | 0.6096 | 0.77 |
| C2H4 | 0.04394 | 0.68 | 0.109728 | 0.65 | 0.329184 | 0.66 | 0.877824 | 0.75 |

**Table 11.** SEC distribution of pilot regions.

| Pilot Zone | Labels | Number of Buildings | Percentage |
|---|---|---|---|
| 1st Pilot zone | C1H4 | 11 | 6.71 |
| | C1L4 | 1 | 0.61 |
| | C1M4 | 7 | 4.27 |
| | C2H4 | 48 | 29.27 |
| | C2L4 | 13 | 7.93 |
| | C2M4 | 83 | 50.61 |
| 2nd Pilot zone | C1L4 | 41 | 25.15 |
| | C1M4 | 8 | 4.91 |
| | C2H4 | 81 | 49.69 |
| | C2L4 | 16 | 9.82 |
| | C2M4 | 17 | 10.43 |
| | C1H4 | 11 | 6.71 |

The distribution of SEC is marginally different when the full Başakşehir district is taken into account. The dominant SEC groups in the Başakşehir district were used for analysis and evaluation. The C3L2 building group, representing 24.96% of structures, is the most common type in the Başakşehir district. The C1L2 (14.96%) and C2L3 (12.21%) structures are the next most prevalent groups (Ergen, 2017).

**Table 12.** Başakşehir District SEC Distribution.

| Labels | Number of Buildings | Percentage |
|---|---|---|
| C3L2 | 4629 | 24.96 |
| C1L2 | 2774 | 14.96 |
| C2L3 | 2265 | 12.21 |
| C3M2 | 1345 | 7.25 |
| C1L3 | 1130 | 6.09 |
| C2H4 | 961 | 5.18 |
| C1L4 | 689 | 3.71 |
| C2M4 | 530 | 2.86 |
| C2H3 | 485 | 2.61 |
| Other | 3739 | 20.16 |
| Total | 18547 | 100.00 |

### 4.1. Assessment of Building Risk Situations

Four response spectrum techniques can be used with ELER to assess earthquake damage losses. These techniques include the Coefficient Method (CM), Reduction Factor Method (RFM), Modified Acceleration-Displacement Response Spectrum Method (MADRS), and Capacity Spectrum Method (CSM). These methods are predicated on vulnerability assessment based on spectral displacement. The performance point, which lies at the intersection of the seismic demand spectrum and the capacity spectrum of equivalent nonlinear single-degree-of-freedom systems, defines the building structure's resistance to ground shaking during earthquakes. Damage occurs once the performance point is reached on the capacity curve. Fragility curves, assuming a log-normal distribution of damage, determine the probability of reaching or exceeding a certain damage level (Gülay et al., 2008).

The 5%-damped elastic response spectrum is used to reflect earthquake demand (Kale, 2017). Two alternatives are offered by ELER for building the response spectrum's form. ELER offers two options for constructing the response spectrum: Eurocode 8 Spectrum (first) and IBC 2006 Spectrum (second). In the analytical stage, IBC 2006 was utilized. Type 1 and Type 2 elastic acceleration response spectrum were proposed by IBC 2006 for the horizontal components of ground motions. Both types of seismic motions are assumed to have the same elastic response spectrum shape (Gulati, 2006).

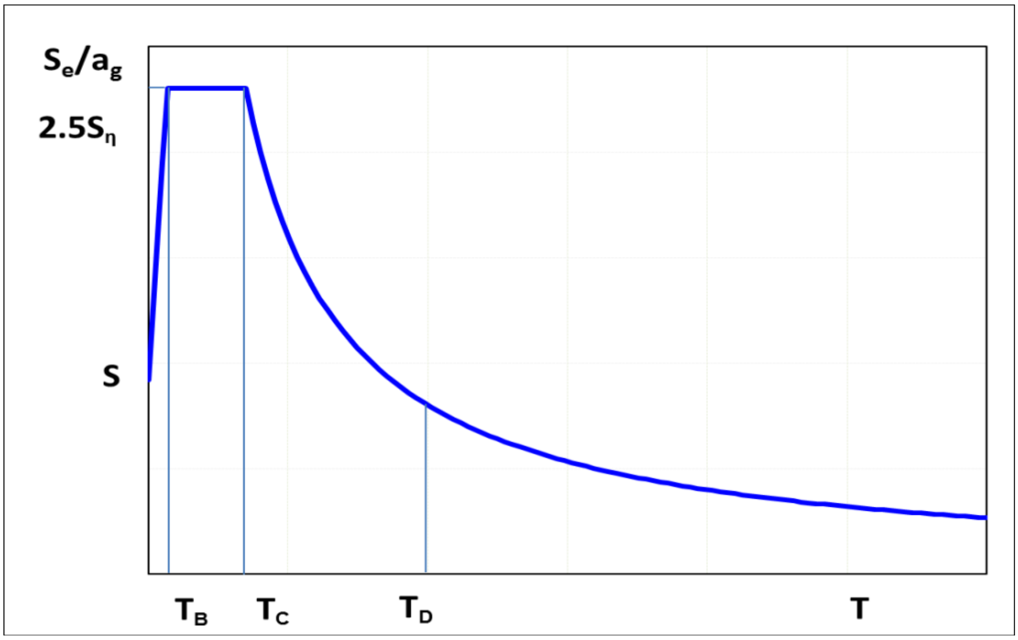


**Figure 12.** Horizontal elastic response spectrum (IBC, 2006).

IBC 2006 provides the corner periods $T_B$, $T_C$, $T_D$, and the acceleration value S for each ground type and spectrum type that will be utilized, along with damping corrections for various damping levels. For evaluation, the MADRS method was employed. The MADRS approach uses the effective period ($T_{eff}$) and effective damping ($\beta_{eff}$) values to calculate the maximum displacement of a nonlinear system in the equivalent linear system. The capacity spectrum, along with the appropriate natural period, damping values, and ductility demand ($\mu$), all influence the effective linear parameters. When damping and effective periods are used, the maximum displacement is produced at the point where the ADRS demand and the radial effective period line connect. $a_{max}$ and $d_{max}$ represent the crossing point (FEMA 440, 2005). In Figure 13 Modified acceleration-displacement response spectrum plot (FEMA 440, 2005) is presented.

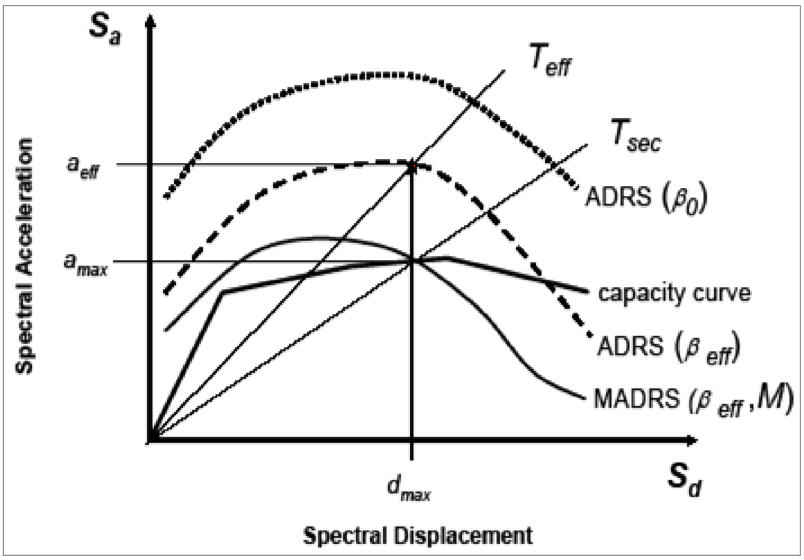


**Figure 13.** Modified acceleration-displacement response spectrum plot (FEMA 440, 2005).

## 4.2. Damage Conditions of Building Types

The building groups that constitute the majority within the research regions are mentioned in section 3. Subsequently, earthquake damage estimation was conducted for the majority of buildings in the Başakşehir district, classified according to the building codes. Finally, earthquake damage analysis of the research pilot areas was carried out. Based on these analyses, comparisons of earthquake damage were made between old and new settlements. The total number of buildings in Başakşehir is given in Table 12. Using data obtained from the pilot areas, an estimation of damage to buildings throughout the district was attempted.

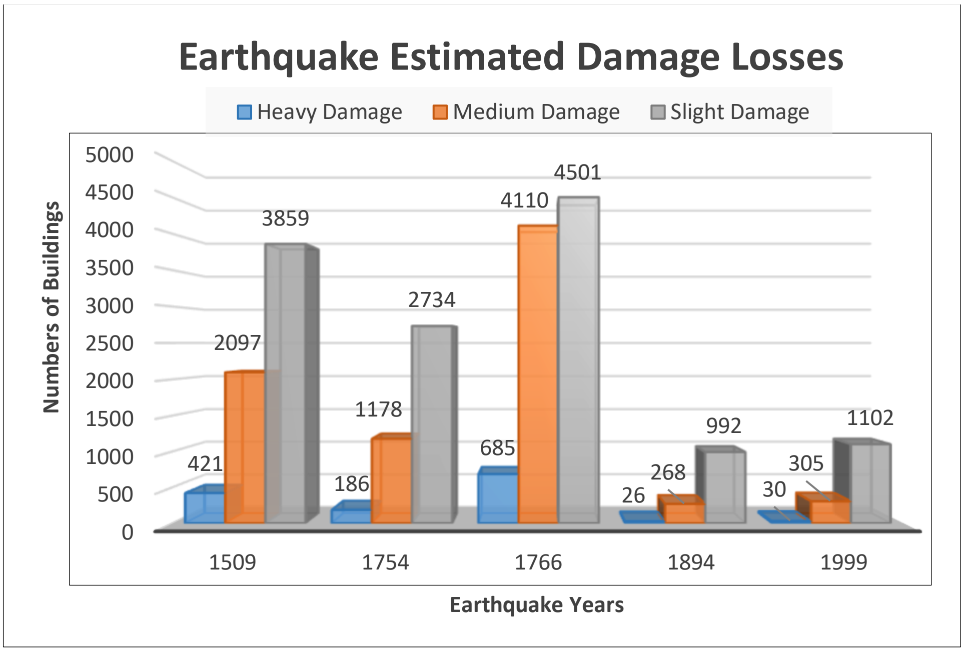


**Figure 14.** Estimated damage losses of Başakşehir 1509, 1754, 1766, 1894, 1999 earthquakes.

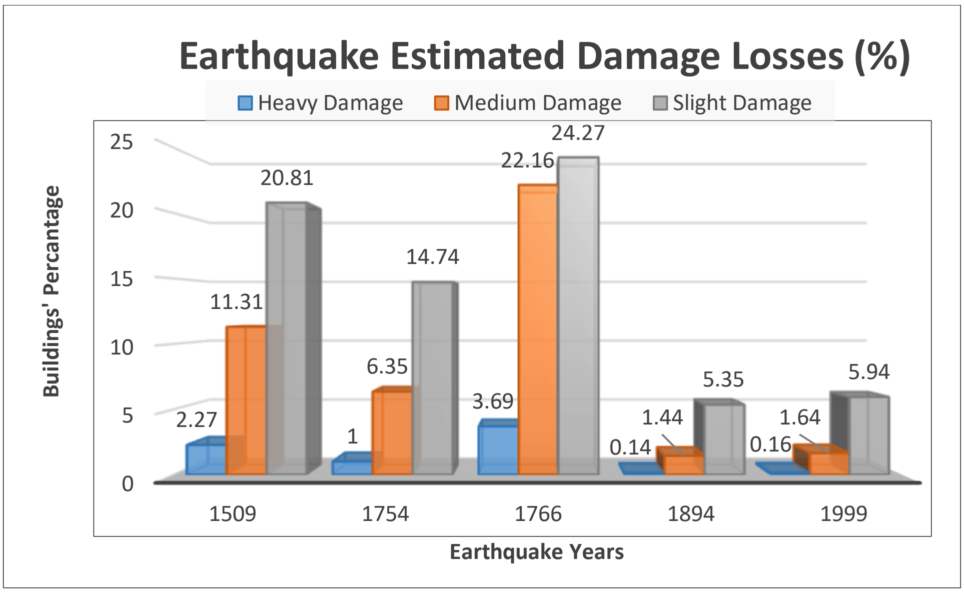


**Figure 15.** Estimated damage percentages of Başakşehir 1509, 1754, 1766, 1894, 1999 earthquakes.

After analyzing the overall damage situation of the districts, a further analysis was conducted considering the Başakşehir district's building ELER categorization, which includes the research regions. The Başakşehir district was analyzed based on the earthquake scenarios presented in Table 7. Table 13 presents the anticipated building damage losses for the majority of building groups in Başakşehir based on the scenario earthquake analyses. Estimated damage losses and damage percentages for the Başakşehir earthquakes of 1509, 1754, 1766, 1894, and 1999 are illustrated in Figures 14 and 15, respectively.

Figure 14 was created using the method described in Section 4.1, 'Assessment of Building Risk Situations. Based on the inputs to the ELER software, the estimated numbers of buildings experiencing heavy, moderate, and minor damage in Başakşehir were calculated for five seismic events. These numbers are also displayed in the figure. Figure 15 was created using the same methodology. The damage figures were divided by the total number of buildings to obtain percentage rates. These percentages were also indicated on the graph.

**Table 13.** Estimated heavy and very heavy damage losses according to Başakşehir SEC scenario earthquakes.

| Event | 1509 İstanbul | 1766 Marmara | 1754 İzmit | 1894 İzmit | 1999 İzmit |
|---|---|---|---|---|---|
| SEC | Number-% | Number-% | Number-% | Number-% | Number-% |
| C3L2 | 240-5.16 | 366-7.87 | 109-2.34 | 15-0.32 | 18-0.39 |
| C1L2 | 49-1.76 | 99-3.56 | 15-0.54 | 1-0.37 | 1-0.37 |
| C2L3 | 28-1.24 | 49-2.16 | 12-0.53 | 1-0.35 | 1-0.35 |
| C3M2 | 14-1.04 | 27-2.00 | 5-2.00 | 1-0.09 | 1-0.09 |
| C1L3 | 12-1.06 | 23-2.03 | 4-0.35 | 0-0.00 | 1-0.07 |
| C2H4 | 0-0.00 | 1-0.12 | 0-0.00 | 0-0.00 | 0-0.00 |
| C1L4 | 2-0.33 | 5-0.82 | 1-0.16 | 0-0.00 | 0-0.00 |
| C2M4 | 0-0.00 | 0-0.00 | 0-0.00 | 0-0.00 | 0-0.00 |
| C2H3 | 1-0.21 | 3-0.62 | 0-0.00 | 0-0.00 | 0-0.00 |
| Other | 75-18.12 | 112-16.35 | 40-21.50 | 8-30.00 | 8-26.6 |
| Total | 421-100.00 | 685-100.00 | 186-100.00 | 26-100.00 | 30-100.00 |

C3L2 type buildings perform worse" or "have lower performance. Their heavy damage ratios are greater than those of other types, especially for the 1766 Marmara (7.87%) and 1509 Istanbul (5.16%) earthquake scenarios. C3L2 type buildings represent 1-3 story buildings that were built between 1980 and 2000, despite their lateral load-bearing system is a concrete frame with concrete shear walls. On the other hand, C2M4 type buildings show the best performance for all scenarios. There is no heavy damage reported for these buildings, which have concrete shear wall lateral load-bearing systems. Although these buildings have 4-7 stories, they were not severely damaged because they were constructed after 2000.

An earthquake damage estimation analysis was conducted for each building group in the Kayabaşı area of the first pilot region to better understand how new residential areas would respond to hypothetical earthquakes. According to Table 14, there is no heavy damage in the Kayabaşı region for any earthquake scenario. However, moderate damage occurs in the 1766 Marmara, 1754 Izmit, and 1509 Istanbul earthquake scenarios. Also, slight damages are seen for every scenario, but worst numbers of slight damages occur in 1766 Marmara earthquake. One important reason for this is that most buildings in this pilot region were constructed after 2000, according to Tables 2 and 11.

**Table 14.** 1st Pilot region (Total 164 buildings) Kayabaşı region earthquake damage estimation numbers.

| Damage | 1509 İstanbul | 1766 Marmara | 1754 İzmit | 1894 İzmit | 1999 İzmit |
|---|---|---|---|---|---|
| Heavy | 0 | 0 | 0 | 0 | 0 |
| Medium | 4 | 8 | 2 | 0 | 0 |
| Slight | 28 | 39 | 20 | 6 | 7 |

The ELER program conducted an earthquake damage estimation analysis f for the Bahçeşehir 2nd part, the second pilot area of the study, based on the scenario earthquake simulations. The results of the analyses based on these earthquake scenarios are presented in Table 15. A comparison between Tables 15 and 14 shows very similar results. There is no heavy damage, while some moderate damage is observed in three earthquake scenarios. Additionally, slight damage is present in all scenarios, with notably higher amounts for the 1766 Marmara and 1509 Istanbul earthquakes. The similarity in performance is attributed to the presence of new buildings in both areas.

**Table 15.** 2nd Pilot region (Total 163 buildings) Bahçeşehir region earthquake damage estimation numbers.

| Damage | 1509 İstanbul | 1766 Marmara | 1754 İzmit | 1894 İzmit | 1999 İzmit |
|---|---|---|---|---|---|
| Heavy | 0 | 0 | 0 | 0 | 0 |
| Medium | 7 | 10 | 1 | 0 | 0 |
| Slight | 40 | 47 | 16 | 4 | 6 |

The pilot regions' responses to hypothetical earthquakes were also investigated based on building code classifications. The objective of this review is to provide a thorough understanding of the expected damage extent during earthquakes, considering building code classifications.

Seismic damage analyses under hypothetical earthquake scenarios were conducted on buildings in the first region. No structures were severely damaged in the pilot zone under any of the earthquake scenarios. Moderate and slight damage was observed in the first pilot region as a result of the assessments. Table 16 shows the results for structures with moderate damage. According to Table 16, there are no moderately damaged buildings for the 1894 İzmit and 1999 İzmit earthquakes. Although these earthquakes have larger magnitudes, their impact on this region is low due to the greater distance between their epicenters and the pilot region. Table 17 lists the number of buildings found to have minor damage according to the analysis. When Table 17 is examined, the number of slightly damaged buildings decreases for the 1894 İzmit and 1999 İzmit earthquakes, whereas it increases for the 1766 Marmara and 1509 İstanbul earthquakes. C2H4-type buildings, constructed after 2007 with concrete shear walls and more than eight stories, have the highest numbers. Based on the information in Table 11, these structures are the predominant type in the first pilot region.

**Table 16.** Pilot area Kayabaşı SEC numbers of moderately damaged buildings.

| SEC Label | 1509 İstanbul | 1766 Marmara | 1754 İzmit | 1894 İzmit | 1999 İzmit |
|---|---|---|---|---|---|
| C1H4 | 1 | 1 | 0 | 0 | 0 |
| C1L4 | 0 | 0 | 0 | 0 | 0 |
| C1M4 | 0 | 1 | 0 | 0 | 0 |
| C2H4 | 1 | 3 | 1 | 0 | 0 |
| C2L4 | 1 | 1 | 0 | 0 | 0 |
| C2M4 | 1 | 1 | 0 | 0 | 0 |
| Total | 4 | 7 | 1 | 0 | 0 |

**Table 17.** Pilot area Kayabaşı SEC numbers of slightly damaged buildings.

| SEC Label | 1509 İstanbul | 1766 Marmara | 1754 İzmit | 1894 İzmit | 1999 İzmit |
|---|---|---|---|---|---|
| C1H4 | 3 | 4 | 2 | 1 | 1 |
| C1L4 | 1 | 1 | 0 | 0 | 0 |
| C1M4 | 2 | 3 | 1 | 0 | 0 |
| C2H4 | 13 | 18 | 9 | 3 | 4 |
| C2L4 | 4 | 6 | 3 | 1 | 1 |
| C2M4 | 5 | 7 | 3 | 1 | 1 |
| Total | 28 | 39 | 18 | 6 | 7 |

Under the scenario earthquakes, earthquake damage analyses were conducted on the structures situated in the Bahçeşehir 2$^{nd}$ part region, the second pilot region of the research regions. No severe or extremely damaged structures were observed as a result of the research done for the pilot zone under the influence of all possible earthquake scenarios. The investigation resulted in the formation of medium and slightly damaged structures for the second pilot region. The results of the analysis are shown in Table 18 for structures with moderate to severe damage. Table 19 lists the number of buildings that were found to have minor damage as a consequence of the analysis.

**Table 18.** Pilot area Bahçeşehir SEC numbers of moderately damaged buildings.

| SEC Label | 1509 İstanbul | 1766 Marmara | 1754 İzmit | 1894 İzmit | 1999 İzmit |
|---|---|---|---|---|---|
| C1L4 | 1 | 1 | 0 | 0 | 0 |
| C1M4 | 2 | 3 | 0 | 0 | 0 |
| C2H4 | 2 | 4 | 0 | 0 | 0 |
| C2L4 | 0 | 1 | 0 | 0 | 0 |
| C2M4 | 0 | 1 | 0 | 0 | 0 |
| Total | 5 | 10 | 0 | 0 | 0 |

**Table 19.** Pilot area Bahçeşehir SEC numbers of slightly damaged buildings.

| SEC Label | 1509 İstanbul | 1766 Marmara | 1754 İzmit | 1894 İzmit | 1999 İzmit |
|---|---|---|---|---|---|
| C1L4 | 3 | 3 | 1 | 0 | 0 |
| C1M4 | 11 | 13 | 4 | 1 | 1 |
| C2H4 | 21 | 24 | 8 | 3 | 3 |
| C2L4 | 3 | 3 | 1 | 0 | 0 |
| C2M4 | 3 | 3 | 1 | 0 | 0 |
| Total | 41 | 46 | 15 | 4 | 4 |

According to Table 18, for İzmit earthquakes, there is no moderately damaged building. Nevertheless, for 1766 Marmara and 1509 İstanbul earthquakes, there are moderately damaged buildings, due to the proximity of these two ground motions to the regions investigated. When Table 19 is examined, the results are nearly the same for both pilot regions. Again, the C2H4 type of buildings show the highest damage numbers. Because Table 11 shows that half of the buildings in Bahçeşehir pilot region are of the C2H4 type.

## 5. Conclusions and Recommendations

Within the scope of this study, no performance analysis was performed on all the buildings in the pilot regions, instead an attempt was made to estimate an approximate damage scenario. Recently, rapid assessment systems such as P25 have been developed. In this method, the fact that the building is designed with new earthquake regulations reduces the potential damage. According to the parametric studies, new buildings perform better in earthquakes (Gülay et al., 2010). In addition, according to the earthquake assessment reports prepared by ITU and Boğaziçi University after the KahramanMaraş earthquake, old buildings were sustained more damage or completely destroyed in the earthquake (İTÜ, 2023; KOERİ, 2023). The reason for this can be explained as follows: Earthquake regulations that have come into force in Türkiye, especially in the last 25 years, calculate the earthquake load more precisely compared to the old versions, consider soil effects more precisely, give great importance to the concept of ductility, emphasize the principle of capacity design and apply important minimum conditions in many sections and elements (TDY, 2007; TBDY, 2018).

It was found that there were no severely damaged structures for any earthquake scenarios in the first and second pilot locations where the research was carried out. Only a small number of structures in the study areas experienced moderate damage during the earthquakes that struck Istanbul in 1509, Marmara in 1766, and İzmit in 1754. It was noted that no moderately damaged structures formed in other earthquake scenarios. The two pilot regions saw slightly damaged structures in all earthquake scenarios.

Examining the 1766 Marmara scenario earthquake in detail revealed that the districts and pilot regions suffered the most from the greatest building damage statistics. Compared to other earthquake scenarios, this one caused more building damage because of its high magnitude and proximity to the Istanbul area. Especially 1754, 1894 and 1999 İzmit earthquakes had lesser effects compared to other scenarios, because of the distance. The distance to fault is more influential than the magnitude of ground motion.

According to the research hypothesis, comparatively less damage was anticipated to occur in Başakşehir district than in other settlements because it is a new settlement (Gülay et al., 2010). Additionally, the number of structures with moderate damage is incredibly minimal. Because of this, the C2H4 building ELER code shows a comparatively higher number of slightly damaged buildings in both pilot regions than other building classes. In addition to the structure's height and lateral load-bearing system, its construction year and the prevalence of building types are key parameters influencing damage.

The building inventory for the entire Başakşehir district was revised as a result of the research. The building inventory update allows for the development of several strategies for the Başakşehir district, which other seismic damage analysis systems can employ. Deterministically, the seismic damage hazard was defined. Using the building inventories created as part of the thesis, earthquake damage estimation analyses can be conducted probabilistically to compare the outcomes in the same program or in various programs. By giving priority to neighborhoods and apartments that need urban renewal, detailed investigations can begin, taking into account the projected building damage results under the effect of the earthquake.

**Authors' Contributions**

All authors contributed equally to the study.

**Statement of Conflicts of Interest**

There is no conflict of interest between the authors.

**Statement of Research and Publication Ethics**

The author declares that this study complies with Research and Publication Ethics.

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