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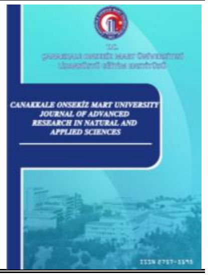

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Seismic Risk Evaluation of Existing Reinforced Concrete Buildings: A Case Study for Çanakkale-Türkiye

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Research Article

Abstract − Türkiye is in an important earthquake zone, and most of the population is under seismic hazard. The high loss of lives in the past earthquakes indicates that our existing building stock is vulnerable. In this study, a field survey was carried out to determine the existing earthquake risks of reinforced concrete buildings in İsmetpaşa, Barbaros, Cevatpaşa, Kemalpaşa, Namıkkemal, Esenler, and Fevzipaşa Neighborhoods of Çanakkale city center. This study was conducted to specify the regional distribution of risky buildings to be examined by the street survey method called "Simplified methods that can be used to determine the regional risk distribution of buildings" in the implementation regulation of Law No. 6306. For this purpose, 585 reinforced concrete buildings were examined with this method, and the earthquake performance scores of these buildings were determined. The performance scores calculated as a result of reflecting the number of stories, earthquake hazard zone, type of structural system, and structural irregularities of the buildings were evaluated based on different parameters. It was seen that soft stories with values ranging from 50% to 100% and heavy overhangs with values ranging from 37% to 63% were the most common irregularities in existing buildings in Çanakkale.

Keywords – *Çanakkale, seismic risk, Law no. 6306, street survey method, building stock*

1. Introduction

Just as many destructive earthquakes have occurred in our country in the past, it is known that such severe earthquakes will occur in a wide area in the future. Buildings to be constructed in earthquake-risk areas must be highly earthquake-resistant and in accordance with current earthquake codes. In addition, the existing structures need to be strengthened or demolished and rebuilt to ensure earthquake safety and avoid the loss of life.

To reveal the collapse risk of a building, it is necessary first to determine the soil and material parameters; then model and analyze the structure. However, determining the earthquake safety of various buildings is time-consuming and expensive. For this reason, the necessity of determining the situation with applicable and realistic approaches arises. It is considered a reasonable approach to use gradual assessment methods, which are done in developed countries that are vulnerable to similar risks, such as earthquakes [1]. There are evaluation methods developed by America and Japan [2-6]. The incompatibilities between the project area and parameters, such as the building stock in these countries and the seismic characteristics of the area to be investigated, require the adaptation of these methods [1]. Studies have been carried out by examining these

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methods and presenting new methods in Türkiye to determine the earthquake resistance of existing buildings in recent years [7-23]. In the studies [7, 11, 14], the authors presented a simplified method of ranking low to mid-rise, monolithic reinforced concrete (RC) buildings according to their vulnerability to seismic damage. Ersoy and Özcebe [8] presented the research carried out by Middle East Technical University related to seismic rehabilitation emphasizing infilled frames, a system extensively used in Türkiye. In the studies [9, 15], the authors developed a computer program using the DURTES algorithm to analyze existing structures' earthquake risk. Ilki et al. [10] applied the first stage of the seismic index method on 4 buildings located in Istanbul and Izmit. In the studies [12, 17, 18], the authors proposed a two-level risk assessment procedure in which the first level is based on recording building parameters from the street, and in the second level, these are extended by structural parameters measured by entering the ground story. In the studies [13, 19, 21], the authors presented an assessment method to rapidly scan existing buildings to prevent loss of life in an earthquake. Boduroğlu and Çağlayan [16] developed a rapid screening method called the Seismic Safety Screening Method, an adaptation of the Japanese Seismic Index Method. Inel et al. [20] carried out a seismic risk assessment for a typical mid-size city based on building inventory from a field study. Özçelik et al. [22] discussed the details of the "multiple decision tree" method used to prioritize buildings in terms of risks. Köksal and Yıldız [23] conducted a sampling study in 54 buildings to estimate the possibility of physical damage. These studies have contributed to creating forms and methods for evaluating existing buildings in our country.

The existence of natural disasters, especially earthquakes, and the state of the existing building stock have made it necessary to initiate the urban transformation process. In this context, Law No. 6306, The Transformation of Areas Under Disaster Risk [24], was published in 2012. The law contains methods and principles for transforming buildings, either on an individual building basis or collectively on an area basis. A section in the law allows risk prioritization in areas containing a significant number of buildings and the examination of the buildings in areas with high-risk priorities according to the results. This section, titled "Simplified methods that can be used to determine the regional risk distribution of buildings," is referred to as Appendix A in the study. After the law was published, some studies using the method were carried out [25-29]. This study is the first and most comprehensive study conducted for Çanakkale.

In this article, after mentioning the previous studies in this field, information about the earthquake risk of the study area was given. The method parameters in the law were introduced, and the works carried out in the study area were explained. Finally, it was evaluated how the results of this method could be used by interpreting the obtained data.

2. Materials and Methods

This section presents the basic definitions needed in the method in the Appendix-A of Law No. 6306 [24].

2.1. Earthquake Hazard of the Study Area

Çanakkale is in the western part of Türkiye, as seen in Figure 1. In the figure, the black frame indicates the maximum ground acceleration values of Çanakkale Province in the earthquake hazard map [30]. The maximum acceleration value of 475-year Çanakkale Province is in the range of 0.3-0.7. These values show that the seismicity of the region is very high.

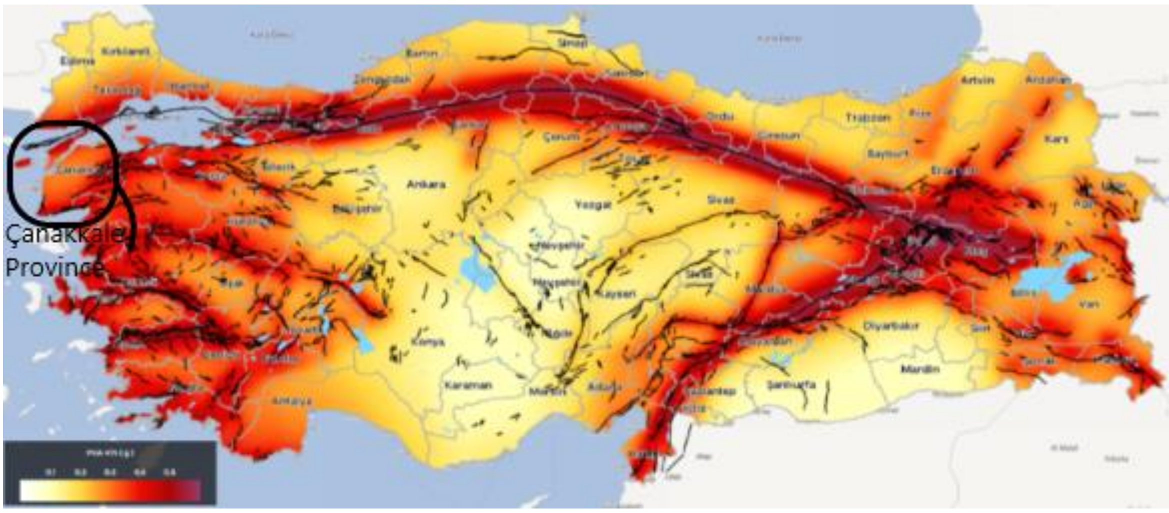

Figure 1. Türkiye earthquake hazard map [30]

The surface area of the central district of Çanakkale is about 94900 hectares. Figure 2 specifies the borders of the study area.

Figure 2. Satellite image of the study area [31]

Fault lines, each extending 50-100 km from Çanakkale city center and causing earthquakes at certain periods, threaten the city. Local conditions that may cause an increase in the earthquake effect in the city center can be listed as follows: high groundwater levels, liquefaction problems, and coastal areas consisting of filled areas.

Saroz-Gaziköy, Etili, Çan-Biga Zone, Sarıköy, and Yenice-Gönen Fractures located around Çanakkale are known as active faults due to the earthquakes they caused [32]. Many earthquakes of different magnitudes have been recorded where the Saros-Gaziköy Fault is located. Among these earthquakes, the most destructive was the Şarköy-Mürefte earthquake in 1912, with a magnitude of $M_S = 7.4$. An earthquake of magnitude $M_S=6.4$ was recorded in the Çan-Biga Fault Zone in 1935. The Yenice-Gönen Fault is one of the Biga Peninsula's most important active tectonic structures. On March 18, 1953, a destructive earthquake ($M_W=7.2$) occurred on this fault, considered part of the southern branch of the North Anatolian Fault Zone [33]. Four moderate size earthquakes hit Ayvacık district of Çanakkale Province on February 6, 2017, $M_W=5.2$ and $M_W=5.1$, February 7, 2017, $M_W=5.2$, February 12, 2017, $M_W=5.3$ [34]. In addition, the $M_W=6.9$ earthquake occurred on May 24, 2014, in the west of Gökçeada Island, in the northern Aegean Sea, and the earthquake caused moderate damage to about 300 buildings (50 of them in Çanakkale city and 200 of them located in Gökçeada Island) [35]. The North Aegean Sea earthquake with a magnitude of $M_W=5.7$, which occurred on January 8, 2013, and with a magnitude of $M_L= 5.3$, which occurred on July 30, 2013, were the earthquakes felt in Çanakkale. Finally, the Tartışık-Ayvacık earthquake with a magnitude of M_W=5.0 on February 20, 2019, the Beypınar Lapseki earthquake with a magnitude of M_L=4.5 on February 27, 2024, and the Karasu Yenice earthquake with a magnitude of M_L=4.9 on March 4, 2024, shows that earthquakes occur frequently in this region. These earthquakes are shown in Table 1.

Table 1. Earthquakes in the region

Date	Magnitude	Location
09.08.1912	M_S=7.4	Şarköy-Mürefte
10.08.1912	M_S=6.2	Şarköy-Mürefte
10.08.1912	M_S=5.3	Şarköy-Mürefte
04.01.1935	M_S=6.4	Çan –Biga zone
18.03.1953	M_W=7.2	Yenice-Gönen
08.01.2013	M_W=5.7	North Aegean Sea
30.07.2013	M_L=5.3	North Aegean
24.05.2014	M_W=6.9	Aegean Sea
06.02.2017	M_W=5.2	Ayvacık
06.02.2017	M_W=5.1	Ayvacık
07.02.2017	M_W=5.2	Ayvacık
12.02.2017	M_W=5.3	Ayvacık
20.02.2019	M_W=5.0	Tartışık-Ayvacık
27.02.2024	M_L=4.5	Beypınar-Lapseki
04.03.2024	M_L=4.9	Karasu-Yenice

2.2. Parameters of the Method

The parameters required in the evaluation method for RC buildings in Appendix-A are as follows: type of structural system, number of stories, apparent quality, soft or weak story, vertical irregularity, heavy overhangs, irregularity in plan torsion, short column, building adjacency, topographic effects, and local soil conditions. These parameters for each building can be determined with approximately 15 minutes of street survey.

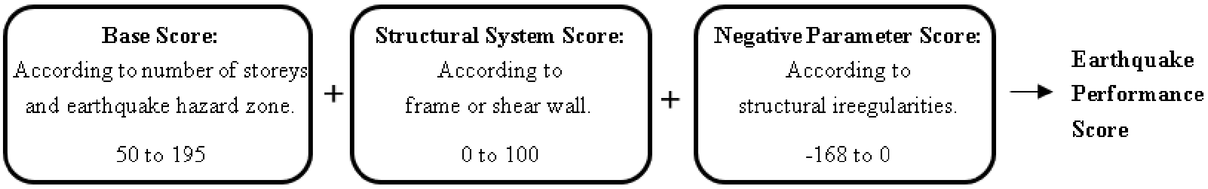

Figure 3. Flowchart of earthquake performance score

The data collected from the buildings was recorded using a form. The earthquake performance score was calculated for each building after evaluating the data. When calculating the performance scores of buildings, (+) points depending on the type of structural system, number of stories and hazard zone, and negative parameter scores in (-) points due to the effect of irregularities in the structural system are evaluated together (Figure 3). The performance scores can be used to determine the risk priorities of the regions. A short description of these irregularities is given below.

2.2.1. Number of Stories

Due to the increase in the number of stories, the building mass and the effects of earthquake forces increase. As a result of many observations and studies, it turns out that there is an almost linear relationship between the number of stories and structural damage in RC structures.

2.2.2. Soft or Weak Story

Many buildings in our country's building stock had soft or weak story irregularities. If the ground floor is used as a shop or store, the infill walls on this floor are usually removed or reduced. Based on the height difference of the floors, a significant difference in the rigidities of stories and soft or weak story damage occurs in such buildings. It will be determined observationally by considering the difference in floor height and the apparent stiffness between floors.

2.2.3. Heavy Overhangs

One of the most significant features of buildings in Türkiye is the difference between the floor area of the ground floor and the floors above. Heavy overhang occurs by creating a larger area on the upper floors of the building. The presence of heavy overhangs causes mass and stiffness irregularities in the structure.

2.2.4. Short Column

Frames with partial infills lead to the formation of short columns, which sustain heavy damage since they are not designed for the high shear forces due to the shortened heights that will result from a strong earthquake [36].

2.2.5. Apparent Quality

The strength of building materials and the importance given to the quality of workmanship directly affect the performance of the building.

2.2.6. Building Adjacency

Since each structure has different vibration periods, structures built without sufficient clearance may result in damage during the earthquake.

2.2.7. Topographic Effects

Building a structure on a hill with a slope of more than 30° will slightly increase the effects of the earthquake load due to the height differences in the structural system elements.

2.2.8. Vertical Irregularity

The presence of discontinuous frames, columns, and shear walls along the height is very risky regarding load transfer during an earthquake.

2.2.9. Irregularity in Plan Torsion

In RC buildings, an unsymmetrical plan and distribution of vertical structural elements may cause additional loadings. As a result of the fact that the center of mass and the center of rigidity of a building do not coincide, torsion occurs due to eccentricity.

2.2.10. Type of Structural System

RC structural systems consist of frames or shear wall+frames. Shear walls are the major earthquake resisting members; therefore, there is an advantage to the shear wall+frame structures.

Using these parameters, 585 RC buildings in all the neighborhoods in Çanakkale city center were selected randomly and recorded in data collection forms. While making these selections, care was taken to reflect a certain distribution. Figure 4 indicates the distribution of building locations in the study. Figure 5 shows two building examples from the study.

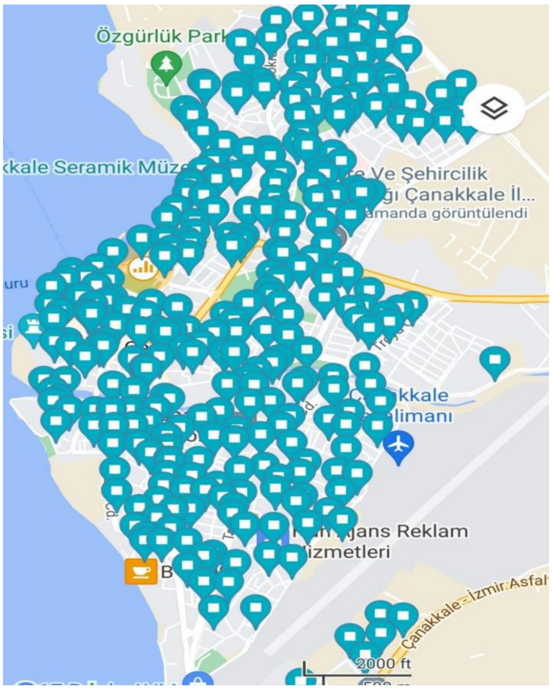

Figure 4. Distribution of building locations

Figure 5. Building examples

In order to obtain the local soil classes of the existing buildings, the data obtained from the geological and geotechnical studies previously carried out for the Çanakkale city center were obtained from Çanakkale Municipality. The vector and raster data obtained from the Çanakkale Municipality were transferred to the ArcGIS application [37], and the average shear wave velocity values for the top 30 meters of depth (Vs)30 values were revealed by obtaining the grid code for each parcel (Figure 6). In the study area, (Vs)30 values are lowest at 152 m/s and highest at 544 m/s. According to these values, according to the Turkish Building Seismic Code, there are ZC, ZD, and ZE local soil classes in the study areas in Çanakkale city center [38]. These soil classes and the coordinates of the buildings were entered into the earthquake hazard maps interactive web application [30]. The hazard zone was determined with the Short Period Design Spectral Acceleration Coefficient values found in the web application, and they were used to determine the base scores of the buildings. DD-2 ground motion level was used in the method. As a result of evaluating the data collected by applying the method to the buildings, a performance score was calculated for each building. Risk priorities between regions can be determined by sorting the calculated performance scores from largest to smallest.

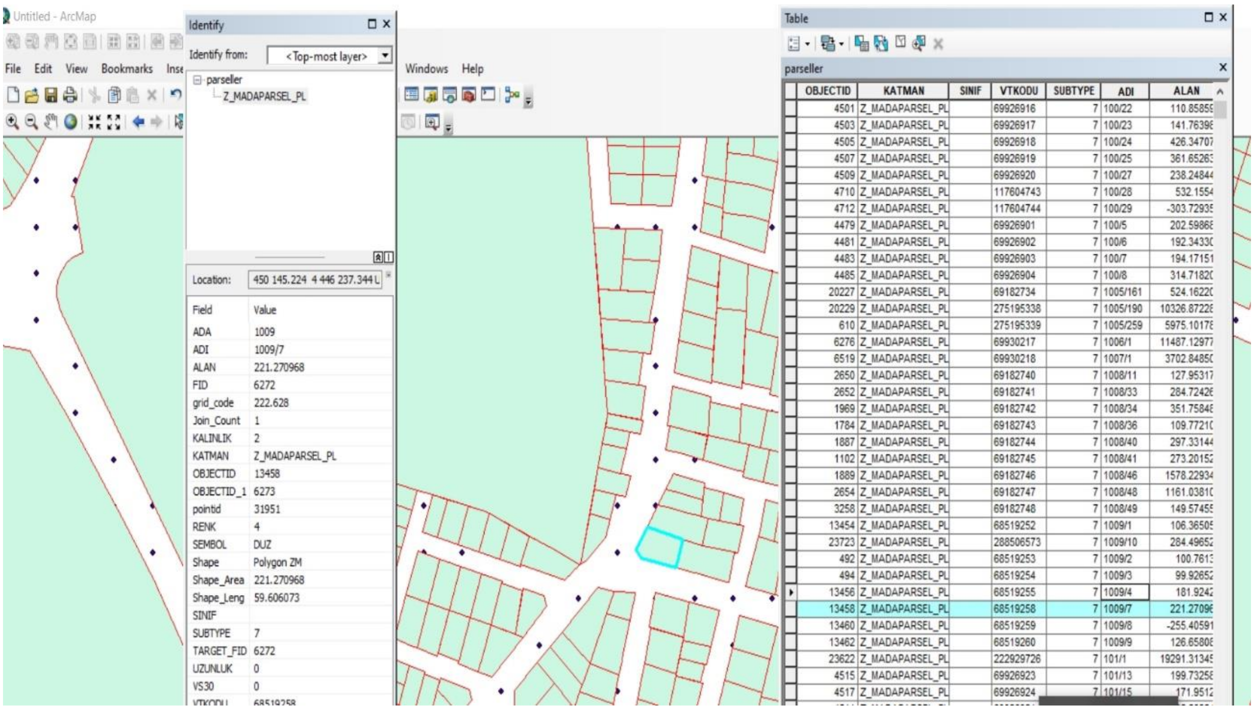

Figure 6. Grid codes from the ArcGIS application

Analyzes were made in the Statistical Package for the Social Sciences (SPSS) program [39] with the values obtained by filling in the data collection forms of 585 buildings in the city center of Çanakkale. By entering all the collected data into the SPSS program, it was aimed to obtain the most accurate results with the fewest errors.

3. Results and Discussion

The distribution of randomly selected buildings in the city center of Çanakkale according to neighborhoods and the total number of buildings in the neighborhoods are shown in Table 2. The number of evaluated buildings was intended to be compatible with the total number of buildings.

Table 2. Number of buildings [40]

Name of Neighborhood	Total Number of Buildings	Evaluated Number of Buildings
Barbaros	3826	169
İsmetpaşa	2215	88
Cevatpaşa	1508	105
Kemalpaşa	655	54
Namıkkemal	432	50
Esenler	1232	77
Fevzipaşa	578	42

The performance scores were classified according to neighborhoods and number of stories (Figure 7). The graph shows that the total score of the buildings decreases as the number of stories increases. The reason is that the base score, considered when calculating the total score, is high in low-rise buildings but decreases as the number of stories increases. In addition, it is seen that as the number of stories increases, there are lower scores in the negativity parameter score, which evaluates the current irregularity in buildings.

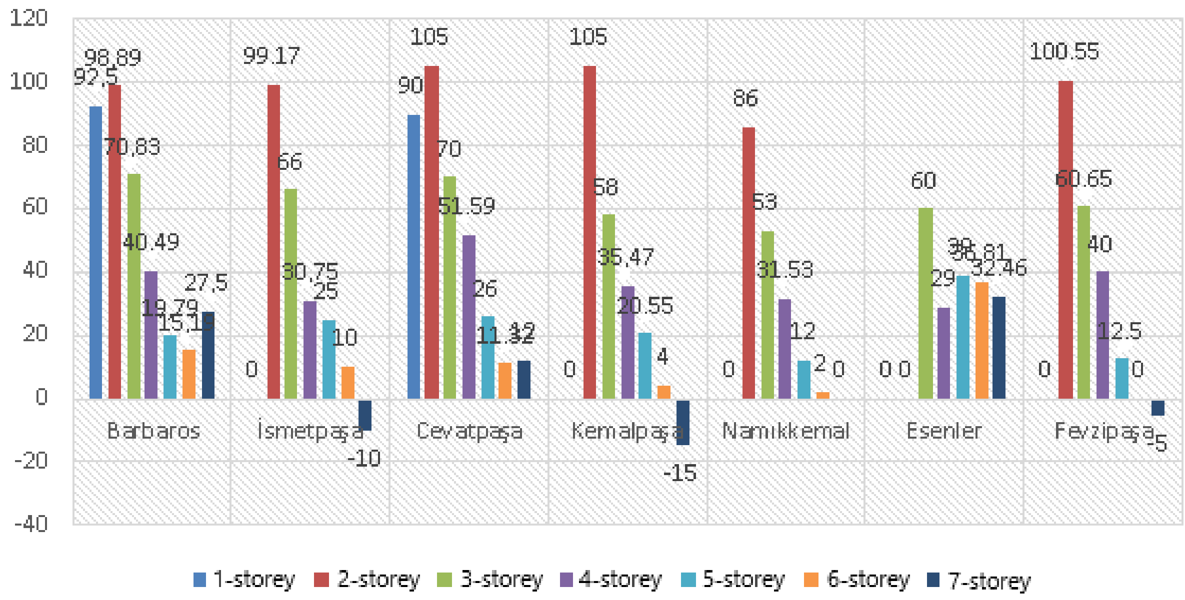

Figure 7. Average scores according to neighborhoods and number of stories

Figure 8 compares the average score calculated for Çanakkale city center and the average score of each neighborhood. The average score of total buildings was found to be 38.56. It is seen that the calculated average scores of the buildings in Cevatpaşa, Kemalpaşa, and Esenler are below the general average score. The reasons can be said to be that there are many structural irregularities in Cevatpaşa; moreover, Cevatpaşa is the region with the highest natural ground slope. In Kemalpaşa, there is a high concentration of workplaces; most buildings are adjacent, and soft stories are present in all the buildings. Esenler is a newly built area, and there are many high-rise buildings. Additionally, 46 of the 77 buildings have heavy overhangs. In Fevzipaşa, where the average score is significantly above the general score average, most existing buildings are low-rise.

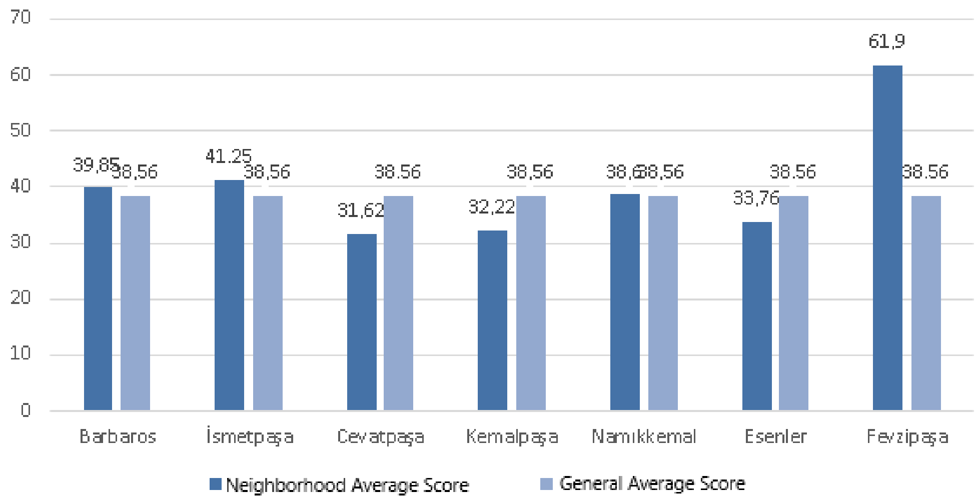

Figure 8. Comparison of the general average score and average score of each neighborhood

Figure 9 indicates the apparent quality distribution according to neighborhoods. When the results are evaluated as a percentage, the percentage with good apparent quality was calculated as 92% in Esenler, 76% in Barbaros, 70% in Cevatpaşa, 67% in İsmetpaşa, 61% in Kemalpaşa, 57% in Fevzipaşa and 40% in Namıkkemal. This ranking was largely accurate regarding the construction process for Çanakkale city center.

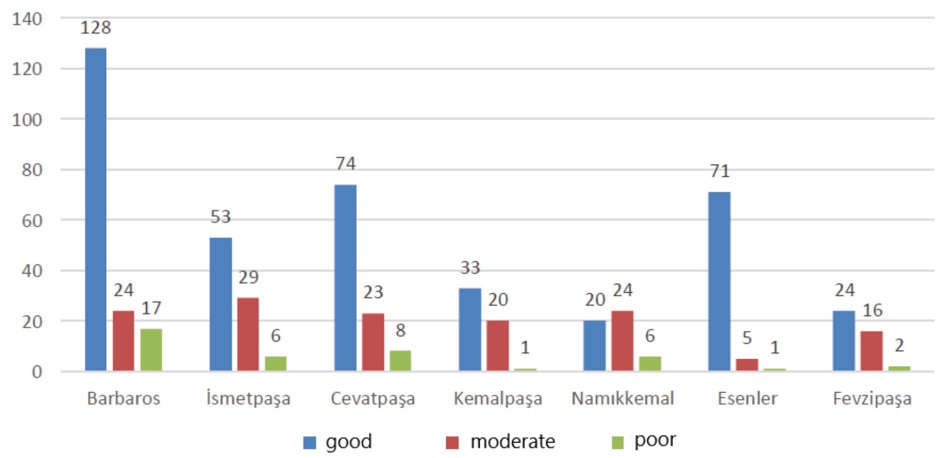

Figure 9. Building apparent quality according to neighborhoods

The distribution of soft or weak stories according to neighborhoods is seen in Figure 10. The soft or weak story rate was calculated as 100% in Kemalpaşa and Namıkkemal, 76% in İsmetpaşa, 69% in Fevzipaşa, 57% in Esenler, 54% in Barbaros and 50% in Cevatpaşa. Looking at these ratios, it is possible to say that a soft or weak story is the type of irregularity that is generally the most common. In the Kemalpaşa and Namıkkemal Neighborhoods, shops and stores are on the ground floors of all buildings, as seen in Figure 10.

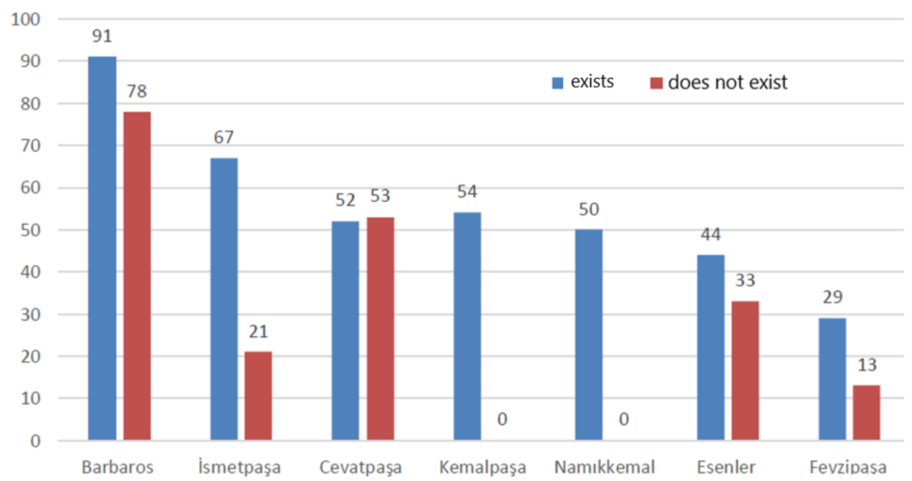

Figure 10. Soft/Weak story based on neighborhoods

Figure 11 shows the distribution of heavy overhangs according to neighborhoods. The percentage of buildings with heavy overhangs was calculated as 63% in Barbaros, 60% in Esenler, 51% in Cevatpaşa, 47% in İsmetpaşa, 45% in Fevzipaşa, 42% in Namıkkemal and 37% in Kemalpaşa Neighborhoods. Based on the ratios, heavy overhang irregularity is the most common irregularity after a soft or weak story.

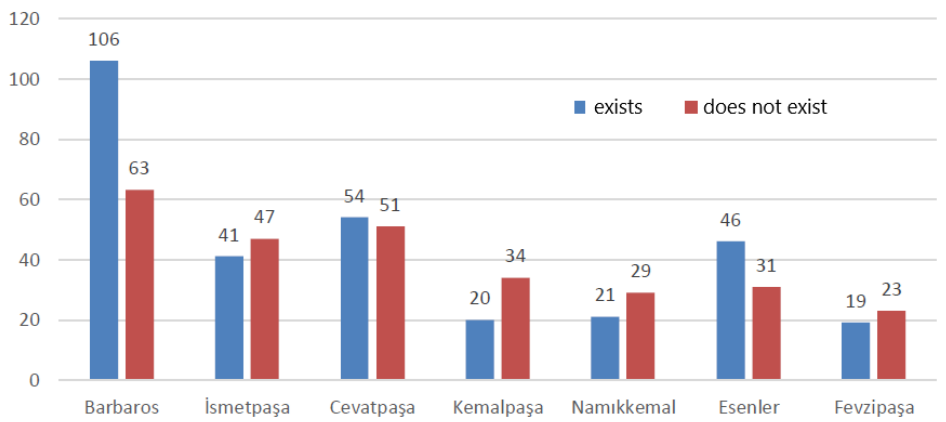

Figure 11. Heavy overhangs, according to neighborhoods

The distribution of irregularities in plan torsion according to neighborhoods is seen in Figure 12. There is an irregularity in the plan at a rate of 22% in Esenler, 21% in Barbaros, 12% in Namıkkemal, 11% in Kemalpaşa, 9% in Cevatpaşa, 7% in Fevzipaşa and 6% in Ismetpaşa Neighborhoods. Compared to other irregularities, it is seen that the rates of irregularity in the plan torsion are low.

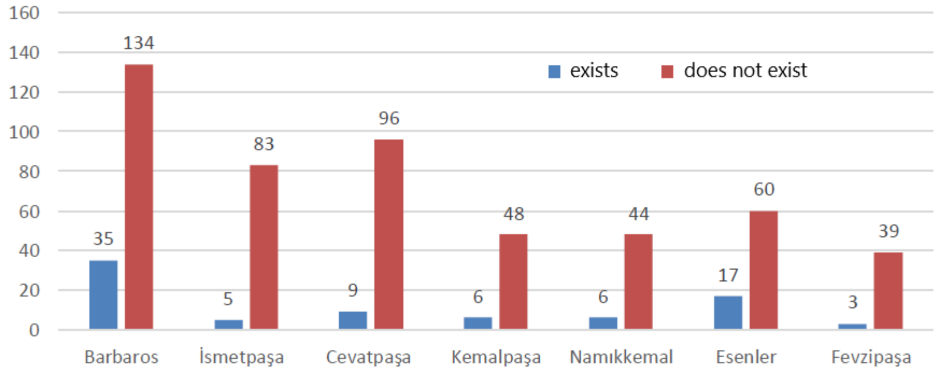

Figure 12. Irregularity in plan torsion according to neighborhoods

Figure 13 shows the existence of short columns in the buildings. The rates are 22% in Esenler, 20% in Kemalpaşa, 14% in Namıkkemal, 11% in Barbaros, 7% in Fevzipaşa, 5% in Cevatpaşa and 1% in Ismetpaşa. Compared to other irregularities, the short column appears to be low.

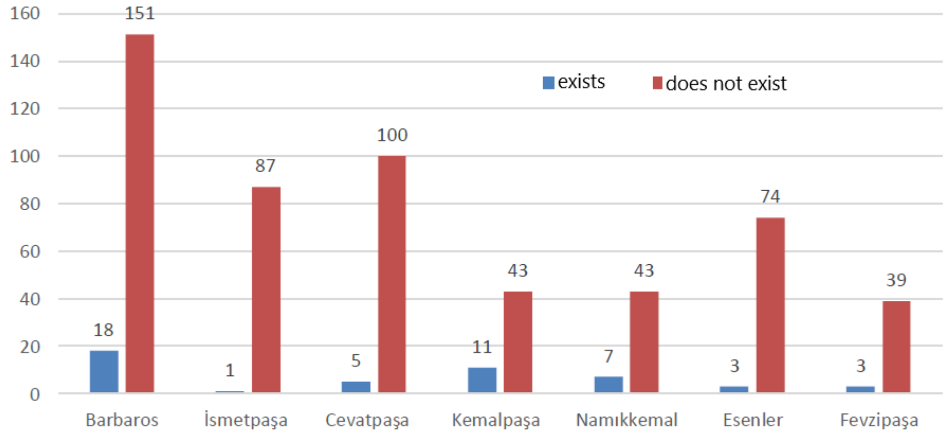

Figure 13. Short columns according to neighborhoods

4. Conclusion

A rapid seismic assessment was conducted in 585 selected RC buildings in the city center of Çanakkale using Appendix-A of Law No. 6306 [24]. In this method in Law No. 6306, building adjacency, short column, and topographic effects have the same negativity value for all heights of buildings. However, the impact of the negativities from building apparent quality, soft or weak story, vertical irregularity, heavy overhangs, and irregularity in plan torsion is considered greater in high-rise buildings. These irregularities increase the risk of earthquakes, especially in buildings with four or more floors. They were evaluated in this way because it is known that they caused more damage and destruction in the past earthquakes.

Our study found soft stories with values ranging from 50% to 100% and heavy overhangs ranging from 37% to 63% were the most common irregularities in existing buildings according to neighborhoods. Soft story, especially with significantly higher story heights, may cause sudden collapse during an earthquake. Buildings with both low-performance scores and also soft stories can be prioritized.

Similar results were found in other studies using this method in the literature. Street survey results showed that 79% of concrete buildings have a pounding effect, 65% have a soft story, and 37% have heavy overhangs [27]. 24% have a soft story, and 22% have a heavy overhang of the 487 RC buildings, and they specified that these buildings must be subjected to a more detailed assessment [25]. Among the total 1550 RC buildings in the study area [26], 36% have short column effect, 28% have heavy overhangs, 28% have a soft story, and 139 buildings with a performance score of below 40 points are considered to have a high-risk level. They should be addressed primarily in the disaster risk assessment studies to be carried out. It has been understood that this method in the law gives much more general results than other rapid assessment methods. It is a suitable method for comparing risky areas rather than buildings [28]. The main aim is not to decide a definitive conclusion about building seismic risk but to identify priority buildings in detailed investigations [27].

Finally, it has been observed that this method is suitable for making a general and rapid evaluation based on existing buildings in a certain region. The results can be evaluated in terms of a wide range of results with statistical programs. Local authorities can consider them within the scope of evaluating existing structures. Until the study is completely accomplished, the results may not make much sense. Considering there are approximately 15000 buildings in Çanakkale city center, it will be important to carry out the work quickly, supporting the more efficient implementation of urban transformation works. Renovating priority buildings should be the most important goal for reducing the loss of life in earthquakes.

Author Contributions

This paper is derived from the first author's master's thesis and supervised by the second author. Both authors devised the main conceptual ideas and developed the theoretical framework. The first author performed the study and analyses under the supervision of the second author. The second author wrote the article. The authors read and approved the final version of the paper.

Conflicts of Interest

All the authors declare no conflict of interest.

Ethical Review and Approval

No approval from the Board of Ethics is required.

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