Research Article
Academic Platform Journal of Natural Hazards and Disaster Management
6(1) 2025: 57-68, DOI: 10.52114/apjhad.1493014

Design and Cost Comparison of Reinforced Concrete Structures Modeled According to TBDY 2018 in Terms of Earthquake Soil Motion

Ahmet Hamdi Serdar[*1]

[1]Department of Civil Engineering, Faculty of Technology, Sakarya University of Applied Sciences, Sakarya, Türkiye

Received: / Accepted: 31-May-2024 / 29-June-2025

Abstract

Türkiye is located in an active earthquake zone. Therefore, it has been exposed to large-scale earthquakes dating back to a long history. Major earthquakes in the past have caused thousands of casualties and damage to structures. For example, events such as the 1939 Erzincan Earthquake, the 1943 Samsun Earthquake and the 1999 Kocaeli Earthquake deeply affected the country. However, two earthquakes on 6 February 2023 were recorded as the largest earthquakes of the last century. These earthquakes occurred on the Eastern Anatolia Fault and directly affected 11 provinces. In terms of loss of life and property, it caused three times more damage than the 1999 Marmara Earthquake. Reinforced concrete structures in Türkiye are built in accordance with defined standards. The construction criteria of buildings in earthquake zones are determined by regulations. The current regulation, which entered into force in 2018, involves classifications according to earthquake levels. These classifications vary between earthquake soil motion Level-1 (DD-1) and earthquake soil motion Level-4 (DD-4). As a minimum criterion for the design of reinforced concrete structures, DD-2 soil motion with a probability of 10% in 50 years is taken into consideration.

However, in this study, a reinforced concrete structure to be constructed in Sakarya province will be modelled according to both DD-1 and DD-2 levels. Studies related to building cost analysis generally focus on several basic areas. These include comparative analyses of different earthquake regulations and cost differences between steel and reinforced concrete building systems. The effect of soil types on the cost of reinforced concrete superstructures is also under investigation. In addition, there are studies investigating the cost of retrofitting existing reinforced concrete buildings. These studies highlight the importance of cost in building construction and many researches have been carried out in this field. However, the effects of earthquake levels on cost have not been sufficiently studied. This study will fill the gap in the literature and examine the effects of earthquake levels on cost. The differences between these two approaches will be analyzed and the losses and additional costs that will arise if DD-1 is taken into account in the design will be evaluated.

Key words: Earthquake, IdeCAD, Numerical analysis, Reinforced concrete structure, Cost estimation

1. Introduction

Türkiye, located on active earthquake zones, has been exposed to large-scale earthquakes for generations. Türkiye has experienced several large-scale earthquakes in recent history. The 1939 Erzincan Earthquake (Ms=7.9) resulted in 32,968 deaths and damage to 116,720

[*] Corresponding Author e-mail: aserdar@subu.edu.tr

structures. The 1943 Samsun Earthquake (Ms=7.2) caused 4,000 deaths and damaged 40,000 structures. The 1999 Kocaeli Earthquake (Ms=7.8) led to 17,480 deaths and damage to 73,342 structures [1]. On February 6, 2023, two major earthquakes occurred, resulting in 50,783 deaths and damage to 1,929,312 residential and industrial buildings. The earthquakes, which occurred 9 hours apart, were recorded as the largest earthquake of the last century [2]. The 6 February earthquakes occurred on the Eastern Anatolian Fault (EAF), an important tectonic structure in the Eastern Mediterranean, separating the Arabian and Anatolian tectonic plates along a 600 km boundary [3]. These earthquakes, which directly affected 11 provinces in Anatolia, caused approximately 3 times more loss of life and property than the 1999 Marmara Earthquake [4]. The magnitude of the earthquake varied between Mw 7.7-7.95 for Pazarcık and Mw 7.5-7.86 for Elbistan according to different sources [5]-[7].

Reinforced concrete structures in Türkiye, which is located on active earthquake zones, are constructed according to certain rules. These rules are collected as a whole in the regulation containing the construction criteria of the buildings to be constructed in earthquake zones.

The current regulation was published in 2018. In the current regulation, classifications have been made regarding earthquake levels. These classifications are Earthquake Motion Level-1 (DD-1), Earthquake Motion Level-2 (DD-2), Earthquake Motion Level-3 (DD-3) and Earthquake Motion Level-4 (DD-4). Of these, DD-1 characterizes very infrequent earthquake motion, where the probability of exceeding the spectral magnitudes in 50 years is 2% and the recurrence period is 2475 years. DD-2 characterizes the rare earthquake activity where the probability of exceeding the spectral magnitudes in 50 years is 10% and the corresponding recurrence period is 475 years. DD-3 characterizes frequent earthquake activity where the probability of exceeding the spectral magnitude in 50 years is 50% and the corresponding recurrence period is 72 years. DD-4 characterizes very frequent earthquake activity where the probability of exceeding the spectral magnitudes in 50 years is 68% (50% probability of exceeding in 30 years) and the corresponding recurrence period is 43 years [8].

DD-2 soil motion in the design of reinforced concrete structures is taken into consideration. This earth movement with 10% probability of occurrence in 50 years determines the limits of the measures to be taken. However, DD-1 soil motion with a probability of occurrence of 2% in 50 years is not taken as a reference as it has a very weak probability of occurrence.

If a reinforced concrete structure is designed according to DD-1, the structure directly becomes more reliable since a low probability earthquake case will be taken into account. Since the design considering such a small probability will make a significant contribution to the behavior in case of DD-2, the topic becomes even more important. In this study, a reinforced concrete structure is designed to be built in Sakarya Province, which is located in an active seismic zone. The structure will be modelled using the IdeCAD software according to DD-1 and DD-2 earthquake design levels. The quantity and area changes between the two approaches are calculated. It is analyzed what kind of losses and additional costs occur when DD-1 is considered in the design. The results obtained are analyzed and interpreted as a whole.

Sakarya is located on one of the active earthquake zones of Türkiye, which significantly affects the structural design criteria in the city. The effects of soil movements on the design of structural and reinforced concrete structures in Sakarya City should be considered in detail. Since Sakarya is located near the North Anatolian Fault Line, the region experiences frequent earthquakes. Historical data show how large-scale earthquakes around Sakarya have affected the structural safety in the city. Therefore, special design criteria have been developed to improve the earthquake resistance of structures in the city. Surface movements observed in Sakarya are intense and variable, especially in the regions near fault lines. Among the main characteristics of soil movements, fault line activities and soil types are decisive. Among these concepts, fault line activity, the activity of fault lines around Sakarya has a direct effect on the frequency and intensity of earthquakes. Soil types can increase or decrease the effects of earthquakes. It is known that seismic frequencies spread more especially in soft soils.

Structural and reinforced concrete designs in Sakarya, concepts and methods such as structural design, seismic isolation, vertical and horizontal stability have been developed to minimize earthquake risk. The most common type of structure that is widely used and sustainable is reinforced concrete structures. Reinforced concrete structures should be built according to certain design standards to be resistant to earthquakes. Reinforced concrete structures behave with the principle of using concrete and reinforcement in a composite form in the carrier system. The correct placement and proper diameter of the reinforcements in reinforced concrete structures increase the durability of the structure during earthquakes. The quality of concrete is an important factor affecting the performance of the structure under seismic loads. The use of high-quality concrete increases the safety of the structure. Understanding the effects of soil movements and earthquake risk on structural designs in City of Sakarya is critical for the construction of safe and durable structures. Structural engineering and reinforced concrete design considerations should be optimized in accordance with the seismic conditions of Sakarya. In addition, the earthquake resistance of structures should be continuously increased by following current research and technologies. In some studies, on cost analyses of structures, comparisons were made between earthquake codes [9], [10]. In some academic studies, the cost values of steel and reinforced concrete structural systems were compared with each other [11], [12]. In some of the studies, the effects of soil classes on the cost of reinforced concrete superstructure were investigated [13], [14]. There are also cost studies on the situation regarding the reinforcement of reinforced concrete structures [15]. As can be understood from these studies and the fact that many studies have been and are being carried out on the subject, cost is a very important parameter in the construction of structures. Therefore, many studies have been carried out in this field [9]-[15]. These studies can form groups within themselves. However, while these studies have focused on many areas, the effects of differentiation on earthquake levels on cost have not been sufficiently investigated. With the realization of this study, it is aimed to contribute to filling the gap in the literature.

In this study, a reinforced concrete structure modelled to be constructed in Sakarya province, which is located in the Active Earthquake Zone, will be modelled according to DD-1 and DD-2 using IdeCAD package program. The quantity and area changes between the two approaches are calculated. It is analyzed what kind of losses and additional costs occur when DD-1 is considered in the design. The results obtained are analyzed and interpreted as a whole.

2. Numerical Model: Identification of Loads, Design Criteria and Modelling Stages of the Structure in IdeCAD

2.1. Identification of loads

IdeCAD is a software used in civil engineering and architectural applications and the definition of loads is one of the basic functions of this software. Loads are defined as forces and moments acting on the structural system of a structure and are generally classified as follows:

2.1.1. Vertical loads

These loads are the forces applied perpendicular to the floor of the structure. Vertical loads are divided into two main groups: fixed loads and live loads.

- Constant Loads (Dead Loads): It is caused by the structure's own weight and permanent structural elements (walls, floors, roof coverings, etc.). Constant loads are usually calculated by considering the material densities and dimensions of the structural elements.
- Live Loads: These are loads that can vary during use and are temporary. People, furniture, vehicles and other moving loads fall into this category.

2.1.2. Horizontal loads

These loads are the forces that cause the structure to be affected horizontally. Horizontal loads include factors such as wind, earthquake and vehicle effects.

- Wind Loads: These are the forces applied to the surfaces of the structure under the influence of wind. These loads are calculated depending on the wind speed, direction and surface area of the structure.
- Earthquake Loads: These are the loads that occur due to the movements of the structure during the earthquake. These loads are determined according to the earthquake zone and seismic characteristics of the structure.

2.2. Identification of loads

In building design, design criteria are rules set to ensure building safety, durability and performance. IdeCAD uses the following standards and parameters to design in accordance with these criteria:

- Standards and Regulations: In Turkiye, these standards are usually based on TS (Turkish Standard) and related regulations. For example, standards such as TS 500 [16], TS EN 1991 [17] and TBDY 2018 [8] are applied.
- Material Properties: The mechanical properties (e.g. tensile strength, compressive strength) of concrete, steel and other building materials are among the design criteria. IdeCAD stores these material properties in the programme database and uses them in the design process.
- Safety Coefficients: The coefficients used to ensure the safety of the structure are the coefficients in which loads and material strengths are evaluated with a certain safety margin. IdeCAD automatically applies these coefficients in accordance with the standards.

2.3. Modelling and definition phase of the structure

The modelling and definition stages of the structure are the basic components of the design process and include the following steps:

- Geometric Modelling: It is the creation of a three-dimensional (3D) model of the structure. This stage includes all physical characteristics of the building (dimensions, shapes, locations, etc.) and usually includes building plans, sections and details.
- Material Identification: The material properties (density, strength, modulus of elasticity, etc.) of the building elements are defined. These material properties affect the load

carrying capacity and durability of the structure.

- Application of Loads: In the modelling phase, the vertical and horizontal loads mentioned above are assigned to the structural elements. The correct definition of these loads ensures that the structure is safe and stable.
- Determination of Boundary Conditions: Support points, connection elements and degrees of freedom are defined in the model of the structure. This affects the stress and deformation behaviour of the structure.
- Analysis and Simulation: Analyses are performed on the model of the structure under various load and boundary conditions. These analyses include various simulations to evaluate the performance of the structure (static, dynamic, seismic, etc.).

3. Widespread Use of IdeCAD in Sakarya Region

3.1. Standard compliance and regulatory compliance

IdeCAD is designed to fully comply with the building standards and regulations in Turkiye. In projects implemented in the Sakarya region, this compliance ensures that the rules set by TS (Turkish Standard) and TSE (Turkish Standards Institute) are followed precisely. In particular, compliance with standards such as TS 500 [16], TS EN 1991 [17] and TBDY 2018 [8] is an important feature that ensures building safety and performance. Therefore, most of the construction projects in Sakarya are modeled using IdeCAD and files are submitted to municipalities through this software.

3.2. High precision and data accuracy

IdeCAD has advanced calculation and modeling tools to ensure high precision and data accuracy in structural engineering. In the projects carried out in Sakarya region, static and dynamic analyzes of the structure must be performed accurately. IdeCAD minimizes the margin of error in the design of structural elements and load calculations by performing these analyzes with high accuracy.

3.3. Comprehensive modeling capability

IdeCAD offers a comprehensive design process with 2D and 3D modeling capabilities. In Sakarya projects, detailed modeling of all elements of the structure is critical for a realistic simulation of the project. The geometric details, material properties and load combinations of the building elements are integrated into IdeCAD's extensive database, allowing an accurate model to be created.

3.4. Interactive and integrated operation

The interactive design tools and integrated analysis modules offered by IdeCAD enable projects to be analyzed in a whole way. Thanks to these features, the design process is carried out more efficiently in engineering projects in Sakarya. In particular, accelerating the project process by ensuring coordination between civil engineers and architects is one of the important advantages of IdeCAD.

3.5. Municipality approval process and standard file formats

In projects submitted to municipalities in Sakarya, IdeCAD files are usually prepared in standard file formats. These formats contain all the data required for the municipality's project review processes and make the file approval processes easier. IdeCAD's support for such standard file formats makes it possible to work in line with municipalities and a fast approval process.

3.6. Training and technical support

The widespread use of IdeCAD in the Sakarya region encourages engineers and designers in the region to receive training and technical support on this software. IdeCAD's comprehensive user support and training materials ensure that local professionals can use the software effectively. This contributes to improving project quality and standardizing engineering practices.
The widespread use of IdeCAD software in the Sakarya region is an indication of the technical advantages it offers and its compatibility with regional construction practices. High accuracy, comprehensive modeling capabilities, compliance with standards and compliance with municipal approval processes are the main reasons why IdeCAD is preferred for projects in the region. This widespread use improves the quality and efficiency of construction projects in Sakarya, raising the region's standards in the construction and engineering sector.

4. Parametric Study

The structure analysed in this study belongs to a duplex type building planned to be constructed in Adapazarı District of Sakarya Province, which is located in the Active Earthquake Zone. The floor settlement of the dwelling measures 10.00m*9.50m and is 95 m^2 in size. The building is modelled as a duplex and the occupancy area is 190 m^2 in total on two floors.

The building is considered to be the same as a whole. C25 type concrete and B500 type reinforcing steel were used in the modeling of both buildings with the same residential and geometric structure. Since both structures are located on the same soil, all linear and non-linear parameters of the soil such as soil bearing capacity and cohesion etc. were considered to be the same. In order to make an evaluation within the scope of a study, the parameters selected as variables should be limited in number. Therefore, reinforced concrete structural system was chosen as the variable in this study. Reinforced concrete structural system is a whole consisting of shear walls, columns, beams, slabs, continuous beams and radial jeneral foundations. Since the building is considered as a whole, the structural system elements are not evaluated separately and are considered as a whole.

In this context, the structure was modeled considering DD-1 and DD-2 soil motion acceptance. Since DD-1 has a greater negative impact than DD-2, any structural system that satisfies DD-1 will also satisfy DD-2. For this reason, in order to understand the difference, the structure was first modeled to meet the criteria of DD-2. In the next step, behavioral improvements were provided by increasing the cross-section of structural system elements such as continuous beams and columns to meet DD-1. In this context, floor thicknesses, beam cross-sections and vertical load-bearing elements such as curtains were considered the same, and the structure was differentiated by making limited changes in column cross-sections and foundation beams. By choosing the same beams and slabs, the structure is ergonomically protected. As a result, the variables between the 2 models are limited only to the columns and continuous beams in terms of usage areas. The images of the structural mould plans of the numerical models of the building, DD-1 in Figure 1 and DD-2 in Figure 2, are given.

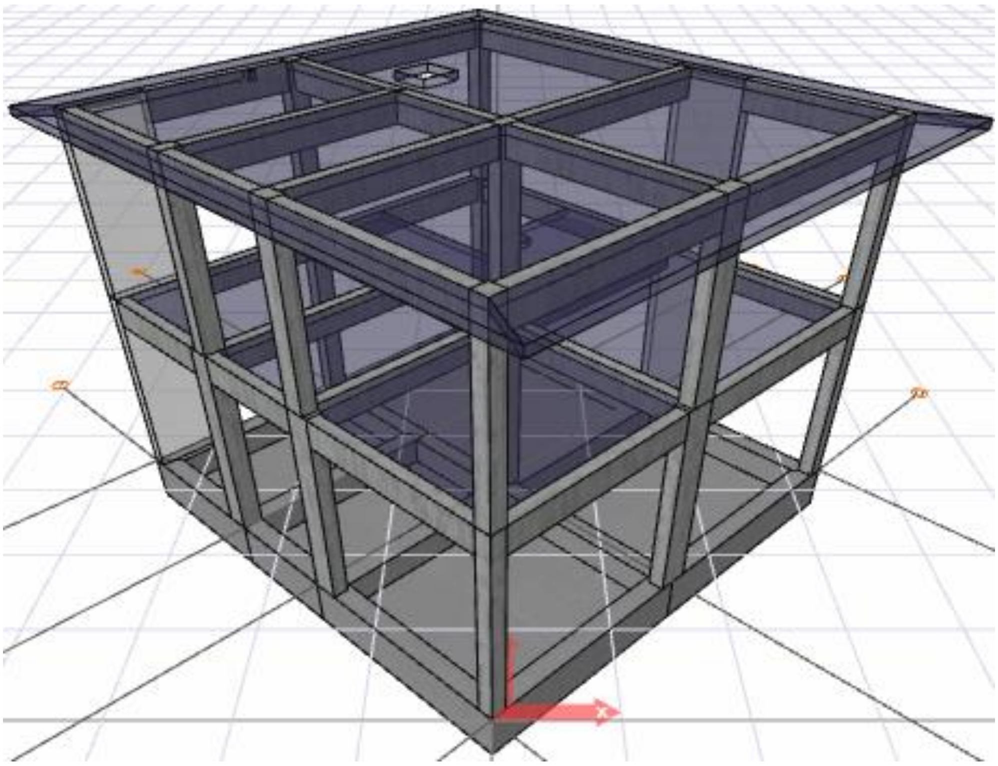

Figure 1. Solid model of the numerical model of the reinforced concrete structure according to DD-1

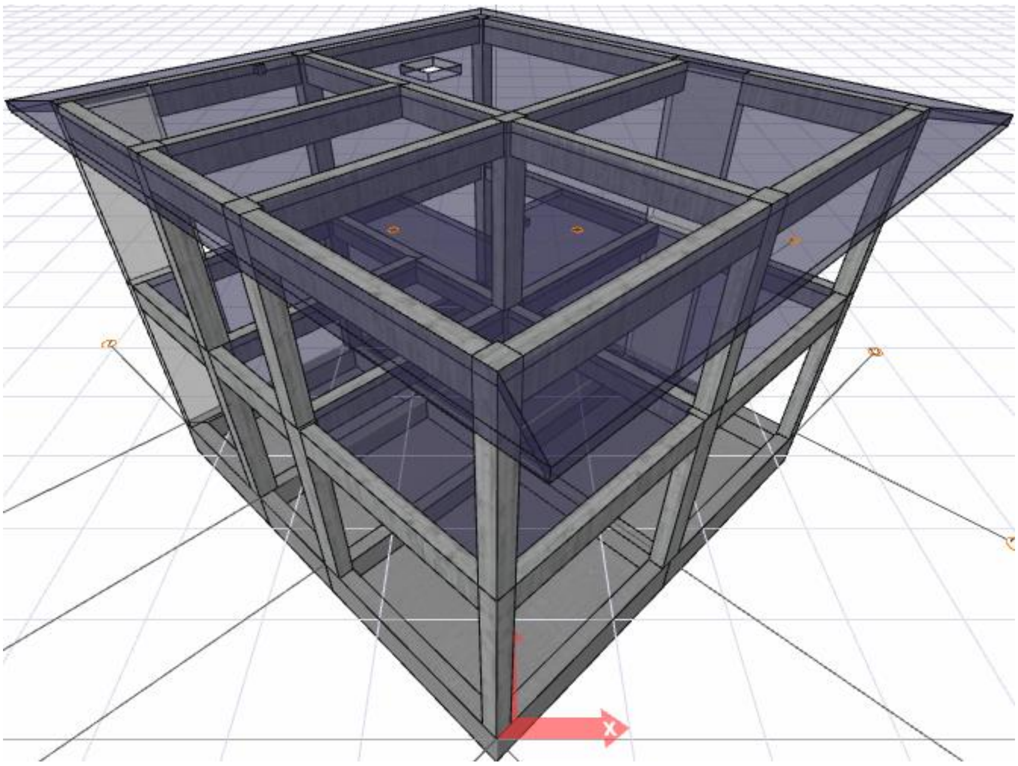

Figure 2. Solid model of the numerical model of the reinforced concrete structure according to DD-2

As a result of the reinforced concrete calculations performed in the design of the design, there have been changes in the reinforcements in the structural system elements. However, the increase in the reinforcement in the cross section does not cause any ergonomic problems. Column application plans of the numerical models are given in Figure 3 (DD-1) and Figure 4 (DD-2).

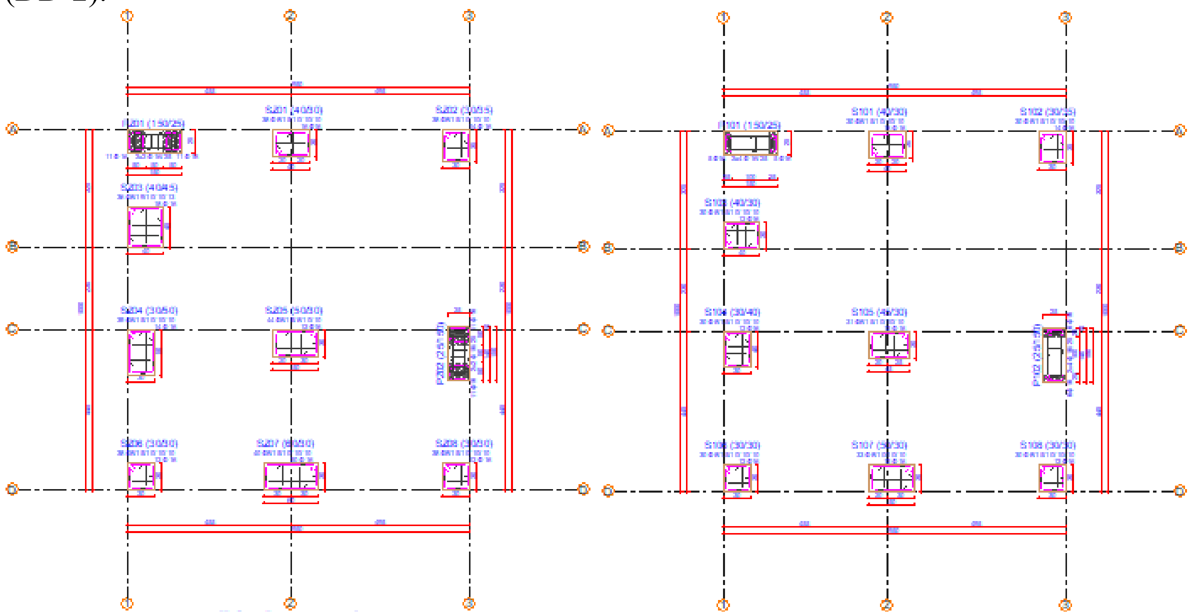

Figure 3. Column application plans of the structure modelled according to DD-1

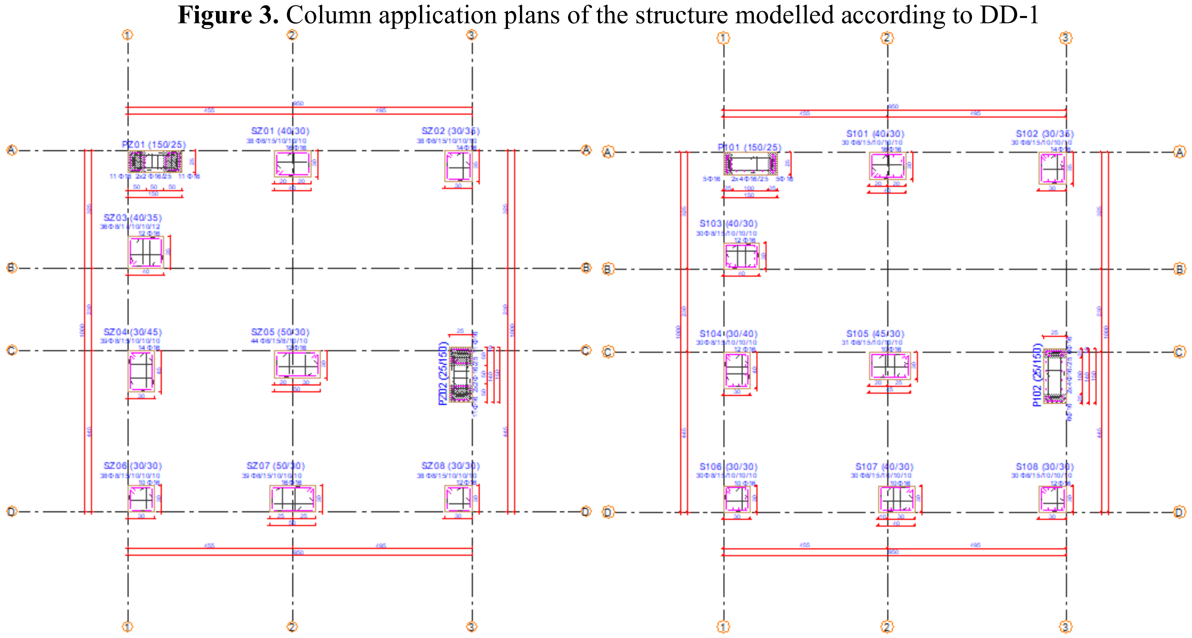

Figure 4. Column application plans of the structure modelled according to DD-2

In the foundation design, the structure modelled according to DD-1 includes foundation beams with dimensions of 40 cm*85 cm. In contrast, the structure modelled according to DD-2 includes two types of foundation beams: some are 30 cm*80 cm, while others are 35 cm*85 cm. Of course, these differences in cross-sectional dimensions caused differences in concrete and reinforcement quantities. The findings and differences obtained are analyzed in the conclusion section.

5. Conclusions

Both models have the same floor session area, the same site plan and the same floor structuring. As it is known, vertical structural elements in building design affect the usable areas. In other words, each structural element causes volume space loss in the volume in which it is located. Therefore, there is a limited amount of net usage area differences between these two models.

The examination within the scope of the study is not only limited to quantity calculations, but also takes into account the differences between the net usage areas. In this context, column cross-sectional areas were calculated. The total cross-sectional area of the vertical load-bearing elements was found to be 3.50 m² in the DD-1 model and 3.39 m² in the DD-2 model. Therefore, the difference between the 2 models was determined as 0.11m^2. Considering that the total construction area of the building is 190 m^2, it is clearly understood that the lost area is 0.058% and does not reach the levels to be taken into consideration.

When the difference is evaluated in terms of quantity and cost, the concrete quantity of the reinforced concrete structure modelled according to DD-1 is 102.55 m^3 and the concrete quantity of the reinforced concrete structure modelled according to DD-2 is 91.3 m^3. The concrete quantity difference between the two models was calculated to be 3.56%. A similar calculation was performed for reinforcement quantities. The total reinforcement in the DD-1 model was 9880 kg, while it was 9475 kg in the DD-2 model. The difference in concrete volume between the two models was calculated as 4.30% (Table 1).

Table 1. Quantity data of both structures

	Total Concrete Quantity (m^3)	**Total Reinforcement Quantity (kg)**
DD-1	102.55	10380
DD-2	91.33	9480
Difference	**11.23 (%12.29)**	**900 (%9.50)**

In the production of reinforced concrete structures, expenditures are made in 2 main items: materials and labor. The variables within the scope of this study do not cause any difference in terms of workers. For this reason, no calculation was made in terms of workers.

It is essential to identify the cost price units of the materials to be used in the cost calculations of both models. These data to be used within the scope of the study were determined by making use of the Construction and Installation Unit prices table for 2024 published by the Ministry of Environment, Urbanization and Climate Change. The results obtained from the lists show that as 2024, concrete price is 2300 TL/m^3 and reinforcement price is 33 TL/kg [18]. Considering the universality of the study, it was concluded that it is more appropriate to calculate the evaluation in US Dollars. For this reason, the cost obtained as a result of the evaluations is stated as 32 TL / Dollar. Total cost was calculated for both cases. The data obtained for concrete are given in Table 2 and the data obtained for reinforcement are given in Table 3.

Table 2. Cost calculation for the structure modelled according to DD1

	Total	Unit Price (₺)	Total Amount (₺)	Dollar Value ($)
Total Concrete (m^3)	102.55	2,300	235,865	7,371
Total Reinforcement (kg)	10,380	33	342,540	10,704
Total			**578,405**	**18,075**

Table 3. Cost calculation for the structure modelled according to DD2

	Total	Unit Price (₺)	Total Amount (₺)	Dollar Value ($)
Total Concrete (m^3)	91.33	2,300	210,059	6,564
Total Reinforcement (kg)	9,480	33	312,840	9,776
Total			473,910	16,340

Considering the construction unit costs published in the Official Gazette and market conditions, the cost of such a building was determined to be approximately 450 USD/m^2 [19]. Since the total construction area of the building is 190 m^2, its cost is determined as approximately 85500 USD. It is known from the field investigations that the structural system costs are approximately half of the total cost. Considering that half of the rough construction cost is material, it is understood that 25% of the total cost should be taken into consideration. Therefore, the cost to be considered is 21375 USD.

The cost difference between the two different design approaches remains at the level of 1735 USD. When this difference is calculated as a proportion of the total cost, a cost difference of 8.12% occurs.

In conclusion, although significant expenses have already been incurred for production and design features, it appears that the cost increase associated with designing a more durable structure is relatively limited. Prioritizing such structural improvements beyond the minimum code requirements will increase life and property safety. The fact that the building models within the scope of the study are 2 story-building and designed according to the minimum cross-section requirements of the regulation in force has caused the cost difference to be lower. Performing the same evaluations in the buildings called apartment buildings, which are designed with collective settlement facilities that allow 2 or more households to live under a single roof and contain multiple floors, will make an additional contribution to the literature.

Conflict of Interest

No potential conflicts of interest were reported by the Author.

Author Contribution

A. H. S. collected the data, designed the models and wrote the whole manuscript.

References

[1] Boğaziçi University, "Kandilli Observatory and Earthquake Research Institute Regional Earthquake-Tsunami Monitoring Center." [Online]. Available: http://www.koeri.boun.edu.tr/sismo/2/tr/. [Accessed: Jun. 29, 2025].

[2] Presidency of Strategy and Budget of Türkiye, "2023 Kahramanmaraş and Hatay Earthquakes Report," *Presidency of the Republic of Türkiye*, pp. 1–140, 2023. [Online]. Available: https://www.sbb.gov.tr/2023-kahramanmaras-ve-hatay-depremleri-raporu/. [Accessed: Jun. 29, 2025].

[3] E. Hussain, S. Kalaycıoğlu, C. W. D. Milliner, and Z. Çakir, "Preconditioning the 2023 Kahramanmaraş (Türkiye) earthquake disaster," *Nature Reviews Earth & Environment*, vol. 4, no. 5, pp. 287–289, Apr. 2023, doi: 10.1038/s43017-023-00411-2.

[4] M. Ozturk, M. H. Arslan, and H. H. Korkmaz, "Effect on RC buildings of 6 February 2023 Turkiye earthquake doublets and new doctrines for seismic design," *Engineering Failure Analysis*, vol. 153, p. 107521, Nov. 2023, doi: 10.1016/j.engfailanal.2023.107521.

[5] AFAD, "Regarding 06 February Pazarcık (Kahramanmaraş) MW7.7 and Elbistan (Kahramanmaraş) MW7.6 Earthquakes Preliminary Assessment Report," 2023. [Online]. Available: https://deprem.afad.gov.tr/. [Accessed: Jun. 29, 2025].

[6] X. Jiang, X. Song, T. Li, and K. Wu, "Moment magnitudes of two large Turkish earthquakes on February 6, 2023 from long-period coda," *Earthquake Science*, vol. 36, no. 2, pp. 169–174, 2023, doi: 10.1016/j.eqs.2023.02.008.

[7] Z. Yang, T. Xu, and J. Liang, "Towards fast focal mechanism inversion of shallow crustal earthquakes in the Chinese mainland," *Earthquake Research Advances*, vol. 4, no. 2, p. 100273, 2024.

[8] TBDY, *Türkiye Building Earthquake Regulation*, Disaster and Emergency Management Presidency (AFAD), Ankara, 2018.

[9] G. Ural, "Cost calculation according to regulations in frame and curtain wall system reinforced concrete buildings," Unpublished manuscript, 2013.

[10] M. E. Coşkun, Ş. Gürsoy, and Z. Ş. Garip, "Comparison of strengthening principles in the reinforced concrete a school building according to 2007 and 2019 Turkish earthquake regulations," *Gümüşhane Üniversitesi Fen Bilimleri Dergisi*, vol. 13, no. 1, pp. 127–144, 2023.

[11] A. Şamandar and A. H. Polat, "Comparison of construction costs for steel and reinforced concrete prefabricated factory buildings," presented at the *3rd Int. Symp. on Innovative Technologies in Engineering and Science (ISITES2015)*, Universidad Politecnica de Valencia, Jun. 2015, pp. 3–5.

[12] A. Kuşu and K. Beyen, "Comparison of 12-storey steel and reinforced concrete structures under the same conditions according to the principles of TBDY 2018," *Kocaeli Üniversitesi Fen Bilimleri Dergisi*, vol. 2, no. 2, pp. 64–73, 2019.

[13] M. Türkmen, H. Tekeli, and A. Kuyucular, "Construction costs of multi storey RC buildings for different soil classes and structural irregularities," *Selçuk Üniversitesi Mühendislik, Bilim ve Teknoloji Dergisi*, vol. 21, no. 1, pp. 57–66, 2006.

[14] S. Ü. Dikmen and S. Özek, "Effects of soil group on the cost of industrial structures," *Teknik Dergi*, vol. 22, no. 108, pp. 5543–5558, 2011.

[15] S. Naimi and S. Kaya, "Reinforcement of reinforced concrete structures with steel cross members," *AURUM Journal of Engineering Systems and Architecture*, vol. 3, no. 2, pp. 191–204, 2020.

[16] Turkish Standards Institute, *TS 500: Design and Construction Rules for Reinforced Concrete Structures*, Ankara, Türkiye, 2000.

[17] Turkish Standards Institute, *TS EN 1991: Effects on Structures*, Ankara, Türkiye, 2007.

[18] Ministry of Environment, Urbanisation and Climate Change, *2024 Construction and Plant Unit Prices*, Ankara, Türkiye, 2024.

[19] Republic of Turkey Ministry of Environment, Urbanisation and Climate Change, *Communication on the 2024 Structural Approximate Unit Costs to be Used in Calculating Architecture and Engineering Service Fees*, Official Gazette No. 32466, Ankara, Türkiye, 2024.