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Araştırma Makalesi/Research Article

Static Analysis and Cost Estimation of Reinforced Concrete Buildings Created Using Different Soil Parameters According to TEC 2007 and TBEC 2018

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Abstract

After every earthquake in our country, there is a significant loss of life and property. The changes in seismic regulations aim to minimize these losses. This study focuses on the differences between the current TBEC 2018 and TEC 2007 seismic codes. Analyzing a five-story reinforced concrete building using the IdeCAD structural analysis computer program, designed according to TEC 2007 and TBEC 2018 seismic regulations, forms the basis of this study. By altering soil and seismic parameters on the designed five-story reinforced concrete building, various analyses were conducted. The results of the analyses, depicted in graphs and tables, illustrate how the cost varies between TBEC 2018 and TEC 2007 seismic regulations based on the derived quantities. Upon examination of the results, it is evident that, overall, TBEC 2018 incurs higher costs, utilizes more reinforcement, and places greater emphasis on soil classes compared to TEC 2007. Furthermore, it is concluded that the new Turkey earthquake hazard mapearthquake hazard map provides more accurate results in determining earthquake zones. TBEC 2018 is observed to be more comprehensive in all aspects and to stand on the safer side.

Keywords: Earthquake Zone, Earthquake-Soil Relationship, Cost Calculation, TBEC 2018, TEC 2007, Soil Classes

Farklı Zemin Parametreleri Kullanılarak Oluşturulan Betonarme Binaların TEC 2007 ve TBEC 2018'e Göre Statik Analizi ve Maliyet Hesaplaması

Özet

Her deprem sonrası ülkemizde birçok can ve mal kaybı meydana gelmektedir. Deprem yönetmeliklerinin değişimi ile bu can ve mal kaybı en aza indirilmeye çalışılmaktadır. Günümüzde kullanılmakta olan TBEC 2018 ile TEC 2007 arasında oluşan farklılıklar bu çalışmada ele alınmıştır. Bu çalışmayla İdeCAD statik analiz bilgisayar programında TEC 2007 ve TBEC 2018 deprem yönetmeliklerine gore hazırlanan beş katlı betonarme bir binada analiz yapılmıştır. Tasarımı yapılan 5 katlı betonarme bina üzerinde zemin ve deprem parametreleri değiştirilerek analizler yapılmıştır. Analiz sonuçlarından çıkan metrajlar doğrultusunda TBEC 2018 ile TEC 2007 deprem yönetmeliklerinde maliyetin ne kadar değiştiği grafik ve tablolarla gösterilmiştir. Sonuçlara bakıldığında genel olarak bütün analizlerde TBEC 2018'de maliyetin daha fazla olduğu, donatının daha fazla kullanıldığı, TBEC 2007'de zemin sınıflarına daha az önem verildiği görülmektedir. Ayrıca deprem bölgelerinin belirlenmesinde yeni Türkiye Deprem Haritasının daha net sonuçlar verdiği kanısına varılmıştır. TBEC 2018'in her açıdan daha kapsamlı olduğu ve daha güvenilir tarafta kaldığı gözlemlenmiştir.

Anahtar Kelimeler: Deprem Bölgesi, Deprem-Zemin İlişkisi, Maliyet Hesabı, TBEC 2018, TEC 2007, Zemin

1. INTRODUCTION

Turkey is a seismically active country where seismic movements are prevalent. Consequently, earthquake-resistant construction practices are implemented, and a set of standards is established. These standards, known as earthquake regulations, aim to ensure that the structural support system effectively transfers all horizontal and vertical loads from the top of the structure to the base soil[1]. To achieve this objective, earthquake regulations are formulated, considering the necessary calculations and rules to guarantee the stability, rigidity, and adequate resistance of the structure[1]. The earthquake regulations are founded on theoretical studies and research conducted since their inception, incorporating insights gained from practical applications of existing structures, as well as findings and discussions on what was done incorrectly or correctly[2]. Since their initial development, earthquake regulations have undergone updates in 1947, 1949, 1953, 1961, 1968, 1975, 1997, 2007, and 2018. These revisions have been made in response to the global and national needs, taking into account the experiences gained, investigations conducted, and the discourse on construction practices. Notably, the Italian Construction Instruction for earthquake-prone areas issued in 1940 has also contributed to shaping these regulations (Table 1).

Table 1. Regulations implemented so far in Turkey

Date	Regulatory Name
1940	Italian Building Instruction for construction in the Zelzele districts
1944	Construction Instruction in Zelzele districts
1949	Turkey's Regulation on the Construction of the Territories of earth Struggling
1953	Regulations on the areas of the earth Strap
1961	Regulations on structures to be carried out in disaster areas
1968	Regulations on structures to be carried out in disaster areas
1975	Regulations on structures to be carried out in disaster areas
1997	Regulations on structures to be carried out in disaster areas
2007	Regulations on structures to be carried out in earthquake areas
2018	Turkey Building earthquake Regulation

In the design of earthquake-resistant structures, from the past to the present, the earthquake and superficial soil parameters of the region, along with certain attributes of the construction model, were considered sufficient [3]. However, the damage to buildings resulting from earthquakes has underscored the necessity for more extensive investigation [4]. Studies indicate that dividing a city into regions based on post-earthquake damage can serve as a valuable guide for reconstruction efforts [4]. Rather than waiting for a new devastating earthquake to occur in construction-exposed areas, it is more rational to apply methods developed by addressing existing data, rather than waiting for damage records to be insufficient and creating strategies as was done previously [3]. Earthquakes passing through floorboards can alter the properties of the ground, causing it to soften and lose strength. Hence, one of the crucial steps in determining earthquake characteristics during the design process for any region involves identifying the soil layers in that area and understanding the properties of the floors under repeated tension [5]. Detailed information about the properties of floorplates can be obtained through field and laboratory experiments. Recordings from vertical measurement networks impact the characteristics of earthquake movement on the floor surface, influencing the properties of the floor layer. The proximity of earthquake records suggests that ground characteristics may vary, even at close distances, due to the interaction between the earthquake source and geotechnical properties [6]. The changes in regulations in Turkey have prompted various studies. In a study titled "Comparing the Iranian Earthquake Regulation with the Turkish Earthquake Regulation," Iran reviewed the earthquake regulations of both countries (2005 and 2007) and highlighted the differences, ultimately concluding that the Turkish earthquake regulation is more comprehensive [7]. Another study, "Review of a Model Structure Sized and Equipped According to the Earthquake Regulation 1997," compared a design based on the earthquake regulations from 2007 with an older regulation dated 1997. The design included two types of models: a symmetrical frame system and a symmetrical curtain frame system[8]. In the study "Comparing TDY 2007 to Eurocode 8 in Terms of Cost in Concrete Buildings," the two regulations were compared regarding design rules using the Sta4-CAD computer program for a 3- and 5-story concrete model. The analysis considered performance targets, design rules, soil conditions, earthquake impact, and cost comparison based on the results [9]. An investigation into the behavior of a concrete building according to old and current design regulations explored principles and developments in regulations issued in 1961, 1968, 1975, 1997, and 2007 in Turkey. Using SAP2000 computer programs for analysis, the study compared the displacement, floor weights, floor vertical carrier concrete, and equipment metals under different regulations [3]. In the study "Proposal for Strengthening a Building According to the 2007 Regulations of a Concrete Structure Made According to the 1998 Earthquake Regulations," performance analysis was conducted according to the 2007 earthquake regulations, and alternative enhancement proposals were made based on the results obtained from the Sta4CAD static analysis computer programs [10]. "The Design and Analysis of a High-Rise Building According to Two Regulations" focused on performance-based design according to the 2007 Turkish earthquake regulations and the Istanbul High Buildings Earthquake Regulation. Linear and nonlinear analyses were conducted, revealing that the carrier elements, curtains, and columns remained elastic, and nonlinear behavior was limited based on the regulations [11].

One of the most critical factors influencing building design is the evolution of earthquake regulations. In Turkey, a total of 10 different regulations have been utilized to date, undergoing revisions or complete transformations over time. When designing a building, it is essential to determine which regulations are currently in effect, understand the rules they encompass, and apply them to the project. The purpose of this article is to address these impactful considerations in building design, specifically focusing on buildings located in earthquake zones identified in 2007. The study further delves into the soil class and soil bed coefficient aspects in a 5-story concrete building according to the 2018 Turkey Building earthquake regulations. The analysis is conducted using a computer program that incorporates soil safety strain and earthquake zone parameters. Additionally, the study aims to compare the costs based on the results obtained from the analysis.

2. MATERIAL AND METHODS

This article aims to establish a 5-story concrete model to examine the variations in metrics and costs in structures resulting from the latest regulatory changes in our country. The models, designed using the IdeCAD static analysis computer program, will be analyzed according to TEC 2007 and TBEC 2018, enabling a comprehensive comparison of changes in the design and analysis phases between the two regulations. Furthermore, the study will involve altering parameters such as soil class, soil bed coefficient, soil safety carrying force, and earthquake zone according to TEC 2007 and TBEC 2018. The program will conduct analyses, and a comparison of construction metrics will be made.

Cost calculations will be based on current prices, utilizing exposure recipes and unit prices available at 2023 prices issued by the Ministry of Environment and Urbanization. Graphics and tables will be used to present the costs according to changing regulations. The study aims to highlight the potential challenges faced by technical personnel in implementing effective earthquake regulations, emphasizing the importance of proper governance to avoid designs that could endanger human life and negatively impact costs. By focusing on the implementation of the 2018 Turkey Building earthquake regulations, effective from January 1, 2019, the study will determine how costs have evolved and attempt to provide insights for the current application of earthquake regulations.

The 5-story concrete building generated by the IdeCAD program comprises frame systems with columns and beams. The analysis is conducted using TBEC 2018 and TEC 2007, wherein the soil bed coefficient and soil carrying force are chosen based on soil classes (refer to Table 2 and Table 3). When determining the floor bed coefficients, the table prepared by Bowles in 1996 is taken into consideration (see Table 4). In TEC 2007, earthquake classes are categorized as 1, 2, 3, and 4. TBEC 2018, on the other hand, conducts seismic assessments based on earthquake zones, which are 1, 2, 3, and 4, as defined in the legislation predating the Turkey earthquake hazard map. Spectrum values are determined by extracting latitude and longitude values corresponding to earthquake zones in degrees. Soil classes based on the two earthquake methods are presented in Table 5 and Table 6.

Table 2. Soil bed coefficients based on the type of soil

Soil Type	K_s (kN/m3)
Loose sand 4800-16000	
Medium-sized sand 9600-80000	
Hard sand 64000-128000	
Clay medium-sized sand 32000-80000	
Medium-sized sand with silo 24000-48000	
Hairy soils:	
qa<200 kPa	12000-24000
200<qa<800 kPa	24000-48000
qa>800 kPa	>48000

Table 3. Soil handling forces linked to the type of soil

Soil Type	qemin (t/m2)
Solid rock	> 100
Hard gravel/hard gravel and sand	> 60
Medium hard gravel/medium hard gravel and sand	20-60
Hard sand	> 30
Medium hard sand	10-30
Loose sand	< 10

Table 4. Soil groups according to the TEC 2007

Soil Assembly	Floor Group Description
(A)	Solid volcanic rocks and solid metamorphic rocks with hard cement Very hard sand, gravel Hard hair and hair with mattress
(B)	Loose volcanic rocks, such as Tuf and aglomera, sedimentary rocks with discontinuous planes Hard sand Very solid hair and hair with mattresses
(C)	Metamorphic rocks and sedimentary rocks with soft discontinuities planes…. Medium hard sand, gravel Solid hair and hair with mattress
(D)	High level of underground water soft, thick layers of aluvation Loose sand Soft hair, silky hair

Table 5. Local soil classes according to the TEC 2007

Local soil Class	Explanation
Z1	(A) assembly soils H1 ≤ 15 m (B) assembly soils
Z2	H1 > 15 m (B) assembly soils H1 ≤ 15 m (C) assembly soils
Z3	15 m < h1 <50 m (C) assembly soils H1 ≤ 10 m (D) assembly soils
Z4	H1 > 50 m (C) assembly soils H1 > 10 m (D) assembly soils

Table 6. Local soil classes according to the TBEC 2018

Local soil Class	Explanation
ZA	Tough, hard rocks
ZB	Low-split, medium-solid rocks
ZC	Very hard sand, gravel and hard clay or very loose, very cracked weak rocks
ZD	Medium hard - hard sand, gravel or multi-ply clay plates
ZE	Loose sand, gravel or soft-solid clay plates, or a layer of soft clay that is thicker than 3 meters in total

In the study, the three-dimensional representation of the 5-story building is depicted in Figure 1. The analysis of the 5-story reinforced building involves mapping ground classes ZA, ZB, ZC, ZD, and ZE in TBEC 2018, and determining bed coefficients based on soil classes Z1, Z2, Z3, Z4 (refer to Table 2), and soil carrying forces (refer to Table 3) in TEC 2007. The analysis considers concrete quantity, mold quantity, and the overall equipment amount, facilitating a cost comparison. Construction details of the 5-story reinforced concrete building are provided in Table 7.

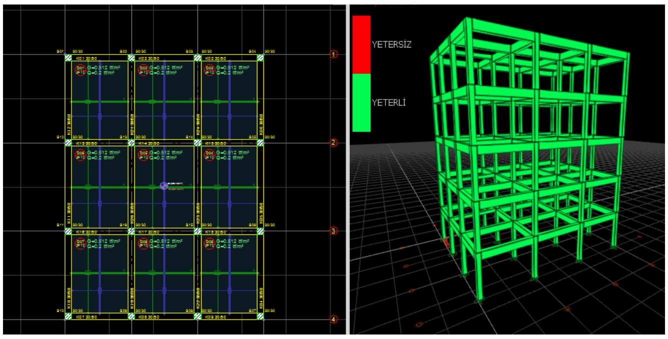

Figure 1. Three-dimensional view of the 5-story reinforced concrete building

Tablo 7. Building features of the 5-storey

Properties	Parameters	Values
Building Properties	Floor height (h)	3 (m)
	Total height (H)	15(m)
	Contruction type	Housing
	Carrier system behavior (R)	8
	Structure importance coefficient (I)	1.0
	Building height class	7
	Earthquake design class (DTS)	1,1a,2,2a
Section Properties	Column dimensions	0,3*0,3m
	Beam dimensions	0,3*0,5m
	Slab thickness	0,12 m
Material Properties	Concrete properties	C30(30 MPa)
	Steel properties	S420(420 MPa)

3. RESULTS AND DISCUSSION

The quantities resulting from the structural analysis of a 5-story reinforced concrete building in the İdeCad program are provided in Figure 2-13.

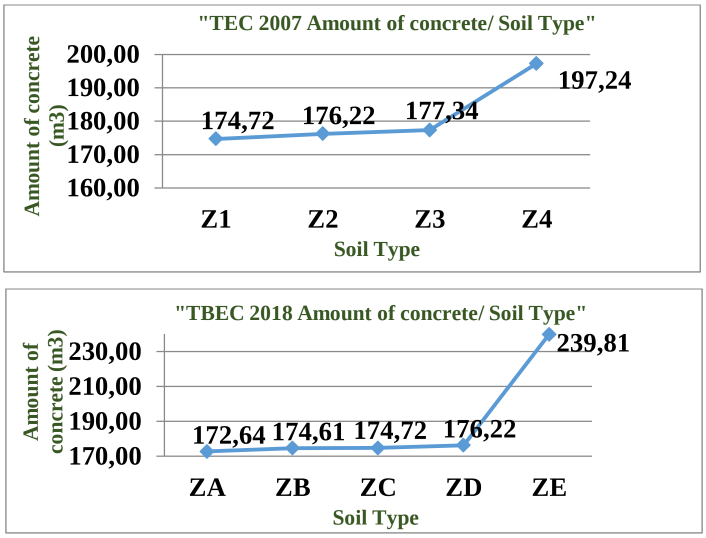

Figure 2. Amount of concrete in the area corresponding to the 1st-degree zone earthquake in TEC 2007

When analyzing the results obtained in the region corresponding to seismic zone 1 according to the TEC 2007, it is observed that as the soil class deteriorates, there is an increase in concrete quantities in both seismic regulations. The most significant difference is observed in the worst soil class.

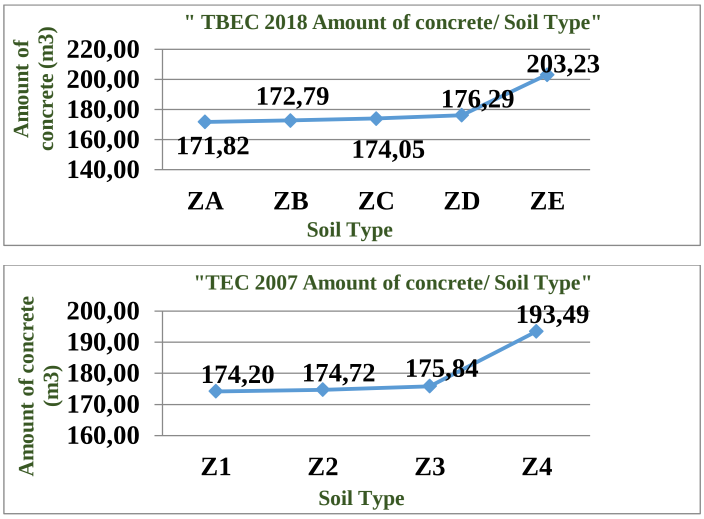

Figure 3. Amount of concrete in the area corresponding to the 2nd-degree earthquake zone in TEC 2007

When analyzing the results obtained in the region corresponding to seismic zone 2 according to the TEC 2007, it is observed that as the soil class deteriorates, there is an increase in concrete quantities in both seismic regulations. The difference between the worst soil classes has decreased compared to the difference in seismic zone 1.

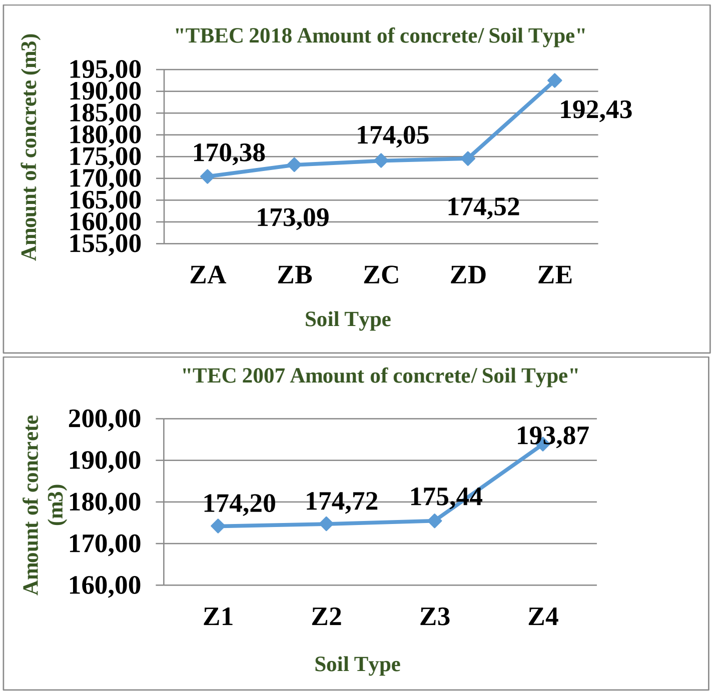

Figure 4. Amount of concrete in the area corresponding to the 3rd-degree earthquake zone in TEC 2007

When analyzing the results obtained in the region corresponding to seismic zone 3 according to the TEC 2007, it is observed that as the soil class deteriorates, there is an increase in concrete quantities in both seismic regulations. However, this increase is not as significant as in seismic zones 1 and 2. When looking at the worst soil classes, almost the same results have been obtained.

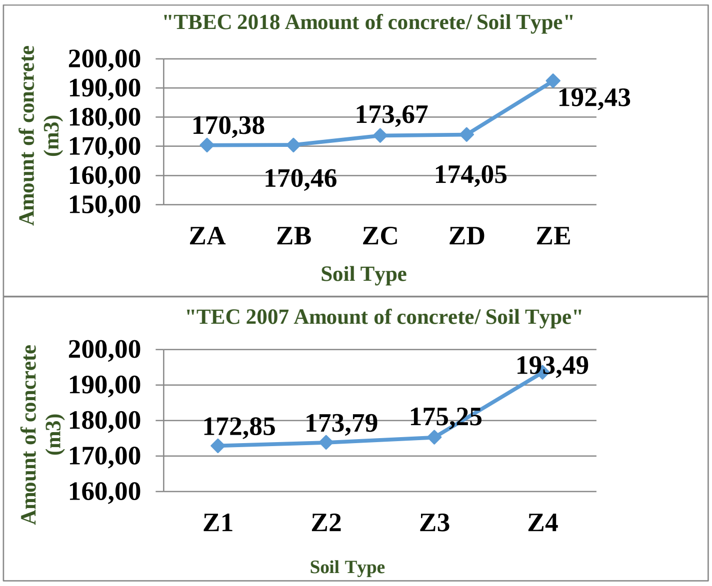

Figure 5. Amount of concrete in the area corresponding to the 4th-degree earthquake zone in TEC 2007

When analyzing the results obtained in the region corresponding to seismic zone 4 according to the TEC 2007, similar outcomes to seismic zone 3 are observed. Comparable results have been obtained in both seismic regulations for areas falling under seismic zones 3 and 4.

The total reinforcement quantity varying according to seismic zones is provided in Figures 6-9.

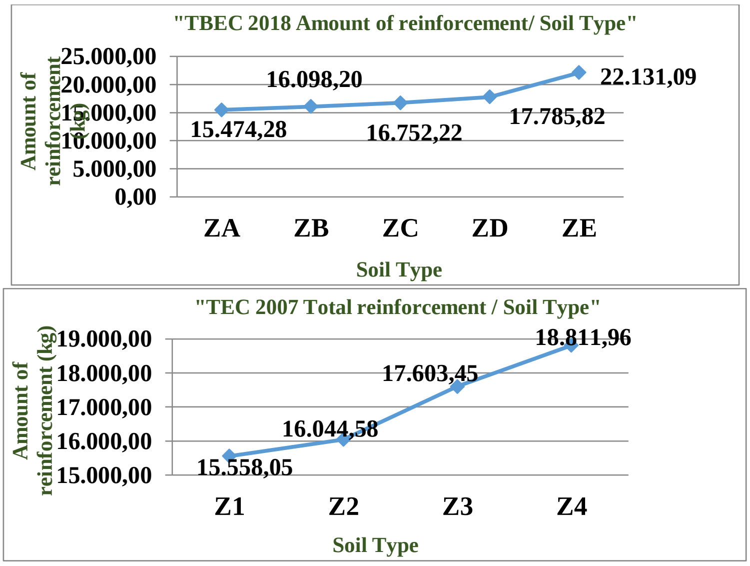

Figure 6. The total reinforcement quantity in the area corresponding to seismic zone 1 according to TEC 2007

As a result of analyses conducted in the region corresponding to seismic zone 1 according to TEC 2007, the total reinforcement quantity has increased as the soil class deteriorates in both seismic regulations. The most significant difference occurred when the soil class was at its worst.

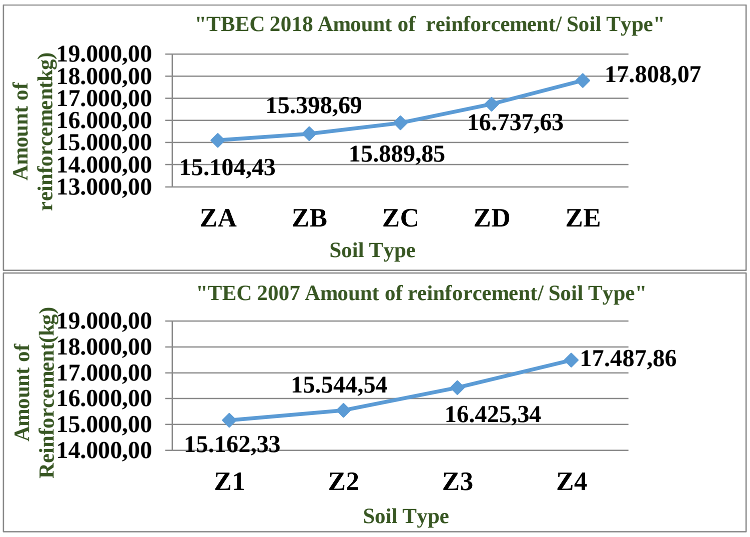

Figure 7. The total reinforcement quantity in the area corresponding to seismic zone 2 according to TEC 2007

As a result of analyses conducted in the region corresponding to seismic zone 2 according to TEC 2007, the total reinforcement quantity has increased as the soil class deteriorates in both seismic regulations. The increase in reinforcement quantity with changing soils is less pronounced compared to seismic zone 1.

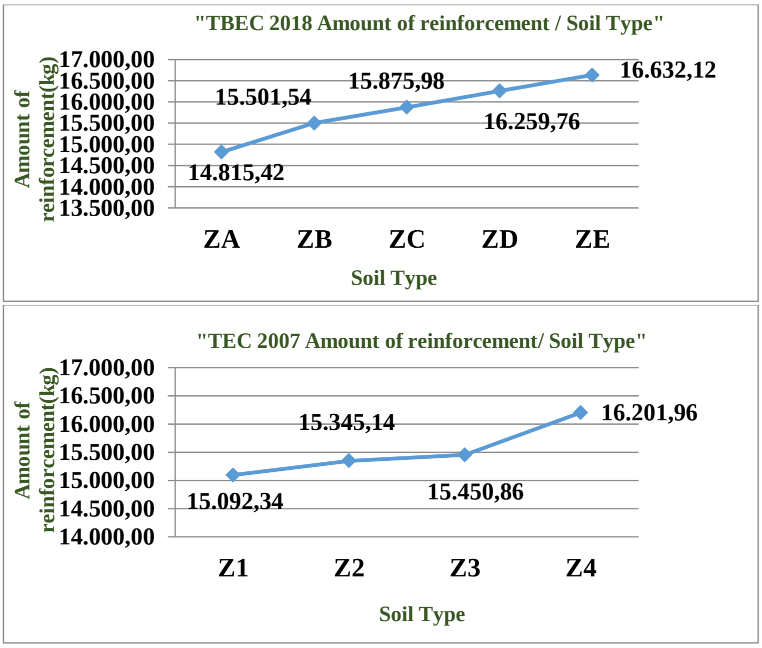

Figure 8. The total reinforcement quantity in the area corresponding to seismic zone 3 according to TEC 2007

As a result of analyses conducted in the region corresponding to seismic zone 3 according to TEC 2007, the total reinforcement quantity has increased as the soil class deteriorates in both seismic regulations. When examining the reinforcement quantity in the best soil classes, it is observed that TEC 2007 uses more reinforcement. However, when looking at the worst soil class, TBEC 2018 utilizes more reinforcement, indicating a greater increase in both concrete and reinforcement quantities with the deterioration of the soil class.

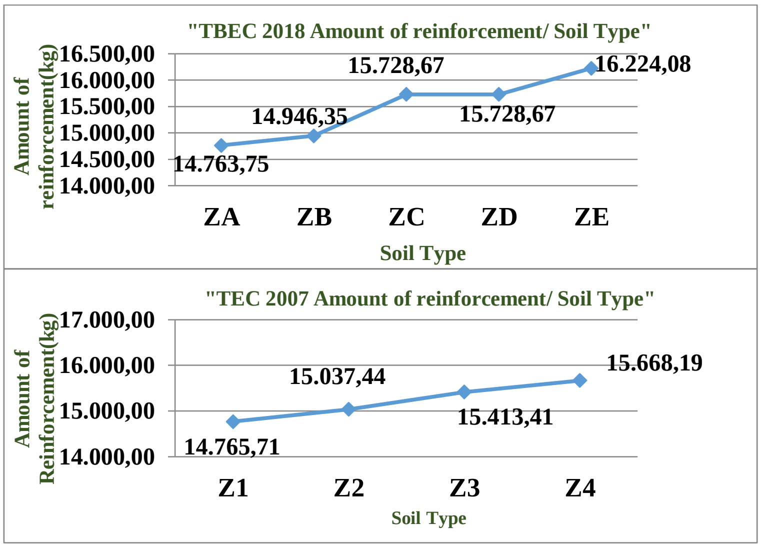

Figure 9. The total reinforcement quantity in the area corresponding to seismic zone 4 according to TEC 2007

As a result of analyses conducted in the region corresponding to seismic zone 4 according to TEC 2007, the total reinforcement quantity has increased as the soil class deteriorates in both seismic regulations. When examining the reinforcement quantity in the best soil classes, similar results are obtained, while looking at the worst soil classes, it is observed that TBEC 2018 uses more reinforcement.

The amount of molding that varies according to earthquake zones is given in Figure 10-13.

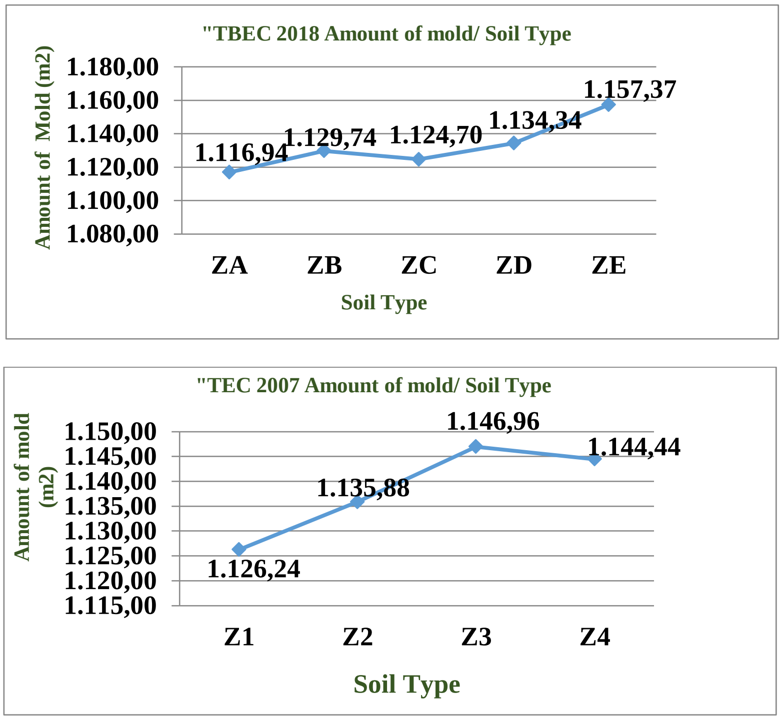

Figure 10. The mold quantity in the area corresponding to seismic zone 1 according to TEC 2007

As a result of analyses conducted in the region corresponding to seismic zone 1 according to TEC 2007, no significant increase has been observed in the total formwork quantity as the soil class deteriorates in both seismic regulations.

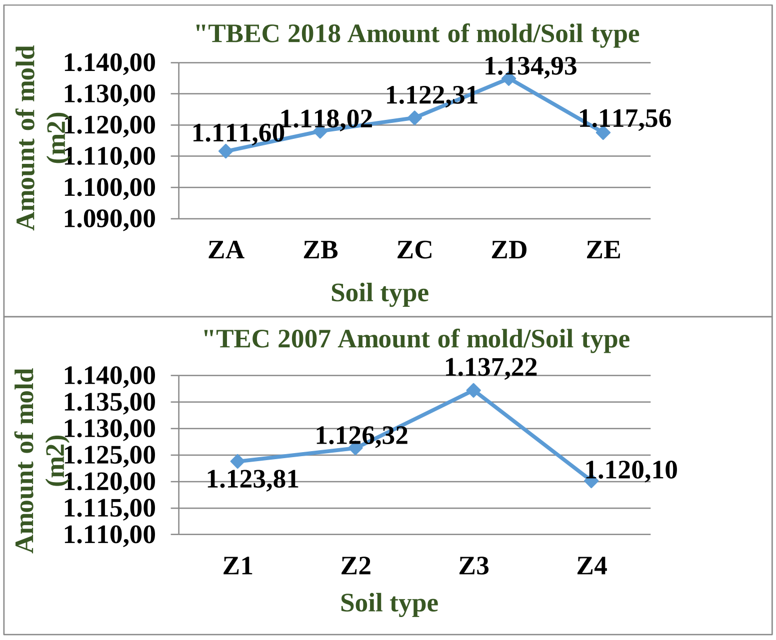

Figure 11. The mold quantity in the area corresponding to seismic zone 2 according to TEC 2007

As a result of analyses conducted in the region corresponding to seismic zone 2 according to TEC 2007, the highest formwork quantity in both seismic regulations has been observed in the soil class just preceding the worst soil class. Overall, there is a slight increase in formwork quantities for both regulations.

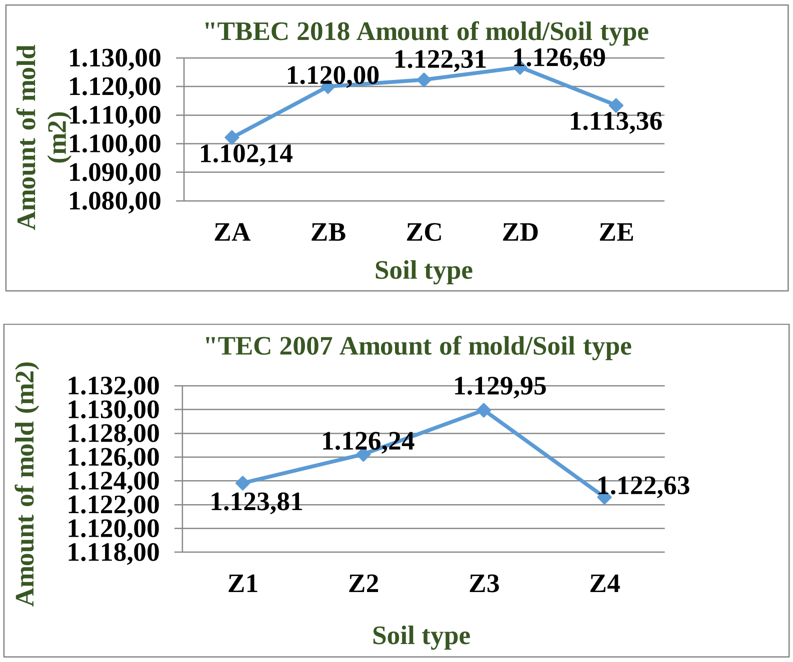

Figure 12. The mold quantity in the area corresponding to seismic zone 3 according to TEC 2007

As a result of analyses conducted in the region corresponding to seismic zone 2 according to TEC 2007, the highest formwork quantity in both seismic regulations has been observed in the soil class just preceding the worst soil class. Overall, there is a slight increase in formwork quantities for both regulations.

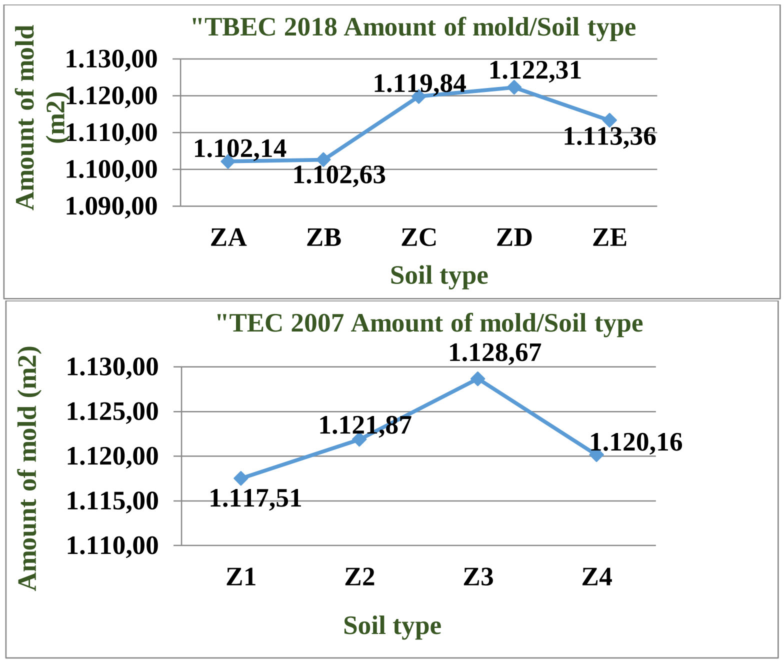

Figure 13. The mold quantity in the area corresponding to seismic zone 4 according to TEC 2007

As a result of analyses conducted in the region corresponding to seismic zone 4 according to TEC 2007, the highest formwork quantity in both seismic regulations has been observed in the soil class just preceding the worst soil class. Overall, there is a slight increase in formwork quantities for both regulations. Similar results were obtained for seismic zone 3.

The quantities of concrete, reinforcement and mold determined in TBEC 2018 and TEC 2007 are determined by the prices of the Ministry of Environment and Urbanization in 2023 and are calculated in Tables 8,and 9.

Table 8. Total equipment costs according to TBEC 2018

Earthquake Zones	TBEC 2018 Soil Classes				
	ZA	ZB	ZC	ZD	ZE
1	□1.154.561,91	□1.179.313,44	□1.194.376,26	□1.227.606,86	□1.461.806,76
2	□1.141.409,28	□1.153.309,31	□1.169.953,25	□1.200.893,28	□1.269.310,28
3	□1.127.590,13	□1.157.293,36	□1.169.594,99	□1.182.101,28	□1.218.460,26
4	□1.126.255,49	□1.127.436,26	□1.164.123,82	□1.165.789,97	□1.207.566,11

Table 9. Total equipment costs according to TEC 2007

Earthquake Zones	TEC 2007 Soil Classes			
	Z1	Z2	Z3	Z4
1	□1.164.149,74	□1.183.249,52	□1.229.953,04	□1.295.426,68
2	□1.047.510,08	□1.059.000,93	□1.087.445,56	□1.128.702,95
3	□1.150.222,24	□1.158.650,28	□1.164.148,12	□1.213.272,42
4	□1.136.860,82	□1.147.297,85	□1.162.329,63	□1.197.818,99

When the total cost is examined, the cost increases as the soil class deteriorates for both regulations in each earthquake zone. The most pronounced increases are observed in the 1st-degree earthquake zone. There is not a significant cost increase for the 4th-degree earthquake zone. Considering both regulations, the highest cost occurs in TBEC 2018 for the Z4 soil class in the 1st-degree earthquake zone.

4. CONCLUSION

This study has been tried to create a prediction in the implementation of the TBEC 2018, and the differences between the TBEC 2018 and TEC 2007 have been established. In TBEC 2018, it is observed that the costs of concrete, reinforcement, and formwork are higher for the 1st-degree earthquake zone. As we move to the 4th-degree earthquake zone, similar costs emerge in both TBEC 2018 and TEC 2007. In response to the earthquakes experienced in our country, TBEC 2018 has deemed it appropriate to construct more robust residential structures by increasing the quantity of concrete and reinforcement, thereby staying on the safer side. This study has been used to determine what changes are made to the cost of building, along with changing regulations. This study has revealed the significant impact of soil class, emphasizing the necessity for careful preparation of soil investigation reports. In future studies, variations in the number of coats such as 7, 11, etc., can be explored. Additionally, besides altering the soil class, changes in concrete types can be considered. The structural frame can be repositioned outside the system and analyzed by adopting a riveted system. This approach applies not only to regular buildings but also to irregular structures, including basement buildings.

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