Influence of Local Soil Conditions on the Structural Design and Associated Costs

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Abstract: It is known that earthquakes occur along the faults as a result of the tectonic plate movements [1]. The North Anatolian, Northeast Anatolian and East Anatolian Faults create three major fault lines in Turkey. In connection with these fault lines, there are various studies concentrated mostly on the seismicity and the topic of earthquake hazard has been examined by many researchers until today. According to the literature, to cope with earthquake related problems, an utmost attention should be given to the existing building stock and currently available design principles used for earthquake resistant structures in the country. In general, the damage to buildings stem from the lack of knowledge and experience in the field, lack of soil survey database, and structural irregularities in plan and elevation. According to building design codes, the seismic load acting on the structures depends on the seismic zone, the soil type, its period of vibration and the mass of the building [2]. In the present study, the main objective is to evaluate the influence of local site effects on the seismic response of buildings in terms of 2018 Turkish Seismic Design Code provisions and to analyze their impact on the cost of construction of buildings. In the study, a two-story reinforced concrete-framed building (residential house) is used as an example. Using the architectural layout of the building, the thickness of floor slabs and column size are determined. The construction cost is estimated roughly by considering unit costs method. The cost of the reinforced concrete structure is determined by considering 2017 unit price list, specified by the Ministry of Environment and Urbanization [3]. It's quite clear that the cost of structure built on soil class ZD is more expensive than the cost of the one built on the soil class ZA. The cost difference is around 22,57% between soil classes ZA and ZD.

Keywords: Earthquake, Turkish Seismic Design Code 2018, Method of Finite Elements, Soil Class, Construction Work Items and Current Unit Prices

1. INTRODUCTION

The Earth's crust, or the lithosphere, is a living entity that constantly changes its internal and external structure. Tectonic plates, gigantic segments of Earth's crust are always moving. We cannot feel this shifting and change in our daily lives. Continuous and slow movements, defined as continent forming movements, are about 1 to 10 mm in size per year. However, there are rapid crust movements that are felt by people and last only seconds, which are called as earthquake. Earthquakes occur mostly due to large elastic fractures along the fault line [1].

Structural safety in a building can be achieved by doing basic structural calculations to provide safety against these large earthquakes. Engineering can be expressed as the art of finding the optimum solution between durability, aesthetics and economy in production. A structure must provide strength, durability, economy, function and aesthetics together. The most important task for engineers on the subject is to combine those elements [4].

In general, the common reasons for damage to buildings are; lack of knowledge and experience in the field, lack of soil survey database, and structural irregularities in plan and elevation. The earthquake forces that acting on structures varies depending on the soil class, the regional seismic ground accelerations and the type of structure [2].

Since the total earthquake load that will affect the structure depends, to a great extent, on the earthquake zone and the local soil class, the seismic response of structures located in that region will also be different [5]. One of the main reasons for buildings sustaining significant damage during an earthquake is that the change in soil class from Z1 to Z4 leads to increase the predominant period of earthquakes. Consequently, the period of vibration of the building will be closer the predominant period of earthquake for soil classes Z3 and Z4 [11].

According to the earthquake zones and local soil class, the expected earthquake intensity will be different from each other. Therefore, the structural dimensions and / or reinforcement details of the structural system and thus the cost of the building will change [6].

2. APPROACH

2.1 Selection of Earthquake Ground Motion for Performing Analyses

In 1996, Seismic Zoning Map of Turkey on the basis of probability methods published by the Ministry of Public Works and Settlement. Table 1 shows the distribution of seismic hazard risk in Turkey. According to this study, 66% of Turkey's surface area is within the 1st and 2nd degree earthquake zones, in other words active fault zones (zone of fractures along the fault line) 71% of population resides in that region [7].

Table 1 Distribution of seismic hazard risk in Turkey, 1996 [8].

SEISMIC HAZARD ZONE	SURFACE AREA (%)	POPULATION (%)	INDUSTRY (%)	DAMS (%)
1st Degree Earthquake Zone	42	45	51	46
2nd Degree Earthquake Zone	24	26	25	23
3rd Degree Earthquake Zone	18	14	11	14
4th Degree Earthquake Zone	16	15	13	17
TOTAL	**100**	**100**	**100**	**100**

As a result of research and analysis done, 1st degree earthquake zone which has high risk level of seismic activity in Turkey is selected as an input (Figure 1).

2.2 TSDC 2018– Local Site Classes

By observing Figure 1 and Figure 2, it is apparent which seismic zones need to be analyzed and designed in detail to avoid the negative consequences of future seismic events. In addition to tectonic activity, there exist important additional factors, such as soil condition. These factors that directly affect the seismic response of structures, should be accounted for in the seismic analysis and design procedure of any building type. In Turkish Seismic Code, there are four different soil groups (ZA, ZB, ZC and ZD) which are classified according to the geological subsurface conditions. These groups further divided into local site classes (Z1, Z2, Z3 and Z4) dependent on the topmost soil layer thickness (h).

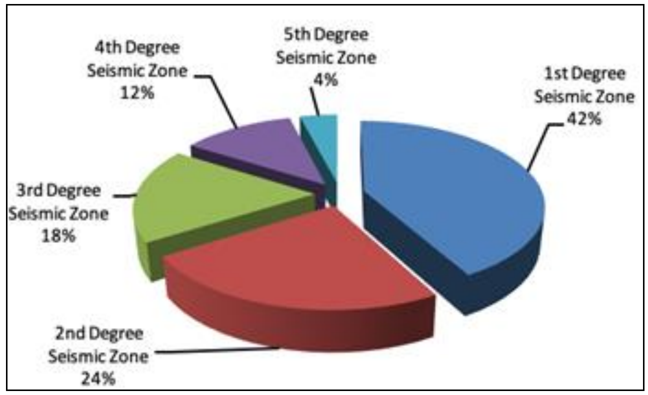


Figure 1. Pie chart presenting the percentages of the seismic hazard Risk in Turkey.

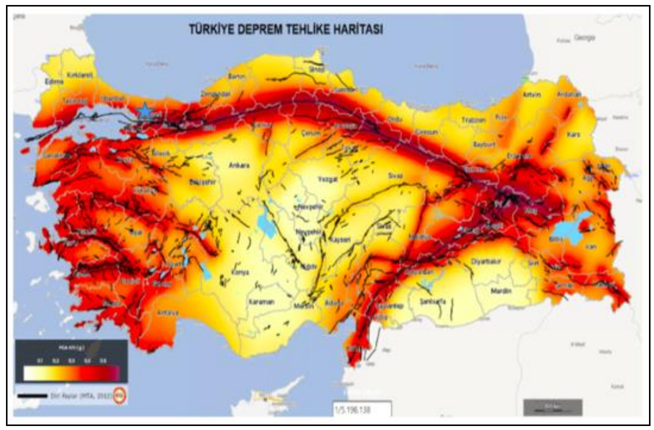


Figure 2. Turkey's seismic hazard map [10].

In order to predict the seismic behavior of structures under strong ground motion levels, the local soil condition at a site must be taken into account due to its amplifying or de-amplifying effects in the response spectrum [12].

For instance, in order to advance the understanding of amplification effects of the soil, the Building Research Institute (BRI) of the Ministry of Construction and the Association for Promotion of Building Research (APBR) in Sendai city, Japan in 1983 started to accumulate earthquake records after installation of seismic recording sites. In the study, the examined surface geology has a variety of soil conditions including outcrop rock site, reclaimed land, and soft soil ground. As a result of this study, although the project duration was not enough to collect enough data, the broad range of findings on the soil amplification and variation of subsurface earthquake motions were obtained by researchers [13].

According to the Turkish Seismic Design Code (TSDC 2018), the soil groups classified as ZA, ZB, ZC and ZD depending on the design acceleration spectrum. If the soil profile belongs to the ZA soil group, the ground display solid, hard rock form; ZB local soil classes display less weathered, medium-solid rocks texture; ZC local floor grade very tight sand, gravel and hard clay layers; ZD local ground grade gravel or clay layers; ZE local soil grade loose sand, soft clay floors; the ZF soil layers require site-specific research and evaluation. The spectral acceleration coefficients of these soil groups are shown in Table 2. When Turkish Earthquake Code 2007 (TEC) and TSDC 2018 regulations are examined, it's accepted that the Z1 soil class reflects the characteristic of the ZA local soil group.

Table 2. Spectral acceleration coefficients [9].

Soil Group	$S_1 \leq 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	S1=0.5	S1≥0.6
ZA	0.8	0.8	0.8	0.8	0.8	0.8
ZB	0.8	0.8	0.8	0.8	0.8	0.8
ZC	1.5	1.5	1.5	1.5	1.5	1.4
ZD	2.4	2.2	2.0	1.9	1.8	1.7
ZE	4.2	3.3	2.8	2.4	2.2	2.0

3. STRUCTURAL MODELING AND ANALYSIS

3.1 Details of Sample Building

The building used in the study, is a two-storey residential (villa) building and has a total floor area of 217,80 m^2. The architectural ground floor plan and an elevation plan of the building are given in Figure 3 and Figure 4, respectively.

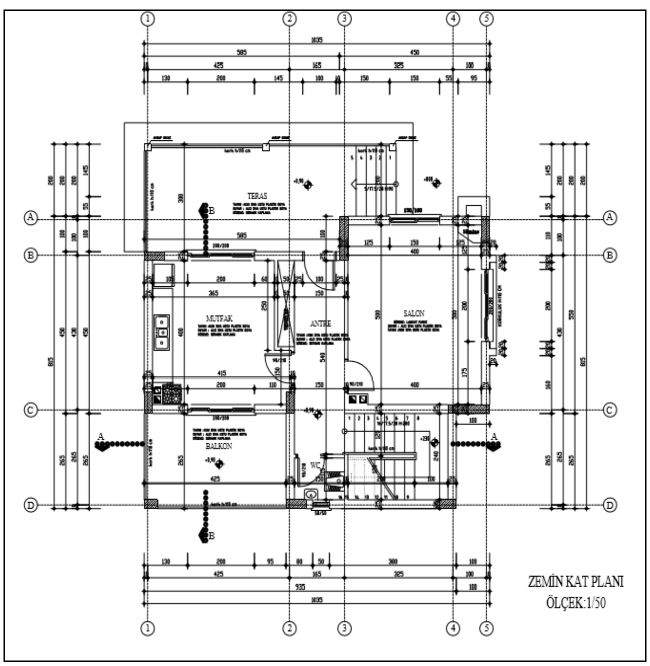


Figure 3. Architectural ground floor plan.

3.2 Static Analysis and Assessment (Results)

In this study, static analysis of the structures, designed according to the different soil classes, were performed by using Sta4-CAD [14] which is the most used structural analysis program in Turkish project market. It's assumed that all buildings are located in the 1st degree seismic zone as shown in Fig.2, and are designed according to different local soil classes. The effective ground acceleration coefficient was taken as 0.40 in the 1st degree earthquake zone as specified in the Turkish Seismic Design Code (TSDC 2018).

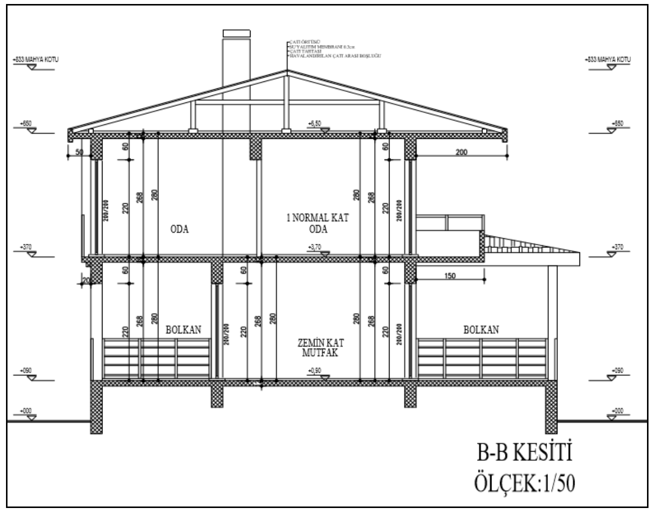


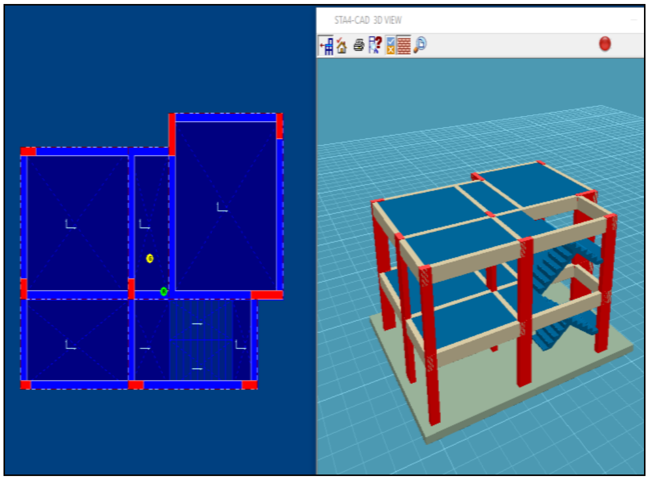
Figure 4. Architectural cross-section for building.

Seismic ground response characteristic periods (Ta and Tb) according to the defined soil categories (ZA-ZD) and soil classes (Z1-Z4) are presented in Table 3.

Table 3. Spectrum characteristic parameters according to the soil classes in TSC 2007.

Soil Group	Local Site Class	I (Building Importance Factor)	Ao (Effective Ground Acceleration Coefficient)	Safe/allowable Stress (Mpa)	Subgrade Reaction Coefficient (KN/m^3)	Ta	Tb
ZA	**Z1**	1	0,4	0.39	5000	0,10	0,30
ZB	**Z2**	1	0,4	0.29	3000	0,15	0,40
ZC	**Z3**	1	0,4	0.20	2000	0,15	0,60
ZD	**Z4**	1	0,4	0.15	1000	0,20	0,90

The three dimensional building model and its raft foundation are given in Figure 5. Figure 6 and Figure 7 shows the column application and formwork plans which are created as a result of static analysis.



a) Floor Plan of Reinforced Concrete (RC) Building b) 3D view of Reinforced Concrete (RC) Building

Figure 5. Finite element modeling of reinforced concrete building.

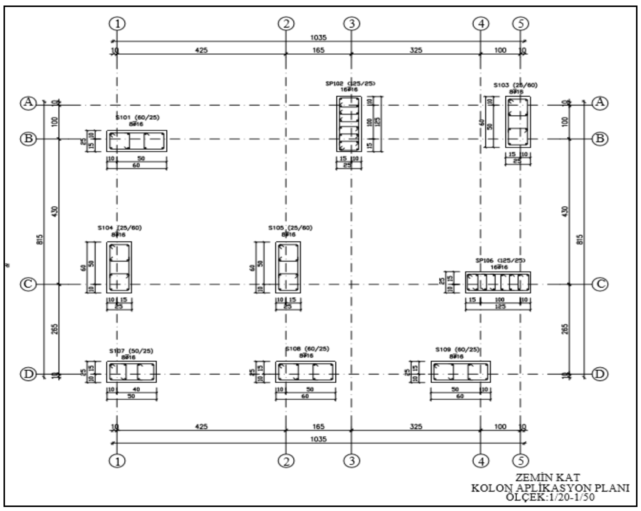


Figure 6. showing different kinds of columns reinforcement.

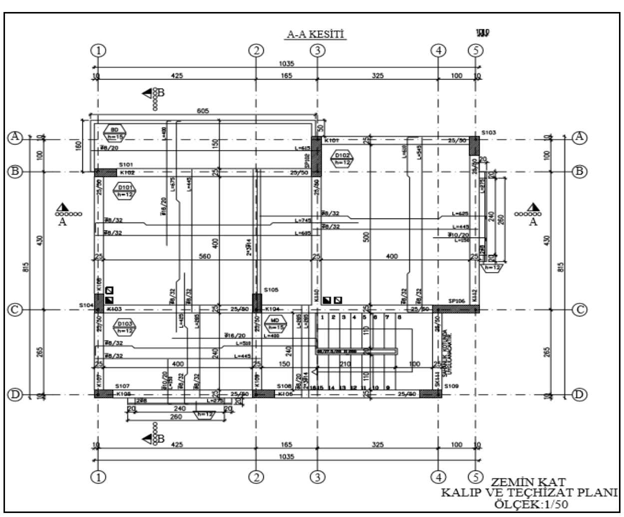


Figure 7. First floor slab reinforcement plan view.

The difference in the local soil classes resulted in different dimensions of the concrete column and the dimensions of the foundation thickness. As a result of analysis performed, the specified maximum soil stresses are shown in Figure 8.

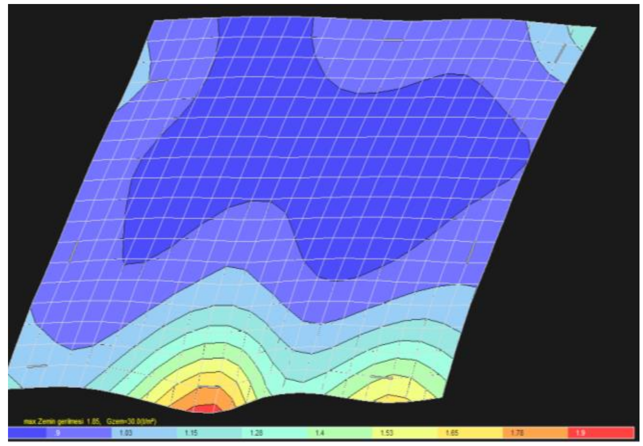


Figure 8. Stress distribution in soil.

Each of the colors resulting from analyzes corresponds to a safe/allowable stress range. The values of the soil safe/allowable stresses corresponding to these colors are given in Table 4.

Table 4. Stress Scale and Stress Distribution Values.

Colors	Corresponding Soil Safe/allowable Stress Scale (Mpa)
Red	≥ 0.019
Orange	0.018-0.019
Yellow	0.016-0.018
Light-yellow	0.015-0.016
Green	0.014-0.015
Turquois	0.013-0.014
Blue	0.012-0.013
Dark blue	0.010-0.012
Navy blue	0.009-0.010
Prussian blue	≤0.009

The steel reinforcement, concrete and formwork obtained from the results of the analysis, which is performed considering different local soil classes. At the same time, it's concluded that different local soil classes cause changes in the building costs.

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4. RESULTS

For different local soil classifications, the concrete, steel reinforcement and formwork of the projects are obtained from the results of static analysis. The estimation of quantity cost is calculated by multiplying with the 2017 unit costs specified by the Ministry of Environment and Urbanization and construction costs were calculated and the results of the calculations are given in Table 5 [3].

Table 5. Estimation of Quantity and Cost for Different Local Site Classes.

1st Degree Earthquake Zone									
Soil Group	**Local Site Classes**	**Quantity**			**Unit Cost**			**Total**
		Concrete	**Rebar**	**Structural Member Formwork**	**Concrete**	**Rebar**	**Structural Member Formwork**	
		m^3	kg	m^2	m^3/ TL	kg / TL	m^2/ TL	TL
ZA	Z1	70.03	6980	323.06	188	3650000	38	50919
ZB	Z2	71.5	7910	325.6	188	3650000	38	54686
ZC	Z3	76.8	8470	328	188	3650000	38	57818
ZD	Z4	79.06	9580	331.1	188	3650000	38	62412

The official unit costs determined by the Ministry of Environment and Urbanization have been used with the idea that there will be price difference in the regional and brand changes of the materials. In the reinforcing pricing, the code number 23.014-15 St III is used, for the timber formwork, the code number 21.011-TAK is used for minimum unit price and in concrete pricing; the maximum unit price was taken as 16.058 / 1.

As a result of the work done, it has been observed that there is a 22.57% cost difference in the construction costs of the buildings in ZA and ZD local soil classes. By observing Fig.9 it is apparent that different soil classes cause changes in the building costs. A comparison of analysis of costs is given in Figure 9.

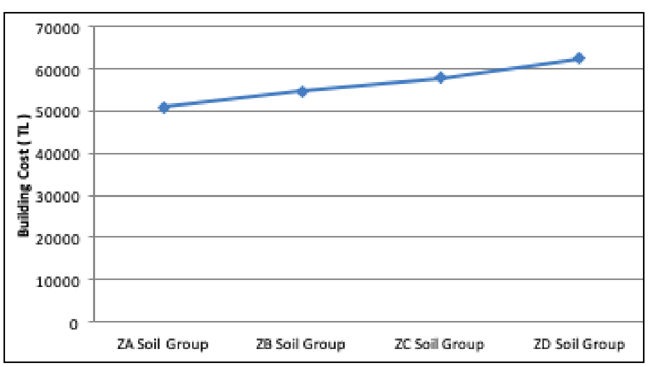

Figure 9. Construction Cost Graph of Structures of Different Local Site Classes.

5. CONCLUSION

In the present study, within the scope of 2018 Turkish seismic building code, the effects of local soil conditions on the seismic response of buildings and the resulting changes in building cost examined with the example structure. As because of the finite element method based software used in this study which is Sta4-Cad is not compatible with the new developed 2018 Turkish seismic building code in regards of soil parameters or etc., in the analysis phases some assumptions must be done and this comes through as a limitation of the study. It has been observed that there is a 22.57% cost difference in the construction costs of the buildings in ZA and ZD local soil classes. As seen from the results, the different type of soil classifications will have significant impacts on the cost of construction of the buildings.

It can be concluded that when designing new structures or assessing the existing structures, corresponding the local soil conditions should be accounted for using the spectral acceleration coefficients in 2018 TBEC.

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