Seismic Design of Mid-Rise Reinforced Concrete Structures According to TEC 2007 and TBEC 2018

S Derogar¹*, I Safkan¹, B Odabas¹
¹ European University of Lefke, Faculty of Engineering, Department of Civil Engineering, Lefke, Northern Cyprus, TR-10 Mersin, Turkey

Abstract: Reinforced concrete (RC) structure are widely used structural system in buildings across the Turkey. The new Turkish standard on earthquake, TBEC 2018: Turkish Building Earthquake Code, was published on 2018 which is replaced for the old earthquake code, TEC 2007: Turkish Earthquake Code-2007. This paper aims to present a comparison between the seismic design provisions of these two codes for the design of mid-rise RC structures. The code provisions in both codes are evaluated and differences in terms of ductility and strength for the design of mid-rise RC structures are highlighted and presented. It was shown that the design base shear is higher when using TBEC 2018 code. A 4-story building is designed according to both codes and then the performance of the structure was evaluated. Due to differences on allowable drift limit, the R and Cd factors, the structure showed different behaviour when design according to both codes which are discussed in detail in this paper. A cost analysis was also carried out and compared for both buildings.

1. Introduction

Reinforced concrete moment-resisting frames are a widely used structural system in buildings across the world, especially in developing countries such as Turkey. Earthquake is one of the major problems in Turkey as the country is located on the Alp-Himalayas fault. Earthquakes, particularly on the north Anatolian faults are very dangerous as they are very close to the surface (about 5-30 km) [1]. Following the 1908 Messina earthquake (Italy), the Royal Government of Italy established a Committee in early 1909 to study the disaster and recommend earthquake disaster mitigation measures. The recommendation was adopted in Royal Decree No. 573 of April 29, 1915. Accordingly, the height of the buildings was limited to two stories, and the first story was assigned to be designed for a horizontal force equal to 1/8 the second-floor weight and the second story for 1/6 of the roof weight. This is believed to be the first known quantitative recommendation of design for seismic forces in the history of seismic codes [2].

Modifications to the design codes are normally accompanied by experiencing destructive earthquakes. Turkey experienced lots of catastrophic earthquakes which led thousands of casualties and are reported in the literature [1]. Main reason of the extent of the damage and losses are generally believed to be the construction malpractice and lack of adequate inspection of enforcement of the application of seismic design code [3].

Turkey adopted the first earthquake code in 1940 and since then the code was revised 9 times [3]. Turkey experienced various kinds of disasters, and earthquakes are the most hazardous kind of these disasters. Each disaster has been an experience for Turkey’s disaster management. Hence, after these major disasters, new laws and new codes enacted or old ones were revised [1]. The Turkish earthquake code of 2007 [4] was the same as the Turkish earthquake code of 1998 except for a few parts and minor changes. Therefore, the scientific studies in earthquake engineering have not been reflected in the design rules since 20 years. The recent Earthquake Code of Turkey has been revised and published in 2018[5]. Almost 120 experts contributed to the whole document and all activities were coordinated by a permanent earthquake code
committee consisting of 15 members. The new Turkish Building Earthquake Code is a comprehensive revision of the previous one dated 2007.

This paper aims to highlight the differences between the 2018 earthquake code and the 2007 earthquake code. For this, the earthquake performance analysis with different ground classes were performed considering a four storey reinforced concrete frame building. In performance evaluation, Equivalent Seismic Load Method which is suggested in Turkish Earthquake Code 2007 and Turkish Earthquake Code 2018 were adopted. Also a cost analysis were carried out for the designed structures according to both codes. All analysis were carried out using Prota Structure [6] and Sap2000 v.20, general-purpose finite element program [7] software programs.

2. Main changes/differences according to the earthquake codes of 2007 and 2018

In the earthquake code, 2007 [4], "Analysis Requirements for Earthquake Resistant Buildings" were consisted of two parts where it is expanded into four sections in the new Turkish Earthquake Code of 2018. The most significant change that was introduced with the earthquake code of 2018 [5] regarding the calculation of earthquake ground motion are Turkey Earthquake Hazard Map (Turkey Earthquake Seismic hazards) [8]. Figure 1 (a & b) shows the change seismic hazard map of Turkey according to both Earthquake codes of 2007 and 2018 respectively.

![Figure 1: a) Earthquake Hazard Map of 2007, b) Earthquake Hazard Map of 2019](image)

According to the earthquake code of 2007 [4], five different earthquake zones were defined in Turkey. However, with the new earthquake hazard maps, the concept of earthquake zones has completely disappeared. The $S_1$ and $S_3$ value can be determine from the map for any location in Turkey.

In the earthquake code of 2007 [4], the soil was divided into four different classes: Z1, Z2, Z3 and Z4. The determination of the soil class was carried out by A, B, C and D soil grouping, respectively. However, in the new earthquake code 2018 [5], soil classes and soil groups are combined from the best ground to worst ground ZA, ZB, ZC, ZD, ZE and ZF are defined. For the ZF soil class, which categorized as worst soil class, the new code requires test to be carried out on site-specific research and evaluation.

Classification of buildings are defined by introducing the importance factor. According to the Turkish earthquake code 2007 [4] structures such as schools, dormitories, prisons and museums were defined at the second level of importance. In the Turkish earthquake code of 2018 [5], the importance factor of these structures were increased to the first level and the coefficient was increased from 1.4 to 1.5. A parametric study on two identical building designed by using both codes of 2007 and 2018 were carried out to assess the effect of importance factor and it was shown that the change in importance factor can lead to an approximate increase of 7% on the calculated earthquake force of the building.

In the new earthquake code 2018 [5], the building performance levels are defined in 4 different categories as "continuous use (CU)", limited damage (LD), controlled damage (CD) and prevention of collapse (PC) which is shown in Figure 2. However, in the earthquake code 2007 [4], performance levels were defined only for the evaluation of existing buildings.
Figure 2. Building Performance Goals

The new earthquake code 2018 [5] introduced the over strength coefficient factor, "D", as a new parameter in the design of reinforced concrete structures. Those structures which are not expected to exhibit ductile behaviour, earthquake loads reduced by the behaviour coefficient are increased by the over strength coefficient. As a result of the application of the over strength coefficient, the shear force demands will increase for all column and beam members.

The most important feature that was introduced by the new earthquake code (2018) [5] was the necessity to use the effective stiffness coefficients. Accordingly, the effective stiffness coefficients were reduced by 70% for columns, 35% for beams and 50% for shear walls. Consequently, the horizontal displacement of the members could be increased and therefore, the dimension of the members need to be increased in order to ensure sufficient rigidity.

Modifications are provided in the new earthquake code 2018 on calculating the spectrum coefficients. Accordingly, Corner periods (TA, TB), which are important factors in determining the spectrum coefficients in the new earthquake code, dependent on SDS and SD1 values. Figure 3 compares the horizontal Elastic Design spectrum obtained for Istanbul-Gebze using earthquake code of 2018 [5] and earthquake code of 2007 [4]. As shown in Figure 3, higher spectral acceleration values are obtained according to Turkish earthquake code of 2018 [5] when compared to the Turkish earthquake code of 2007 [4]. As a result, the earthquake loads will be increased.

Figure 3. Horizontal spectral accelerations for different soil classes in Istanbul- Gebze, a) according to earthquake code 2007, b) according to earthquake code 2018

Earthquake code of 2018 [3] proposed a major change on the calculation and limits of the effective inter-storey drift. In the new earthquake code, the displacement limit is determined separately depending on the contiguous or unified state of the walls and frames. According to this rule, it aimed the walls of the building do not receive any damage during the earthquake and the structure can exhibit more ductile behaviour. According to earthquake code 2007 [4], the drift limit was depending only on the floor height and seismic load reduction factor whereas in new earthquake code, the drift limit depends on the building important factor, the seismic load reduction factor and the building seismic period.
3. Design and cost analysis of R.C. structures according to earthquake codes of 2007 and 2018

As shown in Figure 4, a 4-storey reinforced concrete building was designed according to both earthquake code by using the "Prota Structure [6]" and "Sap2000 [7]" software program to examine the numerical differences that will arise from the design principles that differ in the 2007 [4] and 2018 [5] earthquake codes. It was assumed that the project is located in Gebze district of Istanbul province. Earthquake performance analysis with different soil classifications were performed on this 4 storey reinforced concrete frame system building. In performance evaluation Equivalent Seismic Load Method which is suggested in Turkish Earthquake Code of 2007 [4] and Turkish Earthquake Code of 2018 [53] issues were used.

![Figure 4. floor plan and view of the Building](image)

According to Turkish Earthquake Code of 2007 [4], Gebze district belongs to Earthquake zone one. The short and long periods corresponding to the spectral acceleration coefficients ($S_s$, $S_l$) were calculated by the new seismic hazard maps. The earthquake calculation parameters according to both earthquake codes are given in the Table 1. In this analysis, Concrete of class C25 and Steel S420 were assumed to be used for both design codes of 2007 [4] and 2018[5]. Structural members were designed according to TS 500 [9], whereas the loads were applied according to TS 498 [10].
Table 1, a) Required earthquake parameters for the design of building according to earthquake code of 2018 [5], b) Required earthquake parameters for the designed building according to earthquake code of 2007, [4]

| Earthquake Parameters | Latitude, Longitude | Short Period Map Spectral Acceleration (Ss) | Long Period Map Spectral Acceleration (S1) | Building Usage Class | Importance Factor | Behaviour Factor | Overstrength Coefficient | Building Height Classes | Earthquake Design Classes |
|-----------------------|---------------------|--------------------------------------------|------------------------------------------|---------------------|------------------|-----------------|------------------------|---------------------------|--------------------------|
| TS500-2000 , TS498 , TBDY 2018 | 40.8005 / 29.6446 | 1.445                                      | 0.394                                    | BKS=3               | I=1              | R=8             | D=3                    | BYS=6                     | DTS=1                    |

No expansion joint was considered in the modelled structures, when Earthquake code 2018 was used.

Table 2 shows the fundamental period of the structures when analysed according to earthquake codes of 2007 [4] and 2018 [5] respectively using different ground classes. It was observed that natural period of the structures are higher when the building was designed according to the earthquake code 2018 [5].

Table 2. Buildings time period values on different ground classes which are designed a) according to earthquake code of 2007 [4], b) according to earthquake code of 2018 [5]

| Ground Class | a) Earthquake Code of 2007 [4] | b) Earthquake Code of 2018 [5] |
|--------------|-------------------------------|-------------------------------|
|              | X Direction (MOD 1) | Y Direction (MOD 2) | X Direction (MOD 1) | Y Direction (MOD 2) |
| Z1           | 0.499                        | 0.498                        | 0.614                | 0.579               |
| Z2           | 0.499                        | 0.498                        | 0.614                | 0.579               |
| Z3           | 0.499                        | 0.498                        | 0.614                | 0.579               |
| Z4           | 0.499                        | 0.498                        | 0.614                | 0.579               |
| ZA           | 0.464                        | 0.449                        | 0.464                | 0.449               |
| ZB           | 0.614                        | 0.579                        | 0.614                | 0.579               |
| ZC           | 0.614                        | 0.579                        | 0.614                | 0.579               |
| ZD           | 0.614                        | 0.579                        | 0.614                | 0.579               |
| ZE           | 0.464                        | 0.449                        | 0.464                | 0.449               |
Figure 5. Comparison of natural time period values of the 4-story building on different soil classification according to earthquake codes of 2007 and 2018

As shown in Figure 5, incorporating the effective stiffness coefficients with the new earthquake code led the natural time period of buildings to be increased by approximately 37%. For the buildings designed according to earthquake code of 2018, sections of structural members were increased depending on the ground classes. Due to the use of cracked stiffness coefficient increase in fundamental period was monitored.

Figure 6 represents the base shear force values obtained from the designed buildings in Gebze district according to earthquake codes of 2007 [4] and 2018 [5] considering different soil classifications. As shown in Figure 6, when the structure is designed according to earthquake code 2007 [4], the base shear force for Z2 ground class was increased by approximately 25%, and about 40% in ground class Z3 when compared to results of the structure designed for Z1 ground class. It was observed that the obtained base shear forces were the same when the structures were designed considering ground class Z3 and Z4.
When the structures are designed according to earthquake code 2018 [5], it was observed that the calculated base shear force of the building in the ZA and ZB classes were similar. This is due to the fact that the ZA and ZB ground class spectral acceleration values are very close to each other. It was noticed that the base shear forces of buildings designed with no expansion joints according to earthquake code of 2018 in ZA and ZB ground classes are less than those of buildings designed according to earthquake code 2007 for Z1 and Z2 ground classes. Low spectral acceleration values were obtained in the horizontal spectrum curve corresponding to the high period value and therefore, the values of the base shear forces are reduced.

The effective relative drift and storey drift results on different soil classes of the buildings designed according to the Turkish earthquake code of 2007 [4] and 2018 [5] are given in Table 3 (a & b) respectively.
Table 3-a: The effective inter-storey drift and storey drift values on different soil classes of the building designed according to earthquake code 2007 [4]

| Storey Number | Storey Drift | Ground Zone | Storey Number | Inter-storey Drift |
|---------------|--------------|-------------|---------------|--------------------|
| 1             | 0.002358     |             | 1             | 0.006289           |
| 2             | 0.005349     | Z1          | 2             | 0.007975           |
| 3             | 0.007712     |             | 3             | 0.0063             |
| 4             | 0.009089     |             | 4             | 0.003659           |
| 1             | 0.002956     |             | 1             | 0.007883           |
| 2             | 0.006703     | Z2          | 2             | 0.009992           |
| 3             | 0.009665     |             | 3             | 0.007899           |
| 4             | 0.011461     |             | 4             | 0.004788           |
| 1             | 0.003412     |             | 1             | 0.009098           |
| 2             | 0.007738     | Z3          | 2             | 0.011536           |
| 3             | 0.011156     |             | 3             | 0.009114           |
| 4             | 0.01314      |             | 4             | 0.005292           |
| 1             | 0.003412     |             | 1             | 0.009098           |
| 2             | 0.007738     | Z4          | 2             | 0.011536           |
| 3             | 0.011156     |             | 3             | 0.009114           |
| 4             | 0.01314      |             | 4             | 0.005292           |

Table 3-b: The effective inter-storey drift and storey drift values on different soil classes of the building designed according to earthquake code 2018 [5]

| Storey Number | Storey Drift | Ground Zone | Storey Number | Inter-storey Drift |
|---------------|--------------|-------------|---------------|--------------------|
| 1             | 0.004097     | ZA          | 1             | 0.003108           |
| 2             | 0.010745     |             | 2             | 0.005043           |
| 3             | 0.016656     |             | 3             | 0.004484           |
| 4             | 0.0215       |             | 4             | 0.003098           |
| 1             | 0.004097     |             | 1             | 0.003108           |
| 2             | 0.010745     | ZB          | 2             | 0.005043           |
| 3             | 0.016656     |             | 3             | 0.004484           |
| 4             | 0.0215       |             | 4             | 0.003098           |
| 1             | 0.004097     |             | 1             | 0.003108           |
| 2             | 0.010745     | ZC          | 2             | 0.005043           |
| 3             | 0.016656     |             | 3             | 0.004484           |
| 4             | 0.0215       |             | 4             | 0.003098           |
| 1             | 0.005189     |             | 1             | 0.004893           |
As given in Table 3, the storey drift and inter-story drift of the buildings designed according to earthquake code 2018, increased by about 55% in the Z2 ground class, and about 45% in the ground class Z3 when compared to the structures designed according to earthquake code 2007 [4]. The same spectral acceleration values were obtained for Z3 and Z4 period values corresponding to the resonance region in the horizontal spectral curve. Therefore, there were not any changes for Z4 ground class. Figure 7 represents the story drift and inter-story drift behaviour of the 4 story building designed according to earthquake codes of 2007 [4] and 2018 [5]. It was noticed that the structure designed on ZE ground class is more rigid than the structure designed on ZC and ZD ground classes and therefore, the building shows less storey drift values.

As shown in Figure 7, unlike storey drift values, the inter-storey drift value of the building designed in ZE ground class is higher than the inter-storey drift value of the building designed in ZC ground class. This is true as ZE ground class lambda (λ) value is greater than ZC ground class lambda (λ) value.

![Figure 7](image-url)

Figure 7. a) and b) Storey drift and inter-story drift values on different ground classes buildings designed according to earthquake code of 2007 respectively, c) and d) Storey drift and inter-story drift values on different ground classes buildings designed according to earthquake code of 2018 respectively.

A cost analysis was also carried out for the buildings designed according to earthquake code 2007 [4] and 2018 [5] considering different soil classifications. Only expenses on formwork, concrete and rebars were included for the cost analysis in this paper. The price list provided by approximate unit cost of Turkey
[11] was used for the calculation of the construction expenses. Figure 8 presents the results from cost analysis of the 4-story building considering different soil classifications designed according to earthquake codes 2007 [4] and 2018 [5] respectively. As discussed earlier, the new code considers a reduction in the stiffness of the members and this leads to a higher expense on the construction price of buildings designed with earthquake code 2018 [5].

![Figure 8. Total cost analysis on different ground classes buildings designed a) according to earthquake code 2007, b) according to earthquake code 2018.](image)

### 4. Conclusion

This paper aimed to highlight the differences between Turkish earthquake codes of 2007 [4] and 2018 [5]. A mid-rise structure, 4-story building, considering different soil classifications, was selected and designed according to earthquake code 2007 [4] and 2018 [5]. Equivalent Seismic Load Method which is suggested in both Turkish Earthquake Code 2007 [4] and Turkish Earthquake Code 2018 [5] was adopted in this paper. A detailed comparison was carried out on the design aspects and cost of the construction of the selected structure when designed according to both earthquake codes of 2007 [4] and 2018 [5]. All analysis were carried out using Prota Structure [6] and Sap2000 [7] software programs. The following conclusions are provided:

- It was shown that the increase in importance factor from 1.4 to 1.5 led the calculated earthquake force to be increased by approximately 7%.
- The adoption of effective stiffness coefficient in earthquake code 2018 [5], caused the increase in horizontal displacement of the structure and automatically the member dimensions were increased to ensure sufficient rigidity.
- Higher spectral acceleration values were obtained according to Turkish earthquake code 2018 [5] when compared with the Turkish earthquake code 2007 [4].
- According to the earthquake code 2018 [5], depending to the period of the structure, the seismic load reduction factor values are decreased. Consequently, the earthquake loads are increased.
- When the structures were designed according to earthquake code of 2018 [5] with no expansion joints, the base shear forces of the structures in ZA and ZB ground classes are less than those of structures in Z1 and Z2 ground classes of earthquake code 2007 [4]. Low spectral acceleration values were obtained in the horizontal spectrum curve corresponding to the high period value and therefore the values of the base shear forces are reduced.
- The adoption of effective stiffness coefficients in the design of structures according to earthquake code 2018 [5], caused a dramatic increase in fundamental period of structure when compared to earthquake code 2007 [4]. It was also noticed the depending on this increase, storey drift and inter-storey drifts were increased significantly depending on the period of the structure.

Unlike storey drift values, the inter-storey drift value of the building designed in ZE ground class is higher than the inter-storey drift value of the building designed in ZC ground class. This is because ZE ground class lambda (λ) value is greater than ZC ground class lambda (λ) value.
The adoption of effective stiffness coefficients in structures designed according to the Turkish earthquake code of 2018 [5] led to dramatic increase in the building period. Considering the increase in period of the structure and to ensure adequate rigidity of the buildings, the dimension of the structural members are increased and therefore, the building costs increased significantly.

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