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Examination of buildings with different number of floors using non-linear time history analysis according to TBEC-2018 and EC 8 seismic codes

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Abstract

Earthquakes are among the natural disasters that occur on earth and cause loss of life and property. As a result of the earthquakes that have occurred on the earth from the past to the present, the issue of earthquake performance of structures has come to the fore in structural and earthquake engineering. Within the scope of this research, the carrier system; Consisting of a unhollow reinforced concrete shear wall frame system with high ductility having the same floor formwork plan; The seismic performance evaluation of 10, 15 and 20 storey existing reinforced concrete buildings was made by using nonlinear time history analysis according to Turkish Building Earthquake Code 2018 (TBEC-2018) and Eurocode 8 (EC 8) earthquake codes. Within the scope of the study, SAP200 (v25) computer software was used for modelling of the structures and performance analysis. In scope of the data obtained, it has been determined that TBEC-2018 is on the safer side compared to Eurocode 8.

1. Introduction

Earthquakes are among the natural disasters that occur on earth and cause loss of life and property. Türkiye is in the Alpine-Himalayan seismic zone, which is one of the important and active seismic zones in terms of earthquake risk, starting from the Azores Islands and extending to Southeast Asia in Figure 1 [1].

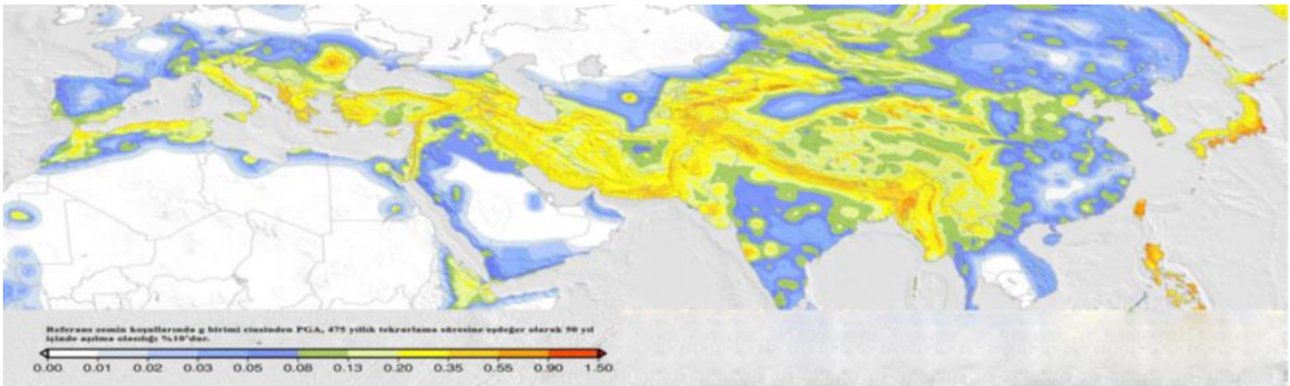

Figure 1. Global seismic hazard map [2].

In the report titled "Disaster Management and Natural Disaster Statistics in Turkey [3]" prepared by Republic of Türkiye Ministry of Internal Affairs, Disaster and Emergency Management Presidency (AFAD) in 2018, it has been mentioned that the most effective disaster type in Türkiye in terms of loss of life and property is earthquakes. A significant portion of the deaths occurring due to disasters, 60 percent, are caused by earthquakes.

As a result of the earthquakes that have occurred since the existence of the universe until today, the subject of seismic performance of structures has gained significant importance in the fields of structural engineering and earthquake engineering [4]. With the opportunities offered by today's construction technology, earthquake-resistant high-rise constructions have become widespread in our lives. The collapse of many buildings and the loss of lives because of the recent severe earthquakes which are Izmir, Elazığ, Van, Kahramanmaraş and Hatay show that sufficient precautions have not been taken regarding the safety of existing constructions [5]. Figure 2 and Figure 3 show some earthquakes that have occurred in Türkiye in the last century.

Figure 2. Some major earthquakes that occurred in Türkiye in the last century [6].

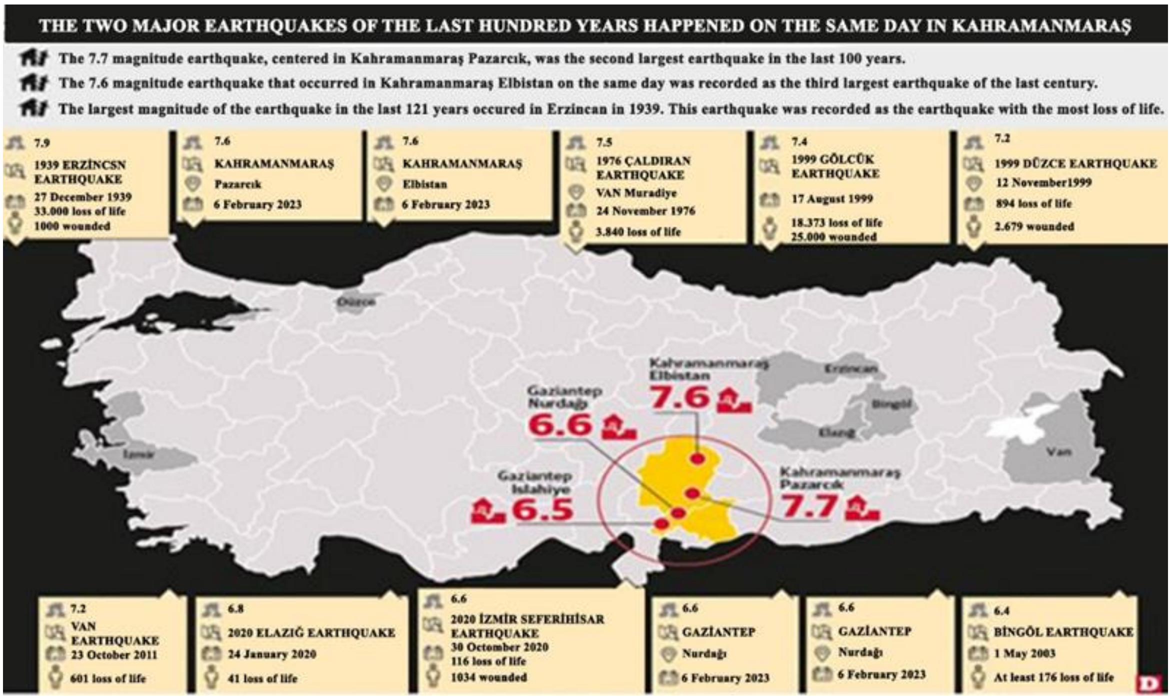

Figure 3. Some major earthquakes, specifically Kahramanmaraş-centered earthquakes [7].

The original versions of the images in Figure 2 and Figure 3 were edited in Photoshop [8]. The original bibliography has identified by end of the figure title. To minimize the damage caused by earthquakes on structures and the loss of life, buildings must be designed to be earthquake resistant.

2. Literature Review

In the literature review, the number of studies comparing the seismic codes used in Türkiye and Eurocode 8 is limited and shows that there is a need for detailed and comprehensive studies in this field.

In the study conducted by Konak [9], the performance of a 14-storey building exposed to significant torsional effects was evaluated using the nonlinear time history analysis method and pushover analysis methods according to TBEC-2018 and EC 8 seismic codes, and the results were compared. C40, C20 and C10 class concrete materials were used to demonstrate the effect of concrete strength and it was observed that as the concrete strength increased, the damage to the structural elements decreased. As a result of the non-linear analysis method in the time domain, it was seen that the number of damaged beams was higher in EC 8 and the number of damaged columns was higher in TBEC-2018. It has been suggested that this difference is due to the differences between the effective section stiffnesses defined for beams and columns in both seismic codes.

In the study carried out by Karakaş [10], a total of 126 reinforced concrete buildings with floor numbers ranging from 2 to 8 were modelled and the modelled buildings were named as old and new, as they were built before and after the Regulation on Buildings to be Built in Disaster Areas (ABYYHY-1998). Section damage limits were determined by the nonlinear time history analysis method based on Türkiye Seismic Code 2007 (TSC-2007), TBEC-2018 and Eurocode 8 (EC 8) seismic codes. Considering the results obtained, it has been observed that the buildings called old or new according to the year of construction and the seismic codes taken as a basis are the effective factors on the section damage possibilities. As a result of the analysis results, it has been determined that the section damage probabilities obtained according to the TBEC-2018 seismic codes are higher than the other 2 seismic codes, and the section damage probabilities obtained according to the TSC-2007 seismic codes are lower than the other 2 seismic codes.

In the study carried out by Buzuku [11], the performance of a 24-storey reinforced concrete building with a height of 84 m, designed according to TSC- 2007, was evaluated using the nonlinear time history analysis method according to TBEC-2018 and EC 8 seismic codes and the results were compared. As a result, it was observed that the damage limit TBEC-2018 and EC 8 observed on a selected column gave very similar results.

In the study carried out by Severcan and Sinani [12], an existing reinforced concrete structure with 8 floors and a height of 24 m was taken as an example, and the performance of the existing structure was evaluated using pushover analysis and equivalent earthquake load method according to TSC-2007 and EC 8. The results were compared. According to the analysis results obtained, the structure; according to TSC-2007, it was determined that it was at the "Collapse State" performance level, and according to Eurocode 8, all columns and beams on the critical floor were not in a state of collapse. They observed that TSC-2007 remains in a safer zone than Eurocode 8, according to the generally evaluated employee performance levels.

In the study carried out by Kazancı [13], reinforced concrete structures with different number of floors designed in 3 different seismic zones and for 3 different soil classes were analysed using the equivalent earthquake load method and mode combining method given in the Turkish Seismic Code 2007 and Eurocode 8. The analysis results were compared according to the seismic codes under 2 categories: equivalent earthquake method and mode combination method. As a result, it was determined that the values obtained by the equivalent earthquake method were higher than the values obtained by the mode combining method.

In the study conducted by Işıltan [14], the determination of seismic performances of existing buildings and building elements and their safety issues against earthquakes were examined and compared according to TSC-2007, Eurocode 8 and FEMA 356 seismic codes. In addition, reinforced concrete column tests performed by different researchers were examined from the PEER database. Reinforced concrete ductile columns with different properties under the influence of horizontal loads; seismic performance was determined according to TSC-2007, EC 8 and FEMA 356 seismic codes and compared with the test results. According to the results obtained, it was observed that the seismic codes gave different results and were quite incompatible with the test results.

3. Material and Method

3.1. General information

In this study there are 3 constructions which are 10, 15 and 20 stories with have 7 spacings for X direction and 5 spacings for Y direction. These constructions have been considered as existing buildings in Bayraklı district of Izmir province, at 38.4633126 north latitude and 27.18229563 east longitude. The carrier system of constructions is a unhollow reinforced concrete shear wall frame system with high ductility. Figure 4-5 and Table 1-10 show detailed information about the structures. These constructions have the same floor plans, and each floor is 3m height. The purpose of use of the buildings is residential.

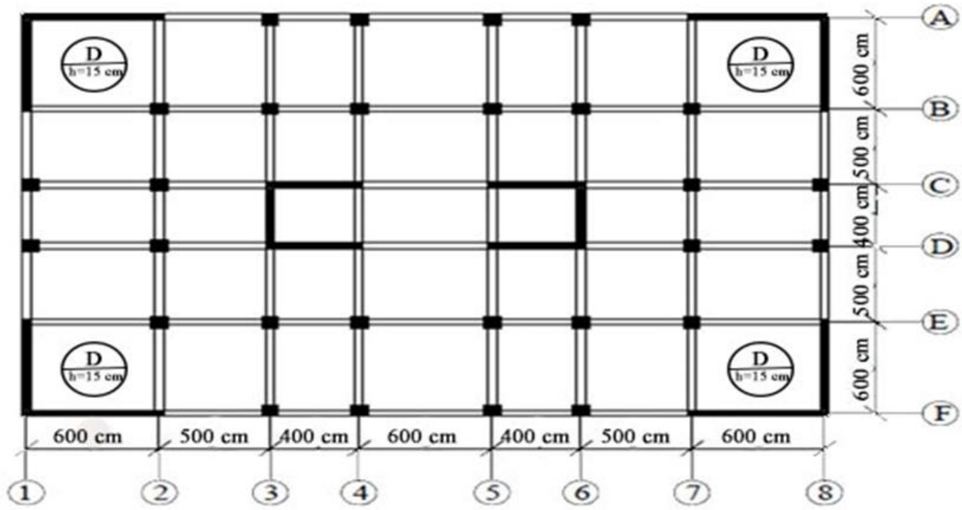

Figure 4. Floor plans for all structures.

Table 1. General information about the structures.

Number of Storeys	10	15	20
Type	Residential	Residential	Residential
Seismic Zone	1	1	1
Soil Class	ZD	ZD	ZD
Height of Storey (m)	3	3	3
Total Height (m)	30	45	60
Concrete Class	C35	C35	C35
Rebar	S420	S420	S420
Column Section (cmxcm)	65x60	85x75	95x90
Beam Section (cmxcm)	25x50	25x50	30x55
Slab Thickness (cm)	15	15	15
Shear Wall Thickness (cm)	25	25	30

Table 2. Beam section detail for 10-storey building

Constructional Component	Section (cmxcm)	Left Upper Support	Left Bottom Support	Mounting Rebar	Bottom Span	Right Upper Support	Right Bottom Support
Beam	25x50	3Ø18	2Ø16	1Ø16	2Ø16	3Ø18	2Ø16

Table 3. Column section detail for 10-storey building

Constructional Component	Section (cmxcm)	Reinforcement	Stirrup
Column	65x 60	20Ø16	Ø10

Table 4. Shear wall section detail for 10-storey building

Constructional Component	Section (cm)	End Zone	Web
Shear wall	25	Ø20	Ø16/200mm

Table 5. Beam section detail for 15-storey building

Constructional Component	Section (cmxcm)	Left Upper Support	Left Bottom Support	Mounting Rebar	Bottom Span	Right Upper Support	Right Bottom Support
Beam	25x50	3Ø20	3Ø16	2Ø16	2Ø16	3Ø20	3Ø16

Table 6. Column section detail for 15-storey building

Constructional Component	Section (cmxcm)	Reinforcement	Stirrup
Column	75x 85	26Ø18	Ø10

Table 7. Shear wall section detail for 15-storey building

Constructional Component	Section (cm)	End Zone	Web
Shear wall	25	Ø20	Ø16/200mm

Table 8. Beam section detail for 20-storey building.

Constructional Component	Section (cmxcm)	Left Upper Support	Left Bottom Support	Mounting Rebar	Bottom Span	Right Upper Support	Right Bottom Support
Beam	30x55	4Ø20	3Ø20	2Ø20	2Ø20	4Ø20	3Ø20

Table 9. Column section detail for 20-storey building.

Constructional Component	Section (cmxcm)	Reinforcement	Stirrup
Column	95x 90	28Ø20	Ø10

Table 10. Shear wall section detail for 20-storey building.

Constructional Component	Section (cm)	End Zone	Web
Shear wall	30	Ø20	Ø16/200mm

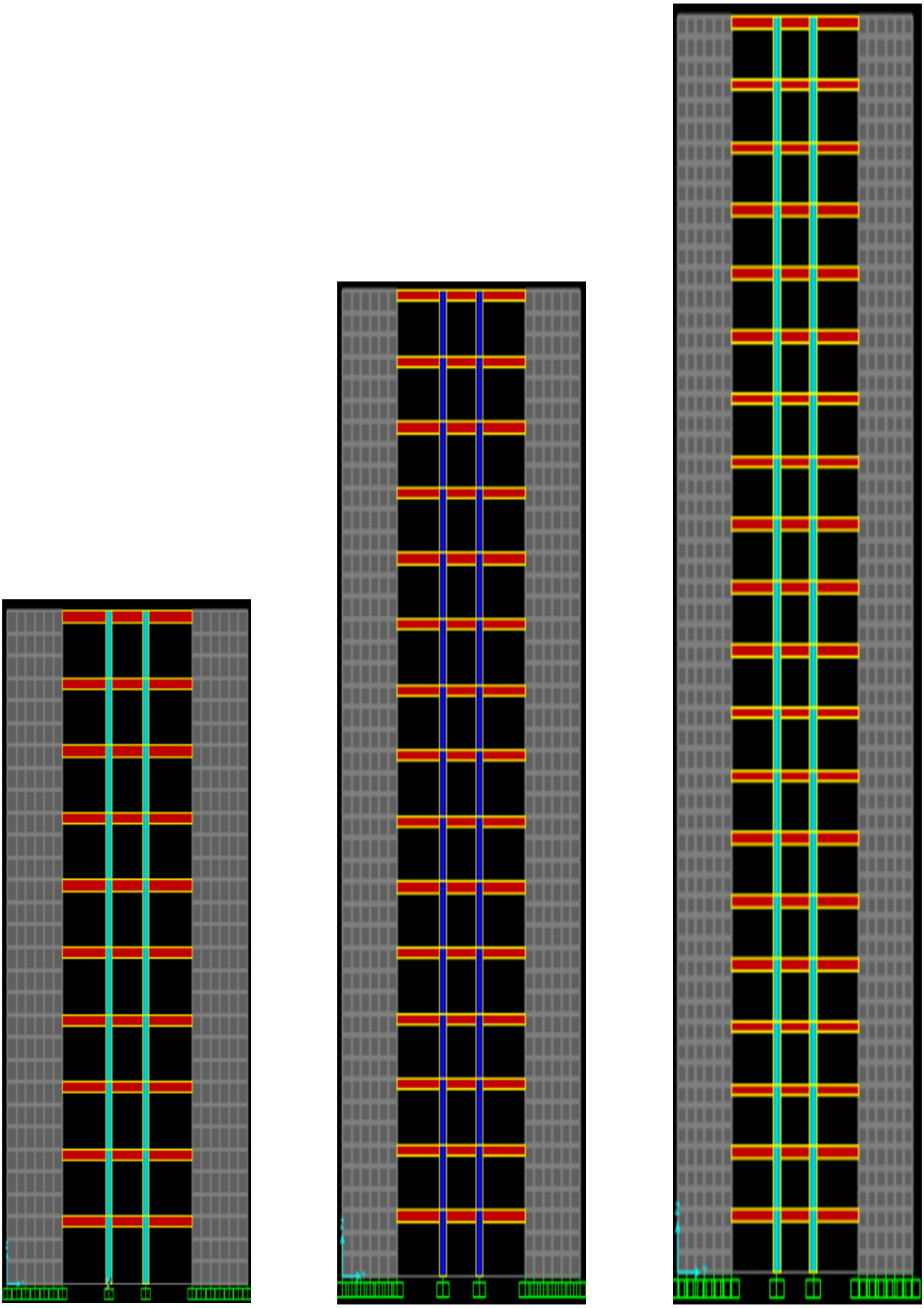

Figure 5. 1-1 sectional view of 10, 15 and 20 storey buildings.

3.2. Research and study method

Within the scope of this study, a nonlinear time history analysis method was preferred to obtain more realistic results within the advantages offered by scientific studies and computer software. In this study, through the PEER [15] (Pacific Earthquake Engineering Research Centre) database, which is based at UC Berkeley University and created in 1996, and the TADAS [16] (Türkiye Acceleration Database and Analysis System) application developed by AFAD in 2020; 11 earthquake ground motion records were selected according to TBEC-2018 [17] part 2 and part 5 as in Table 11. 4 ground motion records were selected according to EN 1998-1 [18] (Eurocode 8 part 1) section 3 and section 4 as in Table 12.

Ground motion records were selected by considering the fault type, magnitude, Joyner-Boore-distance (Rjb) and shear wave speed (Vs30) parameters as in Figure 6.

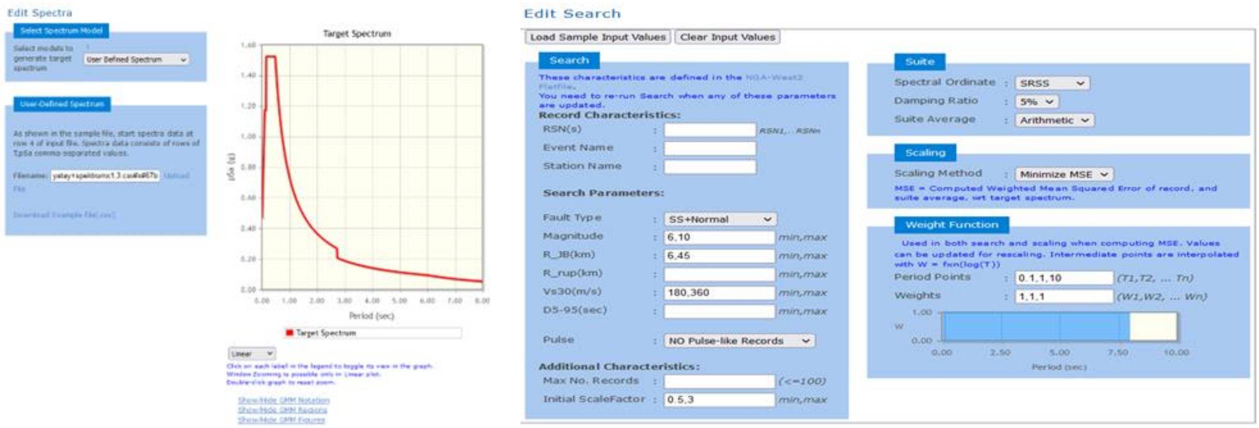

Figure 6. Search criteria for ground motion records on PEER.

Table 11. Selected ground motion records according to TBEC-2018.

PEER Record Number	Earthquake Name	Station Name	Magnitude (Mw)	Fault Type	Shear Wave Speed (m/s)	Rjb (km)	Scaling Factor
6	Imperial Valley	El Centro Array	6.95	strike-slip fault	213.44	6.09	2.11
30	Parkfield	Cholame Shandon Array	6.19	strike-slip fault	289.56	9.58	1.47
162	Imperial Valley	Calexico Fire Station	6.53	strike-slip fault	231.23	10.45	2.07
458	Morgan Hill	Gilroy Array	6.19	strike-slip fault	349.85	13.01	1.72
558	Chalfant Valley	Zack Brothers Ranch	6.19	strike-slip fault	316.19	6.44	1.13
725	Superstition Hills	Poe Road	6.54	strike-slip fault	316.64	11.16	1.63
848	Landers	Coolwater	7.28	strike-slip fault	352.98	19.74	1.5
1118	Kobe, Japan	Tadoka	6.9	strike-slip fault	312.0	31.69	1.26
1158	Kocaeli, Türkiye	Düzce	7.51	strike-slip fault	281.86	13.6	2.04
1615	Duzce, Türkiye	Lamont	7.14	strike-slip fault	338	9.14	2.33
6886	Darfield, New Zealand	Christchurch Hospital	7	strike-slip fault	194	18.4	2.64

Table 12. Selected ground motion records according to EC 8.

PEER Record Number	Earthquake Name	Station Name	Magnitude (Mw)	Fault Type	Shear Wave Speed (m/s)	Rjb (km)	Scaling Factor
6	Imperial Valley	El Centro Array	6.95	strike-slip fault	213.44	6.09	1.82
30	Parkfield	Cholame Shandon Array	6.19	strike-slip fault	289.56	9.58	1.27
1158	Kocaeli, Türkiye	Düzce	7.51	strike-slip fault	281.86	13.6	1.63
1615	Duzce, Türkiye	Lamont	7.14	strike-slip fault	338	9.14	2.03

Selected ground motion records were scaled on the PEER database. The obtained scaling coefficients were tested with the SeismoMatch [19] program (Figure 7).

The selected ground motion records were scaled with the scaling method offered by the PEER database, and it was observed that they were provided with the spectrum curve created as 30% more than the spectral acceleration values between 0.2Tp and 1.5Tp within the scope of TBEC-2018 as in Figure 8.

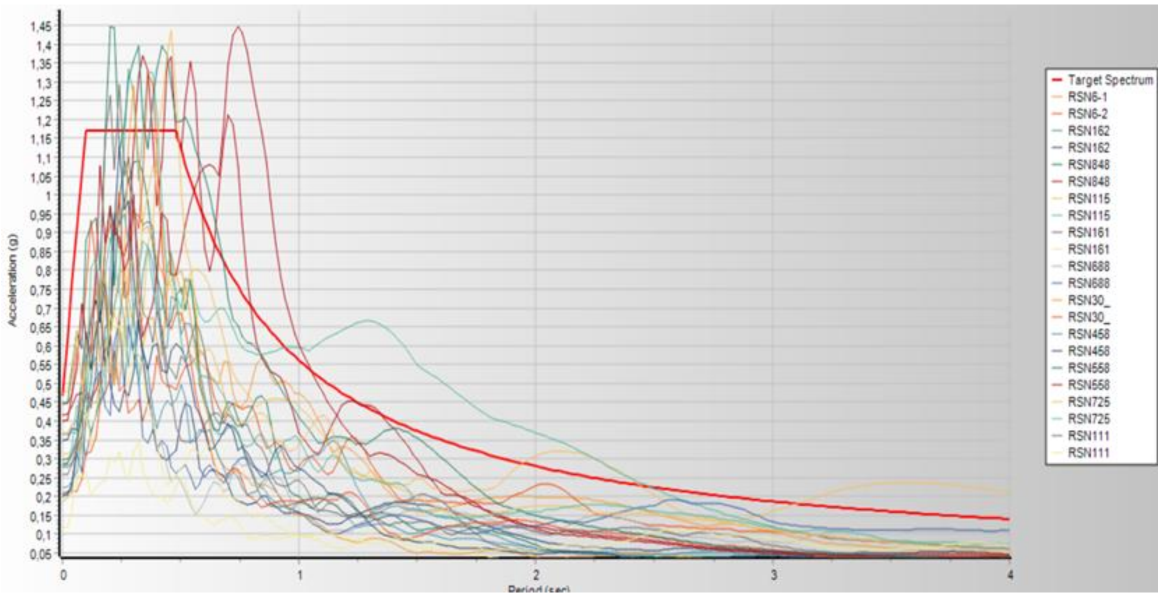

Figure 7. Unscaled view of selected ground motion records according to TBEC-2018 on SeismoMatch program.

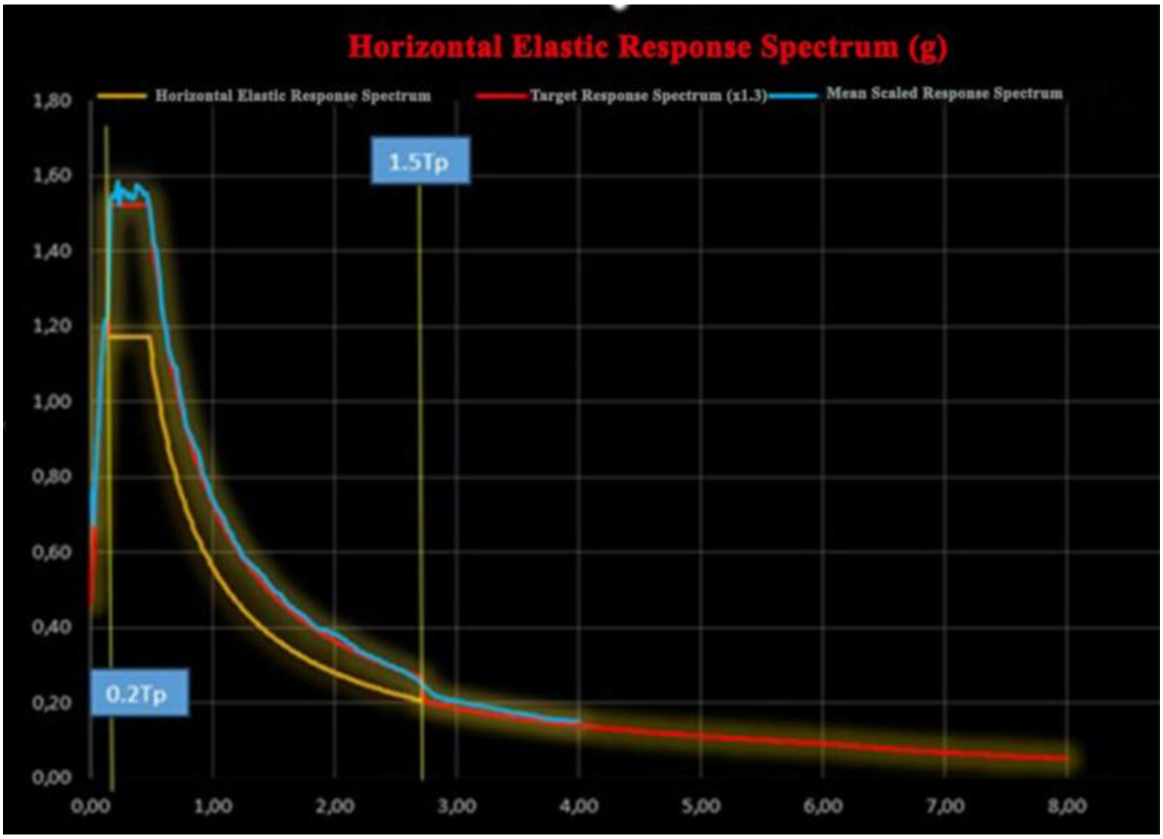

Figure 8. Mean response spectrum curve of scaled ground motion records according to TBEC-2018.

According to Figure 9, the accuracy of the scaling factors obtained from the PEER database has been determined and the condition that the mean spectrum values within the scope of EN 1998-1 should not be less than 90% of the values of the elastic response spectrum with 5% damping ratio in the period between 0.2T and 2T is ensured.

SAP2000 [20], a computer software, was preferred for analysis and calculations. Effective section stiffnesses were assigned for the modelled structures according to both seismic codes, and plastic hinges were defined. Then, the following steps were followed:

For nonlinear time history analysis, the response spectrum is defined according to both seismic codes as in Figure 10.

According to TBEC-2018, AFAD [21] interactive web application was used for response spectrum.

Response spectrum data defined according to Eurocode were taken from the EN 1998-1 seismic code.

Ground motion records were identified with the time history function as in Figure 11, then they were matched with the response spectrum in time domain as in Figure 12.

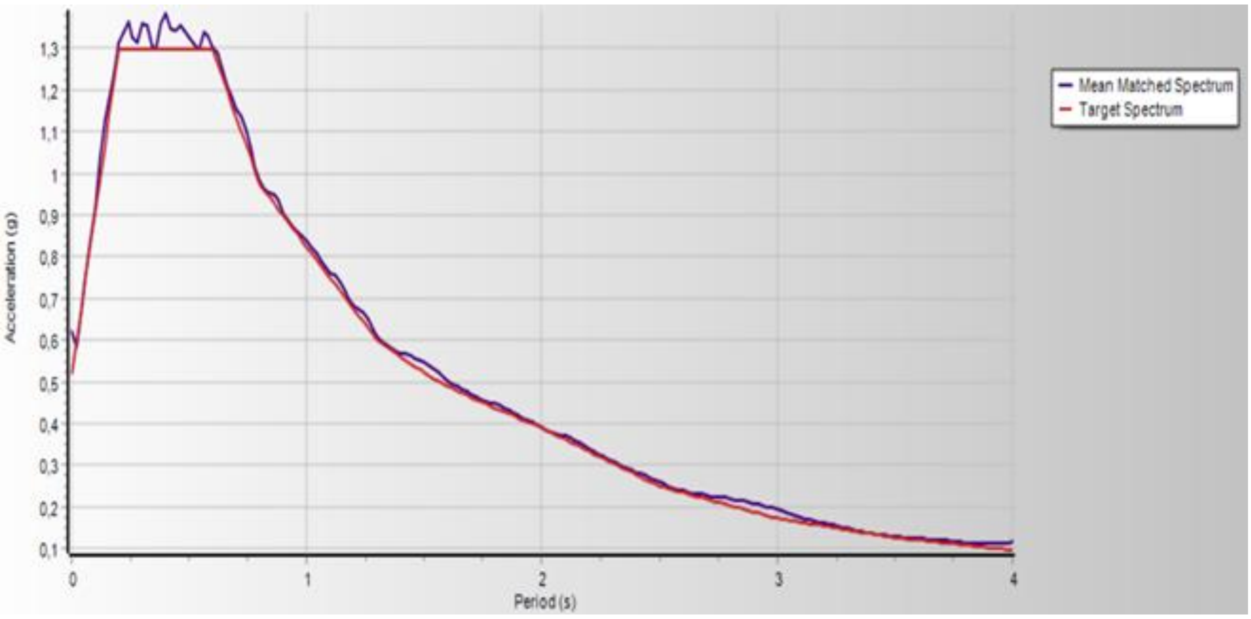

Figure 9. Mean response spectrum curve of scaled ground motion records according to EC 8 on SeismoMatch.

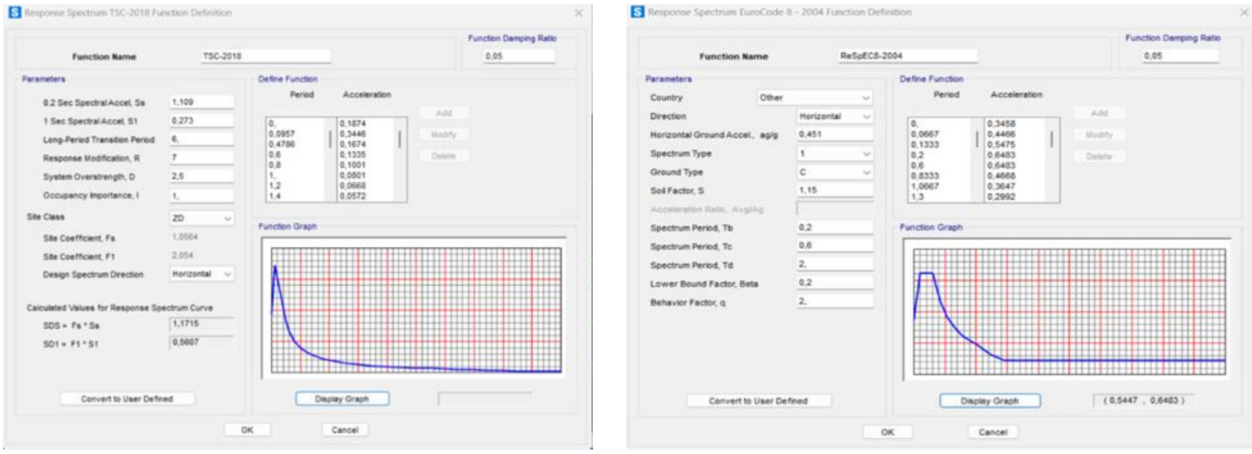

Figure 10. Response spectrum definition to SAP2000 according to TBEC-2018 and EC 8.

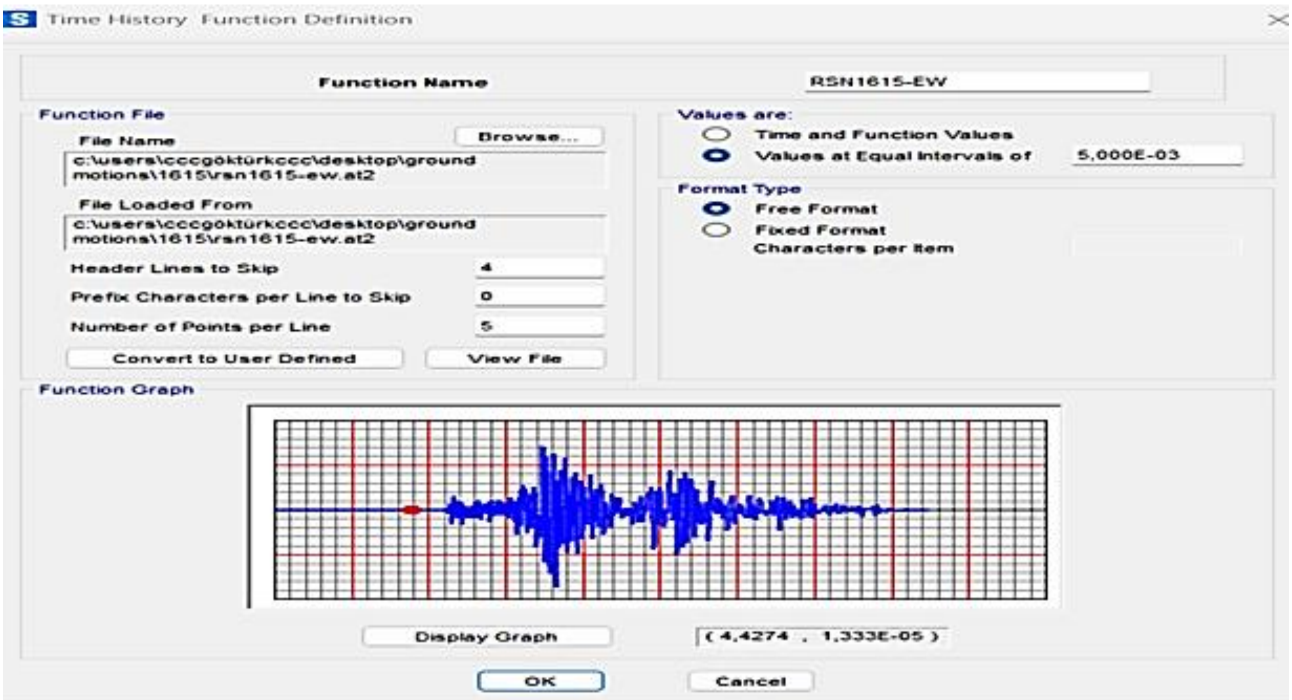

Figure 11. Definition of ground motion records on SAP2000.

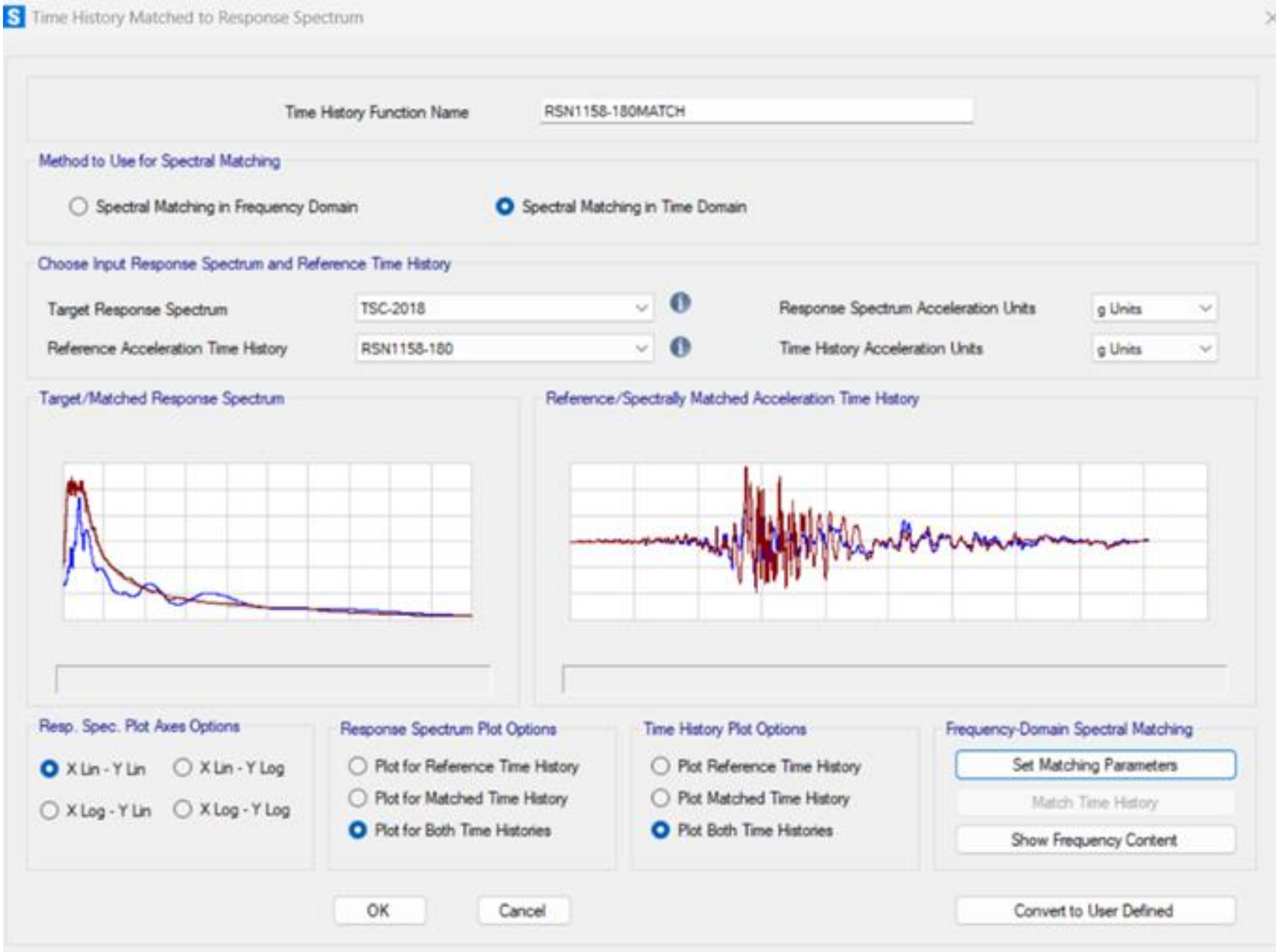

Figure 12. An example of spectral match on SAP2000.

After the matching process was completed, nonlinear time history (direct integration) function was defined as a load case in Figure 13 and analyses were performed.

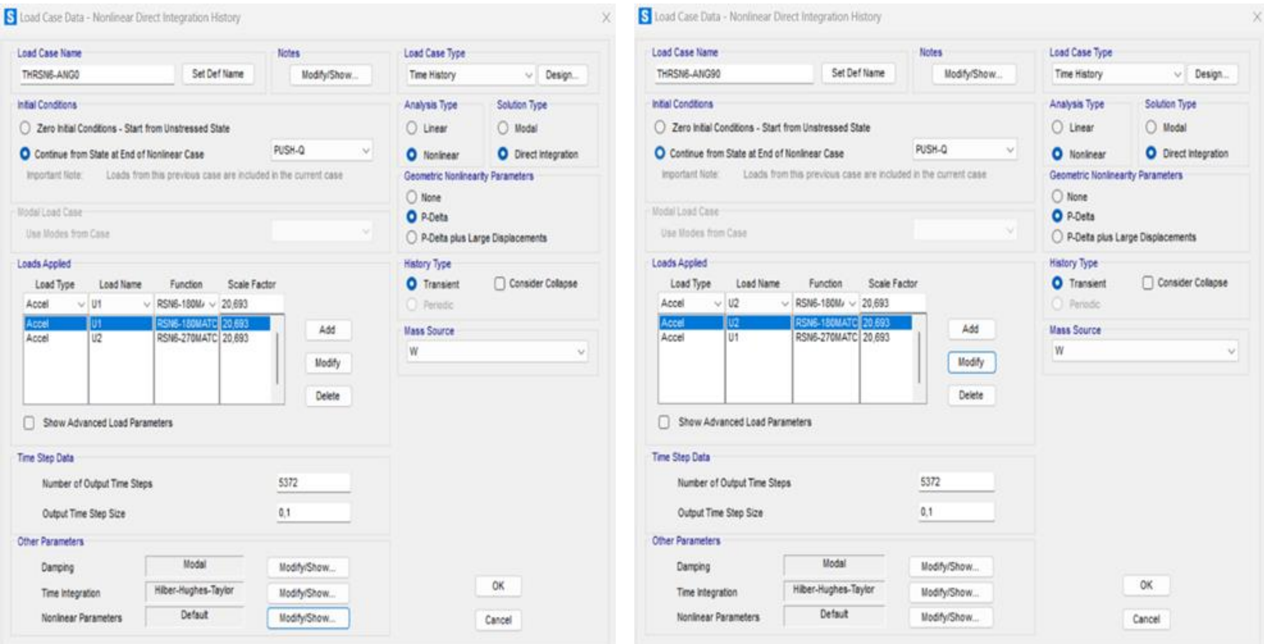

Figure 13. An example of NL time history load function on SAP2000.

Figure 14-16 show the 3D modelled images of the buildings on the SAP2000 program.

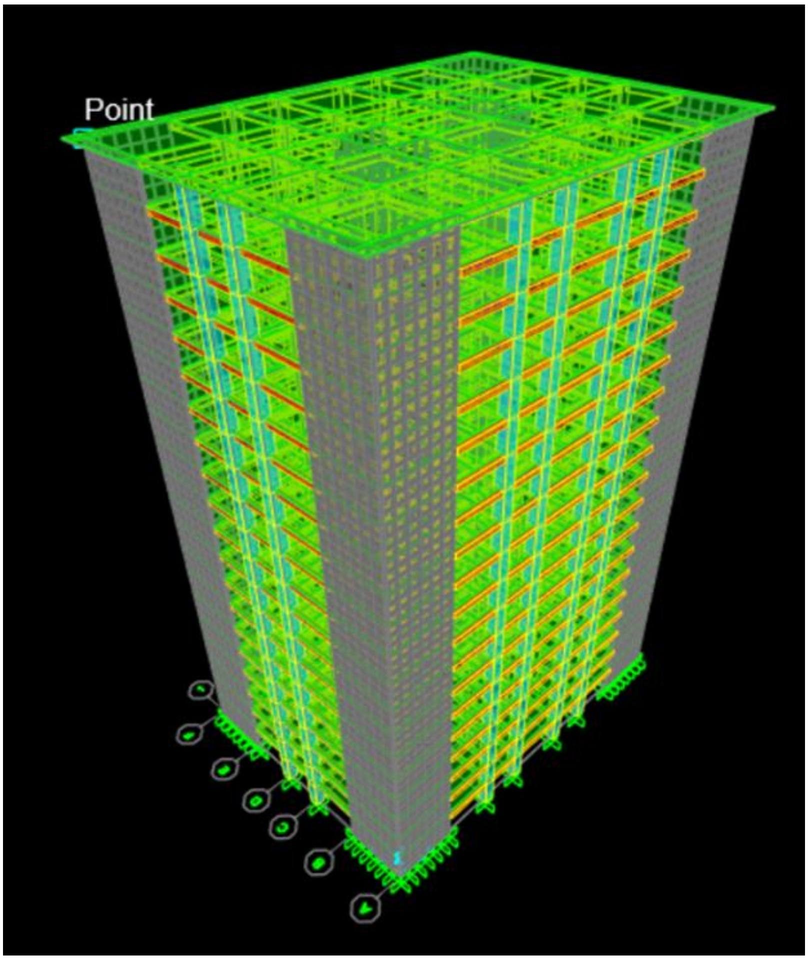

Figure 14. 3D model of the 20-storey building on SAP2000.

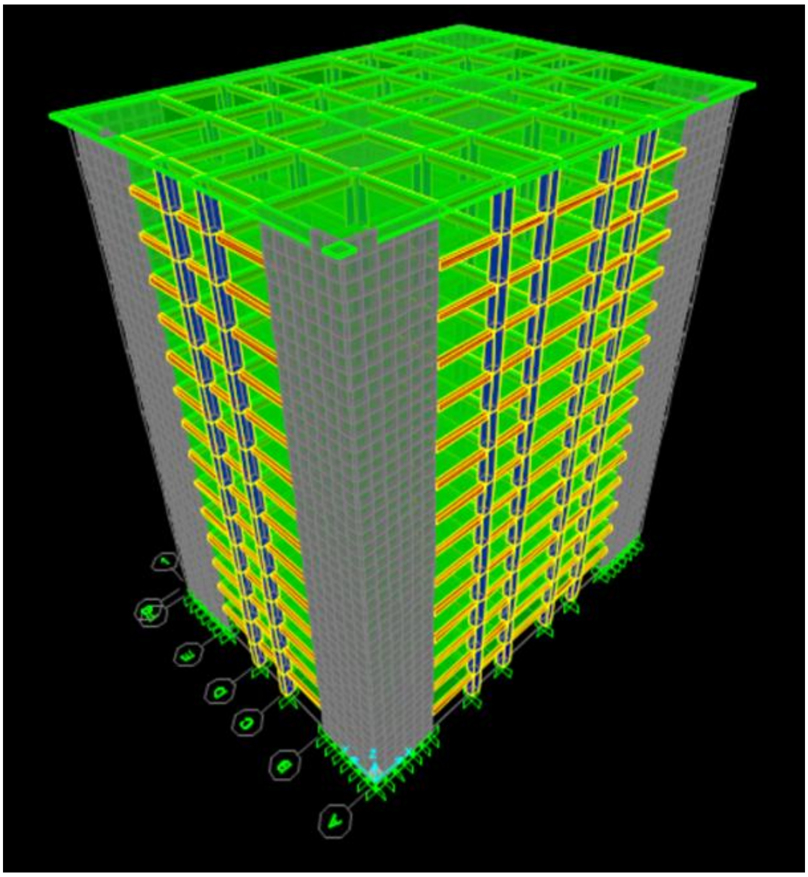

Figure 15. 3D model of the 15-storey building on SAP2000.

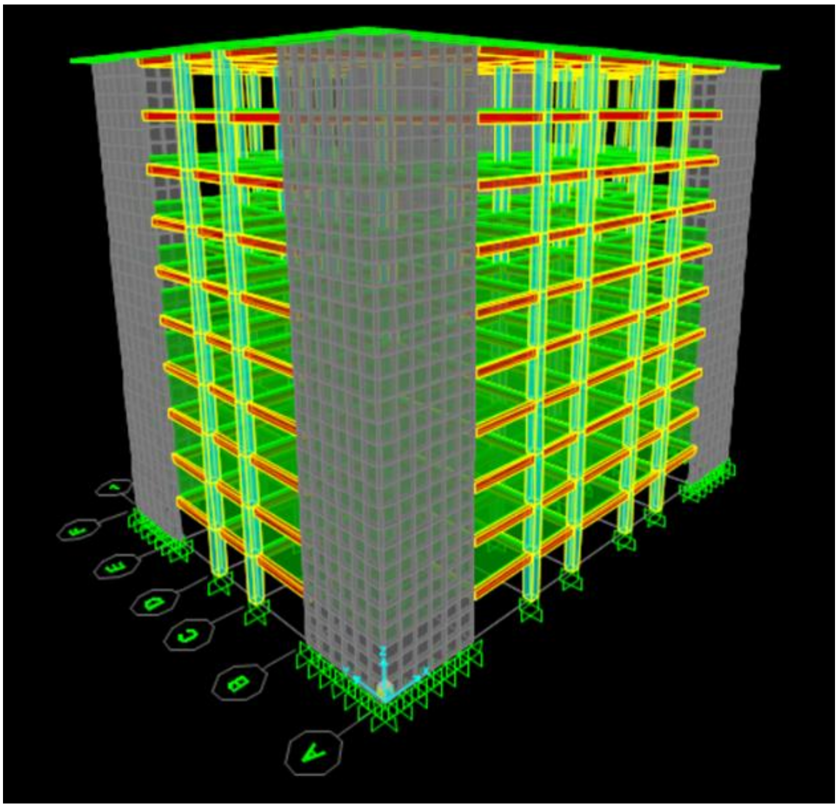

Figure 16. 3D model of the 10-storey building on SAP2000.

4. Results

Data regarding the top floor displacements, building vibration periods, and damage levels of structural elements for the most unfavourable of the analysis performed as an example are included in Table 13-23.

Table 13. Damage performances for beams (20-storey).

Beams	TBEC-2018	EC 8	% (TBEC-2018)	% (EC 8)
SH (DL)	884	775	65	56.98
KH (SD)	473	574	34.78	42.21
GÖ (NC)	3	11	0.22	0.81

Table 14. Damage performances for columns (20-storey).

Columns	TBEC-2018	EC 8	% (TBEC-2018)	% (EC 8)
KK (IO)	275	244	49.11	43.57
SH (DL)	260	279	46.43	49.82
KH (SD)	25	37	4.46	6.61

Table 15. Damage performances for shear walls (20-storey).

Shear walls	TBEC-2018	EC 8	% (TBEC-2018)	% (EC 8)
KK (IO)	114	113	95	94.17
SH (DL)	4	5	3.33	4.17
KH (SD)	2	2	1.67	1.67

Table 16. Damage performances for beams (15-storey).

Beams	TBEC-2018	EC 8	% (TBEC-2018)	% (EC 8)
KK (IO)	54	26	5.3	2.55
SH (DL)	666	622	65.29	60.98
KH (SD)	300	372	29.41	36.47

Table 17. Damage performances for columns (15-storey).

Columns	TBEC-2018	EC 8	% (TBEC-2018)	% (EC 8)
KK (IO)	175	132	41.67	31.43
SH (DL)	209	235	49.76	55.95
KH (SD)	36	53	8.57	12.62

Table 18. Damage performances for shear walls (15-storey).

Shear walls	TBEC-2018	EC 8	% (TBEC-2018)	% (EC 8)
KK (IO)	87	86	96.67	95.56
SH (DL)	2	3	2.22	3.33
KH (SD)	1	1	1.11	1.11

Table 19. Damage performances for beams (10-storey).

Beams	TBEC-2018	EC 8	% (TBEC-2018)	% (EC 8)
KK (IO)	109	56	16.03	8.235
SH (DL)	434	425	63.82	62.5
KH (SD)	137	199	20.15	29.265

Table 20. Damage performances for columns (10-storey).

Columns	TBEC-2018	EC 8	% (TBEC-2018)	% (EC 8)
KK (IO)	74	36	26.43	12.86
SH (DL)	163	176	58.21	62.86
KH (SD)	43	68	15.36	24.28

Table 21. Damage performances for shear walls (10-storey).

Shear walls	TBEC-2018	EC 8	% (TBEC-2018)	% (EC 8)
KK (IO)	58	58	96.67	96.67
SH (DL)	2	2	3.33	3.33
KH (SD)	0	0	0	0

Table 22. Max top floor displacement for all time history analyses.

	Ux (cm)	Uy (cm)
10-storey		
TBEC-2018	10.58	10.54
EC 8	16.28	16.53
15-storey		
TBEC-2018	18.46	19.25
EC 8	28.73	29.41
20-storey		
TBEC-2018	29.63	28.59
EC 8	42.37	42.26

Table 23. Building vibration periods.

	Tx (s)	Ty (s)
10-storey		
TBEC-2018	0.7928	0.7751
EC 8	0.7456	0.7288
15-storey		
TBEC-2018	1.3780	1.3680
EC 8	1.2490	1.2453
20-storey		
TBEC-2018	1.8137	1.8014
EC 8	1.6205	1.6103

5. Discussion

Although there are studies on determining the seismic performance of existing reinforced concrete buildings according to TBEC-2018 or EC 8, the studies carried out with both seismic codes are very few. While most of the identified studies are related to the TSC-2007 and Eurocode 8, very few studies are related to TBEC-2018 and Eurocode 8. Due to the lack of sufficient studies and the lack of common and clear findings among the studies conducted, in this study, the nonlinear time history analysis to be carried out according to Eurocode 8 was investigated more comprehensively. The nonlinear time history analysis in Eurocode 8 chapter 3 and chapter 4 was supplied the conditions, analyses have been made.

6. Conclusion

As a result of the source scans used within the scope of this study and the data obtained from the analysis results, it has been observed that there are differences between the evaluation criteria and approaches of existing structures between TBEC-2018 and Eurocode 8.

While the limits and criteria for the mathematical model are clearly defined within the scope of TBEC-2018, the criteria and limits regarding modelling rules within the scope of Eurocode 8 remain superficial compared to TBEC-2018.

There are also differences between the plastic hinge approaches defined according to both seismic codes. While within the scope of TBEC-2018, the section was considered as approximately h/2 in the working direction, within the scope of Eurocode 8, there are two different approaches depending on the confined concrete model and shear span at member end. As a result, within the scope of the study, three different plastic hinge lengths of the beams were obtained according to Eurocode 8, and the obtained plastic hinge lengths are higher than the value obtained according to TBEC-2018. In columns, the plastic hinge length obtained according to TBEC-2018 was higher than the plastic hinge length obtained according to Eurocode 8.

While there are clear criteria regarding material strength for existing structures according to TBEC-2018, the conditions or criteria regarding material strength for existing structures are limited within the scope of Eurocode 8. The expected average strength values for concrete materials and reinforcement steel within the scope of TBEC-2018 are 30% and 20% higher, respectively, than the values considered within the scope of Eurocode 8. As a result, when the data obtained because of the moment-curvature analysis performed on beams and columns are compared, it is seen that the values obtained according to TBEC-2018 are higher than EC 8.

As a result of the differences between plastic hinge lengths and material strength, the damage limit values of the structural elements calculated according to TBEC-2018 were higher than the values obtained according to Eurocode 8.

In Figure 17, it is seen that the damage status of the beams changes depending on the number of floors. It is seen from the graphs in Figure 17 that the damage rate on beams increases with the increase in the number of floors. As a result of the most unfavourable analysis, beams that passed into the near collapse zone were detected in the 20-storey building according to both seismic codes, but the damage rates obtained were at an acceptable level within the scope of the seismic codes. According to TBEC-2018, 3 pieces, i.e. 0.22% in proportion to all beams, and according to Eurocode 8, 11 pieces, i.e. 0.81% in proportion, have passed into this region. When the average results of the analyses are examined, it is seen that the significant damage level on the basis of beams is achieved in accordance with both seismic codes and damage rates obtained according to TBEC-2018 were lower than EC 8.

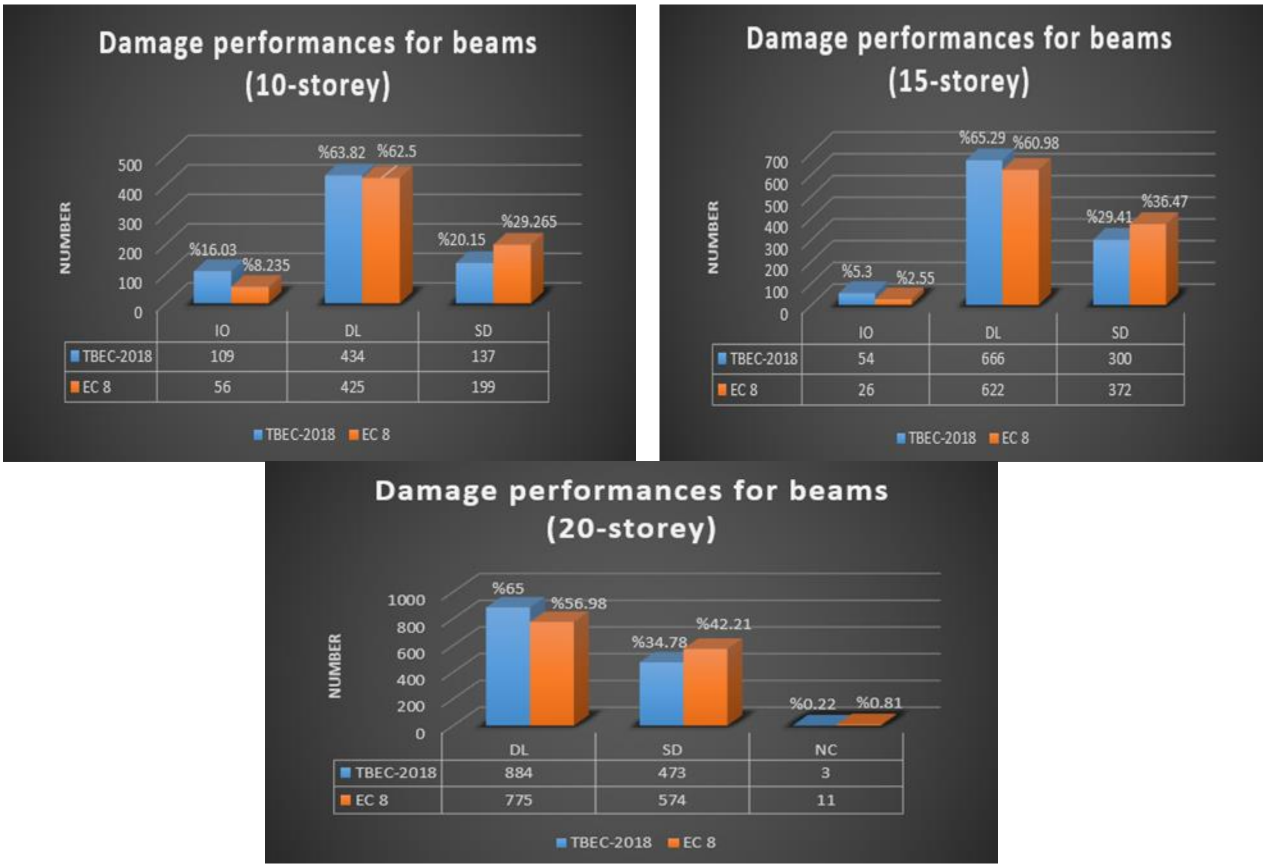

Figure 17. Comparison of beam damage ratios.

In Figure 18, it is seen that the damage status of the columns changes depending on the number of floors. It is seen from the graphs in Figure 18 that the damage rate on columns decreases with the increase in the number of floors. As a result of the most unfavourable analysis, 15.36% of the columns in the 10-storey building are in the significant damage level according to TBEC-2018, while 24.28% of the columns are in the significant damage level according to EC 8. In the 20-storey building, these damage rates were obtained as 4.46% according to TBEC-2018 and 6.61% according to EC 8. When the average results of the analyses are examined, it is seen that the limited damage level on the basis of columns is achieved in accordance with both seismic codes and damage rates obtained according to TBEC-2018 were lower than EC 8.

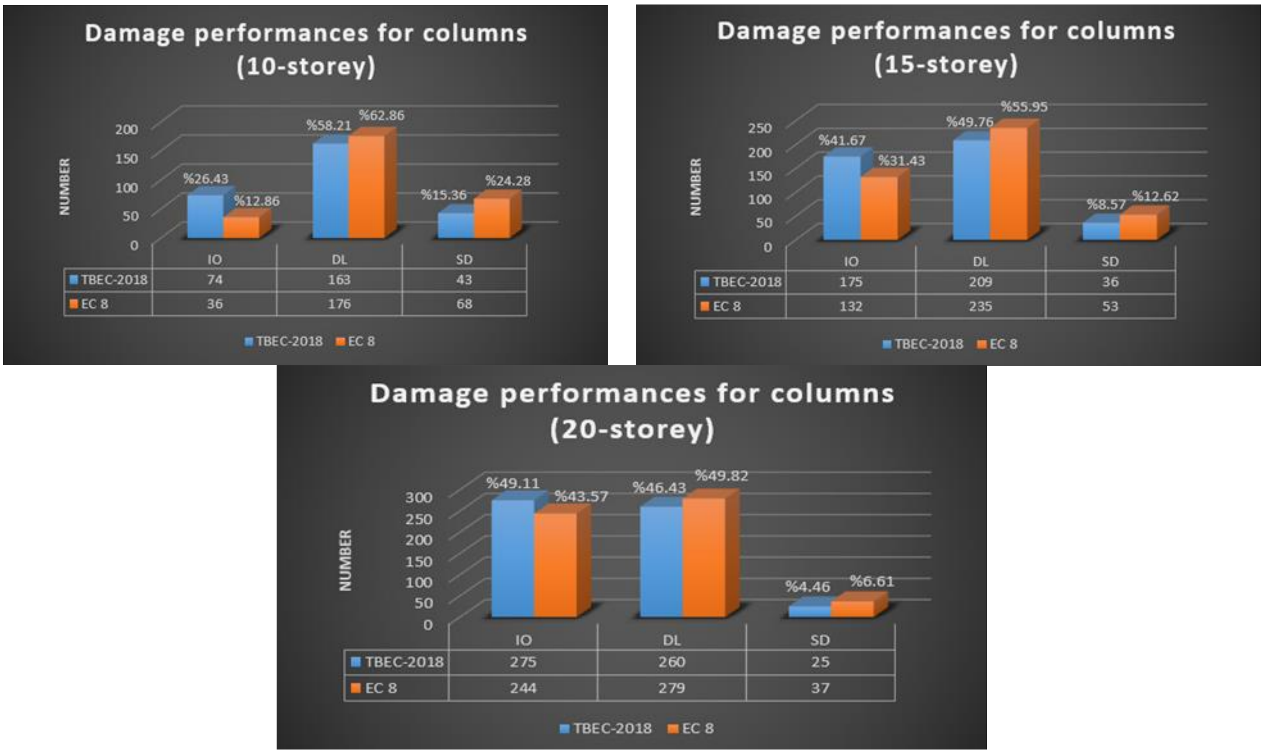

Figure 18. Comparison of columns damage ratios.

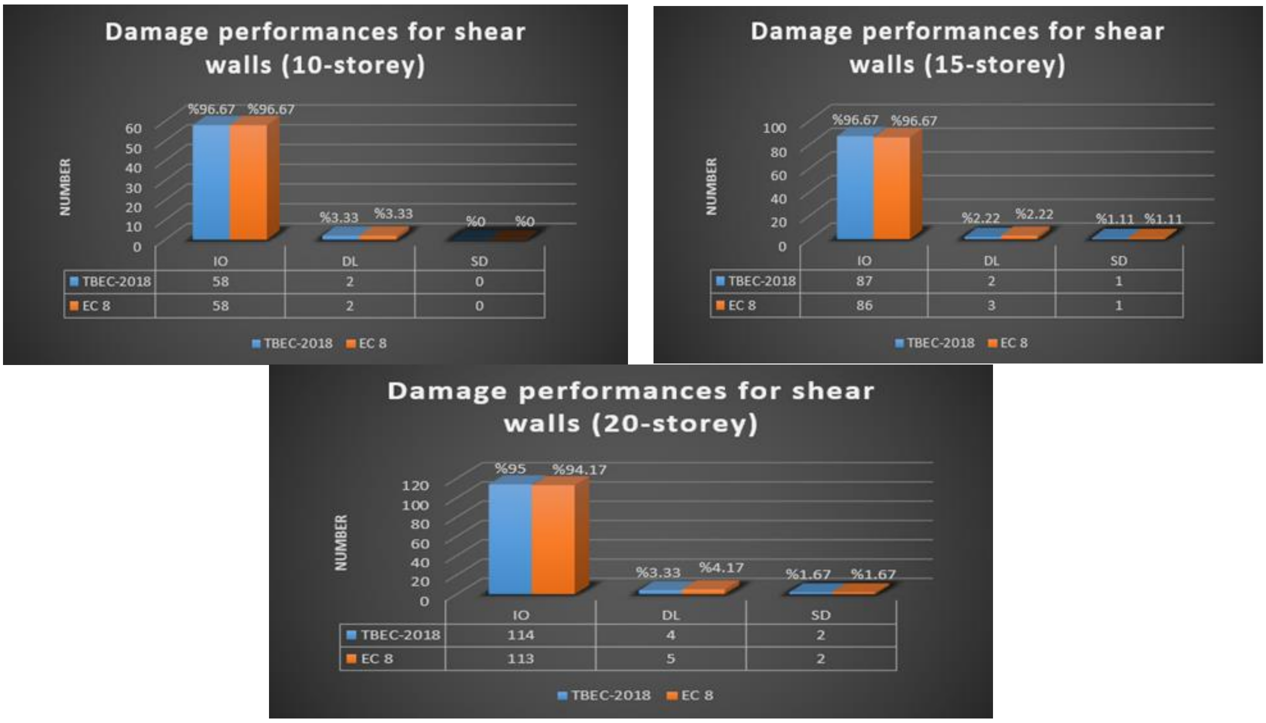

Figure 19. Comparison of shear walls damage ratios.

From the graphs in Figure 19, it is seen that as the number of floors increases, the damage rate on the shear walls increases, partially. In addition, the results obtained according to both seismic codes were very close to each other. When the damage rates are examined, it is seen that the damage level of the shear walls of the buildings is the immediate occupancy (IO) performance level.

There are different definitions and values in both seismic codes in terms of effective section stiffness. While within the scope of TBEC-2018, there are separate values for effective section stiffnesses (flexural, shear, shear and axial) in categories, in the scope of Eurocode 8, in the case of a cracked section, which is a general approach, half of the stiffness of the uncracked section can be taken, that is, a factor of 0.5. As a result, the vibration periods of the structures were higher than in TBEC-2018 as in Table 23.

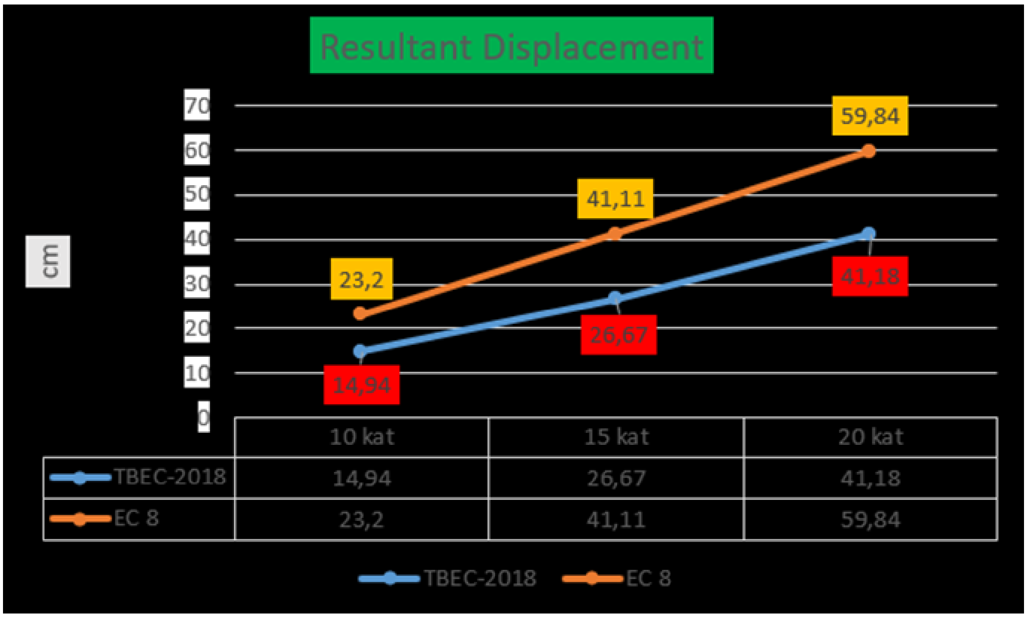

Figure 20. Resultant displacement graphic according to both seismic codes.

As a result of all time history analyses; The maximum displacement values of the buildings were obtained according to TBEC-2018 were lower than those of EC 8. In addition, it is seen in Table 22 and Figure 20 that as the number of floors increases, the numerical difference between the displacement results obtained according to TBEC-2018 and EC 8 increases.

It was determined within the scope of the study that there is a difference between the response spectra defined in both seismic codes for the current location of the buildings. The change in period-based spectral acceleration values due to the differences between the definitions within the scope of both seismic codes is graphically shown below as in Figure 21.

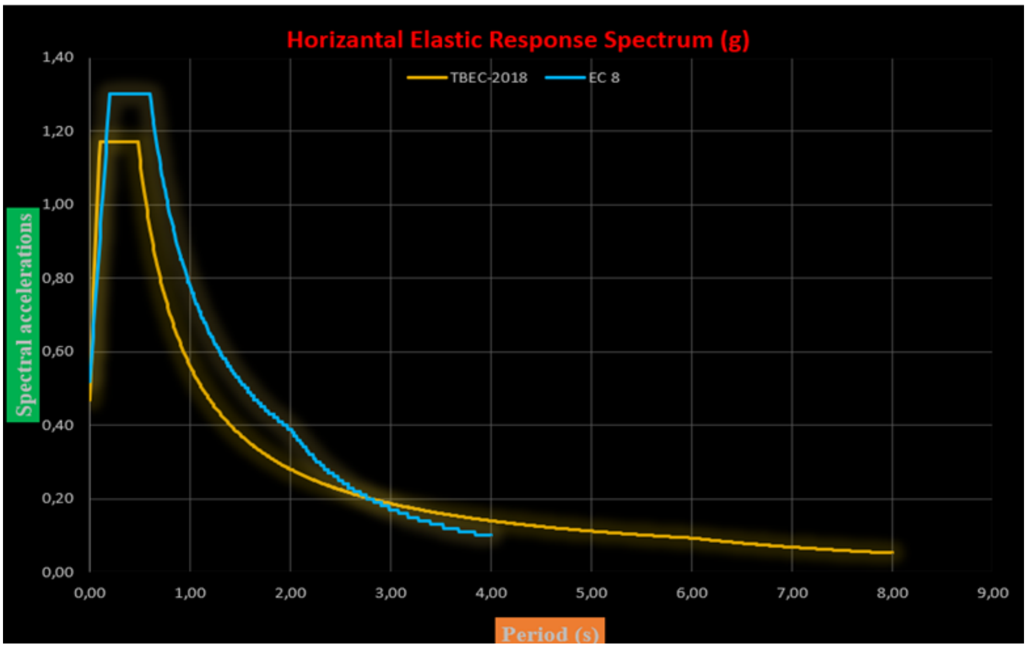

Figure 21. Comparison of response spectra of the location of the structures within the scope of TBEC-2018 and EC 8.

Within the scope of non-linear time history analyses, 22 analyses were made according to TBEC-2018 and 8 analyses were made according to Eurocode 8. When the average of the analyses carried out within the scope of both seismic codes are considered, it is seen that the targeted controlled damage performance level in structure elements is achieved within the scope of TBEC-2018 Section 15.8.4 and EN 1998-3 Section 2.2. According to both seismic codes, the earthquake record that had the most impact on buildings was the Düzce earthquake. The damage performances of the structures from this earthquake are presented in tables on results part.

When the data obtained within the scope of the study was examined, it was determined that TBEC-2018 was on the safer side compared to Eurocode 8.

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Author contributions

Mehmet Yılmaz: Conceptualization, Methodology, Software Data curation, Software, Visualization, Investigation, Writing-Reviewing and Editing. **Hüsnü Can:** Advisor, Review and Verification. **Fatmagül Köktaş:** Visual design, Software and Review.

Conflicts of interest

The authors declare no conflicts of interest.

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