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Tasarım Davranış Spektrumunun Saha Etkisi Dikkate Alınarak Değerlendirilmesi: Kocaeli Bölgesi Uygulaması, Türkiye

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ÖZET

Yeni yapılacak olan veya mevcut binaların güçlendirilmesinde deprem ivme hareketleri önemli bir rol oynamaktadır. Bu nedenle, modern deprem tasarım kodları, uygulama mühendislerine, farklı zemin sınıfları için standart tasarım davranış spektrumu sağlamaktadır. Bu çalışmada, yüksek depremselliğe sahip Kocaeli bölgesindeki EC8 ve TBDY tasarım davranış spektrumu uygulamaları değerlendirilmektedir. Bu amaçla, öncelikle Kocaeli bölgesinin depremselliği, 17 Ağustos 1999 (Kocaeli) depremini de dikkate alarak, sunulmuştur. İkinci olarak, bu iki kodun tasarım davranış spektrumları birbirleriyle ve dört farklı zemin sınıfında kaydedilen gerçek ivme hareketlerinin spektral davranış eğrileri ile karşılaştırılmıştır. Daha sonra iki betonarme bina modelleri davranış spektrum analizleri ile incelenmiştir. Geçmiş sismik hareketler göz önüne alındığında, bölgenin her zaman büyüklüğü 5.0'den büyük olan deprem olaylarına eğilimli olduğu görülmektedir. Ayrıca Kocaeli deprem ivme hareketlerinin zemin özelliklerine bağlı olarak değiştikleri gözlemlenmiştir. Bunun yanında, her iki deprem tasarım kodları da Kocaeli bölgesindeki her zemin sınıfında gerçek spektral değerlerini kapsayan tasarım davranış spektrumu sağlamaktadır. Bina analizlerinin sonuçları, EC8 tasarım tepki spektrumları ile elde edilen kesme kuvvetlerinin TBEC ve gerçek deprem spektral ivme değerlerinin kullanıldığı durumda elde edilen kesme kuvvetlerinden daha muhafazakar sonuçlar verdiği görülmektedir.

Considerations of Design Response Spectrum Involving Site Effect: Application to the Kocaeli Region, Türkiye

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ABSTRACT

Earthquake input motions perform critical role in the design of new or retrofitting of existing buildings. Therefore, modern seismic design codes guide engineering practitioners in delivering standard design response spectra for different soil classes. In this study, the applications of EC8 and TBEC design response spectra in the high-seismicity region of Kocaeli are evaluated. For that purpose, firstly, the seismicity of Kocaeli region involving the 17 August 1999 (Kocaeli) earthquake event is presented. Secondly, design response spectra of these two codes are compared with each other and with the spectral response curves of the actual input motions recorded at four different soil classes. Later, two reinforced concrete building models are analyzed by means of response spectrum analyses. Based on past seismic activities, the area is always prone to earthquake events, possibly occurring with magnitudes greater than 5.0. Also, the characteristics of the Kocaeli earthquake input motions were shown to be altered by the changes in the soil deposits. Besides, both seismic design codes are able to provide design response spectra covering the actual spectral values well at each soil class in the Kocaeli region. The results of building analyses suggest that the EC8 design response spectra offer more conservative building shear forces, followed by the TBEC and the actual ones.

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INTRODUCTION

Involvement of earthquake input motions in the design of structural buildings is very critical for building functioning after the earthquake event and, most importantly, for life safety. In order to verify that a structure can be able to retain its stability during seismic excitation, a seismic performance analysis is required [1]. The analysis involves spectral accelerations that represent the characteristics of the earthquake events prone to occur in the studied area [2]. The spectral acceleration values are greatly influenced by the features of the soil where the building is positioned. Because, depending on the soil characteristics, the frequency content, duration and peak ground values of the earthquake input motions undergo substantial alterations [3]. Such effects were reported following previous major earthquake events [4-6]. Therefore, the seismicity of the site and the local site conditions are pivotal factors shaping the spectral accelerations of an earthquake event (along with its magnitude) on the ground surface [7].

Seismicity of the site is determined by means of seismic hazard analysis based on the fault mechanism, occurrence rate and distance of the site to fault points [8]. Well-known attenuation relationships utilised in the seismic hazard analysis are Abrahamson-Silva [9], Boore [10], Campell [11], Ambraseys [12] and Idriss [13] models. Once the seismicity of the site is described, the local site conditions have to be characterized. Subsequently, proper site response analysis involving the nonlinear soil behavior is necessary to determine local site effect on earthquake input motions. When sufficient information for a site is unavailable, the average shear wave velocity at the top 30 m ($V_{S,30}$) is suggested to represent seismic soil behavior [14-15]. $V_{S,30}$ profile of a site can easily be attained from in-hole (i.e. Down-Hole or Cross-Hole) or surface (SASW, MASW or Microtremors) geophysical tests [16]. Else, it can also be depicted from the results of well-known field tests (i.e. standard penetration or cone penetration tests) [17-18].

Every earthquake event has unique spectral acceleration curves with several spectral peaks at varying periods. Therefore, one cannot rely on one single spectral acceleration curve in seismic performance analysis of a building in a specific site [2]. For this reason, there should be a standard design response spectrum that can represent all possible earthquake events. In the early developments of a standard response spectrum it was thought that, when considerable number of earthquake events are available, a general smooth design spectral acceleration curve can be proposed (e.g., [19-21]). With the increase of the earthquake input motion recordings in parallel with the technological developments enabling to better investigate soil deposits and fault mechanisms, the modern seismic design codes, as American Society of Civil Engineering (ASCE) [22], Eurocode 8 (EC8) [23] and Turkish Building Earthquake Code (TBEC) [24], provide smooth design response spectra. These seismic design codes involve distinct design response spectrum for every soil class classified with respect to the $V_{S,30}$. When the design response spectrum for the stiff soil deposits (having relatively higher $V_{S,30}$) represents the spectral peaks at shorter periods, it, for the soft soil deposits, covers the spectral peaks at longer periods [25-27].

The proxy of EC8 design response spectra are discussed by Rey et al. [28]. The study considered the earthquake input motions from the European Strong Motion Database and recommended different soil factors than the EC8 ones. Another work dealt with actual input motions archived in the K-Net Japanese Database. It was suggested to consider the larger spectral plateau than the ones given in the EC8 design response spectra [29] The studies conducted by Pitilakis et al. [30] and Pitilakis et al. [31] also proposed new soil factors and design response spectra. In a similar way, the suitability of TBEC design response spectra was evaluated by considering the Kahramanmaras earthquake events occurred on February 6, 2023 [32]. It was concluded that the design response spectra are not capable of fully representing the actual spectral accelerations, especially at longer periods for soft soil deposits. The current and previous seismic hazard map over Türkiye was studied in terms of acceleration spectrum intensity (ASI) calculated from the spectral acceleration curves [33]. The results indicated that the ASI of current design response spectra for soft soil classes (i.e. ZE and ZD) are larger than the previous one in most of the studied cities, while at other soil classes (i.e. ZA, ZB and ZC) the ASI values increase in some cities and decrease in others. Similarly, short period and 1 s spectral acceleration values of the current and previous TBEC design response spectra were compared. It was found that the new version of the code provide greater spectral values than the previous one in short period when at 1 s the changes in spectral acceleration values vary depending on the location [34].

Particular interest of this study is an area in Türkiye (i.e., Kocaeli region) with high level of seismic hazard risk, as remembered by the 17 August 1999 Kocaeli earthquake event [35]. In 2018, tTBEC has been modified, particularly, in terms of design response spectrum and seismic soil classification. These modifications are obviously aimed to better design the buildings by, partly, better representing the earthquake input motions and the local site conditions. For this reason, this work aims to address the suitability of the design response spectra recommended by TBEC 2018 and EC8 applied in the Kocaeli province, Türkiye. The paper carries on by, firstly, explaining the seismic soil classifications at both codes. Subsequently, the seismicity of the site inlcuding the site effect observed in the 1999 Kocaeli earthquake event is specifically investigated. Afterwards, the suitability of code suggested design response spectra is represented by comparing them, at each soil class, with each other and with the spectral accelerations of the actual earthquake input motions. Lastly, the seismic performance analyses of 4 and 8 storey buildings are conducted through design response spectrum analysis method by considering the TBEC, EC8 and actual response spectrum curves.

EC8 And TBEC Design Response Spectra

In this study, the design response spectra given by TBEC 2018 and EC8 are assessed by comparing with the actual spectral accelerations of the input motions recorded across Türkiye. The reason to assess the TBEC design response spectra is due to the fact that it is applied in Türkiye as the study area and considered actual input motions are within the country. Besides, consideration of EC8 design response spectra is firstly for comparision purposes. Secondly, it sets up the basis for seismic design in Europe, in particular in seismically active countries (i.e., Italy, Greece, Romania).

It should be stressed that in the previous version of the TBEC code (i.e. [36]), the country was divided into four regions based on different levels of seismic intensity, with each region experiencing ground acceleration during an earthquake as follows: 0.1g, 0.2g. 0.3g and 0.4g.. In addition, it included constant corner periods and soil factors for each soil classes (e.g. soil classes A, B, C and D) in forming the design response spectra (similar approach included in EC8, too). In contrast, in the new version of the code, every specific location within Türkiye has unique PGA level defined by AFAD through the attenuation laws. Moreover, it defines short (0.2 s) and long period (1 s) spectral accelerations, used, which, along with the involvement of soil factors, determine corner periods and spectral accelerations.

The ranges of V_s utilized to classify a soil site are the same in EC8 and TBEC 2018. The difference lies only in the syllables, due to the fact that TBEC 2018 separates rock soil site into two groups as shown in Table 1. This study considers the syllables of EC8 in the classification of the soil site. EC8 makes two different design response spectra for each soil class available, based on earthquake magnitude. When the magnitude is equal or smaller than 5.5 it is regarded as Type 2. If it is greater than 5.5, it is called as Type 1. On the contrary, TBEC does not differentiate the design response spectra in respect to the earthquake magnitude.

Table 1. *Shear wave velocity ranges in classifying seismic soil sites provided by EC8 And TBEC 2018*

Design code/ $V_{S,30}$ (m/s) range	>1500	760-1500	360-760	180-360	<180
EC8	A		B	C	D
TBEC 2018	A	B	C	D	E

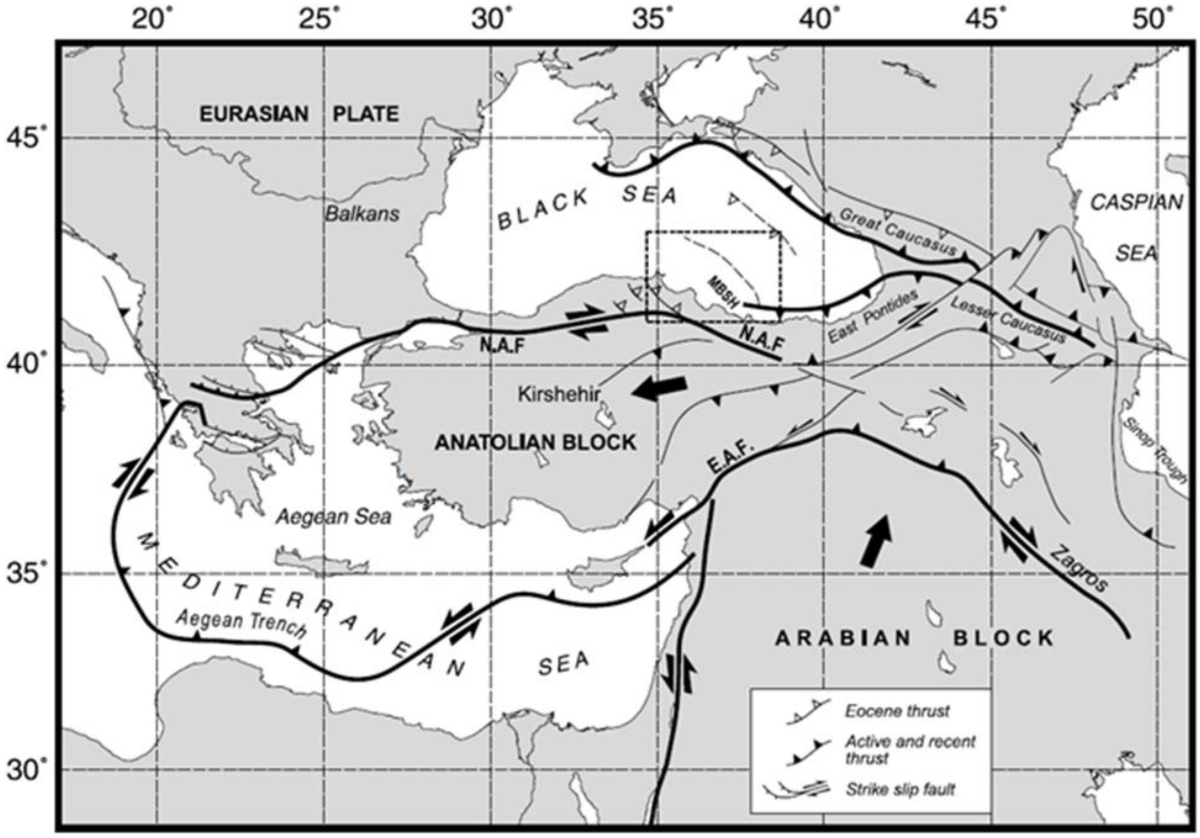

Figure 1. *Tectonic plates and North Anatolian and East Anatolian Fault Zones [37]*

Location And Seismicity Of The Site

The country of Türkiye is located on the borders between the Anatolian and Euroasian plates and between the Anatolian and Arabian plates. The relative movement between the Arabian and Anatolian plates and between the Euroasian and Anatolian plates are regarded as 6-10 mm/yr and 18.7-21.5 mm/yr, respectively [38-39]. This creates inter-plate fault zones along the plate borders named as North Anatolian Fault Zone (NAFZ) and East Anatolian Fault Zone (EAFZ). When NAFZ extends from east to west with 1600 km, EAFZ stretches from east towards southwest with 500 km, as seen in **Hata! Başvuru kaynağı bulunamadı.**.

The seismic intensity levels over the country of Türkiye is presented in **Hata! Başvuru kaynağı bulunamadı.**a. It is clear from the figure that the level of peak ground accelerations (PGA) are greater at sites closer to the fault zones (being as high as 0.76g). The PGA levels at far distant sites get lower with a minimum value of 0.071g. The focused site of Kocaeli region is located in the west-side of the country, neighboring with Istanbul, over NAFZ. The seismic intensity level of the region is closely shown in **Hata! Başvuru kaynağı bulunamadı.**b and is equal to, on average, 0.46g.

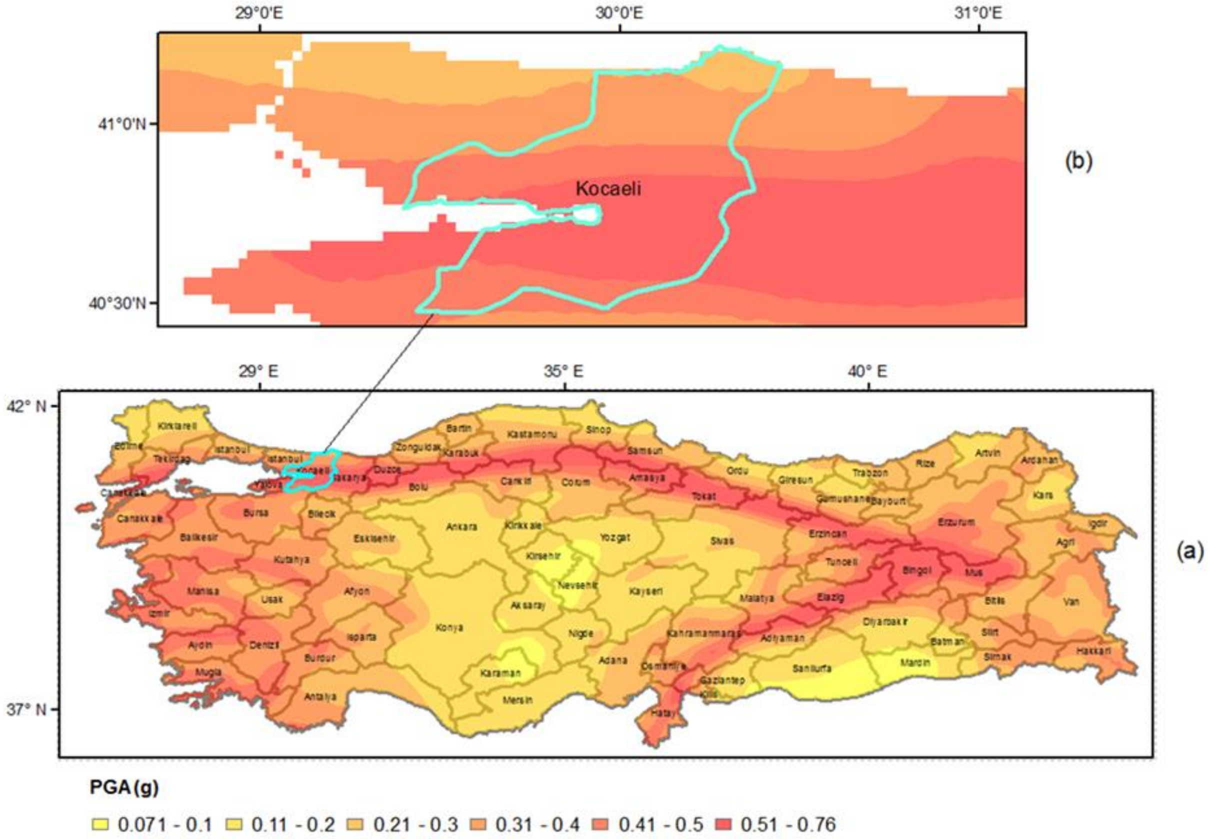

Figure 2. *(a) Seismic map of Türkiye and (b) specifically the Kocaeli Region in terms of PGA level*

Figure 3 exhibits the past earthquake eventswithin and around the Kocaeli region. It is obvious that the greater the magnitude of an earthquake event gets, the rare it takes place. More precisely, the number of recorded earthquake events with different magnitude ranges is given in **Hata! Başvuru kaynağı bulunamadı.** along with the annual rate of exceedance. When magnitudes between 4-4.5 occurs 143 times past 50 years, for 4.51-5.00 and for 5.10 and 5.50 magnitude ranges, the frequency values are 29 and 22, respectively. In addition, only 4 earthquake events with magnitude greater than 5.5 have been recorded around the region. This trend is also reflected in the annual rate of exceedance values getting smaller with the earthquake magnitudes becoming higher.

Table 2. *The number of earthquake event occurrences (in 50 years) with specific magnitude ranges around the Kocaeli Region within the circle of 120 km in radius*

Magnitude range	4.00- 4.50	4.51-5.00	5.10-5.50	5.60-6.00	6.10-7.60
Number of occurrences	143	29	22	2	2
Annual rate of exceedance	2.86	0.58	0.44	0.04	0.04

Kocaeli Earthquake Event And Site Effect Observations

One of the most remarkable and devastating earthquake event took place, within the region, on 17 August 1999 with a moment magnitude of 7.4 [40]. It resulted in 15851 deaths and 43,953 injuries along with estimated 20 billion dollars of economic loss [41-42]. When the epicenter of the earthquake event was within the Kocaeli region (with latitude 40.76 and longitude 29.97 degrees), it was felt quite considerably at neighboring cities including the densely populated city of Istanbul. **Hata! Başvuru kaynağı bulunamadı.** indicates the positons of the stations where the earthquake input motions were recorded. The changes of PGAs with the epicentral distance are plotted in **Hata! Başvuru kaynağı bulunamadı.** along with the empirical models of Campell [43], Idriss [44] and Ulusay [45]. It is clear that only a single recorded PGA is

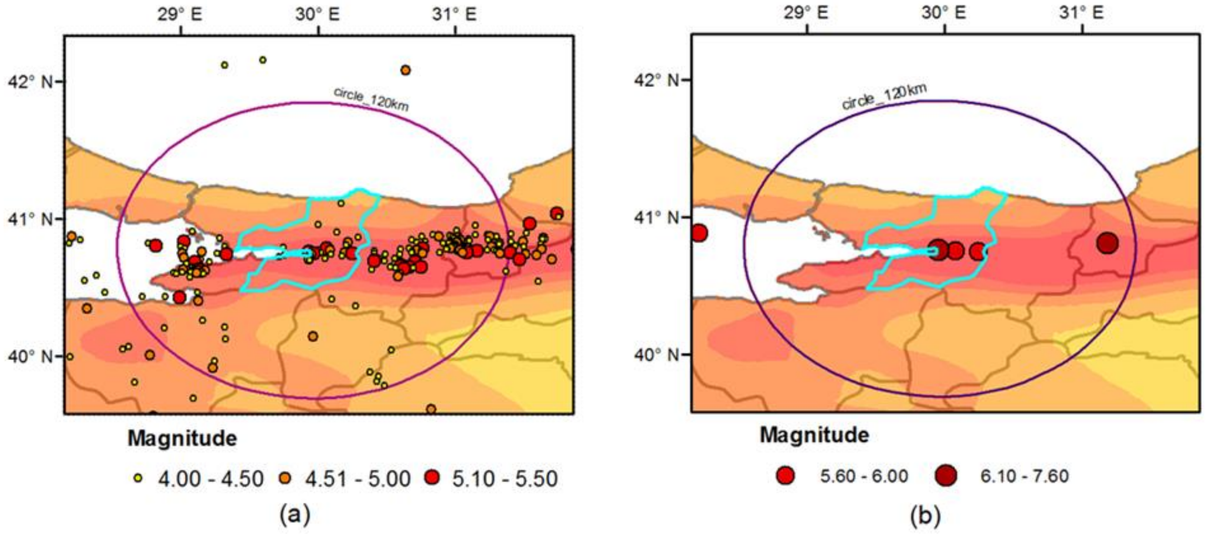

Figure 3. *Past earthquake events since 1900 with magnitudes ranging from; (a) 4 to 5.5 and (b) from 5.5 to 7.6*

in line with the Campell and Idriss approaches at epicentral distance of 3.4 km. Neither of the three empirical approaches can be able to capture the actual recorded PGAs, at epicentral distances ranging from 36 to 561 km, which are always greater than the empirical predictions. Amongst the empirical approaches, Campell and Idriss formula follows similar linear PGA predictions with distance when Ulusay model predictions are almost same from 1 km to 30 km, then draws parabolic curve with decreasing pattern. This prediction pattern of Ulusay model leads to closer matches with the actual recordings at distances from 30 to 150 km.

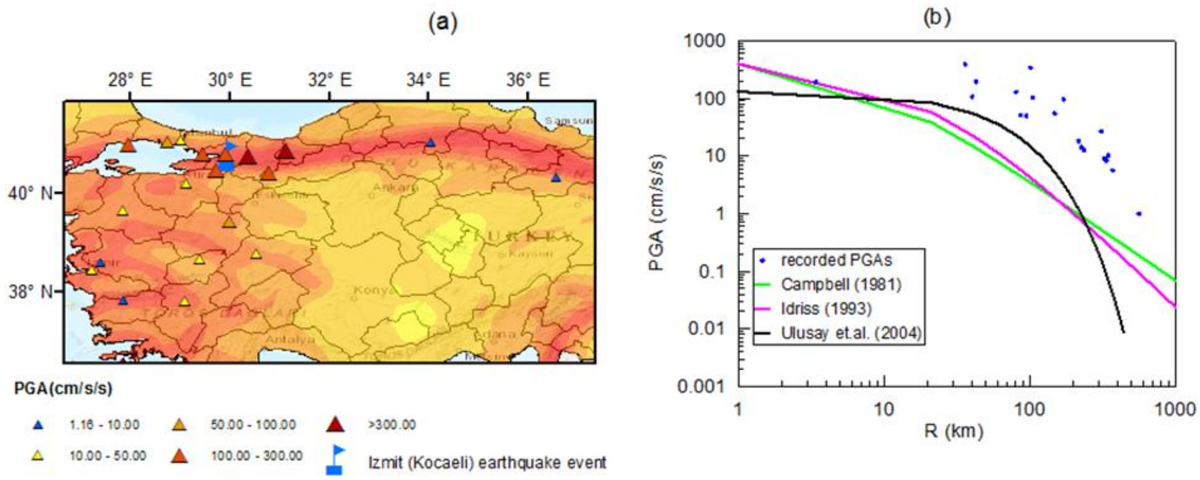

Figure 4. *(a) Location of the Izmit (Kocaeli) earthquake event and positions of the accelerogram stations recorded, (b) the change of PGAs with distance compared with empirical approaches*

Acceleration-time histories of the input motions of the Kocaeli earthquake event are represented in **Hata! Başvuru kaynağı bulunamadı.**. The input motions are recorded at soil class of B with $V_{S,30}$ of 412 m/s (**Hata! Başvuru kaynağı bulunamadı.**a), 459 m/s (**Hata! Başvuru kaynağı bulunamadı.**b) and 662 m/s (**Hata! Başvuru kaynağı bulunamadı.**c) at the epicentral distances of 35.87 km, 94.66 km and 216.49 km, respectively. It is obvious that the seismic waves reach firstly to the closest station at the distance of 35.87 km. This is followed by the stations at the 94.66 km and 216.49 km epicentral distances. Moreover, the far the station gets, the less the acceleration values become. This is due to the fact that earthquake energy dissipates with distances within the crusts and soil deposits, as reflected in the recordings of the earthquake event.

Spectral acceleration curves of the input motions recorded at soil classes B and C are represented in **Hata! Başvuru kaynağı bulunamadı.**a. Spectral acceleration at soil class D is not available since there was not any station positioned on that soil class. Also, spectral acceleration curve for input motion recorded on soil class A is not plotted. Because, only one available recording at soil class A has an epicentral distance of 3.35 km. Therefore, it is thought that this recording may possess near-fault effect.

The input motion with closer epicentral distance (i.e. R=40 km) to the earthquake event has larger spectral accelerations. At farther distances of 94.66 km and 216.49 km, the values become less. concerning the site effect, a clear spectral amplification at periods between 1.2 s and 1.5 s is observed in the recorded input motion at soil class C. In contrast, the two recordings at soil class B exhibit spectral amplifications at relatively early periods (i.e. less than 1 s). This is clearly reflected in the PGA normalized spectral acceleration curves illustrated in **Hata! Başvuru kaynağı bulunamadı.**b.

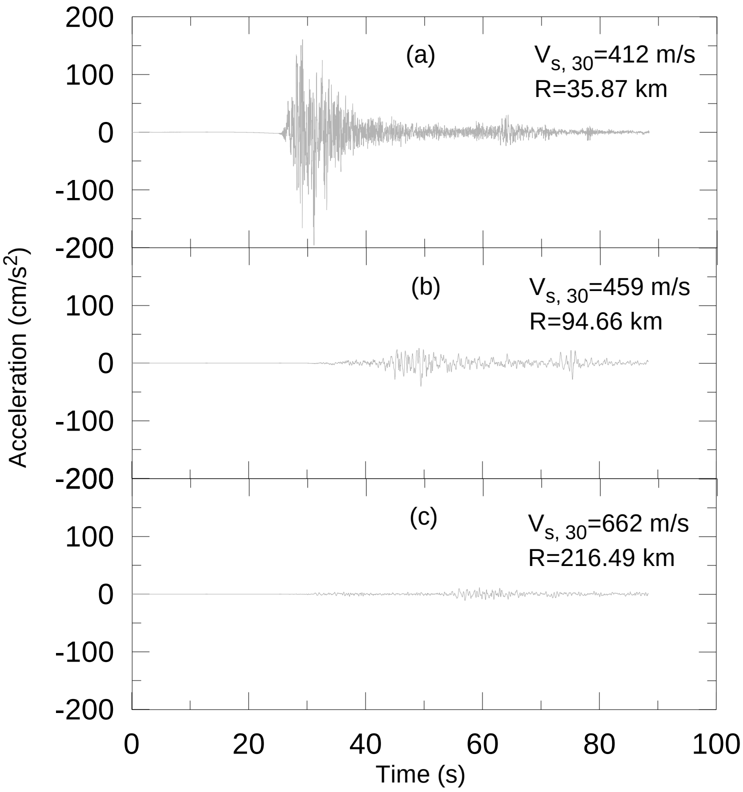

Figure 5. *Acceleration-time histories of three input motions of the Kocaeli earthquake event recorded at the same soil class of B with different epicentral distances*

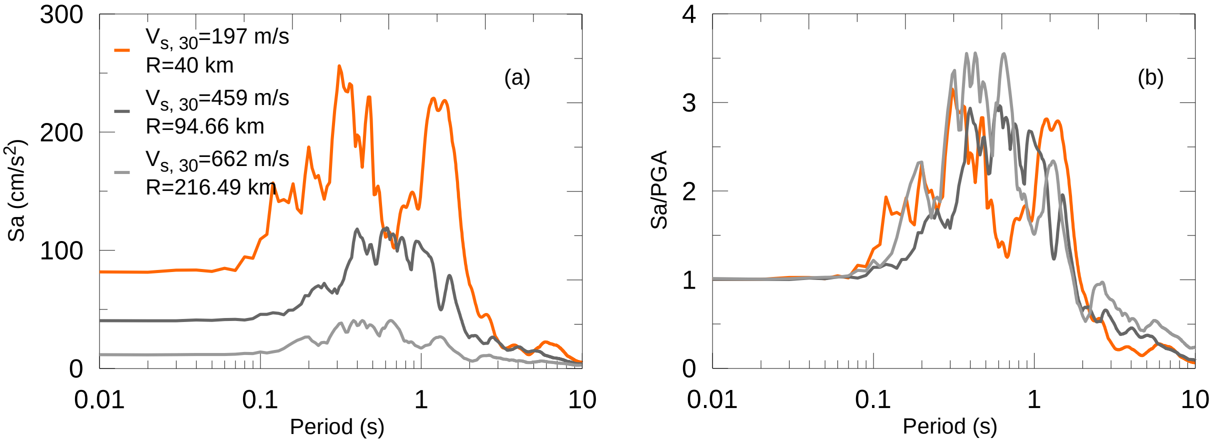

Figure 6. *Actual and PGA normalised spectral accelerations (a and b, respectively) of the input motions at soil classes B and C*

ANALYSES AND DISCUSSIONS

Recorded Spectral Accelerations Along With The Code Design Response Spectra

The recorded input motions are from the earthquake events in Türkiye and are gathered from the website of Disaster and Emergency Management Precidency [46]. The actual spectral accelerations and code given design response spectra for different soil classes are normalized with respect to the PGA values as implemented in the study of Pitilakis et al. [47]. The geometric mean of the 150 actual data recorded at four different soil classes and their 16th and 84th percentiles are exhibited together with the EC8 –Type 1 and TBEC design response spectra (Figure 7). It is clear that the design response spectra given by both codes for soil classes A, B, C and D (Figure 7a-b-c-d, respectively) cover the geometric mean of the actual spectral accelerations. Moreover, TBEC 2018 is capable of representing the 84th percentile of the recorded data for each soil class. While EC8 also reaches same level of plateau, which is 2.5, but it takes place at the longer periods leading to EC8 not being able to cover the 84th percentile of the actual spectral accelerations at the shorter periods. This inefficiency of EC8 design response spectra is particularly obvious in soil classes of A, B and C at period ranges of 0.03-0.15 s, 0.04-0.15 s and 0.04-0.2 s, respectively. In contrast, EC8 design response spectra becomes better proxy than the TBEC ones at period ranges of 0.2-2.5 s for soil class A, 0.28-2.5 s for soil class B, 0.4-2.3 s for soil class C and 0.5-2.4 s for soil class D. The extension of the plateau from soil class A to soil class D is seen in both design response spectra and in the recorded data, as can be interpreted in Table 3. This is due to the fact that when the soil gets softer, the seismic energy of the input motions is shifted to the longer periods.

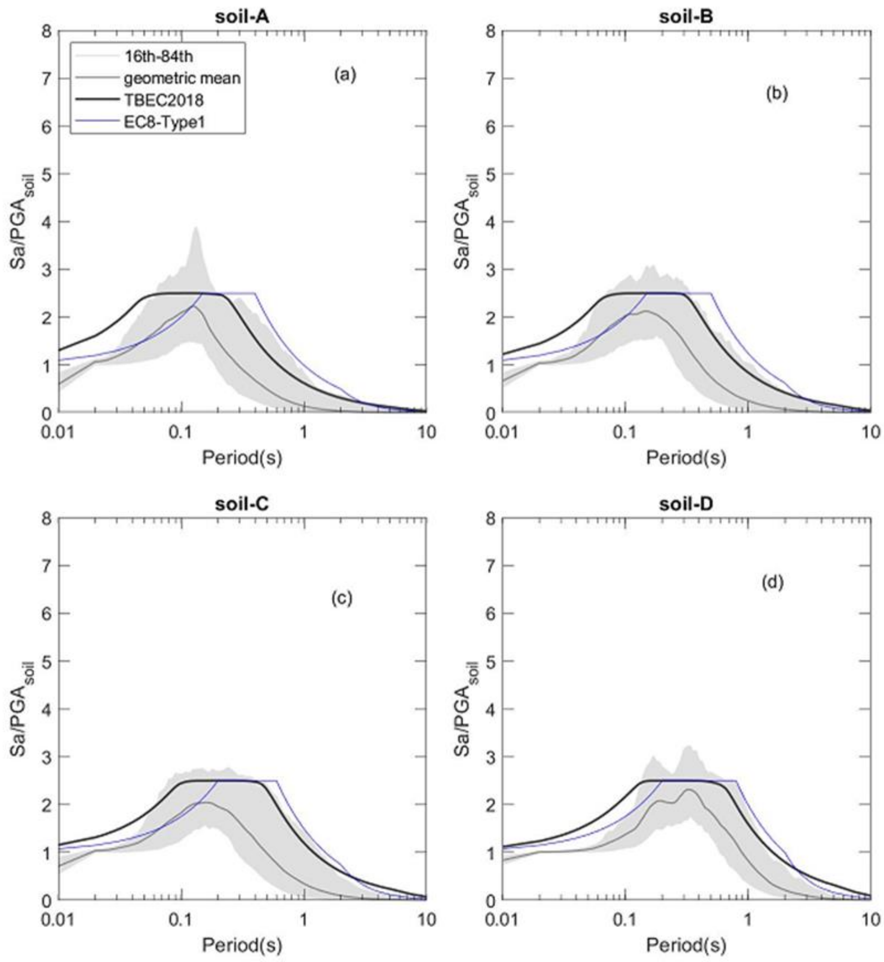

Figure 7. *Normalised real spectral accelerations with their geometric mean and 16th-84th percentiles along with the design response spectra guided by TBEC 2018 and EC8*

Table 3. *The corner periods for different soil classes proposed by EC8 And TBEC 2018 and the extent of the plateau (T_B-T_A)*

	EC8				TBEC 2018			
Soil class	A	B	C	D	A	B	C	D
T_A	0.15	0.15	0.20	0.20	0.055	0.07	0.10	0.14
T_B	0.40	0.50	0.60	0.80	0.21	0.30	0.40	0.53
T_B-T_A	0.25	0.35	0.40	0.60	0.155	0.23	0.30	0.39

Building Models

In order to better demonstrate the disparity between the EC8 and TBEC design response spectra and actual spectral acceleration curves, two reinforced concrete (RC) buildings are modelled in ETABS software [48]. 4 and 8 storey building models are formed and analyzed through response spectrum analyses based on linear elastic approach. Since the objective of building analyses is to illustrate the discrepancies between the aforementioned response spectrum curves, selection of a set of input motions in compliance with the spectral curves is not needed. Behavior and overstrength factors are assigned as 8 and 3, respectivelyThe overall height of the models with 4 and 8 storeys are 13.1 m and 25.9 m, respectively. The periods for the first three modes of 4 storey building model are 0.35 s, 0.28 s and 0.218 s and they are equal to 0.582 s, 0.566 s and 0.36 s for 8 storey building model, as seen in Table 4. Corresponding spectral acceleration values are also demonstrated in Tables 5 and 6 for 4 and 8 storey building models, respectively. The first 12 modes of the models are considered assuring the mass participations of over %95. The modal responses are combined by using square root of sum of squares (SRSS) method.

Table 4. *Periods of the building models at different modes and associated mass participation ratios*

Mode Number	Period (s)	Mass Participation (for 4 storey building)		Period (s)	Mass Participation (for 8 storey building)	
		X direction	Y direction		X direction	Y direction
1	0.35	0.8033	0	0.582	0.7637	5.08E-07
2	0.281	0	0.8099	0.566	7.98E-07	0.7148
3	0.218	0.0001	0.0003	0.361	9.26E-07	0.0387
4	0.107	0.1359	0	0.177	0.1257	1.31E-06
5	0.093	0	0.1395	0.167	2.44E-06	0.1289
6	0.071	3.86E-06	2.02E-05	0.108	7.42E-06	0.0035
7	0.055	0.049	0	0.089	0.0554	0
8	0.051	0	0.0418	0.081	0	0.0558
9	0.038	0	1.37E-06	0.054	0.0277	0
10	0.036	0.0118	0	0.051	0	0.0007
11	0.036	0	0.0086	0.049	0	0.0283
12	0.026	0	0	0.038	0.0156	0
Sum		1	1		0.988	0.970

Table 5. *Spectral acceleration values at periods of first three modes for 4 storey building model*

Mode number	Period (s)	Sa values (in g)											
		TBEC Soil class				EC8 Soil class				Actual Soil class			
		A	B	C	D	A	B	C	D	A	B	C	D
Mode 1-X direction	0.35	0.67	1.21	1.38	1.63	1.12	1.35	1.29	1.52	0.31	0.77	0.85	1.55
Mode 2-Y direction	0.28	0.82	1.31	1.38	1.63	1.12	1.35	1.29	1.52	0.40	0.98	1.01	1.19
Mode 3-Torsional	0.218	0.93	1.32	1.38	1.63	1.12	1.35	1.29	1.52	0.52	1.10	1.12	1.14

Table 6. *Spectral acceleration values at periods of first three modes for 8 storey building model*

Mode number	Period (s)	Sa values (in g)											
		TBEC Soil class				EC8 Soil class				Actual Soil class			
		A	B	C	D	A	B	C	D	A	B	C	D
Mode 1-Y direction	0.58	0.41	0.77	1.14	1.58	0.77	1.16	1.29	1.52	0.15	0.38	0.52	1.88
Mode 2-X direction	0.566	0.42	0.79	1.16	1.59	0.79	1.19	1.29	1.52	0.15	0.40	0.53	1.80
Mode 3-torsional	0.36	0.66	1.19	1.38	1.63	1.12	1.35	1.29	1.52	0.30	0.75	0.84	1.53

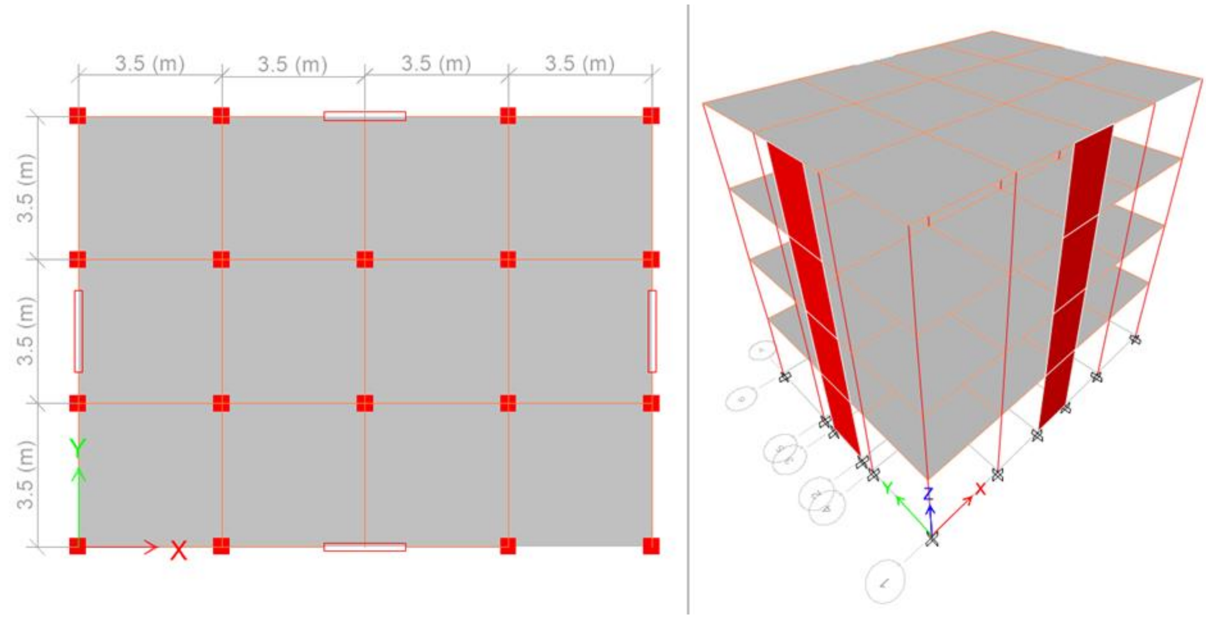

Figure 8. *The plan and three-dimensional views of the 4 storey building model*

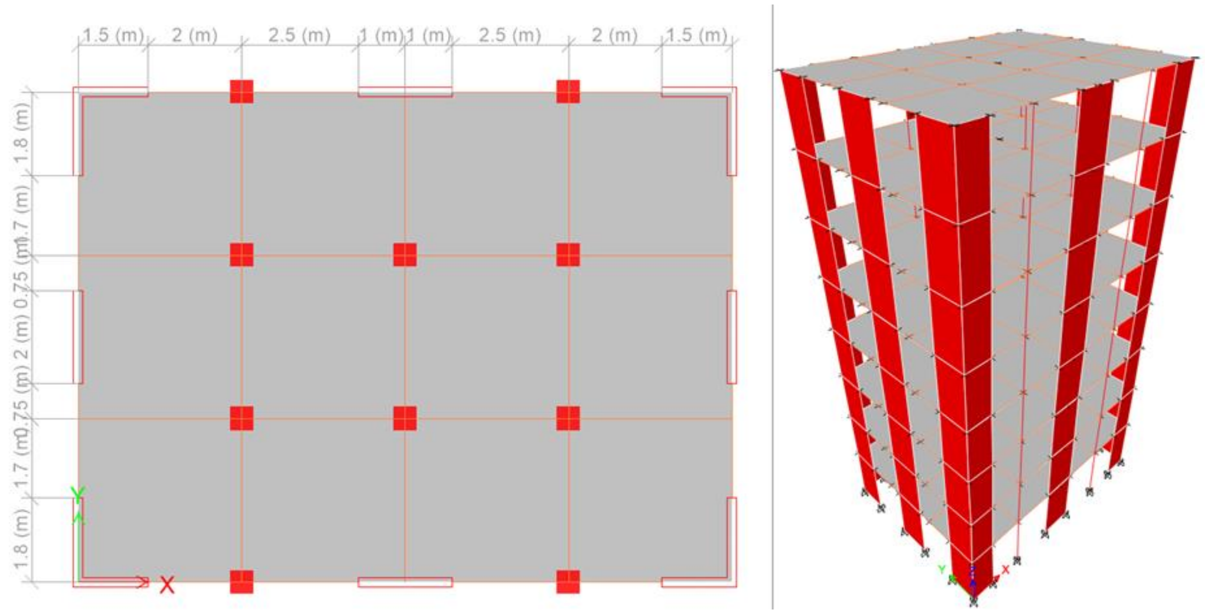

Figure 9. *The plan and three-dimensional views of the 8 storey building model*

The plan and three dimensional views of 4 and 8 storey buildings are demonstrated in Figs. 8 and 9, respectively. For both building models, 2 kN/m^2 live loads and 7.7 kN/m^2 dead loads are assigned. Compressive strength of concrete and yield strength of rebar is equivalent to 30 MPa and 420 MPa, respectively. The models are regarded as residential buildings, hence the importance factor is taken as 1. All the structural elements (i.e. columns, beams, shear walls, slabs) are designed in accordance with the TBEC guidance.

The shear walls and slabs thicknesses through all storeys of both building models are equal to 20 cm and 18 cm, respectively. The length of shear wall sections in the 4 storey building model is 2. In the 8 storey building model, corner shear walls has sectional length of 1.5 m in the x direction and 1.8 m in the y direction when the shear walls in the middle of the facades has sectional length of 2 m. The detailed section properties of the beams and columns are summarized in Table 7 and Table 8.

Table 7. *Sizes of columns at different storey levels for the 4 and 8 storey building models including reinforcement rebars (reinf.)*

Model's name	Storey level	Column size	reinf	Explanations
4 storeys	1-3	60×60	22Φ20	Columns connected to shear walls in the y direction
		50×50	20Φ20	The remaining columns
	4	40×40	16Φ20	All columns
8 storeys	1-3	65×65	24Φ20	Outer columns
		60×60	22Φ20	Inner columns
	4-7	60×60	22Φ20	Outer columns
		50×50	20Φ20	Inner columns
	8	50×50	20Φ20	Outer columns
		40×40	16Φ20	Inner columns

Table 8. *The beam sizes at different storey levels and at different connections for the 4 and 8 storey building models including top and bottom reinforcement rebars (reinf.)*

Model's name	Storey level	Beam size	Top reinf	Bot reinf	Explanations
4 storeys	1-5	30×50	3Φ20	3Φ20	All column to column connections and column to shear wall connections in the x direction
	1-3	40×60	4Φ20	4Φ20	Column to shear wall connections in the y direction
	4		3Φ20	3Φ20	
8 storeys	1-5	40×60	4Φ20	4Φ20	Column to shear wall and shear wall to shear wall connections
	6-8	30×50	4Φ20	4Φ20	
	1-8	30×50	3Φ20	4Φ20	Column to column connections

Results of Response Spectrum Analyses

Figure 10 and Figure 11 exhibit the resulting shear forces acted on different storey levels of building models obtained from response spectrum analyses. In each figure represented in this section, subsections (a), (b), (c) and (d) contain the shear forces attained by considering soil classes A, B, C and D design response spectra of associated codes or actual earthquake data. The shear forces at the 4 storey building model obtained by using the EC8 design response spectra are greater than the shear forces from the TBEC or actual response spectra when class A soil deposit is considered (Figure 10a). At soil class B (Figure 10b), the EC8 design response spectrum results in slightly larger shear forces than the TBEC ones. Specifically, the shear forces for these two design codes are 1342 kN and 1250 kN, respectively. At soil classes of C and D (Figs. 10c-d), the TBEC design response spectra give bigger shear forces than EC8 ones and are equal to 1283 kN and 1380 kN at soil class C and 1506 kN and 1597 kN at soil class D, correspondingly. In contrast, at all soil classes, the actual spectral response curvesgive relatively smaller values, being 369 kN, 869 kN, 922 kN and 1372 kN at soil classes A, B, C and D, accordingly.

Similar patterns in the shear forces according to the different spectral acceleration curves are observed when the 8 storey building model is analyzed, as seen in Figure 11. The shear forces from the EC8 design response spectra are 1302 kN and 2008 kN at soil classes A and B, respectively (Figs. 11a-b). At the same soil classes, the shear forces are 742 kN and 1340 kN with the use of the TBEC design response spectra. The similarities of shear forces from the EC8 and TBEC design response spectra are pronounced, more clearly, at soil classes of C and D (Figs. 11c-d). At all soil classes, the actual response spectra conclude the minimum shear forces on the building model. The shear forces from the actual

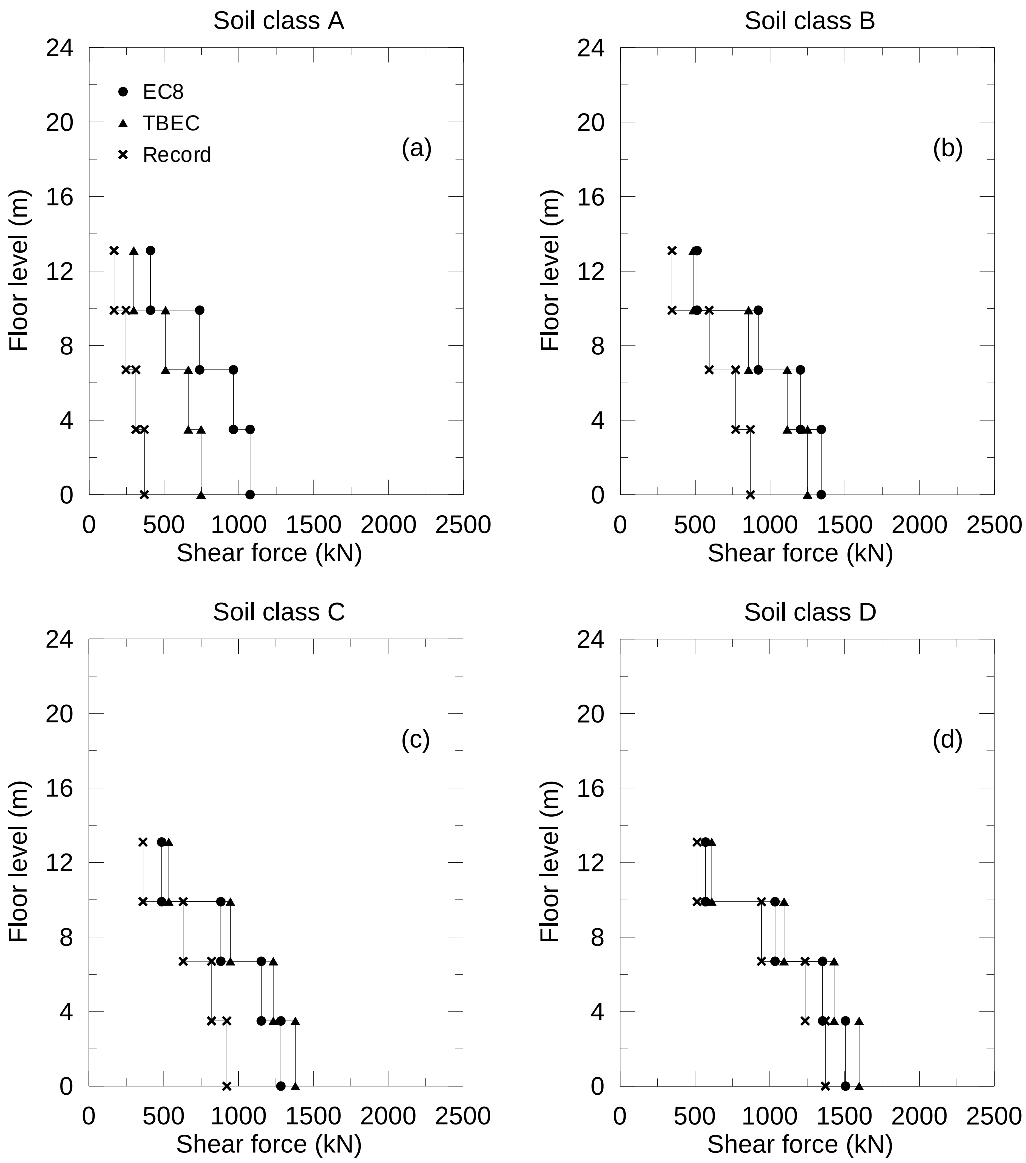

Figure 10. *Shear force distributions, along the 4 storey building model, from the building analyses conducted by considering the EC8, TBEC design response spectra and actual spectral response curves at different soil classes*

response spectra are 303 kN at soil class A, 684 kN at soil class B, 857 kN at soil class C and 2084 kN at soil class D. This can be attributed to the fact that the spectral acceleration value of actual spectral spectrum at around the fundamental period of the 8 storey (and also 4 storey) building model is lower than the EC8 and TBEC design response spectra, indicating the lower shear forces. This clearly reflects the direct relation between the spectral acceleration and the building response. Therefore, the spectral acceleration is always considered to be better proxy regarding the involvement of earthquake effect in the seismic design/retrofitting of building structures.

Regardless of which type of design response spectrum considered, the shear forces acted on the building models are always increasing with the soil becoming softer (i.e. from A to D), as can be depicted from Table 9. For instance, the 4 storey building model is forced by 1075 kN when the EC8 design response spectrum for soil class A is taken into consideration. This value is equal to 1342 kN, 1283 kN and 1506 kN on soil classes B, C and D, respectively. In the same way, concerning the shear forces on the 8 storey building model in accord with the TBEC design response spectra, it is 742 kN, 1340 kN, 1965 kN and 2634 kN when the building model positioned on top of soil classes A, B, or D, correspondingly. Likewise, as the actual response spectrum is used, 303 kN, 684 kN, 857 kN and 2084

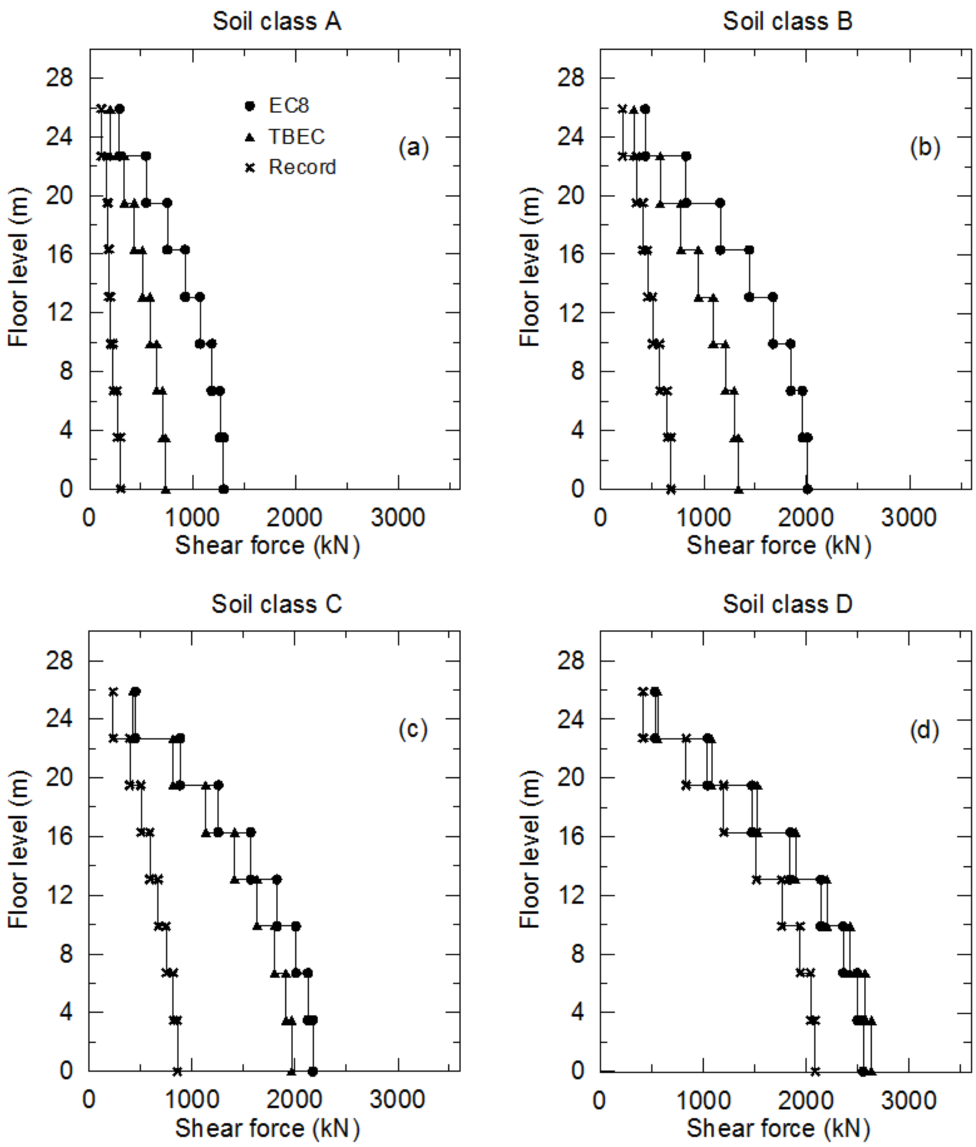

Figure 11. *Shear force distributions, along the 8 storey building model, from the building analyses conducted by considering the EC8, TBEC design response spectra and actual spectral response curves at different soil classes*

kN shear forces are imposed to the 8 storey building model if it is located on soil classes of A, B, C or D, appropriately.

Table 9. *Total shear forces (in kN) acted on 4 and 8 storey building models when EC8, TBEC or actual spectrum applied at different soil classes*

Storey number	Code name	Soil class			
		A	B	C	D
4	EC8	1075	1342	1283	1506
	TBEC	748	1250	1380	1597
	Actual	369	869	922	1372
8	EC8	1302	2008	2174	2552
	TBEC	742	1340	1965	2634
	Actual	303	684	857	2084

CONCLUSIONS

This work, firstly, concentrates on the seismicity of the Kocaeli region and the input motion recordings of the Kocaeli earthquake event related to the site effect. Following that, the design response spectra given by two seismic design codes, TBEC 2018 and EC8, are explained. The code given design response spectrum for each seismic soil class is compared with the spectral accelerations of actual earthquake input motions recorded across Türkiye. Then, the applications of the TBEC 2018 and EC8 design response spectra (as well as the actual response spectra) to the 4 and 8 storey building models are illustrated by locating the building models in different soil classes. The building models are analyzed by means of ETABS software based on the response spectrum analysis method. The main conclusions of the research are as follows:

- The earthquake input motions are significantly influenced by the characteristics of the soil deposits. Therefore, it is always beneficial to conduct site-specific response analysis when a soft soil deposit (i.e., soil classes of C and D) is available.
- The spectral response spectra of the actual input motions recorded at all soil classes are well captured by the design response spectra of both codes.
- At all soil classes, the EC8 design response spectra have plateau starting at relatively longer periods than the TBEC design response spectra. The second corner periods of the plateau at the EC8 design response spectra always greater than that of the TBEC design response spectra, especially for soil classes A and B.
- This results in the EC8 design response spectrum at each soil class owning wider plateau than the TBEC design response spectrum.
- The building model analyses also reflect that the actual spectral acceleration curves results in smaller shear forces, followed by TBEC and then EC8 design response spectra at the same soil type.
- As expected, the softer the soil(from A to D), the greater the shear forces acting on the building models.

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Conflict of Interest

The authors have no conflicts of interest to disclose for this study.

Authorship Contribution Statement

Y.G.: Conceptualization, Methodology, Supervision, Writing - Review & Editing, **F.G.:** Formal Analysis, Investigation, Methodology, Writing - Original Draft

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