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Comparison of loads in Turkish earthquake code with those computed statistically

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Abstract. In this study, earthquake loads are investigated statistically and compared with the nominal earthquake loads calculated according to the Turkish Earthquake Code, namely: "Specifications for Structures to be Built in Earthquake Areas". For this purpose, the "actual" mean load values estimated from statistical methods and the nominal load values computed according the Seismic Code are compared, with respect to some variations in the basic parameters, such as the importance factor, building height, site coefficient, seismic zone and seismic load reduction factor. In addition to the data compiled from different regions of Turkey, the published data and information in the foreign literature are also used in the determination of the earthquake load statistics. Although the dead and live loads acting on a structure are independent of the geographical location of the structure, environmental loads, such as earthquake loads are highly dependent on the location of the structure. Accordingly, for the assessment of statistical parameters associated with earthquake loads, twelve different locations which can represent the different seismic zones of Turkey as accurately as possible are chosen. As a result of the code calibration procedure considered in this study, it is observed that the load values obtained from the Turkish Seismic Code may overestimate or underestimate the actual seismic loads in some of the seismic zones.

Keywords: earthquake load; structure; statistics; seismic code; code calibration; building code

1. Introduction

Some regions in Turkey where there are critical economical activities, density population and intensive energy investments have also seismic activity. As a consequence of the earthquakes occurred in these regions, significant damages and important losses of life and property are observed (Ergunay 2007, Firat 2009). 1992 Erzincan, 1995 Dinar, 1998 Adana-Ceyhan, 17 August 1999 Marmara, 12 November 1999 Duzce, 2002 Afyon-Sultandagi, 2003 Bingol earthquakes and last Kütahya-Simav and Van earthquakes occurred in 2011 may be given as examples to major earthquakes occurred in Turkey. The researches related to these earthquakes put forward the fact that the building stock in Turkey is weak in terms of structural safety (Celep *et al.* 2011, Dogangun and Sezen 2012, Dogangun *et al.* 2013, Sezen *et al.* 2003, Ural 2013). Since the

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earthquake loads are one of the important reasons of the building collapses, which leads to life and property losses, the civil engineers must have proficient knowledge and give more importance especially in the stage of design. On the other hand, if the nominal earthquake loads given in the standards and specifications are less than the real (actual) earthquake loads, the drastic damages and even structural collapses may take place.

The magnitude, time and ground motion acceleration of the earthquake occurred in a region are random events and involve uncertainties which specific to the nature of earthquake. Also, the inadequacies in analytical models of nonlinear structural behavior lead to additional uncertainties. Besides, the structural capacity cannot be computed exactly due to a number of reasons such as material properties, workmanship errors and climatic variabilities. Earthquake load, the response of structure under the influence of earthquake load and determination of structural capacity involve aleatory and epistemic uncertainties. In the earthquake-resistant design of buildings, the reflection of these uncertainties to structural design and uncertainty analysis can be carried out within the framework of reliability-based design criteria (Hwang and Hsu 1993, Real *et al.* 2003, Firat 2007). The safety assessment of a structure under the influence of earthquake load allows the evaluation of the seismic hazard and the determination of the behavior of the structure considering the factors affecting the performance of structure.

In this study, advanced computational methods for probabilistic analysis of structural response related to earthquakes are not addressed with all its specifics. The main purpose of this study is to carry out a code calibration procedure. Regarding the local conditions and data, probabilistic methods are used to determine the earthquake loads by taking the uncertainties into account, supported by the results of studies which have been performed in other countries. The uncertainties in earthquake load can be investigated under two main titles, namely aleatory uncertainty and epistemic uncertainty. Aleatory uncertainty is caused by inherent variability, which is a state of nature, and the control and reduction of aleatory uncertainty cannot be possible. On the contrary, epistemic uncertainties originating from the lack of data and knowledge can be reduced with the additional data and knowledge obtained through time (Firat and Yucemen 2014, Hester 2012). In this study, the sources of aleatory and epistemic uncertainties related to earthquake load are investigated and modeled and also these uncertainties are quantified based on the data available within the framework of statistical methods. In addition, for the sources of epistemic uncertainty, random correction coefficients are proposed and uncertainty analysis is performed.

2. The determination of the peak ground accelerations

The peak ground acceleration is usually compatible with seismic specifications. Accordingly, it is used as the seismic hazard parameter in this study. In other words, the seismic hazard is described in terms of the peak ground acceleration, A. The probability distribution of peak ground acceleration can be described by the Type II extreme value distribution (Ellingwood 1994, Komurcu and Yucemen 1996). In a suitable manner, the cumulative distribution function of A can be obtained from the following relationship

$$F_A(a) = e^{-(a/v)^{-k}} \qquad a \geq 0 \tag{1}$$

where, v is characteristic extreme value and k is the shape parameter of the distribution.

Table 1 Geographical coordinates and seismic zones of selected locations, and corresponding peak ground acceleration values for different return periods

Location	Longitude (North) (in degrees)	Latitude (East) (in degrees)	Seismic Zone	Peak ground acceleration, A (in g)			
				100 years return period	225 years return period	475 years return period	1000 years return period
Ankara	32.853	39.929	4	0.13	0.16	0.19	0.21
Izmir	27.145	38.433	1	0.36	0.43	0.51	0.59
Bursa	29.075	40.196	1	0.35	0.42	0.50	0.58
Antalya	30.709	36.893	2	0.30	0.37	0.44	0.52
Gaziantep	37.389	37.069	3	0.14	0.17	0.20	0.24
Samsun	36.331	41.293	2	0.19	0.24	0.31	0.36
Malatya	38.309	38.355	1	0.29	0.35	0.41	0.48
Erzincan	39.504	39.740	1	0.40	0.49	0.59	0.70
Canakkale	26.414	40.155	1	0.40	0.48	0.57	0.66
Hakkari	43.751	37.568	1	0.38	0.47	0.56	0.65
Istanbul/Goztepe	29.082	40.980	1	0.29	0.35	0.42	0.50
Istanbul/Sile	29.628	41.175	2	0.21	0.25	0.32	0.38

Regarding the 100, 225, 475 and 1000 years return periods, peak ground accelerations for Ankara, Izmir, Bursa, Antalya, Gaziantep, Samsun, Malatya, Erzincan, Canakale, Hakkari, Goztepe/Istanbul Sile/Istanbul are obtained from the Seismic Zones Map of Turkey conducted by Gulkan *et al.* (1993).

The peak ground accelerations in these locations are set equal to the values shown in Table 1 for different return periods. By using the acceleration values for 225 and 475 years return periods, the parameters of Type II distribution can be computed. The probability that the peak ground acceleration will not be exceeded over a period of 50 years is 0.8 and 0.9 for the return periods of 225 and 475 years, respectively. It is to be noted that the economic life of a structure is mostly assumed to be 50 years in codes in different countries. For the purpose of determining the parameters of the Type II distribution, v and k, for each location, Eq. (1) is solved for 225 years and 475 years return period, simultaneously. The calculated v and k values for the locations mentioned above are given in Table 2.

The values of the means and coefficients of variation of peak ground acceleration corresponding to Ankara, Izmir, Bursa, Antalya, Gaziantep, Samsun, Malatya, Erzincan, Canakkale, Hakkari, Goztepe/Istanbul and Sile/Istanbul can be found by substituting the computed v and k values into Eqs. (2)-(3), respectively. The computed values of δ_A indicate only the basic variability (aleatory uncertainty) in peak ground acceleration. In addition, modeling error, which is quite high due to various uncertainties associated with the earthquake process, should be taken into consideration.

$$\overline{A} = v\Gamma\left(1 - \frac{1}{k}\right) \qquad (2)$$

Table 2 Parameters of Type II distribution for peak ground acceleration for different locations

Location / Parameter	Ankara	Izmir	Bursa	Antalya	Gaziantep	Samsun	Malatya	Erzincan	Canakkale	Hakkari	Goztepe/ Istanbul	Sile/Istanb ul
v	0.13	0.32	0.30	0.26	0.12	0.15	0.26	0.34	0.37	0.33	0.35	0.24
k	4.37	4.98	4.30	4.33	4.63	3.36	4.74	4.04	5.06	4.28	3.04	4.11

Table 3 Mean value and total variability of peak ground acceleration for different locations

Location / Parameter	Ankara	Izmir	Bursa	Antalya	Gaziantep	Samsun	Malatya	Erzincan	Canakkale	Hakkari	Goztepe/ Istanbul	Sile/Istanbul
$\bar{A}$	0.15	0.37	0.36	0.32	0.15	0.20	0.30	0.41	0.43	0.40	0.48	0.29
δ_A	0.38	0.32	0.38	0.38	0.35	0.55	0.34	0.42	0.31	0.39	0.66	0.41
Δ_A	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Ω_A	0.98	0.95	0.98	0.98	0.97	1.06	0.96	0.99	0.95	0.98	1.12	0.99

$$\delta_A = \sqrt{\frac{\Gamma\left(1-\frac{2}{k}\right)}{\Gamma^2\left(1-\frac{1}{k}\right)} - 1} \tag{3}$$

where, $\Gamma(.)$ is the gamma function.

In this study, the modeling error in peak ground acceleration, Δ_A, will be taken as 0.9 in view of the studies of Ellingwood *et al*. (1980) and Komurcu (1995) who have reported this uncertainty to be equal to 0.9. Consequently, total variability, Ω_A, is calculated using the basic variability, δ_A and the modeling error, Δ_A according to Eq. (4) (Ang and Tang 1984, Nowak and Szerszen 2003). Results are shown in Table 3.

$$\Omega_A = \sqrt{\delta_A^2 + \Delta_A^2} \tag{4}$$

3. Determination of total equivalent lateral earthquake load

Building codes specify the seismic load with regards to the maximum shear force at the base of the building. In other words, the seismic analysis of buildings can be performed in accordance with Equivalent Seismic Load Method (ESLM). There are some restrictions while using ESLM in Turkish Earthquake Code (Specification for Structures to be Built in Disaster Areas-2007); for example, in third and fourth seismic zone, the ESLM is used for the buildings having the height of building (H) less than 40 m or in third and fourth seismic zone the ESLM is used for the buildings having H<25 m if interstorey strength irregularity exists otherwise again this method is used for buildings having H<40 m. However, in Turkey, the buildings damaged severely due to earthquakes are mid-rise buildings below 25 m (Sengoz and Sucuoglu 2009, Inel *et al.* 2008, Ozhendekci and Ozhendekci 2012). In Turkish Earthquake Code (TEC-2007), it is specified that Mode Superposition Method (MSM) and Analysis Method in Time Domain (AMTD) in addition to ESLM can be used. In practice, AMTD is not used and also in some circumstances, even MSM is used, it is required the computation of equivalent earthquake load. In TEC-2007, it is stated that in some cases, different structural system behavior factors (R) are used for different parts of a building (upper and lower floors) and total earthquake loads are computed and corrected according to these different R values. If MSM is used, this type separation cannot be carried out. In addition, in case the foundation of building is strip or mat foundation, the internal forces should be marked plus and minus; therefore applying the MSM seems to be impossible (Ozmen 2008). In addition to these reasons, for making an uncertainty analysis based on quantifying the uncertainty sources, other methods other than equivalent seismic load procedure are not used properly.

The formal seismic code TEC-2007 is used in determining the nominal earthquake loads for Turkey. It is hard to say which code gives the best estimate of the “true” mean value of the lateral base shear force for buildings in Turkey. TEC-2007 and IBC 2009 (International Building Code) seem to reflect the most up-to-date version of the equivalent lateral force procedure in terms of the estimation of the nominal earthquake load and the mean earthquake load for this study, respectively. However, in IBC- 2009, the earthquake spectral acceleration at short periods (S_s) and at 1-second period (S_1) are taken from the maps which were not mapped for Turkey. If the base shear is taken into consideration, UBC-1994 is compatible with TEC-2007 in terms of design variables, such as response modification factor, site coefficient for soil characteristics. On the other hand, Yuksel (1997) pointed out that the analysis and design of reinforced concrete buildings and its calculation principles in UBC-1994 and TEC-1996 (the draft of TEC-1998) are almost the same. TEC-1996 is the basis of TEC-2007 and the calculation procedure of base shear in TEC-2007 has not been changed since 1996. Therefore, UBC-1994 is used to specify mean earthquake load and, TEC-2007 is used to determine nominal earthquake loads. In addition, while determining mean earthquake loads, TEC-2007 is also taken into consideration. In the following sections, brief information associated with these codes, i.e., UBC-1994 and TEC-2007 is presented.

3.1 UBC-1994

In UBC-1994, the total design base shear, V, in a given direction is determined from the following equations

$$V = \frac{Z\,I\,C}{R_W} W \tag{5}$$

$$C = \frac{1.25\,S}{T^{2/3}} < 2.75 \tag{6}$$

$$\frac{C}{R_W} \geq 0.075 \tag{7}$$

Table 4 Seismic zone factor in UBC-1994

ZONE	1	2A	2B	3	4
Z	0.075	0.15	0.20	0.30	0.40

Table 5 Response modification factor (R_W) for reinforced concrete buildings in UBC-1994

Basic structural system	Lateral force- resisting- system description	R_W
Bearing wall system	Reinforced concrete shear walls	6
Building frame system	Reinforced concrete shear walls	8
Moment resisting frame system	Special moment-resisting frames(SMRF)	12
	Intermediate moment-resisting frames (IMRF)	8
	Ordinary moment-resisting frames (OMRF)	5
Dual system	Dual system with SMRF capable of resisting at least 25%of prescribed seismic forces	12
Dual system	Dual system with IMRF capable of resisting at least 25% of prescribed seismic forces	8

Where Z: seismic zone factor, I: importance factor, W: total building weight, C: numerical coefficient, R_W: response modification factor, S: site coefficient of soil properties, T: fundamental period of vibration of the building for the direction considered.

Seismic zone factor, Z, is the ratio of the design ground acceleration to the acceleration of gravity, g (9.81 m/s^2). Zone 4 in UBC-1994 is the most critical one, whereas Zone 1 in TEC-2007 is the most critical one; that is, Zone 4 in UBC-1994 corresponds to Zone 1 in TEC-2007. The values of the seismic zone factor, Z in UBC-1994 are given in Table 4 for different seismic zones.

The ductility of the structural system, the types of member and material which are normally ignored in linear elastic calculations is quantified by the response modification factor, R_W in connection with the energy dissipation capacity of the structure. The response modification factor in UBC-1994 is given in Table 5.

The first natural vibration period of the building can be calculated by the following expression that gives an approximate value

$$T_1 = C_t H_N^{3/4} \tag{8}$$

C_t value equals to 0.0731 in UBC-1994 for reinforced concrete moment resisting frames and eccentrically braced frames.

3.2 TEC-2007

The general principle of earthquake resistant design in TEC-2007 is to avoid any damage in the structural and non-structural elements of buildings for low intensity earthquakes, to limit the repairable damage levels in structural and non-structural elements for medium intensity earthquakes, and to avoid the partial or overall collapse of buildings for high intensity earthquakes in order to prevent the loss of life.

In TEC-2007, the total design base shear, V_t, is determined by using the following equation for a given direction

Table 6 Effective ground acceleration coefficients (A_0) in TEC-2007

Seismic Zone	A_0
1	0.40
2	0.30
3	0.20
4	0.10

$$V_t = \frac{A(T_1)}{R_a(T_1)} W \geq 0.10 A_0 I W \tag{9}$$

where W:total building weight, $A(T_1)$: spectral acceleration coefficient, $R_a(T_1)$: seismic load reduction factor,T_1:fundamental period of vibration of the building for translation motion in the direction considered, A_0:effective ground acceleration coefficient, I:importance factor.

Total building weight is determined from the following equation

$$W = \sum_{i=1}^{N} w_i \tag{10}$$

In the above equation, w_i is the individual storey weight. The spectral acceleration coefficient corresponding to 5% damping is given by the following equation. Effective ground acceleration coefficient, A_0, can be defined as the ratio of the design ground acceleration to the acceleration due to gravity, g (9.81 m/s2). The effective ground acceleration coefficients specified for different seismic zones in TEC-2007 are shown in Table 6.

$$A(T) = A_0 I S(T) \tag{11}$$

In TEC-2007, there is no equation in order to calculate the first natural period, except for two limitations as the highest and lowest level. In TEC-1998 and UBC 1994, the first natural vibration period of a building can be calculated from the following approximate expression

$$T_1 = C_t \, H_N^{3/4} \tag{12}$$

C_t value equals to 0.07 in TEC-1998 for buildings whose structural system is composed of only reinforced concrete frames or structural steel eccentric braced frames. Approximately, the same calculation procedure is given in both UBC-1994 and TEC-1998 for the value of C_t of buildings where seismic loads are fully resisted by reinforced concrete structural walls.

The spectrum coefficient $S(T)$, which appears in Eq. (11) is determined from the following equations depending on the building's natural period, T, and the local site classes. Spectrum characteristic periods (T_A, T_B) in TEC-2007 are given in Table 7.

$$S(T) = 1 + 1.5T/T_A \qquad (0 \leq T \leq T_A) \tag{13a}$$

$$S(T) = 2.5 \qquad (T_A \leq T \leq T_B) \tag{13b}$$

$$S(T) = 2.5 + (T_B/T)^{0.8} \qquad (T > T_B) \tag{13c}$$

Table 7 Spectrum characteristic periods (T_A, T_B) in TEC-2007

Local site class	T_A (second)	T_B (second)
*Z*1	0.10	0.30
*Z*2	0.15	0.40
*Z*3	0.15	0.60
*Z*4	0.20	0.90

Table 8 Structural system behavior factor (*R*) in TEC-2007 for cast-in-situ reinforced concrete buildings

Lateral force- resisting- system description	System of nominal ductility level	System of high ductility level
Buildings in which earthquake loads are fully resisted by frames	4	8
Buildings in which earthquake loads are fully resisted by coupled structural walls	4	7
Buildings in which earthquake loads are fully resisted by solid structural walls	4	6
Buildings in which earthquake loads are jointly resisted by frames and solid and/or coupled structural walls	4	7

where *T*: fundamental period of vibration of the building in the direction considered; T_A, T_B: spectrum characteristic periods which depend on the local soil class given.

These local site classes are classified according to the thickness of the soil topmost layer and the soil groups, such as massive volcanic rocks, soft deep alluvial layers with high water table, and so on.

In order to account for the specific nonlinear behavior of the structural system, seismic load reduction factor, *Ra*(*T*), which corresponds to response modification factor, R_W, in UBC-1994 is used. Regarding the various structural systems and natural vibration periods, seismic load reduction factors are determined from the following equations in terms of structural behavior factor, *R*, which is given in Table 8 according to TEC-2007

$$Ra(T)=1.5+(R-1.5)T/TA \qquad (0\leq T\leq TA) \tag{14a}$$

$$Ra(T)=R \qquad (T>TA) \tag{14b}$$

4. The ratios of mean earthquake load to nominal earthquake load

In this study, the ratio of mean earthquake load computed statistically to nominal earthquake load based on the specifications and codes, $\overline{E}/E'$, will be used as the parameter of comparison. In order to compute the values of $\overline{E}/E'$, the different cases, in which importance factor, earthquake zone and load reduction factor, Ra(T), (this term is given as response modification factor, R_W, in UBC-1994) are taken into consideration, are investigated under the titles of Case 1, Case 2 and Case 3. It is to be noted that, in these cases, the mean value of earthquake load, $\overline{E}$, is computed from UBC-1994 and the nominal value, E', from TEC-2007 by using a code developed in MathCAD 14.

4.1 Case 1

Considering UBC-1994, importance factor, I, is taken as 1.0 for buildings which are residential and office buildings, hotels, industrial structures, etc., and the response modification factor, R_W, is assumed to be 8 suitable for buildings in which seismic loads are resisted by reinforced concrete shear walls and its basic structural system is building frame system.

As for TEC-2007, the importance factor, I, is taken as 1.0 corresponding to buildings in which small numbers of people live (houses, hotels, employment buildings, restaurants, and industrial buildings) and seismic load reduction factor, $Ra(T)$, is assumed to be 7 in connection with buildings in which earthquake loads are resisted by frames and solid and/or coupled structural walls. In the light of above descriptions and values, the mean to nominal ratios of earthquake load in terms of different local site classes and building heights are computed by using a code written in MathCAD 14, and the results are summarized in Table 9.

For Case 1, the variation of average $\overline{E}/E'$ according to different building heights and different local site classes are given Figs. 1-4. The average $\overline{E}/E'$ ratios mentioned are found taking into consideration the ratios computed for Ankara, Izmir, Bursa, Antalya, Gaziantep, Samsun, Malatya,

Table 9 Mean to nominal ratios of earthquake load in terms of different local site classes and building heights (R_W=8, $Ra(T)$=7)

Parameter \ Location			Ankara	Izmir	Bursa	Antalya	Gaziantep	Samsun	Malatya	Erzincan	Canakkale	Hakkari	Goztepe/ Istanbul	Sile/Istanbul
A			0.19	0.51	0.50	0.44	0.20	0.31	0.41	0.59	0.57	0.56	0.42	0.32
A_0			0.10	0.40	0.40	0.30	0.20	0.30	0.40	0.40	0.40	0.40	0.40	0.30
$\overline{E}/E'$	Z1	H_N=8 m	1.23	0.82	0.81	0.95	0.65	0.67	0.66	0.95	0.92	0.91	0.68	0.69
		H_N=15 m	0.98	0.66	0.64	0.76	0.52	0.53	0.53	0.76	0.74	0.72	0.54	0.55
		H_N=22 m	0.84	0.57	0.56	0.65	0.44	0.46	0.46	0.66	0.63	0.62	0.47	0.47
		H_N=30 m	0.74	0.50	0.49	0.57	0.39	0.40	0.40	0.58	0.56	0.55	0.41	0.42
	Z2	H_N=8 m	1.68	1.13	1.11	1.30	0.88	0.91	0.91	1.31	1.26	1.24	0.93	0.94
		H_N=15 m	0.93	0.63	0.61	0.72	0.49	0.51	0.50	0.72	0.70	0.69	0.51	0.52
		H_N=22 m	0.81	0.54	0.53	0.62	0.43	0.44	0.44	0.63	0.61	0.60	0.45	0.45
		H_N=30 m	0.72	0.48	0.47	0.55	0.38	0.39	0.39	0.56	0.54	0.53	0.40	0.40
	Z3	H_N=8 m	1.68	1.13	1.11	1.30	0.88	0.91	0.91	1.31	1.26	1.24	0.93	0.94
		H_N=15 m	1.23	0.82	0.81	0.95	0.65	0.67	0.66	0.95	0.92	0.90	0.68	0.69
		H_N=22 m	0.75	0.50	0.49	0.58	0.40	0.41	0.41	0.58	0.56	0.55	0.42	0.42
		H_N=30 m	0.67	0.45	0.44	0.52	0.35	0.37	0.36	0.52	0.50	0.50	0.37	0.38
	Z4	H_N=8 m	1.68	1.13	1.11	1.30	0.88	0.91	0.91	1.31	1.26	1.24	0.93	0.94
		H_N=15 m	1.23	0.82	0.81	0.95	0.65	0.67	0.66	0.95	0.92	0.90	0.68	0.69
		H_N=22 m	1.01	0.68	0.67	0.78	0.53	0.55	0.55	0.79	0.76	0.75	0.56	0.57
		H_N=30 m	0.87	0.58	0.57	0.67	0.46	0.47	0.47	0.67	0.65	0.64	0.48	0.49

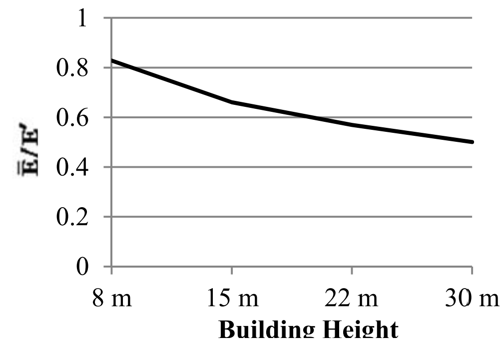

Fig. 1 The variation of average $\overline{E}/E'$ in *Z*1 local site class for all locations (Case 1)

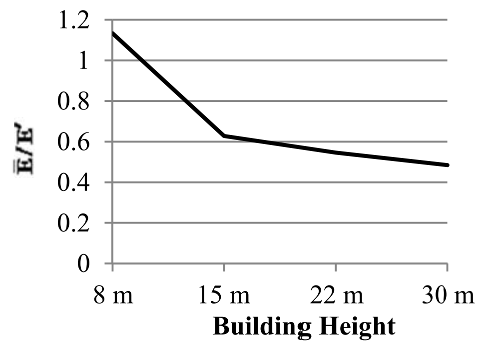

Fig. 2 The variation of average $\overline{E}/E'$ in *Z*2 local site class for all locations (Case1)

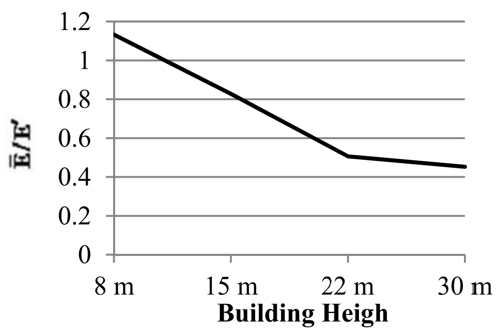

Fig. 3 The variation of average $\overline{E}/E'$ in *Z*3 local site class for all locations(Case1)

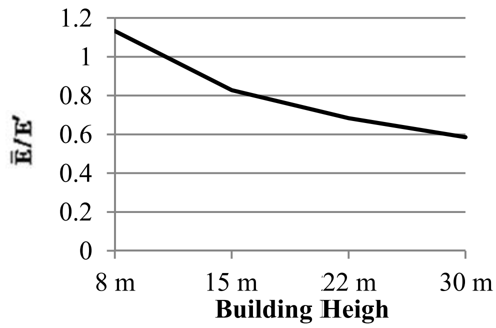

Fig. 4 The variation of average $\overline{E}/E'$ in *Z*4 local site class for all locations (Case 1)

Erzincan, Canakkale, Hakkari, Istanbul (Goztepe and Sile). The similar results are achieved in all local site classes with respect to building heights. That is, if the building heights increase the ratio of $\overline{E}/E'$ decreases. Additively, the least ratios of $\overline{E}/E'$ are observed for local site class *Z*1 and the highest ratios of $\overline{E}/E'$ are observed for local site class *Z*4. The minimum variation on $\overline{E}/E'$ according to only building height is observed for local site class *Z*1 and the maximum variation on $\overline{E}/E'$ is examined for local site class *Z*3.

4.2 Case 2

Considering UBC-1994, the importance factor, *I*, is taken as 1.0 for buildings which are residential and office buildings, hotels, industrial structures, etc. and the response modification factor, R_W, is assumed to be 6 corresponding to buildings in which seismic loads are resisted by reinforced concrete shear walls and its basic structural system is bearing wall system.

Regarding TEC-2007, importance factor, *I*, is used as 1.0 corresponding to buildings in which small number of people live (houses, hotels, employment buildings, restaurants, industrial buildings) and seismic load reduction factor, *Ra*(*T*), is assumed to be 6 corresponding to buildings in which earthquake loads are fully resisted by solid structural walls

In view of above descriptions and values obtained from UBC-1994 and TEC-2007, which are used for the calculation of the mean earthquake load, $\overline{E}$, and the nominal earthquake load, E', respectively. The mean to nominal ratios of earthquake load corresponding to different local site classes and building heights are computed and summarized in Table 10.

Table 10 Mean to nominal ratios of earthquake load in terms of different local site classes and building heights (*RW*=6, *Ra*(*T*)=6)

Parameter \ Location		Ankara	Izmir	Bursa	Antalya	Gaziantep	Samsun	Malatya	Erzincan	Canakkale	Hakkari	Goztepe/ Istanbul	Sile/Istanbul
A		0.19	0.51	0.50	0.44	0.20	0.31	0.41	0.59	0.57	0.56	0.42	0.32
A_0		0.10	0.40	0.40	0.30	0.20	0.30	0.40	0.40	0.40	0.40	0.40	0.30
$\overline{E}/E'$ *Z*1	H_N=8 m	1.41	0.95	0.92	1.09	0.75	0.76	0.77	1.10	1.06	1.04	0.79	0.80
	H_N=15 m	1.12	0.75	0.74	0.87	0.89	0.61	0.60	0.87	0.84	0.83	0.62	0.63
	H_N=22 m	0.97	0.65	0.64	0.75	0.51	0.53	0.52	0.75	0.72	0.71	0.53	0.54
	H_N=30 m	0.85	0.57	0.56	0.66	0.65	0.46	0.46	0.66	0.64	0.63	0.47	0.48
*Z*2	H_N=8 m	1.92	1.29	1.26	1.48	1.01	1.04	1.04	1.49	1.44	1.42	1.06	1.08
	H_N=15 m	1.06	0.71	0.70	0.82	0.56	0.58	0.57	0.83	0.80	0.78	0.59	0.60
	H_N=22 m	0.92	0.62	0.61	0.71	0.49	0.50	0.50	0.72	0.69	0.68	0.51	0.52
	H_N=30 m	0.82	0.55	0.54	0.63	0.43	0.45	0.44	0.64	0.62	0.60	0.45	0.46
*Z*3	H_N=8 m	1.92	1.29	1.26	1.48	1.01	1.04	1.04	1.49	1.44	1.42	1.06	1.08
	H_N=15 m	1.40	0.94	0.92	1.08	0.74	0.76	0.76	1.09	1.05	1.03	0.78	0.79
	H_N=22 m	0.86	0.58	0.56	0.66	0.45	0.47	0.46	0.67	0.64	0.63	0.47	0.48
	H_N=30 m	0.77	0.52	0.51	0.59	0.40	0.42	0.41	0.60	0.58	0.57	0.43	0.43
*Z*4	H_N=8 m	1.92	1.29	1.26	1.48	1.01	1.04	1.04	1.49	1.44	1.42	1.06	1.08
	H_N=15 m	1.40	0.94	0.92	1.08	0.74	0.76	0.76	1.09	1.05	1.03	0.78	0.79
	H_N=22 m	1.16	0.78	0.76	0.89	0.61	0.63	0.62	0.90	0.87	0.85	0.64	0.65
	H_N=30 m	0.99	0.67	0.65	0.77	0.52	0.54	0.54	0.77	0.74	0.73	0.55	0.56

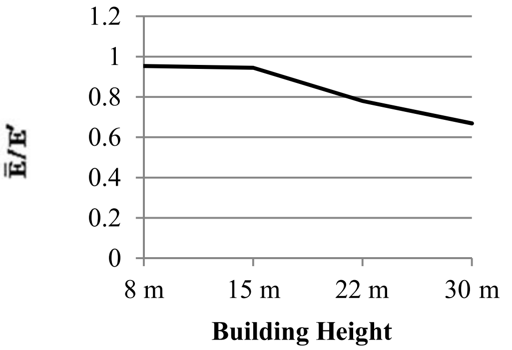

Fig. 5 The variation of average $\overline{E}/E'$ according to *Z*1 local site class for all locations (Case 2)

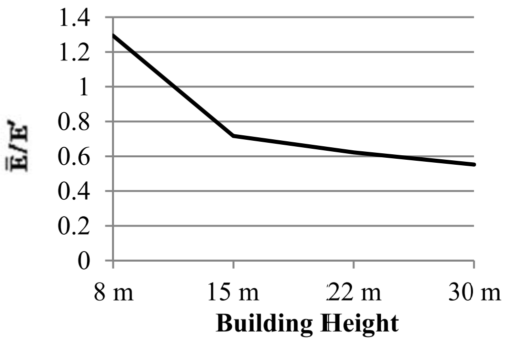

Fig. 6 The variation of average $\overline{E}/E'$ according to *Z*2 local site class for all locations (Case 2)

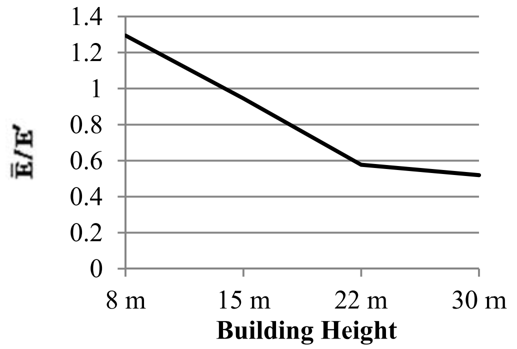

Fig. 7 The variation of average $\overline{E}/E'$ according to *Z*3 local site class for all locations (Case 2)

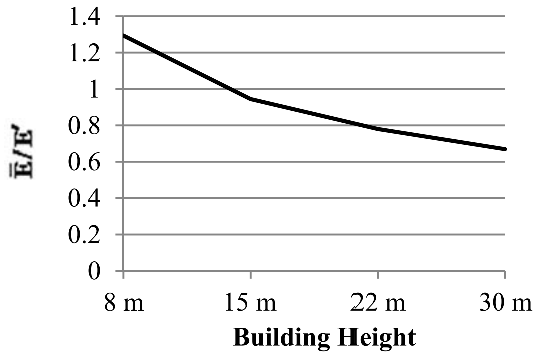

Fig. 8 The variation of average $\overline{E}/E'$ according to *Z*4 local site class for all locations(Case 2)

For Case 2, the variation of average $\overline{E}/E'$ according to different building heights and different local site classes are given Figs. 5-8 taking into consideration all locations. In these graphs, it is seen that as the building heights increase the ratio of $\overline{E}/E'$ decreases for all local site class. However the minimum variation on $\overline{E}/E'$ according to only building heights is observed for local site class *Z*1 and the maximum variation on $\overline{E}/E'$ is examined for local site class *Z*3. In addition, the least ratios of $\overline{E}/E'$ are observed for local site class *Z*1 and the highest ratios of $\overline{E}/E'$ are observed for local site class *Z*4.

4.3 Case 3

Considering the UBC-1994, the importance factor *I* is taken as 1.0 for buildings which are residential and office buildings, hotels, industrial structures, etc. and the response modification factor, R_W, is assumed to be 6 suitable for buildings in which seismic loads are resisted by reinforced concrete shear walls and its basic structural system is bearing wall system.

In TEC-2007, however, the importance factor *I* is used as 1.0 corresponds to buildings in which small number of people live (houses, hotels, employment buildings, restaurants, industrial buildings) and the seismic load reduction factor, $Ra(T)$, is assumed to be 4 for systems with normal ductility level in connection with buildings in which earthquake loads are fully resisted by solid structural walls

In the light of above descriptions based on UBC-1994 and TEC-2007, the mean to nominal ratios of earthquake load according to different local site classes and building heights are obtained, and results are presented in Table 11. For Case 3, the variation of average $\overline{E}/E'$ according to different building heights and different local site classes are given in Figs. 9-12. As presented in these figures, the similar observations are obtained if the results obtained from Case 1 and Case 2 are compared to Case 3.

In view of Case 1, Case 2 and Case 3, the average mean to nominal ratios of earthquake load, $\overline{E}/E'$, corresponding to different local site classes and building heights are given in Table 12. It should be drawn attention that, in these cases, the mean value of earthquake load, $\overline{E}$, is computed from UBC-1994 and the nominal value, E', from TEC-2007. The average values belong to all local site classes and building heights. The average ratio of $\overline{E}/E'$ is 1.03 for Ankara and this ratio varies between 0.55 and 0.80 for other cities. The highest $\overline{E}/E'$ values are obtained for the Case 1 that the response modification factor, R_W, is assumed to be 6 and seismic load reduction factor, $Ra(T)$, is assumed to be 6.

Table 11 Mean to nominal ratios of earthquake load in terms of different local site classes and building heights (R_W=6, $Ra(T)$=4)

Parameter \ Location		Ankara	Izmir	Bursa	Antalya	Gaziantep	Samsun	Malatya	Erzincan	Canakkale	Hakkari	Goztepe/ Istanbul	Sile/Istanbul
A		0.19	0.51	0.50	0.44	0.20	0.31	0.41	0.59	0.57	0.56	0.42	0.32
A_0		0.10	0.40	0.40	0.30	0.20	0.30	0.40	0.40	0.40	0.40	0.40	0.30
$\overline{E}/E'$ *Z*1	H_N=8 m	0.94	0.63	0.62	0.72	0.49	0.51	0.51	0.73	0.70	0.69	0.52	0.53
	H_N=15 m	0.75	0.50	0.49	0.58	0.39	0.41	0.40	0.58	0.56	0.55	0.41	0.42
	H_N=22 m	0.64	0.43	0.42	0.50	0.34	0.35	0.35	0.50	0.48	0.47	0.36	0.36
	H_N=30 m	0.57	0.38	0.37	0.44	0.30	0.31	0.31	0.44	0.43	0.42	0.31	0.32
*Z*2	H_N=8 m	1.28	0.86	0.84	0.99	0.67	0.70	0.69	0.99	0.96	0.94	0.71	0.72
	H_N=15 m	0.71	0.48	0.47	0.55	0.37	0.39	0.38	0.55	0.53	0.52	0.39	0.40
	H_N=22 m	0.62	0.41	0.41	0.48	0.32	0.34	0.33	0.48	0.46	0.45	0.34	0.35
	H_N=30 m	0.55	0.37	0.36	0.42	0.29	0.30	0.29	0.42	0.41	0.40	0.30	0.31
*Z*3	H_N=8 m	1.28	0.86	0.84	0.99	0.67	0.70	0.69	0.99	0.96	0.94	0.71	0.72
	H_N=15 m	0.94	0.63	0.62	0.72	0.46	0.51	0.50	0.73	0.70	0.69	0.52	0.53
	H_N=22 m	0.57	0.38	0.38	0.44	0.30	0.31	0.31	0.44	0.43	0.42	0.32	0.32
	H_N=30 m	0.51	0.34	0.34	0.40	0.27	0.28	0.28	0.40	0.38	0.38	0.28	0.29
*Z*4	H_N=8 m	1.28	0.86	0.84	0.99	0.67	0.70	0.69	0.99	0.96	0.94	0.71	0.72
	H_N=15 m	0.94	0.63	0.62	0.72	0.49	0.51	0.50	0.73	0.70	0.69	0.52	0.53
	H_N=22 m	0.77	0.52	0.51	0.60	0.41	0.42	0.42	0.60	0.58	0.57	0.43	0.43
	H_N=30 m	0.66	0.44	0.44	0.51	0.35	0.36	0.36	0.51	0.50	0.49	0.37	0.37

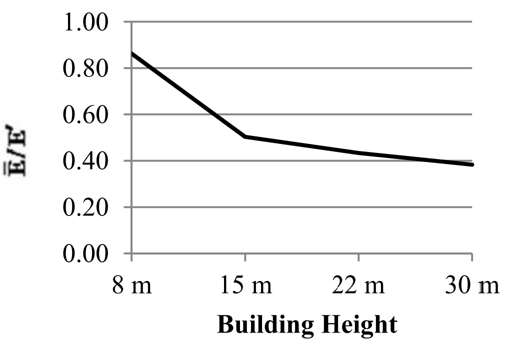

Fig. 9 The variation of average $\overline{E}/E'$ according to *Z*1 local site class for all locations (Case 3)

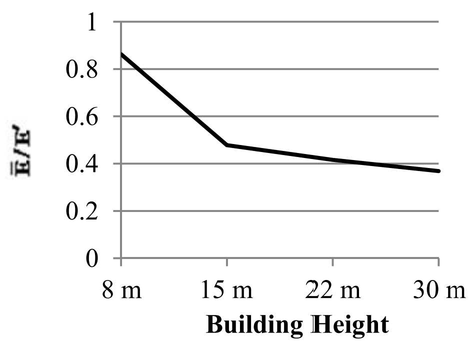

Fig. 10 The variation of average $\overline{E}/E'$ according to *Z*2 local site class for all locations (Case 3)

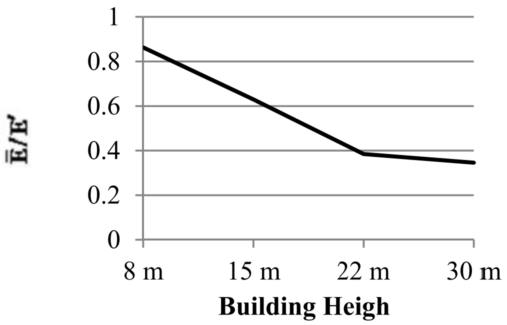

Fig. 11 The variation of average $\overline{E}/E'$ according to *Z*3 local site class for all locations (Case 3)

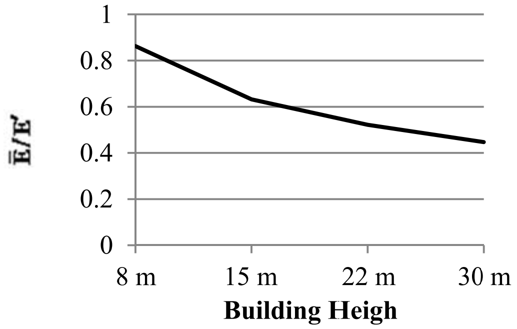

Fig. 12 The variation of average $\overline{E}/E'$ according to *Z*4 local site class for all locations(Case 3)

Table 12 The average mean to nominal ratios of earthquake load obtained from UBC 1994 and TEC-2007 for different locations

Situation \ Location	Ankara	Izmir	Bursa	Antalya	Gaziantep	Samsun	Malatya	Erzincan	Canakkale	Hakkari	Goztepe/ Istanbul	Sile/Istanbul
Case 1	1.07	0.72	0.71	0.82	0.56	0.58	0.58	0.83	0.8	0.79	0.59	0.6
Case 2	1.22	0.82	0.8	0.94	0.67	0.66	0.66	0.95	0.91	0.9	0.67	0.69
Case 3	0.81	0.55	0.54	0.63	0.42	0.44	0.44	0.63	0.61	0.6	0.45	0.46
Average of Cases	1.03	0.70	0.68	0.80	0.55	0.56	0.56	0.80	0.77	0.76	0.57	0.58

Table 13 Mean to nominal ratios of earthquake load for different locations where both values (mean and nominal) are computed based on TEC-2007

Parameter \ Location	Ankara	Izmir	Bursa	Antalya	Gaziantep	Samsun	Malatya	Erzincan	Canakkale	Hakkari	Goztepe/ Istanbul	Sile/Istanbul
$\overline{E}/E'$	1.90	1.28	1.25	1.47	1.00	1.03	1.03	1.48	1.43	1.40	1.05	1.07

On the other hand, assuming that TEC-2007 gives the best estimate of the “true” mean value of lateral base shear force for buildings in Turkey, this code can also be used to compute “true” mean value of the earthquake load. However, since the nominal earthquake load is also computed based on TEC-2007, the ratio of $\overline{E}/E'$ will be equal to A/A_0. The resulting mean to nominal ratios of earthquake load are shown in Table 13.

In his study, Ellingwood (1994) stated that the uncertainty in earthquake load is dominated by the uncertainty involved in the seismic hazard analysis; the coefficient of variation (COV) in A is typically around 0.80 or more while the COV due to other structural response parameters is 0.30 or less. Komurcu and Yucemen (1996) assumed that the basic variability due to other factors different than those involved in the estimation of A in the earthquake load is equal to 0.6. In the light of these studies, we can take the COV to be 0.45 as the average of the two values given above for the modeling error associated with the seismic load in terms of maximum shear forces at the base of buildings.

It is assumed that mean to nominal ratio of earthquake load exhibits a Type II extreme value distribution like the peak ground acceleration. The results of the average mean to nominal ratio of earthquake load and total variability are shown in Table 14. It is to be noted that in this table, the mean to nominal ratio of earthquake load is the average value obtained from the mean to nominal ratios given in Tables 12 and 13. Also in Fig. 13, the comparison of mean to nominal earthquake loads are shown according to different locations considered in this research.

Table 14 Statistical parameters of the mean to nominal ratio for earthquake load

Parameter \ Location	Ankara	Izmir	Bursa	Antalya	Gaziantep	Samsun	Malatya	Erzincan	Canakkale	Hakkari	Goztepe/ Istanbul	Sile/Istanbul
A	0.15	0.37	0.36	0.32	015	020	0.30	041	0.43	0.40	0.48	0.29
Ω_A	0.98	0.95	0.98	0.98	0.97	1.06	0.96	0.99	0.95	0.98	1.12	0.99
$\overline{E}/E'$	1.47	0.99	0.97	1.14	0.78	0.80	0.80	1.14	1.10	1.08	0.81	0.83
Δ	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
$\Omega_{\overline{E}/E'}$	1.08	1.05	1.08	1.08	1.07	1.15	1.06	1.09	1.05	1.08	1.21	1.09

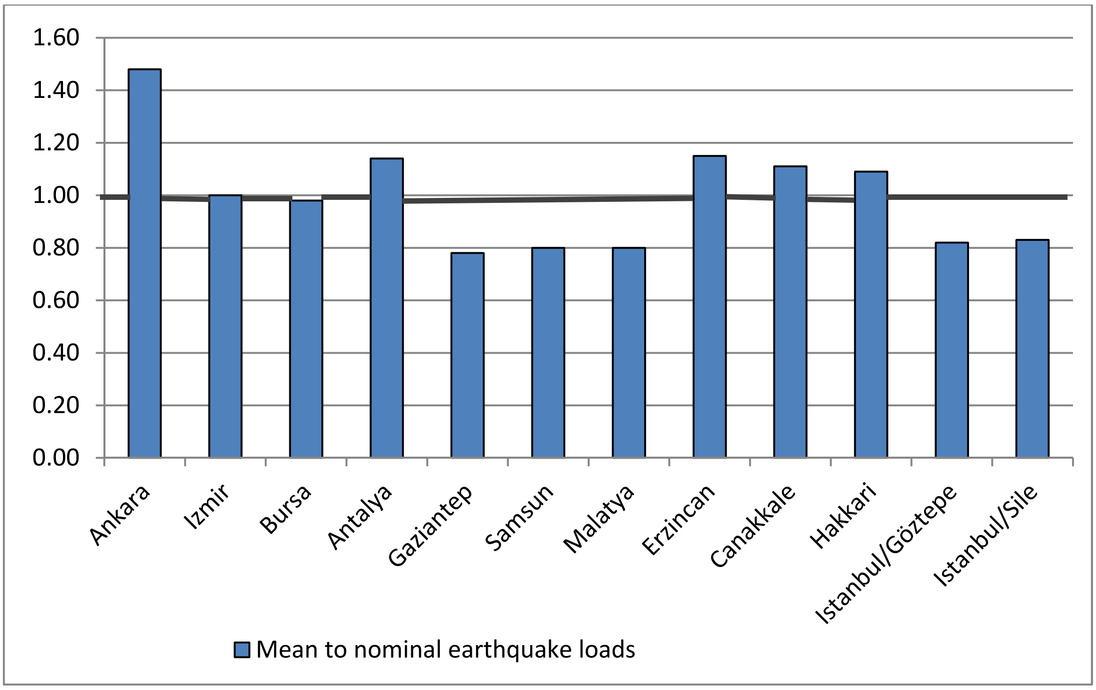

Fig. 13 Mean to nominal earthquake loads according to different locations

5. Conclusions

The specifications and standards developed for earthquake load are usually compatible with peak ground accelerations. For this reason, it is utilized as the seismic hazard parameter in this study. After the nominal earthquake loads, E', are determined depending on the effective ground acceleration coefficient proposed in the Turkish Earthquake Code (TEC-2007), the ratios of mean earthquake load computed by statistical methods to nominal earthquake loads, $\overline{E}/E'$ are determined for the purpose of code calibration. In this study, advanced seismic analyses of the locations mentioned are not addressed with all its specifics. However, the first stage of code calibration process is carried out regarding the differences between TEC-2007 and UBC-1994 based on the local conditions and the available data. In computing $\overline{E}/E'$ values, for the three different cases, earthquake zone, load reduction factor, $Ra(T)$ and importance factor are considered for the purpose of comparison (Case 1, Case 2 and Case 3). It is to be noted that, in these cases, the mean value of earthquake load, $\overline{E}$, is computed from UBC-1994 and the nominal value, E', from TEC-2007 by using a computer code developed in MathCAD 14. In this study, the sources of aleatory and epistemic uncertainties of earthquake load are investigated and these uncertainty sources are quantified with the possible models based on the data and knowledge available; and uncertainty analyses are carried out in combining these uncertainty sources.

Similar behavior depending upon building heights and local site classes are observed in all cases (Case 1-Case 3). If the building height increases, the ratio of $\overline{E}/E'$ decreases. In addition, the highest ratios of $\overline{E}/E'$ are generally observed for local site class $Z4$ and the least ratios of $\overline{E}/E'$ are observed for local site class $Z1$. The maximum variation on $\overline{E}/E'$ depending on only building height is observed for local site class $Z3$ and the minimum variation on $\overline{E}/E'$ is observed for local site class $Z1$.

In this study, the mean earthquake loads are computed statistically according to both UBC-1994 and TEC-2007 while nominal earthquake loads are computed according to only TEC-2007. If UBC-1994 is taken into consideration while determining mean earthquake load, all locations except Ankara stay on the safe side (Table 12). The average ratio of $\overline{E}/E'$ is 1.03 for Ankara and this ratio varies between 0.55 and 0.80 for other cities. The highest $\overline{E}/E'$ values are obtained for the case that the response modification factor, R_W, is assumed to be 6 corresponding to buildings in which seismic loads are resisted by reinforced concrete shear walls and its basic structural system is bearing wall system and seismic load reduction factor, $Ra(T)$, is assumed to be 6 corresponding to buildings in which earthquake loads are fully resisted by solid structural walls. In this case the ratio of $\overline{E}/E'$ is 1.22 for Ankara and this ratio varies between 0.66 and 0.95 for other cities. If TEC-2007 is taken into consideration while both determining mean earthquake load and nominal earthquake load, it is seen that the results of $\overline{E}/E'$ are very high; that is the ratios of the mean earthquake load computed statistically to nominal earthquake load based on Turkish Earthquake Code (TEC-2007) for different cities are found to be range from 1.00 to 1.90 (Table 13).

It is concluded that, the average ratio of mean to nominal earthquake load varies from 0.78 to 1.47 for the locations taken into consideration in this study (Table 14 and Fig. 13). In addition, the total uncertainty on earthquake load based on aleatory and epistemic uncertainty sources, quantified in terms of coefficient of variation, varies from 1.05 to 1.21. These results put forward the fact that the variabilities and uncertainties of earthquake load computed from the structural codes and regulations are extremely high.

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