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Statistical evaluation of maximum displacement demands of SDOF systems by code-compatible nonlinear time history analysis

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ABSTRACT

By the developments in structural and earthquake engineering, modern seismic codes have begun to recommend nonlinear static and dynamic procedures to approximate the maximum displacement demands which have uttermost importance for seismic assessment of buildings. Dynamic procedure is the most accurate and reliable among them and requires the selection of real/artificial ground motion records compatible to considered elastic design spectra. In this study, maximum displacement demands of SDOF systems with various lateral strength ratios and vibration periods are determined via nonlinear time history analyses using the code-compatible different records sets constructed by real accelerograms. For this purpose, 30 ground motion record sets compatible with elastic design spectra defined for each local soil class in Turkish Earthquake Code are used separately. Evaluations have highlighted that i) variation of maximum displacement demands in the sets are high; ii) Distinct ground motion record sets may result in different displacement demands even though they are compatible with the same design spectra; iii) maximum displacement demands of different ground motion record sets can be simply accepted as random samples of the same population at 95% confidence level. In addition to dynamic analysis results, maximum displacement demands of static procedure are determined for the same target spectra and results of both methods are compared. Comparisons showed that special attention should be made to static procedure estimations for the buildings with long periods on stiff soils. Finally, linear regression models, depending on the fundamental periods for each lateral strength ratio and soil type, are proposed for rapid prediction of displacement demands in reliability based manner.

1. Introduction

Performance-based design is currently the popular design philosophy in which design criteria are expressed in terms of achieving stated performance objectives when the structure is subjected to required levels of seismic hazard [1]. Performance objectives can be depended on the level of damage to the structure, which in turn can be related to displacement and drift. Thus, structural response parameters such as maximum displacement, global or interstory drift ratio, ductility demands, etc. have been widely used as design targets [2,3]. In order to identify various performance levels for the seismic performance evaluation of existing buildings, similar parameters are also utilized [4,5].

In order to estimate the response of structures to seismic excitation, nonlinear time history analysis of three-dimensional structural models is the most comprehensive and accurate method. However, it can be said that nonlinear time history analysis of three-dimensional structural models are complex and difficult. For this reason, many research efforts have focused on simpler approaches. Using equivalent single degree of freedom (SDOF) system is one of the simpler approaches. SDOF systems have been preferred as structural models to estimate and evaluate the response of structures to seismic excitation [6–13]. In these studies, various criteria are used in the selection of ground motion records for nonlinear time history analyses.

Nowadays, thanks to easily accessible digital ground motion database, real ground motion records are increasingly preferred for time history analysis. It should be noted that ground motion records vary based on magnitude of the earthquake, faulting type, local soil properties, the distance between the site and recording station, etc. In addition, ground motion records used for time history analysis directly affect the response parameters such as displacements or drift demands that would be considered for seismic design or evaluation of structures. Thus, selection of ground motion records based on the seismicity of the region and the local soil conditions that a structure located is important

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for accurate estimation of the seismic behavior of that structure in a possible earthquake [14–17].

Time history analysis is accepted as one of the structural analysis method for seismic design or performance evaluation by modern seismic design codes [18–21]. Turkish Earthquake Code (TEC) [22] is one of the design codes. In these codes, relatively similar procedures with minor differences for simulating the seismic actions are described. For example, seismic loads are represented by ground motion records used for time history analyses. Synthetic, artificial, or real ground motion records could be used as long as they are compatible with regional design spectra defined in the seismic codes within a stated period range. The mean of the structural responses can be used for seismic design and/or performance evaluation if at least seven ground motion records are selected, otherwise the maximum of structural responses is considered [23–25].

It is possible to obtain various code-compatible ground motion record sets by selecting and scaling from hundreds of ground motion records in digital databases [16,26–28]. As mentioned earlier, ground motion records used for time history directly affect the displacement and/or drift ratio demands that would be considered for seismic design or performance evaluation. Hence, seismic demands could be accepted as random variables that vary according to ground motion record sets used for time history analyses. Moreover, modern seismic codes consider only the mean spectrum of selected ground motion records and target design spectrum for compatibility without considering random variability of the individual ground motion records. For this reason, the dispersion of seismic demands obtained using code-compatible ground motion record sets is generally high [29–31].

The aim of this study is to statistically evaluate the central tendency and dispersion of maximum displacement demands of SDOF systems using different code-compatible ground motion record sets. 21 different SDOF systems with various vibration periods and lateral strength ratio are used in order to consider a broad range of SDOF systems. Ground motion record sets compatible with design spectra described for local soil classes defined in TEC are used for nonlinear time history analyses. For each local soil class, 30 different ground motion record sets are used to obtain statistically significant number of random samples. Performing nonlinear analysis of the SDOF system, maximum displacement demands are calculated for each of the ground motion records in the record sets. Then, the mean of maximum displacement demands are calculated for each of the record sets. Coefficient of variation is used to numerically evaluate the dispersion of the displacement demands within the records sets. One-way analysis of variance is also used to evaluate the difference between the mean of the displacement demands of the record sets compatible with the same design spectra. The problem of estimating the displacement demands for seismic design and performance evaluation has attracted growing attention in recent years. In this study, confidence intervals of displacement demands for each of the SDOF systems and local soil classes are estimated at 95% confidence level. Linear regression models, depending on the fundamental periods for each lateral strength ratio and soil type, are also proposed for rapid prediction of displacement demands in reliability based manner.

2. Elastoplastic SDOF systems

Actually, all the structures possess infinite number of degrees of freedom and are called as multi degree of freedom (MDOF) systems. Nowadays, nonlinear response of MDOF systems to seismic excitation can be estimated through three-dimensional nonlinear time history analysis. However, time history analysis of the structures with a large number of degrees of freedom may require a significant amount of time. For this reason, a number of research efforts have focused on simple procedures to estimate the structural response of MDOF systems under seismic actions. For example, an equivalent SDOF system can be used as a basis for estimating the response of a MDOF model of the structures [4]. In this way, the nonlinear response of the structures can be estimated from the response of equivalent SDOF system.

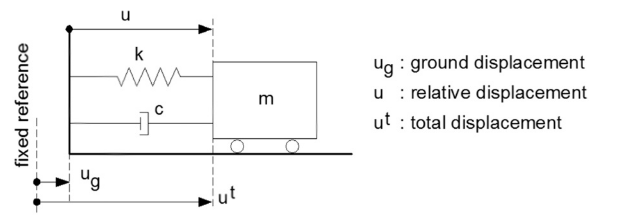

Fig. 1. Mechanical model of a SDOF system subjected to seismic excitation.

The mechanical model of a SDOF system subjected to seismic excitation is given in Fig. 1. Equation of motion of a SDOF system is given in Eq. (1). In Eq. (1), k is the lateral stiffness of the system, c is the viscous damping coefficient and m is the mass of the system.

$$m\ddot{u} + c\dot{u} + ku = -m\ddot{u}_g \tag{1}$$

When subjected to severe excitations such as strong earthquake ground motion, structures would respond inelastically and exhibit hysteretic behavior. Eq. (1) can be readily extended to inelastic systems. For such systems, the equation of motion is given in Eq. (2). In Eq. (2), $F(u)$ is the resisting force of inelastic system.

$$m\ddot{u} + c\dot{u} + F(u) = -m\ddot{u}_g \tag{2}$$

Hysteretic models have been used for the inelastic earthquake-resistant design of structures [32]. The most commonly used model for describing the nonlinear hysteretic restoring force-displacement behavior is the perfectly elastoplastic model with no stiffness and strength degradation. This model is parameterized by yield force (F_y) and initial stiffness (k_0). In Fig. 2, force-displacement relationship for elastoplastic model is given. In this study, the SDOF systems are characterized by perfectly elastoplastic cyclic behavior. It should be noted that different hysteretic models can be used to represent the behavior of different type of structures subjected to earthquake motions.

A robust method for the estimation of the fundamental period of vibration is essential both for the design of new buildings and the performance assessment of existing ones. Several design codes provide formulas for estimating the fundamental period of buildings. Typically, such formulas are derived from regression analysis of numerical values, which have been obtained from measured periods of vibrations of real buildings during past earthquakes. Despite the fact that several other parameters affect the period of vibration, the formulas given by design codes are, typically, a function of the building's height or the number of stories. For example, according to EUROCODE-8 [19], fundamental period of vibration and height (in meters) of the buildings relationship given in Eq. (3) is specified for force-based design of the moment resistant concrete frames with heights of up to 40 m. Similar relationship (see Eq. (4)) is specified in ASCE 07-05 [20]. In NEHRP-94 [33] and National Building Code of Canada (NBCC) [34] an alternative formula given in Eq. (5) is recommended for RC buildings based on the number

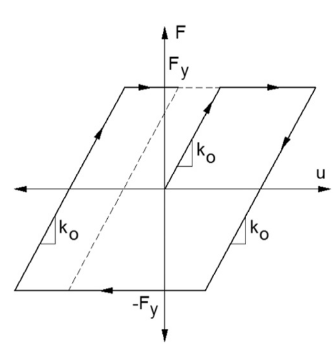

Fig. 2. The force-displacement relationship for elastoplastic model.

Table 1
Description soil classes according to EUROCODE-8 and TEC.

Definition		Shear wave velocity (m/s)		Soil class	
EC-8	TEC	EC-8	TEC	EC-8	TEC
Rock or other rock-like geological formation	Very dense sediment, gravel and solid clay	> 800	> 700	A	Z1
Very dense sand or gravel or very stiff clay	Dense sediment gravel, very stiff clay	360–800	300–700	B	Z2
Dense or medium dense sand, gravel or stiff clay	Medium dense sediment and gravel, stiff clay	180–360	200–400	C	Z3
Loose to medium cohesionless soil or soft to firm cohesive soil	Weak sediment, soft clay alluvial layer with high water level	< 180	< 200	D	Z4
Surface alluvium layer C or D with water level on stiffer material				E	

of stories, N:

$$T = 0.075H^{0.75} \quad (3)$$

$$T = 0.0466H^{0.9} \quad (4)$$

$$T = 0.1N \quad (5)$$

If the Eqs. (3)–(5) are carefully examined, it can be deduced that RC buildings with 10 stories and/or 30 m in height or less have the fundamental period equal or less than 1.0 s. These buildings also constitute an important part of existing RC buildings. In addition to fundamental period of the buildings, lateral strength ratio of the building, the ratio of the yield force to seismic weight of the building (F_y/W), should be determined to perform nonlinear time history analysis. Evaluation of various studies in lateral strength ratio of low and mid-rise buildings have indicated that this ratio generally range between 0.1 and 0.3 [35–37].

In order to obtain structural analysis results which can represent the structural response of low and mid-rise RC buildings up to 10 stories, natural vibration period of the SDOF systems used in this study is selected between 0.4 s and 1.0 s with increments of 0.1 s and the lateral strength ratio of the SDOF systems used in this study is selected as 0.1, 0.2 and 0.3.

3. Ground motion record sets

In most of the modern seismic codes including the Turkish Earthquake Code [22] time history analysis is accepted as one of the analysis method for design and/or performance evaluation, and required conditions are defined (FEMA-368 [18], EUROCODE-8 [19], ASCE 07-05 [20], GB [21]). In these codes, in order to simulate the seismic actions to be used as dynamic loading, relatively similar procedures are described. According to these codes, the mean response spectra of the selected ground motion records for time history analysis should be compatible with the regional design spectra defined in the codes within a stated period range [23].

In this study, ground motion records compatible with TEC used for time history analysis of the SDOF systems. Elastic design spectra defined in TEC for each local soil class is considered separately to select ground motion record sets. European Ground Motion Database [38] is used to select real ground motions for the record sets.

3.1. Time history analysis requirements in TEC

According to TEC, in order to perform linear or nonlinear time history analysis of buildings previously recorded, artificially generated or simulated ground motions can be used. Recorded and simulated ground motions should be obtained by considering appropriate local site conditions. Moreover, ground motion records should meet the following conditions:

- The duration of strong motion part shall be equal or bigger than 5 times the fundamental vibration period of the building in the considered direction and 15 s;
- Mean spectral acceleration of ground motion records for zero period shall be equal or bigger than design ground acceleration;
- Mean spectral accelerations of ground motion records for 5% damping ratio shall be equal or bigger than 90% of design spectral accelerations in the period range between 0.2T and 2.0T with respect to fundamental vibration period T of the building in the considered direction.

In time history calculations, at least three ground motions shall be used. The mean structural responses can be considered for the design or seismic performance evaluation if at least seven ground motions are utilized. Otherwise, the maximum of structural responses shall be considered.

3.2. Ground motion database and record sets

Four seismic zones (1st, 2nd, 3rd and 4th degree seismic zones), depicted in Seismic Zoning Map of Turkey prepared by the Ministry of Public Works and Settlement [39] are cited in TEC. Effective ground acceleration is 0.4g, 0.3g, 0.2g and 0.1g for the 1st, 2nd, 3rd and 4th degree seismic zones, respectively for a probability of exceedance of 10% in 50 years (for a return period of 475 years). In TEC, four local soil classes (Z1, Z2, Z3, and Z4) are defined. In Table 1, the information about local soil classes defined in TEC and EUROCODE-8 is given. Depending on the considered seismic zone and local soil class the elastic design spectrum are described to determine seismic loads.

In this study, the 1st degree seismic zone is considered to account for high seismic regions. Spectral Acceleration Coefficient $A(T)$ that would be used to calculate seismic loads based on the TEC specifications for the 1st seismic zone and local soil classes are demonstrated in Fig. 3.

In order to obtain ground motion record sets, first, a catalog of ground motion records is obtained by selecting ground motion records from the European Strong Motion Database following these criteria: the epicentral distance of the record stations be in the range of 10–50 km; the magnitude of the source earthquake be greater than 5.5; and the peak ground acceleration of the ground motion records be 0.10g and higher. As known, five soil classes are defined in EUROCODE-8; A, B, C, D and E. In European Strong Motion Database, there is not sufficient number of ground motion records from soil class D and E satisfying the considered criteria. Thus, these soil classes are ignored in this study and

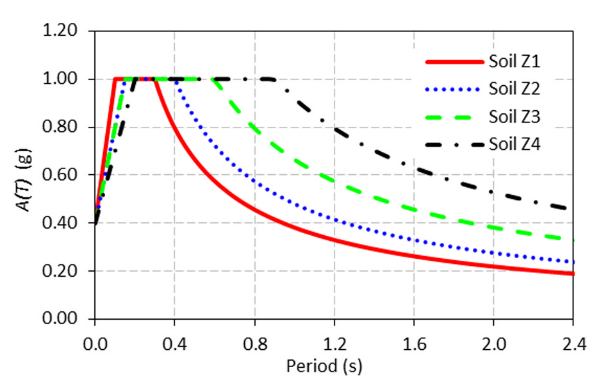

Fig. 3. Spectral acceleration coefficient for local soil classes.

only soil class A, B and C are considered to obtain the ground motion catalog. A total of 542 horizontal components of 271 ground motion records are selected for the catalog. Ground motion records in the catalog are grouped based on the soil class that they are recorded on. There are 190 horizontal components of 95 ground motion records, 236 horizontal components of 118 ground motion records, and 116 horizontal components of 58 ground motion records for soil class A, B and C, respectively, in the catalog. It can be seen from the Table 1 that A, B, C soil classes correspond to Z1, Z2 and Z3 soils classes, respectively.

Ground motion record sets are obtained by selecting ground motion components from the catalog. The detailed information about ground motion selection procedure performed in this study can be found in Kayhan et al. [16] and Kayhan [28]. As mentioned before, recorded ground motions to be used for time history analysis should be obtained considering appropriate local site conditions according to TEC. For this reason, ground motion records sets compatible with soil classes Z1, Z2 and Z3 are obtained by selecting the ground motion records from the catalog considering relevant soil classes A, B and C, respectively.

The scaling coefficient for ground motion records is constrained to be in the range of 0.50–2.00. As the vibration period of the SDOF system is assumed to be range between 0.40s and 1.00s, compatibility of mean and target spectrum should be considered in the period range of 0.08–2.00s according to requirements given in TEC (Section 3.1). For each considered soil class, 30 ground motion record sets are obtained. Each set has seven ground motion components.

In Fig. 4, mean spectra of ground motion records in the record sets and corresponding target spectra are given in order to show the compatibility between mean and target spectra. It should be noted that four of the 30 record sets for each local soil class are selected as examples to show the compatibility.

The information about all the ground motion record sets is given in Appendix A. Appendix A includes ground motion record number, horizontal component indices and scaling coefficient. Detailed information about the ground motion records in the sets including record number, source earthquake, date of source earthquake and record station is also given in Appendix B.

4. Statistical evaluation of time history analysis results

4.1. The mean and dispersion of maximum displacement demands

Performing nonlinear time history analysis using ground motion records in the record sets, maximum displacement demands (Δ_{max}) for the SDOF systems are calculated. In Fig. 5, Δ_{max} values of 30 ground motion sets for soil Z1 and the SDOF system with $T = 0.4$ s and $F_y/W = 0.1$ as a representative example. As can be shown from the figure, for each of the ground motion records in a record sets, various Δ_{max} values are calculated. According to TEC, mean values of the seismic demands can be used if at least seven ground motion records used for time history analysis. Hence, mean of the seven Δ_{max} values (m_Δ) are also calculated for each of the record sets. In Fig. 5, m_Δ values of the record sets are also given as connected by a continuous line.

As shown from the Fig. 5, different values of m_Δ are calculated for 30 ground motion record sets although the record sets are compatible with the same design spectrum. For example, value of m_Δ is 5.13, 5.63, 5.37 and 6.73 cm for Set 1, Set 2, Set 3 and Set 4, respectively. It can be said that there is also a significant dispersion of Δ_{max} values around the m_Δ values in each of the record sets.

In Figs. 6a-6c, values of m_Δ of first four representative ground motion record sets are given for all the considered SDOF systems and local soil classes. m_Δ values calculated for all the SDOF systems and ground motion records sets can be found in Appendix C. According to Figs. 6a-6c, different values of m_Δ are calculated for a SDOF system using different ground motion record sets although the record sets are compatible with the same design spectrum. For example, for the SDOF system with $T = 0.5$ s and $F_y/W = 0.1$, m_Δ values of the first four record sets are 6.49, 6.68, 6.91 and 6.92*cm* for soil Z1, 12.60, 10.23, 12.86 and 8.40 for soil Z2, and 13.99, 12.79, 14.26 and 13.11*cm* for soil Z3. As expected, m_Δ values increase when soil class changes from Z1 to Z3. This is valid for all the SDOF systems. In this study, well-known effects of T and F_y/W on displacement demands of structures are also observed. As can be shown clearly from Figs. 6a-6c, values of m_Δ increase with increasing T of the SDOF systems and decrease with increasing F_y/W of the SDOF systems.

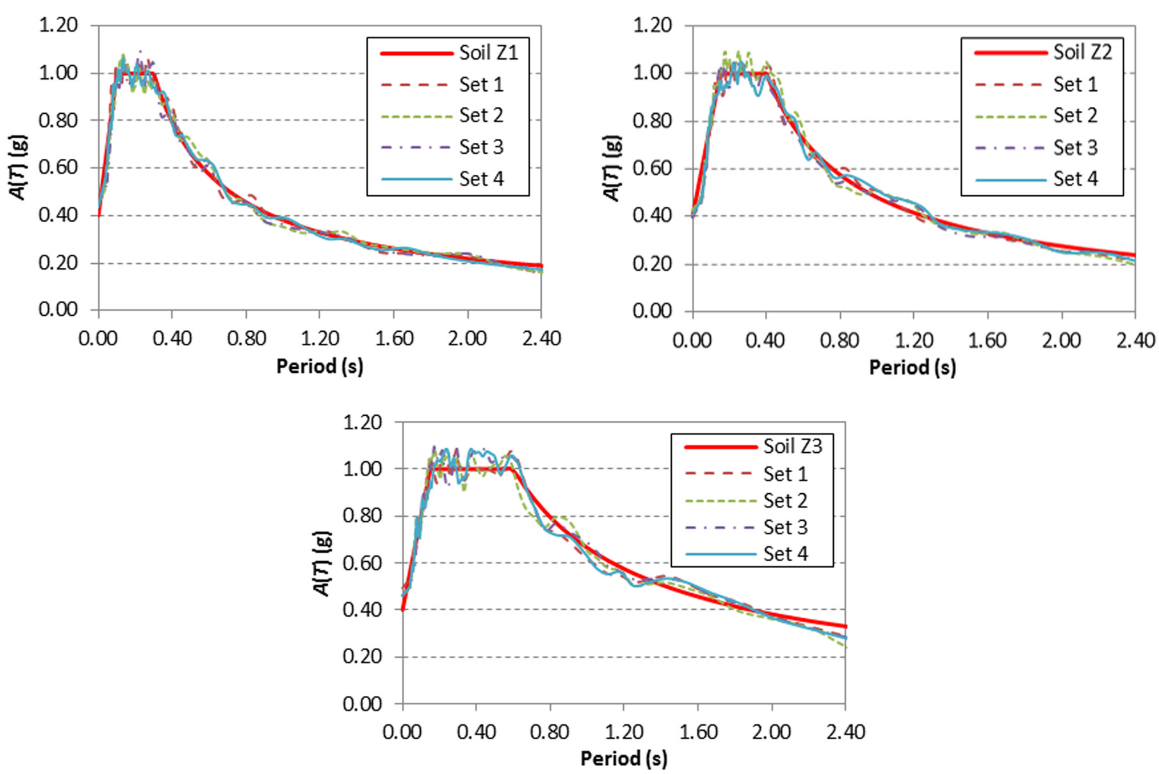

Fig. 4. The mean spectra of representative ground motions sets and target spectra.

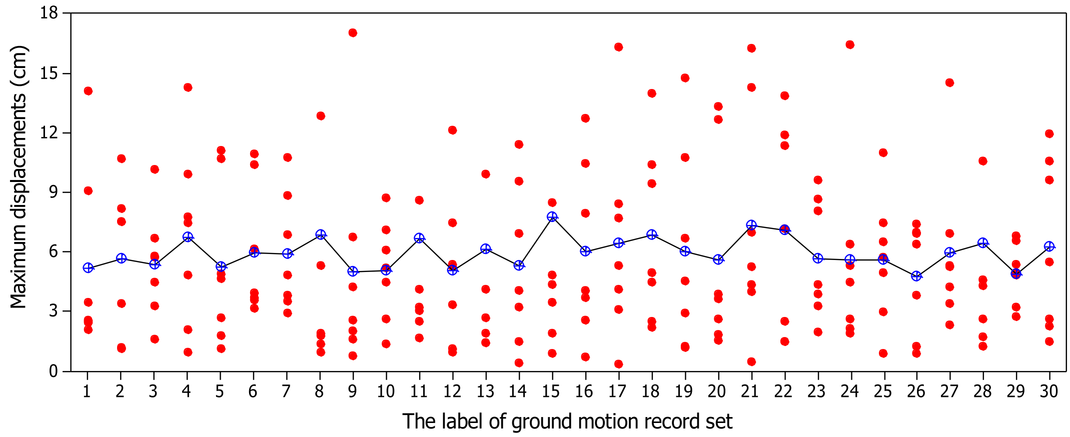

Fig. 5. Δ_{max} values calculated for SDOF system with $T = 0.4$ s, $F_y/W = 0.1$ (Soil Z1).

In order to numerically evaluate the dispersion of Δ_{max} around the m_Δ, coefficient of variation (CoV_Δ), ratio of standard deviation to mean, is calculated for each of the record sets. Values of CoV_Δ calculated for all the record sets are given in Appendix C. In Fig. 7, representative samples for values of CoV_Δ are illustrated. The SDOF systems with minimum and maximum T and F_y/W are selected as representative samples. Considering the SDOF system with minimum T (0.4s), CoV_Δ values of 30 ground motion record sets randomly vary between 0.315 and 1.339, 0.463–1.677 and 0.545–1.255 for soil Z1, Z2 and Z3, respectively (Fig. 7a). In Fig. 7b, CoV_Δ values for the SDOF system with maximum T (1.0s) are given. These values also vary between 0.368 and 0.876, 0.332–1.085 and 0.433–1.009 for soil Z1, Z2 and Z3, respectively.

The central tendency of variation of the maximum displacement demands in the record sets is also evaluated. For this purpose, the mean

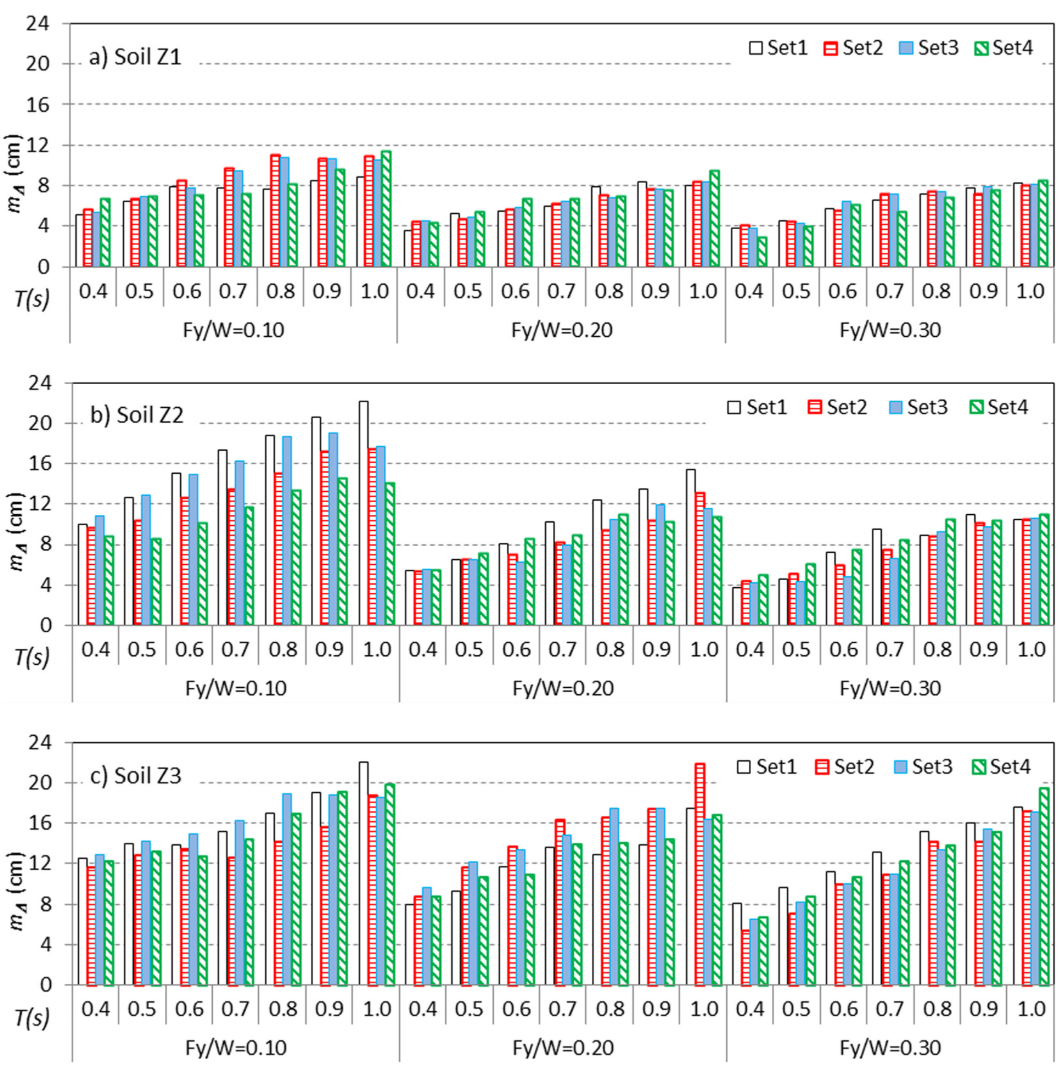

Fig. 6. The graphical representation of the effect of T and F_y/W on m_Δ values.

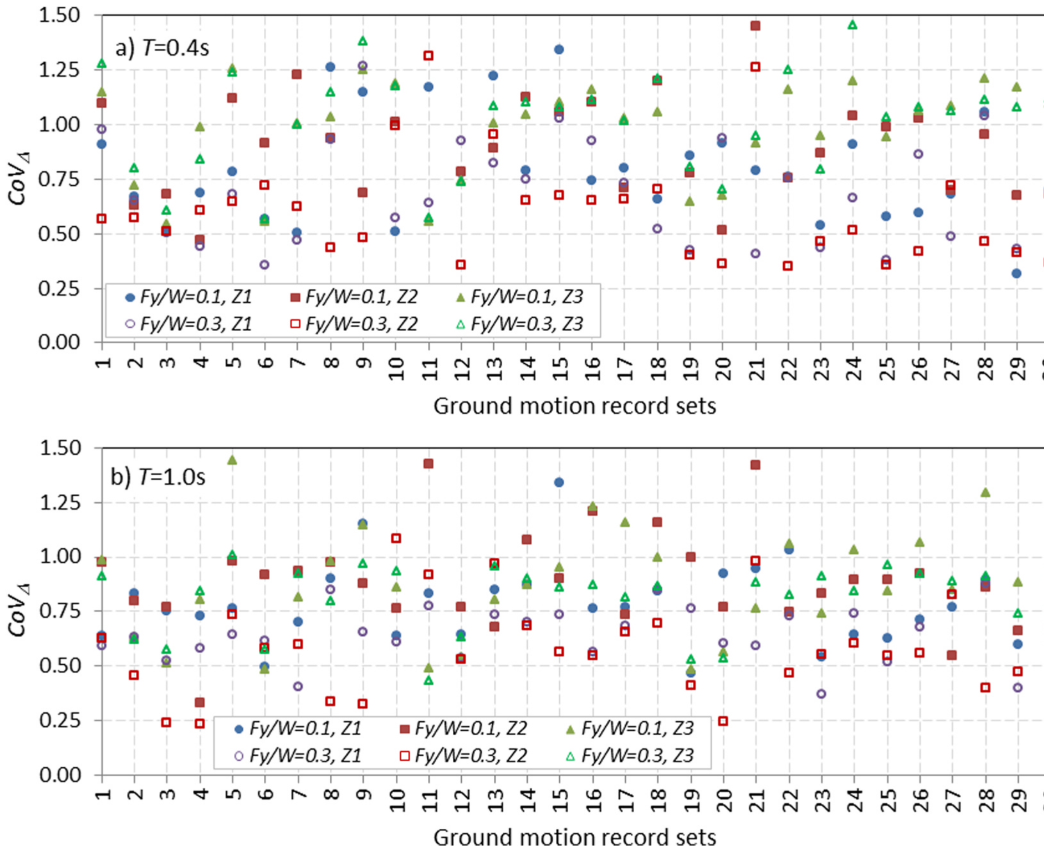

Fig. 7. CoV_{Δ} values calculated for ground motion record sets.

of the CoV_{Δ} values of 30 ground motion record sets are calculated for each of the SDOF systems and local soil classes, separately. As can be shown in Fig. 8, these values change between about 0.50 and 1.00. This result numerically indicates that dispersion of the Δ_{max} around the m_{Δ} is remarkably high and valid for all the SDOF system and local soil classes considered in this study. Similar result has also been stated that by Iervolino et al. [40], Catalan et al. [14], Sextos et al. [29], Katsanos and Sextos [30] and Ergun and Ates [41] for code-compatible nonlinear time history analysis. In this study, the remarkably high variation of the maximum displacement demands obtained from code-compatible nonlinear time history analysis are observed for the broad range of SDOF systems with various T and F_y/W.

4.2. One-way analysis of variance

The results summarized in Fig. 5 and Fig. 6 show that different m_{Δ} values can be obtained for a SDOF system using different ground motion record sets although the record sets are compatible with the same design spectrum. Therefore, it can be said that m_{Δ} is random variables depending on ground motion record sets used for nonlinear time history analysis.

There are several methods and/or parameters to be used to statistically evaluate the differences between m_{Δ} values calculated for different ground motion record sets. In this study, one-way analysis of variance (ANOVA) is used Gamst et al. [42]. The one-way ANOVA is used to evaluate whether there are any statistically significant differences between the means of several independent groups. Suppose k independent groups drawn different populations, each of size n. The members of the groups are assumed as normally distributed with

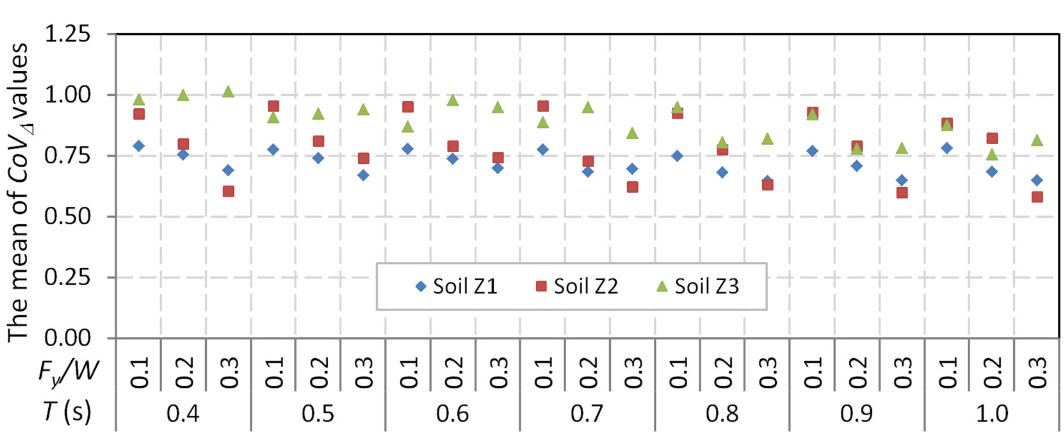

Fig. 8. The mean of CoV_{Δ} values calculated for 30 ground motion record sets.

Table 2
Typical one-way ANOVA model used in this study.

	Set 1	Set 2	Set 3	…	Set k	
	X_{11}	X_{21}	X_{31}	…	X_{k1}	
	X_{12}	X_{22}	X_{32}	…	X_{k2}	
	X_{13}	X_{23}	X_{33}	…	X_{k3}	
	X_{14}	X_{24}	X_{34}	…	X_{k4}	
	X_{15}	X_{25}	X_{35}	…	X_{k5}	
	X_{16}	X_{26}	X_{36}	…	X_{k6}	
	X_{17}	X_{27}	X_{37}	…	X_{k7}	
Total	T_{1+}	T_{2+}	T_{3+}	…	T_{k+}	T_{++}
Mean	X_1	X_2	X_3	…	X_k	X

unknown mean μ and unknown variance σ^2. The relevant null hypothesis is all the population means are equal (Eq. (6)).

$$H_0\colon \mu_1 = \mu_2 = \mu_3 \dots \mu_k \tag{6}$$

In this study, the H_0 is the mean of populations represented by Δ_{max} are equal. Thus, Δ_{max} values obtained using ground motion records in each sets are supposed as independent groups drawn from different populations. For example, considering a SDOF system with $T = 0.4s$ and $F_y/W = 0.1$, there are 30 ground motion record sets for soil Z1 and each of the record sets has seven ground motion records. Therefore, there are 30 independent groups and each of the groups contains seven Δ_{max} values for the SDOF system and soil Z1.

In Table 2, typical model of one-way ANOVA, for $k = 30$ and $n = 7$, is shown. Δ_{max} values are represented by X_{ij} (i and j are the labels of ground motion set and ground motion record in the set, respectively). T_{1+}, T_{2+}, T_{3+} and T_{4+} represents the total of X_{ij} values in the record sets and T_{++} represents the total of all the X_{ij} values. X_i and X refer the mean of the X_{ij} values in the record sets and the mean of all the X_{ij} values, respectively.

In order to test H_0, the test statistic F is used (Eq. (7)). F is the ratio of the variance between groups to the variance within groups. In Eq. (7), ${s_0}^2$ represents the variance within groups and it is calculated as the error sum of squares divided by its degrees of freedom (Eq. (8)), and ${s_M}^2$ represents the variance between groups and it is calculated as the group sum of squares divided by its degrees of freedom (Eq. (9)). In other words, ${s_0}^2$ and ${s_M}^2$ measure the variability due to random causes and differences between the mean of groups, respectively.

$$F = \frac{{s_M}^2}{{s_0}^2} \tag{7}$$

$${s_0}^2 = \frac{\sum\sum X_{ij}^2 - \sum (T_{i+}^2/n_i)}{\sum n_i - k} \tag{8}$$

$$s_M^2 = \frac{\sum_{i=1}^{k} \frac{T_{i+}^2}{n_i} - \frac{T_{++}^2}{N}}{k-1} \tag{9}$$

In Table 3, a typical tabular format used to summarize the calculations for one-way ANOVA is given. If F value is lower than F-critical value, H_0 is accepted. In this study, significance level for the test is accepted as $\alpha = 0.05$. According to F distribution table, F-critical value is 1.53 for significance level $\alpha = 0.05$ and degrees of freedom k-1 = 29 and Σn_i-k = 180.

Table 3
The tabular form of the calculation for one-way ANOVA.

Variation source	Sum of squares	Degrees of freedom	Variance	F
Treatments	$\sum \frac{{T_{i+}}^2}{n_1} - \frac{{T_{++}}^2}{N}$	k-1	s_M^2	$\frac{s_M^2}{s_0^2}$
Error	$\sum\sum {X_{ij}}^2 - \sum \frac{{T_{i+}}^2}{n_1}$	Σn_i-k	s_0^2	
Total	$\sum\sum {X_{ij}}^2 - \frac{{T_{++}}^2}{N}$	Σn_i-1		

Using Δ_{max} values, F values are calculated for each SDOF system and local soil class, and compared with F-critical value. As can be shown in Fig. 9, all the F values are much lower than F-critical. Maximum F values, calculated for soil Z2 and the SDOF system with $T = 0.6s$ and $F_y/W = 0.20$, is even 0.352. The lower values of F indicate that the effect of variability due to differences between the mean of groups on the total variability is smaller than the effect of variability due to random causes. In this case, H_0 is accepted. Thus, it can be said that the differences between the mean of groups are accepted as statistically insignificant for significance level $\alpha = 0.05$. In other words, Δ_{max} values in different ground motion record sets compatible with the same target spectra can be accepted as random samples drawn from the same population. This result is valid for all the SDOF systems and local soil classes considered in this study.

4.3. Sampling distributions of mean of displacement demands

According to one-way ANOVA results, Δ_{max} values obtained using different ground motion record sets that are compatible with a particular design spectrum can be accepted as random samples selected from the same populations. Thus, some conclusions could be drawn about the distribution of populations. In order to this, related Δ_{max} values can be considered.

If it is impossible to observe the whole set of populations, statistics can be calculated from the random samples selected from population to make inferences about unknown population parameters. As known, all statistics are functions of the random variables that depend on the sample. Therefore, they have probability distributions, which are called their sampling distributions. Two important statistics of a probability distribution are the sample mean (m) and the variance (s^2). The sampling distribution of the mean is the probability distribution of m, and identifies the variability of m around the population mean μ.

In this study, it is aimed to obtain interval estimates for population parameter μ. In this case, rather than specifying a certain value as estimate of μ, it is specified an interval for a certain degree of confidence that μ lies within. An interval estimate of μ is an interval of the form $l \le \mu \le u$, where l and u are random variables depend on the numerical value of the sample mean m for a particular sample. Different values of m will be calculated considering different samples. Thus, L and U will be different values of random variables l and u, respectively. The values of L and U can be calculated from the sampling distribution of the sample mean m such that the probability statement given in Eq. (10) is true.

$$P(L \le \mu \le U) = 1 - \alpha \quad 0 < \alpha < 1 \tag{10}$$

In Eq. (10), L and U are called as lower and upper confidence limits, respectively, and the interval (L, U) is known as a 100(1-α)% confidence interval for the parameter μ. The 1-α is defined as the confidence coefficient. If an infinite number of random samples are obtained a 100(1-α)% confidence interval for μ can be calculated from each sample.

If a random sample of n observations is taken from a population normally distributed with mean μ and variance σ^2, the value of the sample mean m is calculated using the values of the random variables in the sample. Thus, m is also a random variable. The value of the sample mean and sample variance is the population mean μ and $1/n$ times the population variance σ^2 (Eq. (11)), respectively. In such circumstances, m is also centered about the population mean μ, but its spread decreases when the sample size increases.

$$E[m] = \mu \text{and } Var(m) = \frac{\sigma^2}{n} \tag{11}$$

According to the Central Limit Theorem, if a sample size n drawn from a population with mean μ and variance σ^2 is large, sample mean m is approximately normal with mean μ and variance σ^2/n. In addition, the sample standard deviation s may be close to σ. In this situation; the

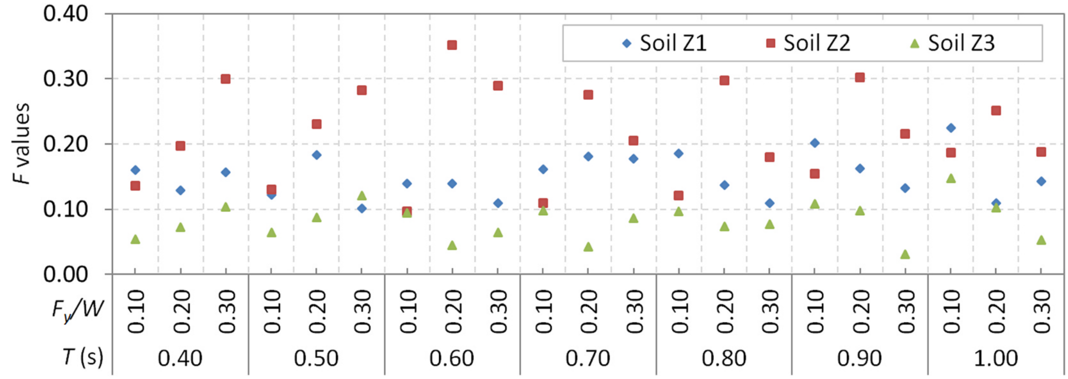

Fig. 9. F values calculated for SDOF systems and local soil classes.

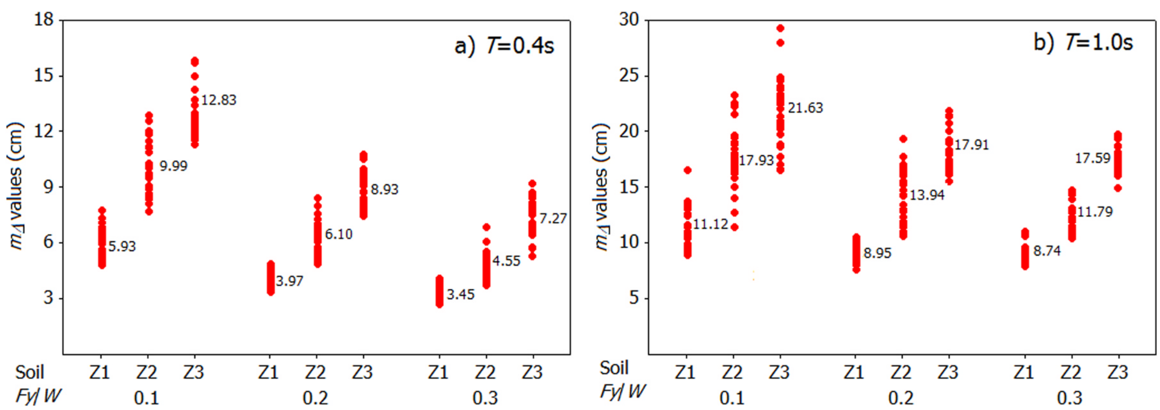

Fig. 10. Variation of m_{Δ} values of ground motion sets.

Table 4
95% confidence interval of μ for SDOF systems and local soil classes (cm).

T (s)	F_y/W	Soil Z1				Soil Z2				Soil Z3			
		m	s	L	U	m	s	L	U	m	s	L	U
0.4	0.1	5.93	0.77	5.65	6.21	9.99	1.40	9.49	10.50	12.83	1.13	12.43	13.23
0.4	0.2	3.97	0.42	3.82	4.12	6.10	0.93	5.76	6.43	8.93	0.94	8.59	9.26
0.4	0.3	3.45	0.39	3.31	3.58	4.55	0.70	4.30	4.80	7.27	0.95	6.93	7.61
0.5	0.1	6.95	0.77	6.68	7.23	11.85	1.67	11.25	12.45	14.33	1.19	13.91	14.76
0.5	0.2	5.15	0.68	4.91	5.39	7.59	1.27	7.13	8.04	10.78	1.15	10.37	11.19
0.5	0.3	4.47	0.39	4.34	4.61	6.16	1.12	5.76	6.56	9.27	1.22	8.83	9.71
0.6	0.1	7.60	0.91	7.28	7.93	13.70	1.65	13.11	14.29	15.05	1.58	14.49	15.62
0.6	0.2	5.94	0.66	5.70	6.17	8.44	1.74	7.82	9.06	12.59	0.98	12.24	12.94
0.6	0.3	5.57	0.50	5.39	5.75	7.18	1.30	6.71	7.65	10.76	1.02	10.39	11.13
0.7	0.1	8.28	1.06	7.90	8.66	15.29	1.93	14.60	15.98	16.22	1.79	15.58	16.86
0.7	0.2	6.86	0.79	6.57	7.14	9.94	1.72	9.33	10.56	15.05	1.12	14.65	15.45
0.7	0.3	6.45	0.79	6.17	6.73	8.47	1.02	8.11	8.84	12.33	1.24	11.88	12.77
0.8	0.1	9.49	1.23	9.05	9.93	16.73	2.14	15.96	17.50	18.02	2.11	17.27	18.77
0.8	0.2	7.28	0.73	7.02	7.54	11.68	2.17	10.91	12.46	15.23	1.27	14.77	15.69
0.8	0.3	6.96	0.59	6.75	7.17	9.39	1.04	9.02	9.76	14.84	1.36	14.35	15.33
0.9	0.1	10.40	1.42	9.89	10.91	17.56	2.55	16.65	18.47	20.09	2.45	19.22	20.97
0.9	0.2	8.12	0.92	7.79	8.45	12.83	2.45	11.96	13.71	15.71	1.50	15.17	16.25
0.9	0.3	7.71	0.71	7.46	7.97	10.61	1.19	10.18	11.03	15.39	0.81	15.10	15.68
1.0	0.1	11.12	1.66	10.53	11.71	17.93	2.78	16.93	18.92	21.63	3.03	20.55	22.72
1.0	0.2	8.95	0.79	8.67	9.23	13.94	2.50	13.05	14.83	17.91	1.71	17.29	18.52
1.0	0.3	8.74	0.83	8.44	9.04	11.79	1.28	11.33	12.24	17.59	1.26	17.14	18.04

population mean μ can be accepted as normally distributed to estimate confidence interval. Thus, for a random sample, a 100(1-α)% confidence interval on μ is estimated using Eq. (12). In Eq. (12), $z_{\alpha/2}$ is the upper 100α/2% point of the standard normal distribution and $s/\sqrt{n}$ is standard error of sample means.

$$m - z_{\alpha/2}\frac{s}{\sqrt{n}} \leq \mu \leq m + z_{\alpha/2}\frac{s}{\sqrt{n}} \tag{12}$$

In Fig. 10, distribution of m_{Δ} values for representative SDOF systems with T = 0.4s and T = 1.0s depending on the F_y/W values and local soil classes are given. As known, for each local soil class, n = 30 values of m_{Δ} are calculated. The mean of the m_{Δ} values (sample mean, m) are also given in Fig. 10. m values increase if soil class changes from Z1 to Z3. For example, considering the SDOF system with T = 0.4 s and F_y/W = 0.1, m values are 5.93, 9.99 and 12.83cm for local soil class Z1, Z2

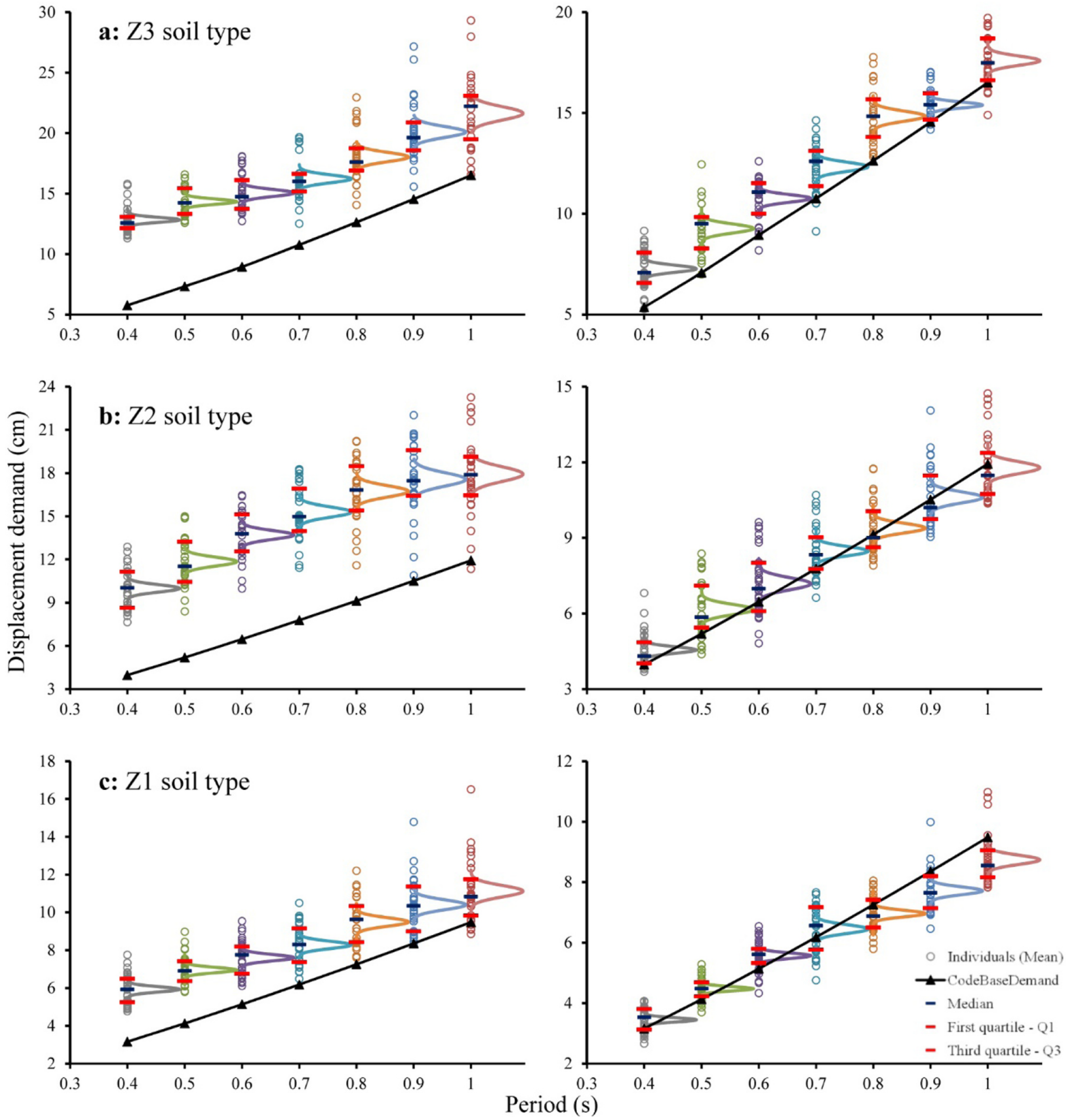

Fig. 11. Distribution of displacement demands according to nonlinear static and dynamic procedures (Left: $F_y/W = 0.1$, Right: $F_y/W = 0.3$).

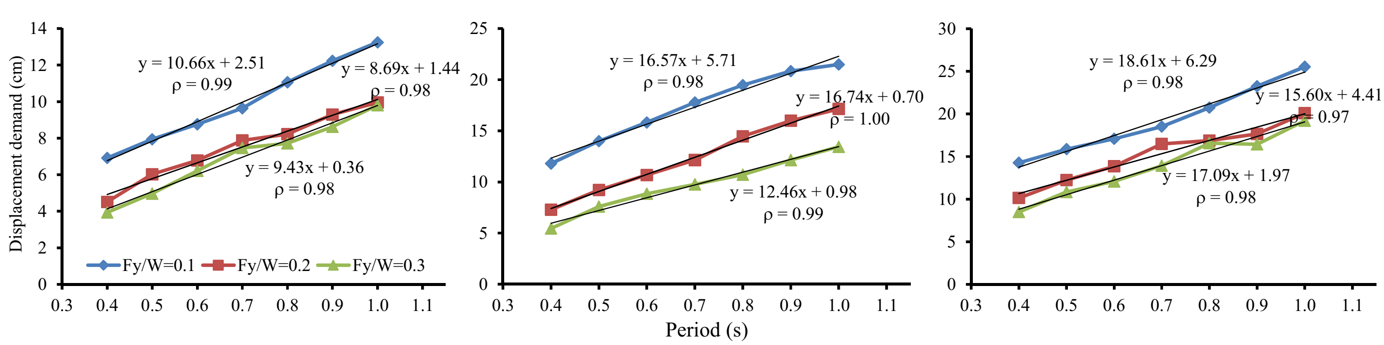

Fig. 12. Relationship between fundamental period and 10% exceedance probability of seismic demands for SDOF systems (soil type, Z1 to Z3 from left to right).

and Z3, respectively (Fig. 10a). According to Fig. 10, both the mean and dispersion of m_Δ values decrease with increasing F_y/W.

In practice, generally 90% or 95% confidence level are taken for confidence intervals. In this study, 95% confidence level is accepted. It should be noted that any confidence level and corresponding confidence limits can be used for specific seismic design and/or assessment study. For 95% confidence coefficient, $z_{\alpha/2}$ of the standard normal distribution is 1.96. In order to estimate confidence interval of mean of the populations (μ), initially, sample mean (m) and sample standard deviation (s) are calculated, then, 95% confidence intervals of

μ are calculated using Eq. (12). In Table 4, 95% confidence intervals (L, U) of mean of the populations are given. For instance, considering the SDOF system with $T = 0.40s$ and $F_y/W = 0.10$, 95% confidence interval of μ is 5.65–6.21cm for soil Z1. Hence, it can be said that the resultant interval indeed contains μ with confidence 95%. Considering the same SDOF system, 95% confidence interval of μ is 9.49–10.50cm for soil Z2, and 12.43–13.23cm for soil Z3. For the other SDOF systems considered in this study, 95% confidence interval can also be shown in Table 4.

5. Reliability-based demand estimation and comparison of code procedures

It was argued with ANOVA and sampling distributions that seismic displacement demands obtained for the ground motion record sets compatible with the same design spectrum are randomly selected samples from the same population and possibility of demand ranges for each fundamental period and lateral strength ratios was determined.

In addition to nonlinear dynamic analysis procedures, nonlinear static procedures are also suggested in code based applications considering the same seismic hazard levels to perform fast approximation of seismic demand for performance evaluation purposes. Code conformed static procedures, on the other hand, with minor differences use the similar approaches and they generally require the identification of capacity curve and natural period of the structure [19,22,43,44]. Although nonlinear dynamic analysis technique is more reliable method to determine demands and structural behavior of the buildings, static procedures can also be used for preliminary assessment and foresee the seismic demands. But, unlike static procedures, estimations of nonlinear dynamic analyses are variable even for the same seismic hazard as the behavior of structure is completely affected from the characteristics of earthquakes. For this reason, seismic demands of static procedure of the considered code are determined in addition to dynamic analysis results. By this way, the use of both methods in seismic codes is compared and some important implications and recommendations are given for the practitioners in the field.

In Fig. 11, demand estimation of static and dynamic results is plotted for each lateral strength ratio, fundamental period and soil classes. For evaluation, some descriptive statistics like mean, median and first and third quartile of the dynamic analysis results are also determined. In the figure, probability distribution of dynamic analysis results is also given according to fundamental period of the structure considering the 95% confidence level previously determined in Section 4.3. It can be seen from the figure that static procedure approximations are increasing with an increasing period and even it may result in higher than dynamic results from Z3 to Z1 especially at high lateral strength ratios ($F_y/W = 0.3$). Furthermore, static procedure estimations get closer to dynamic results at long structural periods and stiff soils. This situation implies that special attention should be made to nonlinear static procedure estimations for buildings with high periods. Nevertheless, it can be accepted that in general, dynamic analysis give more conservative results compared to static one.

A generally accepted view in the seismic codes is that if more than seven records are used, mean of structural responses are used for the constructed record set. However, if one uses, more than one record set that compatible to considered target response spectrum (seismic hazard) then which of the descriptive statics should be used for the performance evaluation? This arising question also becomes clear from the illustrations of the Fig. 11 and the figure clearly manifests that mean and median values of the record sets are almost identical. In other words, results show that both statistical measures can be used, but the means of the records are still slightly conservative compared to median one. It is also worth noting that the means can be affected from outliers.

The first and third quartile of dynamic analysis results has also revealed a very striking finding in comparison of seismic demand estimation of dynamic analysis results. It can be inferred from the figures that first and third quartile of the individual means of records range between lower and upper confidence limits that are determined from the sampling distribution of dynamic analysis result with 95% confidence level and this finding is also valid for each soil class and lateral strength ratios. In addition, it was observed that average of first and third quartile values are very close the mean of individual mean of records sets. When the proportion of these values (average of quartiles and individual mean of records sets) are calculated, it was determined that the ratio is 1.01 and the lowest and highest values were obtained as 0.98 and 1.03, respectively.

Considering the sampling distribution of the mean displacements and overall statistical assessments on the seismic demands, reliability based demand estimations can be performed for different structures represented by equivalent SDOF systems. For this purpose, 10% exceedance probability of displacement demands are estimated for all SDOF systems considering all the record sets used in this study. Furthermore, linear regression analysis was performed to investigate correlation between fundamental period and seismic demands for each soil class and lateral strength ratio. Calculated correlation coefficient between period and displacement demand have shown the good agreement as can be seen form the Fig. 12.

In the figure, equations of the linear curves are also given depending on the fundamental periods for each lateral strength ratio and soil type. Observed high correlations show that derived equations can be used for rapid prediction of seismic demands in reliability based manner. In other words, predicted demands have 10% exceedance probability and it can be said that one may predict the seismic demands very simply with very low risk (10% probability) without performing any nonlinear time history analysis and/or statistical assessment by only using the fundamental period of the structure.

6. Results

In this study, maximum displacement demands of SDOF systems obtained from nonlinear time history analysis using different real ground motion record sets compatible with TEC are statistically evaluated. In order to consider the broad range of SDOF systems, vibration period and lateral strength ratio for SDOF systems are selected between 0.4 s–1.0 s and 0.1–0.3, respectively. 30 ground motion record sets compatible with elastic design spectra defined for each local soil classes Z1, Z2 and Z3 in TEC are used for the analyses. Totally, 13,230 nonlinear time history analysis (21 SDOF systems and 90 ground motion record sets each of them has seven ground motion records) are performed. Performing nonlinear time history analysis of the SDOF systems, maximum displacement demands are calculated for each of the ground motion records in the record sets. Then, the mean of maximum displacement demands are calculated for each of the record sets, separately. In order to evaluate the dispersion of the maximum displacement demands obtained from ground motion records around the mean of the sets, coefficient of variation values are calculated. The significance of the difference between the mean displacement demands calculated for different ground motion record sets is also evaluated using one-way ANOVA. In addition, confidence intervals are calculated for mean displacement demands for each SDOF system and local soil class considered in this study. Finally, linear regression models are proposed to estimate seismic displacement demands of the SDOF systems for a certain value of exceedance probability. The results of the study could be summarized as follows:

a) In modern seismic design codes, ground motion selection procedures for time history analysis only consider the mean spectrum of the selected ground motions and target design spectrum without considering random variability of the ground motion records. Thus, the variation of the seismic demands of SDOF systems obtained using code-compatible ground motion record sets is generally high. This variation may be considered for detailed probabilistic seismic performance assessment and/or seismic design of a specific structure.

b) The mean displacement demands calculated for a SDOF system using different ground motion record sets may differ although the record sets are compatible with the same design spectrum. Therefore, mean displacement demands can be accepted as random variables which change depending on the code-compatible record sets used for time history analysis.
c) According to one-way ANOVA results, the variance of the maximum displacement demands obtained from the individual ground motion records in the sets due to random causes is quite larger than the variance due to the differences between the mean displacement demands of the record sets compatible with the same design spectrum. Hence, the differences between the mean displacement demands of ground motion record sets can be accepted as statistically insignificant at significance level $\alpha = 0.05$. In other words, maximum displacement demands in ground motion record sets can be accepted as simply random samples drawn from the same population at 90% confidence level.
d) The abovementioned results are valid for all the SDOF systems and local soil classes considered in this study.
e) Considering one-way ANOVA results, it is possible to make inferences about unknown parameters of the distribution of the populations. In order to do this, statistics can be calculated evaluating the nonlinear analyses results using the large number of ground motion record sets. For example, confidence interval can be estimated for the population mean at the desired level of confidence. In this circumstance, confidence interval at selected 95% level of confidence for the population means are also estimated using relevant maximum displacement demands of 30 ground motion records as random samples, separately, for each of the SDOF systems and local soil classes used in this study.
f) Mean and median values of the seismic displacement demands obtained for the different record sets compatible with the same design spectrum are almost identical. Therefore, both statistical measures can be used for seismic design or performance evaluation if more than one ground motion records are used for time history analysis. But, it is also worth noting that means of the demands are still slightly conservative compared to median of the demands.
g) Using sampling distribution of the populations of mean displacement demands, it is also possible to perform reliability based demand estimation for different structures represented by equivalent SDOF systems. In this study, the mean displacement demands of ground motion record sets for 10% exceedance probability are calculated for each SDOF system and local soil class considered in this study. Then, linear regression models, depending on the fundamental periods for each lateral strength ratio and soil type, are proposed for rapid prediction of displacement demands in reliability based manner. Predicted demands have 10% exceedance probability and it can be said that one may predict the demands very simply with very low risk (10% probability) without performing any nonlinear time history analysis and/or statistical assessment by only using the fundamental period and lateral strength ratio of the structure.

In this study, TEC compatible ground motion record sets are used to perform nonlinear time history analyses. Thus, the results are valid for TEC and considered hazard zonation map. In the near future, the new seismic code TBEC [45], and new hazard zonation map (https://tdth.afad.gov.tr) will be effective in Turkey. It should be noted that many of modern seismic codes (FEMA-368 [18]; EUROCODE-8 [19]; ASCE 07-05 [20]; GB [21]), including TBEC, describe relatively similar procedures with TEC in terms of requiring spectral matching between the design spectrum and the response spectrum of a selected record set within a stated period range. Thus, it can be said that similar results of this study are obtained when the ground motion record sets compatible with the abovementioned seismic design codes are used for nonlinear time history analyses. Hence, using code-compatible different ground motion sets for nonlinear time history analyses of a structure it is possible to obtain information about the distribution of the population of the seismic demands which are used for design or assessment of that structure according to modern seismic codes.

Based on these results, it can be stated that there is a significant requirement for the consideration of variability in structural responses, numerically. For instance, reducing the variation of maximum displacement demands in the record sets may become a matter in future studies. In order to this, not only mean spectra of the record sets but also individual spectra of ground motion records in the record sets may be considered for compatibility with the target spectra. In addition, using two or three-dimensional structural models to perform code-based nonlinear time history analysis would provide remarkable results for evaluating the various seismic response parameters such as; global drift ratio, interstory drift ratio, internal forces or ductility demands etc. Different type of structures such as mid- or high-rise buildings, bridges etc., which have their fundamental periods are longer than 1.0 s, would also be considered. Probability based approaches may also become the future direction of taking the variability of structural responses into consideration numerically. The FEMA P-58 methodology [46] can be used to assess the probable seismic performance of buildings for particular earthquake scenario intensity, or considering all earthquakes that could occur, and the likelihood of each, over a specified period of time.

Appendix A

See Appendix Tables A1–A3

Table A1
Ground motion record sets obtained for Soil Z1.

Set 1		Set 2		Set 3		Set 4		Set 5		Set 6	
Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale
5270-Y	1.014	646-Y	0.816	5272-Y	1.440	6272-X	1.848	6331-X	0.671	6272-X	1.961
410-X	1.782	383-Y	1.449	6331-X	1.132	5272-Y	1.698	467-X	1.317	6262-Y	0.778
292-X	1.344	362-X	1.475	382-X	1.448	6327-Y	1.151	410-X	2.000	603-Y	1.967
362-X	1.554	292-X	0.971	5655-X	0.787	605-X	0.924	243-X	1.834	6269-Y	0.621
7158-X	0.632	1243-X	0.789	6270-Y	0.894	368-X	0.851	6278-X	0.511	6267-X	1.818
6272-Y	1.224	5272-Y	1.664	292-X	0.818	383-Y	0.993	960-X	1.104	598-Y	1.965
6327-Y	0.519	6331-X	1.166	362-Y	0.972	467-Y	1.277	5272-Y	0.669	6100-X	1.565
Set 7		Set 8		Set 9		Set 10		Set 11		Set 12	
Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale
6269-Y	0.576	6331-Y	1.493	369-X	1.058	6272-Y	1.590	6100-Y	1.140	647-X	1.574
368-Y	0.878	646-Y	0.891	292-X	1.751	467-X	1.012	467-X	1.196	412-X	1.322

(continued on next page)

Table A1 (*continued*)

Set 1		Set 2		Set 3		Set 4		Set 5		Set 6	
Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale
6337-X	1.772	1891-Y	0.545	410-Y	0.604	369-Y	0.723	1891-Y	1.854	410-X	0.953
6272-Y	1.399	4557-X	1.413	1891-Y	1.517	6262-X	1.054	6341-X	0.846	6331-X	0.841
604-X	1.829	292-Y	1.361	140-Y	0.590	646-X	0.872	5272-X	1.854	598-Y	1.077
6331-Y	1.732	6269-Y	1.492	6267-Y	1.261	292-Y	1.002	292-Y	0.983	467-Y	1.933
6262-X	0.781	6262-X	0.545	4679-Y	0.553	6337-X	1.486	646-Y	1.272	292-X	1.209
Set 13		Set 14		Set 15		Set 16		Set 17		Set 18	
Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale
6761-X	0.725	1891-Y	1.262	6265-Y	0.847	6341-X	0.503	5272-Y	1.773	646-Y	1.247
6333-Y	0.522	1243-X	0.868	6326-Y	0.646	647-X	2.000	6336-Y	1.281	6269-Y	1.125
234-Y	0.748	628-X	0.500	5270-Y	1.280	369-X	1.002	5270-Y	1.418	467-Y	1.305
5272-Y	1.970	6278-Y	0.840	357-Y	1.997	292-X	1.116	410-Y	1.022	292-X	0.668
1891-Y	1.465	5271-X	2.000	369-X	0.903	603-Y	1.999	357-Y	0.826	369-X	1.934
243-X	1.702	412-X	1.584	603-Y	1.340	6327-Y	1.027	603-Y	1.809	6333-X	1.663
638-Y	1.190	6331-X	1.207	6327-Y	0.794	605-X	1.088	234-Y	0.667	382-X	1.068
Set 19		Set 20		Set 21		Set 22		Set 23		Set 24	
Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale
960-Y	1.285	359-Y	0.508	604-X	1.918	292-Y	1.269	6270-X	0.987	1243-X	1.265
1891-Y	1.058	243-X	1.985	410-X	1.384	362-Y	0.897	385-Y	0.580	6272-Y	1.668
6331-Y	0.978	4679-Y	0.743	629-Y	0.579	598-X	0.978	5272-Y	1.728	6337-X	1.097
368-Y	0.840	6100-X	1.112	6327-Y	1.149	6333-X	1.889	369-Y	1.002	646-Y	1.459
6262-Y	0.801	292-X	1.240	605-X	1.554	646-Y	1.217	410-X	1.038	5272-Y	1.523
6333-X	1.202	5272-Y	0.921	6333-X	1.992	5272-Y	1.622	6336-Y	1.364	243-Y	1.954
383-Y	1.747	6331-X	1.270	6331-Y	1.230	6270-Y	1.307	4678-Y	0.688	598-X	1.063
Set 25		Set 26		Set 27		Set 28		Set 29		Set 30	
Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale
368-Y	1.191	357-Y	1.999	639-X	1.084	6267-X	0.992	4678-X	0.539	641-X	0.935
603-Y	1.780	642-Y	0.936	960-Y	0.570	646-Y	1.523	5271-X	1.998	604-Y	1.095
292-Y	0.635	5270-Y	0.673	412-X	1.318	410-Y	1.183	960-X	0.683	646-Y	1.510
243-X	1.238	6272-Y	1.895	6262-Y	0.987	467-Y	1.172	6278-Y	0.993	6337-X	1.760
6327-Y	0.905	292-Y	0.501	6333-X	1.430	385-X	1.116	6331-X	0.928	6270-Y	1.313
6331-Y	1.425	5272-Y	1.523	604-X	1.932	243-Y	1.264	410-X	0.781	292-Y	1.138
6333-X	1.477	467-Y	1.759	642-X	0.674	6262-Y	0.788	6272-X	1.161	5272-Y	1.403

Table A2
Ground motion record sets obtained for Soil Z2.

Set 1		Set 2		Set 3		Set 4		Set 5		Set 6	
Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale
645-Y	1.394	1859-X	0.992	6496-Y	1.721	6447-Y	1.919	572-Y	1.626	352-Y	1.167
352-Y	1.275	946-Y	1.786	1735-X	0.835	352-Y	0.592	759-Y	0.673	7155-Y	1.219
548-X	0.711	6496-Y	1.803	532-Y	1.061	232-Y	1.273	1859-X	0.630	645-Y	0.861
6422-X	1.600	645-Y	1.182	595-X	0.910	142-Y	1.023	645-Y	1.592	630-Y	0.775
946-Y	0.903	1720-Y	0.636	760-X	0.870	760-X	1.054	352-Y	1.239	946-Y	0.764
760-Y	1.467	595-X	0.819	142-Y	1.523	1735-X	1.688	7161-X	0.925	572-X	1.514
572-Y	1.747	142-Y	1.501	352-Y	0.982	6496-Y	1.309	6144-X	1.093	6138-Y	1.103
Set 7		Set 8		Set 9		Set 10		Set 11		Set 12	
Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale
1984-X	0.715	6138-X	1.125	1711-X	0.745	761-Y	0.628	1984-X	1.899	352-Y	0.782
1881-Y	0.963	760-X	0.826	532-Y	0.975	1859-X	0.832	129-Y	0.875	1735-X	0.719
1735-Y	0.606	352-Y	1.333	142-Y	1.196	595-X	1.093	611-Y	0.518	232-X	0.980
6447-Y	1.995	620-X	0.787	352-Y	0.884	759-X	0.781	6138-X	1.958	572-X	0.765
612-X	0.614	232-X	0.736	548-X	0.511	6142-Y	0.817	142-Y	1.021	6138-Y	1.402
129-X	1.221	548-X	0.992	6138-X	1.136	502-Y	0.770	1859-X	1.830	759-X	1.195
572-X	1.378	549-Y	0.807	946-X	1.770	946-Y	1.713	49-Y	0.522	142-Y	0.974
Set 13		Set 14		Set 15		Set 16		Set 17		Set 18	
Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale
572-X	1.093	6144-Y	0.685	352-Y	1.058	760-X	1.541	7155-Y	0.974	7067-X	1.948
611-Y	0.861	1859-X	1.684	5798-Y	0.876	572-Y	0.689	6494-Y	0.667	6145-X	1.211
6447-Y	1.498	1996-X	0.993	620-Y	0.839	6499-X	1.028	6138-Y	1.018	1720-X	1.552
5813-X	0.919	1720-X	1.341	1996-X	1.712	595-X	0.922	1881-X	0.749	760-X	0.707
6142-Y	0.803	352-Y	1.497	129-X	1.267	532-Y	1.197	569-Y	0.748	572-Y	1.086
595-X	0.510	645-Y	1.074	1720-X	1.477	620-Y	0.517	6142-Y	0.604	142-X	1.377
352-Y	0.921	572-Y	0.720	5813-Y	0.868	352-Y	1.560	572-X	1.393	352-Y	1.420
Set 19		Set 20		Set 21		Set 22		Set 23		Set 24	
Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale
502-X	1.026	532-Y	0.791	6329-Y	1.083	572-Y	1.189	532-Y	1.300	244-Y	1.180
645-Y	0.681	6496-Y	1.670	946-Y	1.096	244-Y	1.787	946-X	1.437	129-X	1.415
1720-X	0.958	49-Y	0.500	6494-Y	1.274	352-Y	1.072	6138-Y	1.472	1881-Y	0.543
232-X	1.064	142-Y	0.936	645-Y	1.597	502-X	0.926	474-Y	0.994	502-Y	1.953
760-X	1.080	352-Y	0.850	1859-X	1.411	142-Y	1.119	129-X	0.741	6138-Y	1.574

(*continued on next page*)

Table A2 (*continued*)

Set 1		Set 2		Set 3		Set 4		Set 5		Set 6	
Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale
352-Y	1.212	645-Y	1.103	1996-X	0.779	6138-Y	1.111	352-Y	0.828	1735-Y	0.975
142-Y	1.326	232-X	0.942	5798-Y	0.776	1881-Y	0.780	142-Y	1.115	142-Y	1.438
Set 25		Set 26		Set 27		Set 28		Set 29		Set 30	
Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale
6138-X	1.120	572-Y	0.961	530-Y	0.520	142-Y	1.408	474-Y	0.661	6447-Y	1.578
5798-Y	1.283	6494-Y	0.838	244-Y	1.280	7067-X	1.874	352-Y	0.870	1720-X	0.792
946-Y	1.221	946-Y	1.161	7067-X	1.736	6144-X	1.165	759-X	1.014	572-X	0.965
759-X	0.798	211-Y	0.622	6142-Y	0.716	6447-X	1.903	6138-Y	1.266	352-Y	0.910
6142-Y	0.637	7161-X	1.351	352-Y	0.610	760-Y	1.352	142-Y	1.426	6142-Y	0.660
129-X	1.163	612-X	0.519	761-Y	0.740	232-X	1.127	7067-X	1.642	244-Y	1.876
1735-X	1.167	474-X	0.997	7257-X	1.344	352-Y	1.192	232-X	1.106	5813-X	0.783

Table A3
Ground motion record sets obtained for Soil Z3.

Set 1		Set 2		Set 3		Set 4		Set 5		Set 6	
Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale
360-X	0.704	601-Y	1.008	141-X	1.988	6962-X	1.998	7010-Y	1.084	6962-Y	1.998
374-Y	0.672	648-Y	0.743	151-X	0.923	7104-X	0.728	1230-Y	0.617	360-X	0.591
602-X	0.999	360-X	0.831	7010-X	1.378	375-Y	0.904	141-Y	1.161	141-X	1.993
6962-Y	1.355	6606-Y	1.105	1230-X	0.540	1230-X	0.693	6975-Y	0.917	6978-Y	0.700
6978-Y	0.622	1230-X	0.548	6606-Y	1.301	360-X	1.044	151-X	0.597	6606-Y	1.463
6606-Y	0.582	6975-Y	1.096	6978-Y	0.819	6978-Y	0.757	602-X	0.717	1230-X	0.546
1230-X	0.788	375-Y	0.600	6962-Y	1.984	7010-Y	1.913	643-X	1.340	151-X	0.916
Set 7		Set 8		Set 9		Set 10		Set 11		Set 12	
Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale
6606-Y	0.664	375-Y	0.604	1959-Y	1.914	1230-X	0.766	7010-X	1.838	7104-Y	0.581
439-Y	0.553	6962-Y	0.932	6975-Y	0.867	602-X	0.816	1230-X	0.501	1230-X	0.540
6975-Y	0.779	602-X	0.834	360-X	0.658	7104-Y	0.645	6975-Y	0.965	141-X	1.927
1230-X	0.660	360-X	0.839	7010-Y	1.083	375-Y	0.655	648-Y	0.532	648-X	0.615
633-X	1.468	1230-X	0.799	601-Y	1.185	360-X	0.919	141-X	2.000	151-X	0.761
360-X	0.669	6606-Y	0.692	1230-Y	0.618	6975-Y	0.579	6606-Y	1.323	6978-Y	1.036
141-X	1.190	6978-Y	0.769	375-Y	0.625	7010-Y	1.057	151-X	0.812	6962-Y	1.548
Set 13		Set 14		Set 15		Set 16		Set 17		Set 18	
Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale
1908-X	0.673	6975-Y	0.679	375-Y	0.743	1230-Y	0.572	1230-Y	0.528	375-Y	0.645
6975-Y	0.622	7010-Y	1.193	6606-Y	0.626	151-X	0.752	6962-X	1.988	6606-Y	1.073
602-X	1.082	1230-X	0.740	6978-Y	0.718	6975-Y	0.856	6978-Y	0.803	141-X	1.725
360-X	0.814	360-X	0.848	6962-X	1.808	7010-X	1.808	141-X	1.642	6978-Y	1.165
6606-Y	0.934	375-Y	0.619	1230-X	0.755	6963-Y	0.503	151-X	1.183	7010-Y	0.742
374-Y	0.619	602-X	0.835	602-X	0.791	141-Y	1.142	7010-X	0.832	360-X	0.798
1230-X	0.709	6606-Y	0.890	360-X	0.830	602-X	0.655	6963-Y	0.881	1230-X	0.773
Set 19		Set 20		Set 21		Set 22		Set 23		Set 24	
Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale
1230-X	0.505	6975-Y	0.915	6978-Y	0.666	7010-X	1.690	360-X	0.674	6978-Y	0.525
151-X	1.015	1230-X	0.543	602-X	0.869	601-Y	0.995	6606-Y	1.566	375-Y	0.539
1908-X	0.962	602-X	0.742	6962-Y	1.632	1230-Y	0.572	6975-Y	0.716	1230-X	0.820
141-X	1.999	648-Y	0.655	360-X	0.849	1959-Y	1.860	141-X	1.255	6962-Y	1.464
6962-Y	1.421	151-X	0.593	6606-Y	0.728	6975-Y	0.897	602-X	0.873	360-X	0.862
6606-Y	1.077	360-X	0.572	1230-X	0.699	360-X	0.708	374-Y	0.544	602-X	0.958
6978-Y	1.026	6606-Y	1.024	374-Y	0.652	375-Y	0.693	1230-X	0.663	6606-Y	0.628
Set 25		Set 26		Set 27		Set 28		Set 29		Set 30	
Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale	Record	Scale
374-Y	0.530	1230-X	0.762	6975-Y	0.706	7010-Y	1.470	360-X	0.981	375-Y	0.648
6606-Y	1.119	6978-Y	1.108	1230-X	0.737	151-X	0.548	7010-Y	1.797	6606-Y	1.183
6975-Y	0.651	375-Y	0.649	648-Y	0.571	1908-X	1.490	6962-Y	0.869	141-X	1.281
1230-X	0.727	360-Y	0.852	7010-Y	1.117	602-X	0.788	1230-X	0.577	360-X	0.949
1908-X	1.064	141-X	0.502	360-X	0.779	6975-Y	0.848	648-X	0.662	6978-Y	1.240
602-X	0.930	602-X	0.609	602-X	0.684	379-Y	0.547	555-Y	1.937	950-X	0.539
141-X	1.890	6606-Y	0.821	375-Y	0.885	1230-Y	0.584	6978-Y	1.293	1230-X	0.731

Appendix B

See Appendix Table B1

Table B1
Detailed information about selected ground motion records for the record sets.

Record	Earthquake Name	Date	M	Station	Record	Earthquake Name	Date	M	Station
49	Friuli	06/05/76	6.5	ST14	530	Racha (aftershock)	15/06/91	6.0	ST200
129	Friuli (aftershock)	15/09/76	6.0	ST14	532	Racha (aftershock)	15/06/91	6.0	ST202
140	Friuli (aftershock)	15/09/76	6.0	ST36	548	Izmir	06/11/92	6.0	ST43
141	Friuli (aftershock)	15/09/76	6.0	ST12	549	Izmir	06/11/92	6.0	ST162
142	Friuli (aftershock)	15/09/76	6.0	ST14	555	Kallithea	18/03/93	5.8	ST10
151	Friuli (aftershock)	15/09/76	6.0	ST33	569	Patras	14/07/93	5.6	ST166
211	Montenegro (aftershock)	15/04/79	5.8	ST67	572	Patras	14/07/93	5.6	ST178
232	Montenegro (aftershock)	24/05/79	6.2	ST77	595	Umbria Marche	26/09/97	5.7	ST83
234	Montenegro (aftershock)	24/05/79	5.8	ST68	598	Umbria Marche	26/09/97	6.0	ST222
243	Valnerina	19/09/79	5.8	ST82	601	Umbria Marche	26/09/97	5.7	ST224
244	Valnerina	19/09/79	5.8	ST83	602	Umbria Marche	26/09/97	6.0	ST224
292	Campano Lucano	23/11/80	6.9	ST98	603	Umbria Marche	26/09/97	5.7	ST225
352	Biga	05/07/83	6.1	ST131	604	Umbria Marche	26/09/97	6.0	ST225
357	Umbria	29/04/84	5.6	ST134	605	Umbria Marche	26/09/97	5.7	ST84
359	Umbria	29/04/84	5.6	ST136	611	Umbria Marche	26/09/97	5.7	ST228
360	Umbria	29/04/84	5.6	ST41	612	Umbria Marche	26/09/97	6.0	ST228
362	Umbria	29/04/84	5.6	ST137	620	Umbria Marche (aftershock)	06/10/97	5.5	ST83
368	Lazio Abruzzo	07/05/84	5.9	ST143	628	Umbria Marche (aftershock)	06/10/97	5.5	ST226
369	Lazio Abruzzo	07/05/84	5.9	ST109	629	Umbria Marche (aftershock)	06/10/97	5.5	ST225
374	Lazio Abruzzo	07/05/84	5.9	ST148	630	Umbria Marche (aftershock)	06/10/97	5.5	ST228
375	Lazio Abruzzo	07/05/84	5.9	ST149	633	Umbria Marche (aftershock)	14/10/97	5.6	ST227
379	Lazio Abruzzo (aftershock)	11/05/84	5.5	ST1034	638	Umbria Marche (aftershock)	14/10/97	5.6	ST233
382	Lazio Abruzzo (aftershock)	11/05/84	5.5	ST140	639	Umbria Marche (aftershock)	14/10/97	5.6	ST226
383	Lazio Abruzzo (aftershock)	11/05/84	5.5	ST153	641	Umbria Marche (aftershock)	14/10/97	5.6	ST84
385	Lazio Abruzzo (aftershock)	11/05/84	5.5	ST155	642	Umbria Marche (aftershock)	14/10/97	5.6	ST225
410	Golbasi	05/05/86	6.0	ST161	643	Umbria Marche (aftershock)	14/10/97	5.6	ST224
412	Golbasi	06/06/86	5.8	ST161	645	Umbria Marche (aftershock)	14/10/97	5.6	ST83
439	Spitak	07/12/88	6.7	ST173	646	Umbria Marche (aftershock)	14/10/97	5.6	ST234
467	Chenoua	29/10/89	5.9	ST181	647	Umbria Marche (aftershock)	14/10/97	5.6	ST222
474	Filippias	16/06/90	5.5	ST123	648	Umbria Marche (aftershock)	14/10/97	5.6	ST221
502	Racha (aftershock)	03/05/91	5.6	ST200	759	Umbria Marche	26/09/97	5.7	ST265
760	Umbria Marche	26/09/97	6.0	ST265	6262	South Iceland	17/06/00	6.5	ST2496
761	Umbria Marche (aftershock)	14/10/97	5.6	ST265	6265	South Iceland	17/06/00	6.5	ST2494
946	Potenza	05/05/90	5.8	ST103	6267	South Iceland	17/06/00	6.5	ST2565
950	Sicilia-Orientale	13/12/90	5.6	ST288	6269	South Iceland	17/06/00	6.5	ST2497
960	Sicilia-Orientale	13/12/90	5.6	ST296	6270	South Iceland	17/06/00	6.5	ST2556
1230	Izmit	17/08/99	7.6	ST576	6272	South Iceland	17/06/00	6.5	ST2568
1243	Izmit (aftershock)	13/09/99	5.8	ST575	6278	South Iceland	17/06/00	6.5	ST2552
1711	Ano Liosia	07/09/99	6.0	ST1255	6326	South Iceland (aftershock)	21/06/00	6.4	ST2496
1720	Dinar	01/10/95	6.4	ST543	6327	South Iceland (aftershock)	21/06/00	6.4	ST2552
1735	Adana	27/06/98	5.7	ST581	6329	South Iceland (aftershock)	21/06/00	6.4	ST2485
1859	Near NW coast of Kefallinia island	27/02/87	5.7	ST1303	6331	South Iceland (aftershock)	21/06/00	6.4	ST2486
1881	South Aegean	23/05/94	6.1	ST1310	6333	South Iceland (aftershock)	21/06/00	6.4	ST2487
1891	Kranidia	25/10/84	5.5	ST1320	6336	South Iceland (aftershock)	21/06/00	6.4	ST2563
1908	Filippias	16/06/90	5.5	ST126	6337	South Iceland (aftershock)	21/06/00	6.4	ST2494
1959	Kyllini	16/10/88	5.9	ST214	6341	South Iceland (aftershock)	21/06/00	6.4	ST2497
1984	Kefallinia island	23/01/92	5.6	ST1353	6422	Izmit (aftershock)	13/09/99	5.8	ST3135
1996	Anchialos	30/04/85	5.6	ST1355	6447	Izmit (aftershock)	11/11/99	5.6	ST3140
4557	Bovec	12/04/98	5.7	ST750	6494	Duzce 1	12/11/99	7.2	ST3134
4678	South Iceland	17/06/00	6.5	ST2557	6606	Izmit (aftershock)	11/11/99	5.6	ST2571
4679	South Iceland	17/06/00	6.5	ST2563	6761	Vrancea	30/08/86	7.2	ST40
5270	Mt. Vatnafjoll	25/05/87	6.0	ST2486	6962	Izmit (aftershock)	13/09/99	5.8	ST3271
5271	Mt. Vatnafjoll	25/05/87	6.0	ST2483	6963	Izmit (aftershock)	13/09/99	5.8	ST3268
5272	Mt. Vatnafjoll	25/05/87	6.0	ST2487	6975	Izmit (aftershock)	13/09/99	5.8	ST3272
5655	NE of Banja Luka	13/08/81	5.7	ST2950	6978	Izmit (aftershock)	13/09/99	5.8	ST3273
5798	Gulf of Akaba (aftershock)	23/11/95	5.6	ST2989	7010	Izmit (aftershock)	11/11/99	5.6	ST772
5813	Itea	05/11/97	5.6	ST857	7067	Altinsac	15/11/00	5.5	ST608
6100	Kozani	13/05/95	6.5	ST1315	7104	Ishakli (aftershock)	03/02/02	5.8	ST856
6138	Aigion	15/06/95	6.5	ST1330	7155	Firuzabad	20/06/94	5.9	ST3290
6142	Aigion	15/06/95	6.5	ST1331	7158	Firuzabad	20/06/94	5.9	ST3293
6144	Aigion	15/06/95	6.5	ST1332	7161	Firuzabad	20/06/94	5.9	ST3296
6145	Aigion (aftershock)	15/06/95	5.6	ST1332	7257	Masjed-E-Soleyman	25/09/02	5.6	ST3373

Appendix C

See Appendix Tables C1–C6

Table C1
m_{Δ} values for all the SDOF systems and ground motion record sets for Soil Z1 (cm).

T (s)	0.40			0.50			0.60			0.70			0.80			0.90			1.00		
F_y/W	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30
Set1	5.13	3.54	3.83	6.49	5.20	4.48	7.92	5.46	5.71	7.76	6.00	6.54	7.64	7.85	7.16	8.46	8.35	7.72	8.86	7.95	8.20
Set2	5.63	4.37	4.07	6.68	4.67	4.39	8.53	5.63	5.55	9.67	6.26	7.17	11.02	7.05	7.40	10.65	7.60	7.15	10.88	8.34	7.96
Set3	5.37	4.45	3.83	6.91	4.85	4.27	7.71	5.87	6.38	9.42	6.39	7.20	10.81	6.76	7.36	10.70	7.59	7.89	10.51	8.39	8.17
Set4	6.73	4.30	2.81	6.92	5.38	3.98	7.06	6.66	6.07	7.21	6.67	5.38	8.15	6.89	6.84	9.52	7.50	7.58	11.34	9.47	8.53
Set5	5.24	3.75	3.03	5.84	5.42	4.58	6.28	5.46	5.62	6.84	6.24	6.11	7.69	7.59	7.50	8.94	9.70	8.54	9.56	9.02	9.26
Set6	5.94	3.59	2.66	6.70	4.27	4.22	7.09	6.19	5.74	7.43	7.87	6.22	8.38	8.04	6.59	9.67	9.06	7.98	10.54	9.73	10.80
Set7	5.90	3.73	3.65	7.55	4.67	4.49	9.15	6.02	5.36	9.83	6.26	5.94	11.37	7.03	6.88	11.43	8.55	8.29	13.00	10.47	9.14
Set8	6.83	4.75	3.85	8.09	7.09	4.50	8.41	7.03	5.42	9.40	6.81	7.05	11.46	6.46	6.56	11.69	7.91	7.43	11.56	9.00	8.16
Set9	4.96	3.35	3.64	6.12	5.97	4.80	6.80	6.49	5.75	8.46	8.69	7.26	8.44	8.80	7.94	9.00	7.99	6.96	11.46	9.43	8.66
Set10	5.04	3.73	3.80	7.40	4.91	4.26	7.43	5.55	4.96	7.10	6.60	5.74	9.64	6.73	6.63	11.18	6.41	7.91	10.87	8.60	8.33
Set11	6.63	4.33	3.69	8.98	6.19	4.66	8.27	6.71	5.69	8.09	8.35	6.80	9.80	8.59	7.42	11.39	9.24	8.77	12.61	10.08	9.55
Set12	5.06	3.77	3.63	6.57	5.47	4.94	7.98	6.79	6.54	8.88	8.44	7.59	9.15	8.49	7.76	10.27	7.77	8.39	10.32	8.04	8.48
Set13	6.11	4.82	3.68	7.34	5.62	4.68	7.95	6.60	5.94	8.65	5.97	5.42	9.00	6.52	5.99	8.67	7.11	7.11	9.83	8.10	7.83
Set14	5.26	3.86	3.28	6.64	4.15	4.53	7.84	5.00	4.72	8.75	6.24	7.39	9.90	8.29	7.60	10.10	9.12	8.18	10.81	9.52	8.93
Set15	7.75	3.74	2.96	8.45	4.31	4.42	9.54	5.11	4.67	10.50	6.45	4.76	10.85	6.99	7.25	12.23	7.75	6.92	13.21	8.58	8.03
Set16	5.99	3.36	3.20	7.00	4.88	4.12	7.93	5.30	5.33	8.78	7.66	5.79	9.95	7.38	6.95	10.71	7.30	7.38	11.53	8.81	8.84
Set17	6.45	4.41	4.05	6.15	4.89	4.67	6.66	5.98	6.00	6.87	7.29	6.77	8.05	6.23	6.42	9.01	6.88	7.25	10.45	7.59	7.84
Set18	6.81	4.16	3.25	8.05	5.31	5.10	7.75	6.37	5.13	8.52	6.84	7.22	9.17	6.83	6.51	9.97	8.10	6.46	10.72	8.13	8.56
Set19	5.98	4.00	2.99	6.90	5.24	5.29	6.51	6.83	5.32	7.21	6.58	5.69	8.42	7.16	6.48	10.30	9.30	7.90	10.71	9.38	10.57
Set20	5.59	4.01	3.89	7.18	5.08	4.41	9.02	4.97	5.73	9.74	6.95	7.66	9.89	7.27	7.42	10.40	7.46	7.27	9.84	9.08	8.26
Set21	7.34	3.87	3.34	7.42	5.02	3.96	8.18	4.97	5.07	9.47	6.14	5.94	12.20	7.36	7.11	14.79	9.67	8.29	16.51	10.37	8.33
Set22	7.07	4.44	3.44	7.48	6.40	4.24	7.81	6.39	5.54	8.43	7.28	6.75	10.84	6.96	6.40	12.71	8.47	7.12	13.70	8.14	7.91
Set23	5.65	3.72	3.48	6.48	4.75	3.86	6.94	5.42	5.59	7.50	6.04	6.11	9.80	7.03	6.88	11.74	7.68	6.97	12.34	8.39	8.40
Set24	5.58	3.64	3.14	6.37	4.14	3.70	7.34	5.03	4.34	8.06	6.31	5.23	9.62	6.90	6.18	8.99	7.17	7.73	9.09	8.59	8.57
Set25	5.60	3.76	3.14	6.16	5.33	4.48	6.56	5.21	6.24	7.47	6.23	6.26	9.63	6.02	6.63	11.38	7.97	7.72	13.35	9.16	9.32
Set26	4.77	3.65	3.58	5.79	4.98	5.02	6.35	5.82	5.48	7.50	5.86	5.47	8.50	6.57	5.79	8.83	7.69	7.01	9.14	9.76	9.03
Set27	5.96	3.65	3.12	6.98	4.51	4.23	7.77	5.77	5.69	8.16	7.56	7.09	9.00	8.65	8.05	10.42	10.30	9.99	10.93	10.17	10.98
Set28	6.40	4.42	3.59	6.37	5.42	5.12	6.12	6.74	6.29	6.48	7.73	7.39	7.61	7.53	6.86	8.36	8.70	7.58	9.35	8.98	8.83
Set29	4.88	3.37	2.90	6.09	4.58	4.75	6.52	6.13	5.51	7.11	6.53	6.91	8.65	6.96	7.90	9.79	7.74	8.39	9.64	9.45	8.75
Set30	6.26	4.65	3.86	7.46	5.84	4.08	8.66	6.70	5.66	9.08	7.46	6.59	10.18	7.45	6.39	10.81	7.56	7.58	11.00	7.92	7.94

Table C2
m_{Δ} values for all the SDOF systems and ground motion record sets for Soil Z2 (cm).

T (s)	0.40			0.50			0.60			0.70			0.80			0.90			1.00		
F_y/W	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30
Set1	10.06	5.38	3.80	12.60	6.49	4.56	15.10	8.10	7.27	17.40	10.22	9.59	18.80	12.36	8.88	20.65	13.47	10.96	22.20	15.48	10.45
Set2	9.52	5.18	4.30	10.23	6.47	5.03	12.52	6.95	5.81	13.39	8.10	7.33	15.00	9.26	8.73	17.15	10.33	9.99	17.42	13.03	10.37
Set3	10.85	5.56	4.26	12.86	6.46	4.38	14.94	6.28	4.82	16.31	8.02	6.63	18.68	10.45	9.24	19.06	11.95	9.80	17.74	11.61	10.61
Set4	8.66	5.32	4.84	8.40	7.03	5.95	9.98	8.41	7.35	11.62	8.83	8.33	13.28	10.82	10.37	14.52	10.15	10.32	13.98	10.59	10.89
Set5	10.25	5.63	3.69	13.01	6.99	5.17	15.72	7.83	8.03	17.97	9.02	8.50	19.40	12.01	9.16	22.02	14.74	10.26	23.26	16.31	12.28
Set6	10.19	5.63	3.94	12.21	7.11	5.57	13.97	7.49	6.01	14.93	9.12	8.46	15.48	9.94	9.81	17.91	12.59	9.48	19.40	13.43	11.45
Set7	9.49	6.92	4.32	10.45	7.89	5.68	13.08	9.13	6.61	13.50	11.77	8.47	15.97	12.76	8.95	17.43	12.92	9.32	18.79	16.88	12.25
Set8	12.55	6.92	4.46	15.00	9.08	6.61	16.47	8.63	7.59	18.27	11.17	8.76	20.18	15.15	9.96	19.92	16.19	14.05	22.57	14.16	11.84
Set9	11.45	5.45	4.77	13.41	7.54	6.53	15.72	7.96	7.03	18.24	9.61	8.17	20.23	11.65	8.66	19.48	12.14	11.40	18.78	10.64	11.45
Set10	8.38	6.04	5.49	10.29	7.10	7.78	11.96	8.02	9.37	12.30	8.65	7.27	11.60	11.38	8.58	10.90	15.72	10.14	11.35	17.75	14.74
Set11	12.89	8.40	6.81	14.86	9.78	8.04	15.28	10.80	6.89	16.46	11.79	9.27	17.47	12.47	10.49	16.60	14.23	10.98	15.01	16.40	12.67
Set12	8.57	4.89	4.00	11.10	5.85	5.70	12.24	5.95	6.15	14.87	9.44	7.89	17.40	9.44	9.05	17.70	9.13	9.04	17.01	11.85	10.46
Set13	9.05	6.37	5.33	11.46	7.12	7.98	13.95	6.82	8.82	14.79	8.96	8.00	15.86	12.02	8.97	15.95	13.99	9.94	16.25	16.02	14.27
Set14	11.86	7.02	4.79	14.90	8.88	6.57	16.39	12.65	7.41	18.17	15.25	10.28	18.43	16.12	11.73	20.48	16.61	12.28	21.59	16.71	11.51
Set15	9.08	5.74	4.27	11.93	7.63	5.49	12.84	10.24	7.78	14.58	10.77	10.07	15.25	12.30	10.88	16.48	12.70	11.87	16.87	11.37	11.87
Set16	12.03	7.54	5.14	13.52	9.35	6.37	15.39	9.90	6.12	17.59	12.54	7.67	18.22	16.60	10.95	18.63	18.27	11.85	19.05	16.30	11.03
Set17	8.32	6.70	4.12	10.00	9.85	7.22	12.58	9.87	8.94	13.99	9.18	9.46	15.08	10.40	9.89	15.82	11.40	9.60	15.84	14.70	12.04
Set18	11.11	7.23	5.11	13.47	8.23	6.26	14.45	10.94	8.01	15.09	13.28	10.70	16.14	15.81	11.75	17.19	14.99	11.72	18.85	14.26	11.14
Set19	11.18	5.28	4.22	12.18	6.95	5.57	14.23	6.70	5.19	15.03	9.56	8.04	16.12	11.73	8.61	16.54	11.16	11.16	17.15	11.34	10.37
Set20	10.28	5.57	4.60	11.22	5.85	4.72	11.51	7.17	5.87	15.01	8.36	8.11	17.52	9.18	8.88	19.88	10.58	10.02	18.47	11.38	10.80
Set21	11.19	7.98	6.02	13.42	10.13	7.84	15.70	11.81	9.62	17.67	11.86	10.42	19.26	14.50	10.50	20.75	17.73	12.31	22.21	19.32	14.51
Set22	10.28	5.52	4.47	10.97	6.64	5.38	13.89	6.84	6.48	16.02	9.74	7.62	17.50	11.11	8.85	20.52	12.92	10.34	19.63	12.82	11.85
Set23	8.85	5.44	4.23	10.89	6.01	6.25	13.67	7.23	6.05	16.78	8.71	7.36	18.82	9.12	8.52	19.50	9.92	9.61	18.03	12.30	10.85
Set24	8.65	5.36	3.97	11.48	6.12	5.76	12.76	7.86	6.94	14.54	10.10	8.33	16.19	8.48	8.18	16.31	10.25	9.95	16.54	12.91	11.14
Set25	8.08	6.39	4.04	10.94	9.50	8.38	12.89	10.00	9.46	14.69	8.15	8.50	17.01	12.87	9.47	16.65	13.48	12.59	16.58	15.22	13.10
Set26	11.15	6.21	3.85	13.19	8.23	5.53	14.35	9.97	6.69	13.48	10.42	7.80	13.89	10.72	8.29	13.64	10.13	9.51	15.79	11.43	11.85
Set27	7.65	6.80	4.92	9.15	7.83	7.11	10.52	8.34	9.14	11.42	8.31	8.95	12.60	11.14	8.12	12.17	13.61	10.64	12.73	17.04	13.87
Set28	9.70	4.85	4.00	11.58	6.48	4.68	12.74	6.40	6.25	13.94	9.66	8.33	16.63	10.81	8.64	17.50	11.52	9.91	18.96	10.93	10.57
Set29	10.00	5.06	4.04	10.45	7.01	5.47	12.58	6.43	5.99	14.42	8.34	7.12	16.56	8.82	7.91	17.41	9.46	9.19	18.41	10.75	10.42
Set30	8.51	6.55	4.78	10.41	8.05	7.13	13.67	8.47	7.71	16.28	9.39	8.73	17.30	11.11	9.59	18.03	12.73	9.97	17.29	15.28	12.92

Table C3
m_Δ values for all the SDOF systems and ground motion record sets for Soil Z3 (cm).

T (s)	0.40			0.50			0.60			0.70			0.80			0.90			1.00		
F_y/W	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30
Set1	12.53	7.99	8.06	13.99	9.34	9.60	13.86	11.71	11.19	15.20	13.66	13.20	17.03	12.92	15.20	19.09	13.86	15.99	22.01	17.42	17.55
Set2	11.61	8.70	5.27	12.79	11.59	7.00	13.34	13.58	9.94	12.52	16.25	10.89	14.07	16.56	14.17	15.57	17.41	14.17	18.72	21.82	17.08
Set3	12.91	9.66	6.51	14.26	12.16	8.20	15.01	13.36	9.95	16.29	14.84	11.01	18.93	17.47	13.33	18.84	17.53	15.37	18.59	16.34	17.16
Set4	12.24	8.74	6.67	13.11	10.68	8.70	12.73	10.90	10.67	14.39	13.92	12.21	16.91	13.97	13.75	19.09	14.36	15.13	19.74	16.73	19.45
Set5	12.96	10.74	8.44	15.73	12.26	10.50	18.04	13.23	11.19	19.68	16.77	14.21	21.59	15.80	16.80	23.13	18.75	14.66	24.11	21.36	16.34
Set6	12.18	9.65	6.52	13.37	12.08	8.31	14.07	13.33	10.04	16.68	14.07	11.60	18.71	17.14	12.95	18.93	16.33	15.57	18.82	15.48	17.54
Set7	11.84	8.02	7.06	13.14	10.19	9.41	14.73	11.97	11.85	16.17	14.25	11.32	18.26	14.97	12.95	20.90	13.69	14.84	20.34	17.96	17.19
Set8	14.25	9.08	9.16	15.42	10.96	10.50	15.28	12.91	12.61	16.17	14.55	14.64	18.10	14.06	16.60	20.52	15.47	16.67	23.02	18.95	19.30
Set9	12.89	9.95	7.69	15.18	11.66	9.67	17.52	13.57	11.04	19.24	16.48	13.66	22.96	15.91	15.62	27.16	17.75	14.52	29.31	21.49	16.70
Set10	11.64	7.42	7.53	12.75	8.34	9.81	14.08	11.19	11.11	15.97	13.64	12.33	16.87	13.26	14.98	20.21	14.45	15.45	23.73	16.97	17.86
Set11	11.95	7.94	5.75	14.27	11.02	7.54	16.75	13.53	9.28	15.97	16.59	11.40	17.50	15.86	13.97	17.93	17.43	15.83	16.51	19.02	16.86
Set12	12.98	9.10	6.87	14.28	10.20	7.68	13.41	11.26	8.18	15.15	13.57	9.13	17.99	15.37	13.05	17.73	16.49	14.51	17.01	16.41	16.05
Set13	12.04	7.80	6.47	13.22	9.56	8.74	14.15	11.45	11.18	15.29	15.00	11.77	15.70	14.61	14.02	20.00	13.64	14.72	22.59	16.63	18.13
Set14	12.37	7.58	7.00	13.56	9.30	9.73	14.64	11.90	11.45	16.07	14.98	12.08	17.01	14.54	14.84	20.35	14.23	15.77	22.53	17.29	18.72
Set15	12.37	8.20	7.72	13.62	9.89	9.86	13.79	11.66	11.24	14.74	14.01	12.92	16.44	13.80	14.84	18.67	14.04	16.13	20.60	16.88	19.30
Set16	12.79	9.89	7.88	15.58	11.70	9.36	18.08	12.93	10.23	19.26	17.02	13.10	21.09	14.87	15.84	23.22	17.21	15.10	24.82	19.23	16.05
Set17	13.72	10.53	7.51	15.77	13.43	9.73	16.63	14.19	11.45	19.54	16.68	13.78	21.02	17.81	14.21	22.15	16.67	14.93	23.34	18.14	14.90
Set18	15.80	9.07	8.62	16.58	11.20	11.10	15.97	14.01	11.51	16.40	15.30	12.73	17.89	15.74	17.77	19.63	16.20	17.00	22.49	17.90	19.34
Set19	13.71	9.28	6.38	15.28	11.74	8.23	15.24	13.71	9.11	15.39	15.40	10.52	18.43	17.19	12.83	18.37	16.53	14.66	17.68	17.01	16.43
Set20	11.32	8.39	5.67	13.49	10.54	6.99	14.75	11.88	9.32	14.88	15.19	10.53	15.68	15.63	14.15	16.90	16.56	14.68	16.56	18.33	16.78
Set21	12.38	8.41	6.59	13.39	10.07	8.90	13.35	11.12	10.70	14.46	13.38	11.95	16.36	14.51	13.55	18.40	14.04	15.09	20.28	17.18	18.63
Set22	12.74	9.58	7.09	15.19	11.37	9.01	17.45	13.04	10.42	18.63	16.61	13.07	21.82	15.41	15.84	26.09	16.95	14.17	27.99	20.70	16.32
Set23	11.52	9.29	6.77	12.59	11.23	9.76	13.64	12.59	11.75	16.03	15.08	12.56	17.26	15.06	14.55	19.28	13.83	15.61	20.94	16.29	17.43
Set24	12.59	7.61	8.16	13.43	9.14	9.84	13.45	11.83	11.77	15.73	13.48	13.44	17.88	12.61	15.63	19.71	14.58	16.00	22.61	17.91	17.05
Set25	12.84	8.12	6.99	14.21	9.92	9.68	15.58	12.44	11.77	16.62	15.19	12.91	17.71	15.28	15.08	19.64	14.91	15.46	22.42	16.06	18.08
Set26	14.96	9.26	8.72	16.27	10.74	10.88	15.45	12.63	11.61	16.03	15.15	12.89	17.16	15.54	16.83	18.35	15.34	16.83	20.41	17.20	18.70
Set27	12.23	8.01	6.99	13.22	9.13	9.19	14.06	12.12	10.95	15.89	14.69	12.62	17.33	14.25	15.09	20.91	14.16	15.98	22.95	16.64	19.29
Set28	12.45	10.56	8.18	15.57	11.03	9.87	17.73	12.48	10.75	19.31	15.94	13.77	20.86	15.44	15.48	22.44	17.87	14.42	24.58	20.06	15.98
Set29	13.41	9.43	7.50	14.45	10.87	7.83	13.40	12.72	9.01	13.63	14.00	10.94	14.92	15.29	13.84	19.46	15.36	15.48	21.35	16.63	17.84
Set30	15.69	9.78	8.38	16.30	11.94	12.45	15.46	14.44	11.57	15.37	15.91	12.69	17.14	16.03	17.45	20.16	15.72	17.03	22.92	17.13	19.71

Table C4
CoV_Δ values for all the SDOF systems and ground motion record sets for Soil Z1.

T (s)	0.40			0.50			0.60			0.70			0.80			0.90			1.00		
F_y/W	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30
Set 1	0.910	0.805	0.974	0.938	0.937	0.802	0.959	0.792	0.755	0.875	0.783	0.804	0.697	0.777	0.654	0.637	0.828	0.552	0.636	0.608	0.593
Set 2	0.668	0.752	0.654	0.800	0.657	0.622	0.827	0.649	0.809	0.918	0.685	1.015	0.842	0.662	0.869	0.800	0.762	0.739	0.831	0.807	0.629
Set 3	0.507	0.659	0.503	0.496	0.468	0.455	0.723	0.544	0.559	0.752	0.508	0.941	0.693	0.553	0.829	0.708	0.671	0.634	0.750	0.717	0.524
Set 4	0.686	0.519	0.443	0.570	0.484	0.492	0.623	0.557	0.599	0.597	0.628	0.545	0.591	0.545	0.566	0.715	0.644	0.619	0.727	0.721	0.580
Set 5	0.782	0.878	0.678	0.820	0.835	0.688	0.894	0.631	0.699	0.821	0.705	0.647	0.661	0.908	0.806	0.661	0.923	0.740	0.764	0.620	0.645
Set 6	0.566	0.501	0.357	0.561	0.596	0.446	0.443	0.752	0.694	0.484	0.511	0.350	0.425	0.604	0.363	0.545	0.752	0.500	0.496	0.582	0.616
Set 7	0.505	0.416	0.471	0.549	0.463	0.339	0.634	0.534	0.434	0.736	0.400	0.313	0.655	0.287	0.260	0.687	0.488	0.333	0.703	0.506	0.401
Set 8	1.259	1.024	0.928	1.199	1.202	1.012	1.138	1.208	0.984	1.102	0.970	0.958	0.977	0.860	0.822	0.978	0.882	0.853	0.901	0.870	0.848
Set 9	1.147	1.087	1.266	0.981	1.330	1.278	1.035	1.273	1.060	0.879	0.999	1.001	0.956	1.004	0.775	0.908	0.929	0.600	1.152	0.897	0.654
Set 10	0.506	0.591	0.573	0.573	0.585	0.420	0.569	0.571	0.434	0.671	0.585	0.395	0.642	0.516	0.470	0.613	0.447	0.572	0.635	0.591	0.610
Set 11	1.171	0.742	0.640	1.029	0.732	0.603	1.011	0.846	0.692	0.955	0.849	0.729	0.870	0.927	0.858	0.912	0.907	0.791	0.834	0.891	0.772
Set 12	0.774	0.800	0.926	0.810	0.843	0.767	0.811	0.677	0.698	0.753	0.646	0.664	0.703	0.603	0.573	0.631	0.631	0.621	0.645	0.533	0.536
Set 13	1.219	0.963	0.822	1.087	0.914	0.808	1.076	0.976	0.908	0.945	0.926	0.821	0.931	0.907	0.808	0.897	0.753	0.810	0.847	0.701	0.736
Set 14	0.788	0.763	0.750	0.737	0.658	0.583	0.910	0.750	0.898	1.051	0.797	1.038	0.970	0.833	0.897	0.915	0.829	0.823	0.870	0.819	0.702
Set 15	1.339	1.289	1.030	1.458	1.179	1.062	1.483	1.021	0.736	1.410	0.868	0.642	1.432	0.910	0.954	1.357	0.937	0.731	1.340	0.957	0.735
Set 16	0.743	0.837	0.926	0.758	0.674	0.624	0.782	0.628	0.636	0.752	0.598	0.525	0.652	0.583	0.498	0.739	0.546	0.535	0.764	0.626	0.561
Set 17	0.798	0.764	0.732	0.724	0.680	0.811	0.609	0.847	0.744	0.572	0.929	1.037	0.638	0.734	0.809	0.787	0.604	0.721	0.768	0.615	0.681
Set 18	0.659	0.636	0.522	0.740	0.509	0.638	0.694	0.560	0.469	0.650	0.554	0.674	0.684	0.585	0.544	0.791	0.678	0.571	0.843	0.637	0.850
Set 19	0.858	0.821	0.426	0.810	0.827	0.865	0.800	0.746	0.567	0.833	0.648	0.542	0.712	0.788	0.605	0.615	0.823	0.657	0.468	0.650	0.761
Set 20	0.914	0.918	0.935	0.968	0.878	0.760	0.995	0.878	0.928	1.086	0.761	1.000	1.084	0.860	0.879	0.901	0.873	0.693	0.923	0.789	0.605
Set 21	0.788	0.483	0.408	0.683	0.524	0.424	0.640	0.463	0.432	0.622	0.576	0.467	0.682	0.539	0.565	0.820	0.621	0.523	0.945	0.688	0.591
Set 22	0.758	0.852	0.757	0.820	0.944	0.784	0.756	0.880	0.821	0.712	0.767	0.754	0.794	0.616	0.622	0.939	0.709	0.722	1.029	0.669	0.728
Set 23	0.537	0.368	0.433	0.507	0.482	0.484	0.488	0.493	0.416	0.440	0.418	0.443	0.446	0.380	0.439	0.483	0.491	0.461	0.543	0.361	0.368
Set 24	0.908	0.913	0.661	0.891	0.749	0.618	0.833	0.783	0.712	0.830	0.737	0.590	0.677	0.796	0.658	0.731	0.733	0.745	0.641	0.761	0.738
Set 25	0.579	0.527	0.378	0.463	0.697	0.553	0.475	0.713	0.739	0.517	0.411	0.481	0.535	0.425	0.432	0.682	0.448	0.470	0.626	0.472	0.518
Set 26	0.592	0.768	0.862	0.630	0.737	0.860	0.562	0.684	0.700	0.587	0.529	0.524	0.719	0.672	0.503	0.720	0.688	0.594	0.710	0.805	0.676
Set 27	0.683	0.726	0.486	0.610	0.479	0.450	0.601	0.497	0.722	0.610	0.506	0.479	0.669	0.713	0.539	0.681	0.753	0.795	0.767	0.707	0.825
Set 28	1.054	0.987	1.040	0.965	0.885	0.858	0.777	0.955	0.966	0.789	0.973	1.147	0.832	0.859	0.865	0.935	1.002	0.921	0.896	0.887	0.876
Set 29	0.315	0.544	0.432	0.302	0.368	0.396	0.463	0.435	0.453	0.593	0.606	0.756	0.573	0.463	0.509	0.535	0.339	0.530	0.595	0.400	0.398
Set 30	0.701	0.708	0.692	0.780	0.871	0.544	0.738	0.763	0.664	0.728	0.659	0.584	0.760	0.519	0.448	0.783	0.548	0.616	0.769	0.627	0.688

Table C5
CoV_{Δ} values for all the SDOF systems and ground motion record sets for Soil Z2.

T (s)	0.40			0.50			0.60			0.70			0.80			0.90			1.00		
F_y/W	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30
Set 1	1.093	0.811	0.567	1.086	0.791	0.661	1.033	0.673	0.654	1.050	0.674	0.541	1.055	0.931	0.578	1.068	0.889	0.640	0.977	0.846	0.628
Set 2	0.626	0.763	0.571	0.712	0.509	0.356	0.640	0.590	0.472	0.695	0.505	0.475	0.731	0.525	0.551	0.846	0.622	0.470	0.799	0.646	0.454
Set 3	0.682	0.580	0.510	0.640	0.521	0.470	0.658	0.437	0.387	0.790	0.426	0.303	0.732	0.409	0.422	0.753	0.434	0.314	0.769	0.441	0.239
Set 4	0.469	0.359	0.607	0.403	0.785	0.502	0.390	0.965	0.791	0.361	0.789	0.866	0.207	0.474	0.547	0.257	0.307	0.327	0.332	0.273	0.231
Set 5	1.116	0.852	0.647	1.109	0.881	0.637	1.053	0.782	0.779	1.086	0.741	0.706	1.045	0.968	0.633	0.967	0.917	0.590	0.981	0.922	0.736
Set 6	0.912	0.696	0.722	0.956	0.763	0.696	0.993	0.597	0.640	1.069	0.638	0.715	1.102	0.835	0.651	0.983	0.705	0.609	0.915	0.606	0.583
Set 7	1.224	0.914	0.623	1.034	0.976	0.718	0.840	0.948	0.614	0.863	0.817	0.698	0.891	0.844	0.671	0.968	0.770	0.687	0.935	0.752	0.596
Set 8	0.938	0.691	0.438	1.007	0.734	0.693	1.062	0.664	0.556	1.076	0.718	0.398	0.997	0.883	0.519	1.068	0.752	0.535	0.977	0.813	0.336
Set 9	0.686	0.696	0.481	0.750	0.786	0.706	0.673	0.464	0.547	0.666	0.374	0.351	0.659	0.604	0.483	0.717	0.525	0.645	0.877	0.448	0.323
Set 10	1.012	1.191	0.991	1.074	0.934	1.377	1.009	0.740	1.365	0.912	0.787	0.767	0.900	1.112	0.869	0.829	1.197	0.985	0.765	1.208	1.085
Set 11	1.677	1.517	1.309	1.686	1.667	1.478	1.678	1.535	1.202	1.488	1.493	0.954	1.419	1.388	1.195	1.390	1.446	0.959	1.428	1.498	0.915
Set 12	0.780	0.617	0.357	0.753	0.664	0.728	0.857	0.815	0.676	0.867	0.576	0.376	0.803	0.532	0.606	0.891	0.595	0.525	0.772	0.891	0.529
Set 13	0.890	1.027	0.955	0.949	0.880	1.294	0.856	0.752	1.446	0.841	0.661	0.660	0.851	0.933	0.750	0.811	1.211	0.848	0.680	1.217	0.970
Set 14	1.122	0.958	0.651	1.092	0.982	0.682	1.173	0.919	0.643	1.158	1.006	0.756	1.158	1.166	0.748	1.122	1.127	0.719	1.076	1.057	0.685
Set 15	1.055	0.865	0.673	1.010	0.742	0.710	0.997	1.009	0.790	0.979	0.956	0.900	1.034	0.695	0.799	0.956	0.545	0.510	0.899	0.492	0.563
Set 16	1.099	0.977	0.649	1.185	1.027	0.581	1.257	1.092	0.424	1.200	1.298	0.639	1.153	1.198	0.734	1.169	1.115	0.661	1.209	1.156	0.544
Set 17	0.708	0.752	0.656	0.741	0.792	0.810	0.721	0.841	0.850	0.783	0.621	0.790	0.852	0.653	0.669	0.857	0.777	0.685	0.736	0.832	0.653
Set 18	1.198	0.967	0.702	1.231	1.024	0.711	1.280	1.156	0.984	1.367	1.108	0.999	1.329	1.045	0.844	1.258	1.094	0.649	1.155	1.086	0.695
Set 19	0.776	0.649	0.401	1.008	0.528	0.364	0.982	0.571	0.348	1.101	0.671	0.420	1.050	0.765	0.507	1.055	0.784	0.458	1.000	0.694	0.412
Set 20	0.512	0.503	0.364	0.581	0.341	0.381	0.695	0.488	0.340	0.646	0.341	0.393	0.644	0.334	0.432	0.745	0.367	0.251	0.769	0.502	0.242
Set 21	1.446	1.391	1.259	1.370	1.258	1.194	1.381	1.235	1.108	1.345	1.319	1.116	1.257	1.226	1.136	1.328	1.146	0.978	1.421	1.144	0.979
Set 22	0.755	0.433	0.348	0.930	0.532	0.305	0.859	0.469	0.430	0.879	0.418	0.361	0.941	0.530	0.347	0.775	0.575	0.413	0.747	0.560	0.468
Set 23	0.867	0.724	0.461	0.985	0.665	0.765	0.869	0.725	0.741	0.865	0.819	0.578	0.843	0.617	0.670	0.879	0.696	0.614	0.832	0.914	0.550
Set 24	1.037	0.666	0.515	1.032	0.844	0.955	1.117	0.873	0.688	1.124	0.875	0.546	1.067	0.663	0.667	1.079	0.849	0.742	0.892	0.844	0.606
Set 25	0.988	0.852	0.356	0.930	0.908	0.845	0.922	0.749	0.868	0.885	0.447	0.719	0.766	0.678	0.537	0.803	0.724	0.720	0.897	0.826	0.547
Set 26	1.026	0.730	0.416	0.957	0.740	0.518	0.949	0.656	0.511	0.982	0.706	0.534	0.972	0.666	0.505	1.006	0.673	0.502	0.923	0.729	0.559
Set 27	0.695	0.849	0.720	0.849	0.950	1.168	1.067	0.958	1.142	0.903	0.682	0.718	0.725	0.823	0.523	0.723	0.947	0.669	0.546	0.995	0.826
Set 28	0.951	0.719	0.461	0.989	0.629	0.410	1.050	0.506	0.583	1.129	0.499	0.318	0.988	0.710	0.411	0.977	0.676	0.336	0.861	0.615	0.396
Set 29	0.674	0.469	0.410	0.818	0.530	0.581	0.738	0.638	0.539	0.764	0.491	0.377	0.745	0.472	0.484	0.839	0.560	0.415	0.660	0.786	0.470
Set 30	0.680	0.723	0.367	0.786	0.914	0.926	0.766	0.886	1.179	0.784	0.438	0.709	0.817	0.579	0.490	0.756	0.706	0.550	0.668	0.877	0.621

Table C6
CoV_{Δ} values for all the SDOF systems and ground motion record sets for Soil Z3.

T (s)	0.40			0.50			0.60			0.70			0.80			0.90			1.00		
F_y/W	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30	0.10	0.20	0.30
Set 1	1.147	0.934	1.280	0.930	0.916	1.165	1.004	1.139	1.218	1.102	1.122	1.040	1.134	0.774	1.071	1.059	0.900	0.999	0.985	0.779	0.912
Set 2	0.722	0.858	0.800	0.813	0.768	0.610	0.759	0.791	0.616	0.704	0.811	0.620	0.802	0.724	0.459	0.651	0.779	0.511	0.634	0.870	0.623
Set 3	0.545	0.707	0.607	0.554	0.615	0.458	0.442	0.727	0.528	0.506	0.675	0.466	0.483	0.554	0.417	0.529	0.460	0.519	0.515	0.528	0.575
Set 4	0.987	0.895	0.837	0.891	0.786	0.845	0.908	1.021	1.034	0.841	0.998	0.771	0.882	0.850	0.797	0.824	0.665	0.787	0.804	0.653	0.845
Set 5	1.255	1.412	1.238	1.205	1.368	1.241	1.173	1.269	1.105	1.157	1.144	1.181	1.249	1.162	1.062	1.375	1.114	0.946	1.440	1.045	1.009
Set 6	0.554	0.733	0.566	0.517	0.666	0.571	0.516	0.769	0.622	0.483	0.770	0.460	0.513	0.563	0.488	0.513	0.541	0.540	0.485	0.532	0.576
Set 7	1.005	1.078	0.996	0.901	0.926	1.036	0.856	0.962	1.011	0.791	1.006	0.856	0.814	0.805	0.794	0.800	0.729	0.765	0.815	0.688	0.923
Set 8	1.033	0.860	1.148	0.899	0.809	1.073	0.935	1.062	1.081	1.058	1.029	0.956	1.087	0.690	0.995	1.002	0.824	0.953	0.979	0.730	0.795
Set 9	1.248	1.542	1.379	1.243	1.441	1.361	1.189	1.225	1.126	1.198	1.128	1.228	1.183	1.138	1.149	1.133	1.172	0.934	1.144	1.004	0.969
Set 10	1.186	1.004	1.175	1.017	1.002	1.044	0.940	1.155	1.162	0.999	1.101	1.038	1.091	0.797	0.999	0.955	0.778	1.001	0.861	0.758	0.934
Set 11	0.553	0.685	0.574	0.591	0.694	0.563	0.571	0.611	0.554	0.548	0.618	0.392	0.581	0.516	0.370	0.620	0.515	0.329	0.487	0.723	0.433
Set 12	0.742	0.907	0.737	0.703	0.769	0.611	0.648	0.786	0.663	0.525	0.705	0.412	0.522	0.751	0.529	0.529	0.604	0.535	0.539	0.564	0.630
Set 13	1.004	1.000	1.086	0.859	0.906	0.998	0.820	0.970	1.023	0.901	0.937	0.883	1.068	0.783	0.857	0.884	0.757	0.902	0.802	0.711	0.959
Set 14	1.043	0.986	1.100	0.907	0.874	0.963	0.870	0.979	1.048	0.965	0.947	0.940	1.072	0.751	0.898	0.950	0.731	0.906	0.869	0.681	0.900
Set 15	1.102	0.934	1.077	0.932	0.801	1.012	0.948	1.057	1.116	1.047	1.050	0.928	1.095	0.805	0.975	1.010	0.794	0.913	0.949	0.735	0.858
Set 16	1.158	1.334	1.111	1.086	1.260	1.214	1.010	1.133	1.067	1.079	1.007	1.091	1.175	1.116	1.013	1.234	1.050	0.762	1.231	1.017	0.873
Set 17	1.025	1.148	1.018	0.983	1.046	0.998	0.958	1.114	0.911	0.916	1.098	1.023	1.069	0.954	1.056	1.154	0.913	0.825	1.159	0.939	0.813
Set 18	1.056	1.037	1.209	1.008	0.877	1.022	0.957	0.961	1.151	1.014	1.020	1.044	1.087	0.748	0.885	1.041	0.782	0.939	0.997	0.780	0.868
Set 19	0.648	0.748	0.807	0.617	0.669	0.592	0.576	0.714	0.542	0.617	0.673	0.513	0.571	0.609	0.486	0.567	0.557	0.564	0.484	0.618	0.527
Set 20	0.673	0.818	0.702	0.670	0.700	0.541	0.670	0.727	0.586	0.624	0.684	0.412	0.704	0.643	0.357	0.738	0.571	0.411	0.565	0.568	0.535
Set 21	0.915	0.891	0.947	0.852	0.809	0.896	0.815	0.953	1.030	0.852	1.065	0.795	0.947	0.765	0.834	0.873	0.677	0.818	0.765	0.615	0.883
Set 22	1.160	1.384	1.248	1.122	1.311	1.261	1.033	1.120	1.037	1.088	1.054	1.094	1.125	1.057	1.004	1.062	1.059	0.767	1.058	0.934	0.824
Set 23	0.946	0.909	0.796	0.856	0.884	0.794	0.834	0.900	0.913	0.775	0.906	0.735	0.870	0.746	0.691	0.854	0.676	0.729	0.743	0.691	0.914
Set 24	1.195	0.979	1.452	1.046	1.011	1.216	1.117	1.193	1.215	1.133	1.107	1.114	1.141	0.806	1.148	1.092	0.921	0.992	1.033	0.796	0.845
Set 25	0.942	0.907	1.030	0.779	0.860	0.934	0.723	0.915	0.988	0.857	0.929	0.802	0.943	0.710	0.837	0.959	0.654	0.886	0.842	0.753	0.962
Set 26	1.062	0.984	1.080	0.950	0.853	0.992	0.927	1.033	1.094	1.015	1.005	0.967	1.129	0.772	0.905	1.101	0.813	0.914	1.065	0.821	0.925
Set 27	1.086	0.945	1.062	0.972	0.935	1.037	0.953	0.974	1.128	0.997	0.987	0.890	1.056	0.783	0.871	0.921	0.736	0.876	0.851	0.721	0.887
Set 28	1.209	1.273	1.113	1.094	1.254	1.195	1.058	1.232	1.037	1.079	1.113	1.080	1.202	1.093	1.090	1.329	1.033	0.839	1.297	0.993	0.911
Set 29	1.168	1.076	1.077	1.152	1.003	0.953	0.906	0.951	0.786	0.732	0.823	0.626	0.870	0.894	0.757	0.835	0.735	0.716	0.882	0.601	0.739
Set 30	1.096	0.981	1.116	1.083	0.888	1.021	0.985	0.898	1.051	0.979	0.956	0.905	1.042	0.812	0.814	0.988	0.782	0.896	0.966	0.801	0.927

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