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DISPERSION OF ELASTIC AND INELASTIC SPECTRA WITH REGARD TO EARTHQUAKE RECORD SELECTION

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ABSTRACT

During the determination of an earthquake record set matching a target design spectrum an inherent dispersion arises. The amount of dispersion changes relevant to the chosen earthquake record set. Actually, the expected value of this dispersion is not known exactly today because of the inadequate number of recorded earthquake events. However, it may be useful to interpret and understand the relationship between the dispersion of elastic spectra and the dispersion of inelastic spectra for seismic performance assessment and design. In this study, a design spectrum per SEI/ASCE7-10 is used and various target spectrum matched sets consisting 7 number of earthquake records are determined. Elastic spectra are constructed for each record set and dispersions for the periods of 0.2 s and 1 s are studied. For each set, ductility demand spectra are also constructed with a constant ductility reduction factor of 3. Similarly, the dispersions of 0.2 s and 1 s periods are obtained. These steps are repeated for each earthquake set and the relationship between the dispersions of elastic and inelastic spectra for 0.2 s and 1 s periods are presented.

INTRODUCTION

Earthquake hazard is given by the spectral response values in design codes. For example, for the inelastic dynamic analysis methods hazard level of the selected earthquake records are determined by matching their spectra to a target design spectrum. If it is regarded as aleatory uncertainty we can not intend to reduce it but may expect to have more information via observations in order to reach an accurate approximation for the distribution. Since strong earthquakes are infrequent events and databases do not include enough number of records, aleatory uncertainty in earthquake hazard is not well known today. Although there is nothing much to do with aleatory uncertainty since it is inherent to the earthquake characteristics there is no impediment to investigate the relationship between aleatory and epistemic uncertainties. This kind of information allows to predict the level of epistemic uncertainty before dynamic analyses are conducted. And if the predicted amount of uncertainty is unrealistic, one can reconsider the representation of hazard by improving the algorithm of selection of the earthquake records matching to a target design spectrum.

The algorithm of record selection of PEER strong ground motion database (PGMD, 2010) is adopted here to select one component from a record location instead of performing selections by using the square root of sum of the squares of the two orthogonal components. To create different dispersion values, 17 number of earthquake record sets each consisting of 7 number of records matching to the design acceleration spectrum are selected. Elastic spectral acceleration response spectra and inelastic ductility demand spectra are calculated for the selected 17 number of record sets.

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The above mentioned relationship between the elastic spectra and inelastic spectra are constructed for 0.2s and 1s periods by performing linear regression with and without nonlinear terms. All the calculations are performed by the coded MATLAB (The Math Works Inc., 2012) scripts.

EARTHQUAKE RECORD SELECTION

23 number of earthquake records properties of which are given in Table.1 are used to construct 17 number of record sets each consisting of 7 records. Those records are obtained from PEER strong ground motion database (PGMD, 2010). Web page of PGMD (2010) provides a search engine and average value of the spectra of the selected and scaled earthquakes matches to a target design spectrum. A spectrum used for the searches is the square root of sum of the squares of the spectra of the records for the two orthogonal directions from the same event and location. However, in this study the search algorithm is adopted as it uses response spectra of individual records for searches. Mean square error (MSE) of each records are calculated and the records are sorted with regard to their MSE (PEER, 2011) values. 23 number of the earthquake records are obtained by this approach. The records are selected from different events with distances closer than 25km and from fault normal components only.

Table 1. Earthquake records used to construct 17 number of record sets

Record num.	Event	NGA No	Station	Mag., M_w	Distance
1	Duzce- Turkey, 1999	1602	Bolu	7.14	12
2	Coalinga-05, 1983	405	Burnett Construction	5.77	8.4
3	Cape Mendocino, 1992	829	Rio Dell Overpass - FF	7.01	7.9
4	Mammoth Lakes-03, 1980	236	Convict Creek	5.91	1
5	Chalfant Valley-02, 1986	549	Bishop - LADWP South St	6.19	14.4
6	Managua- Nicaragua-01, 1972	95	Managua- ESSO	6.24	3.5
7	Imperial Valley-06, 1979	158	Aeropuerto Mexicali	6.53	0
8	Dinar- Turkey, 1995	1141	Dinar	6.4	0
9	Kocaeli- Turkey, 1999	1158	Duzce	7.51	13.6
10	Loma Prieta, 1989	752	Capitola	6.93	8.7
11	Northridge-01, 1994	949	Arleta - Nordhoff Fire Sta	6.69	3.3
12	Parkfield, 1966	30	Cholame - Shandon Array #5	6.19	9.6
13	Mammoth Lakes-01, 1980	230	Convict Creek	6.06	1.1
14	Coalinga-07, 1983	418	Coalinga-14th & Elm (Old CHP)	5.21	7.6
15	Mt. Lewis, 1986	502	Halls Valley	5.6	12.3
16	Coalinga-01, 1983	368	Pleasant Valley P.P. - yard	6.36	7.7
17	Erzican- Turkey, 1992	821	Erzincan	6.69	0
18	Kobe- Japan, 1995	1106	KJMA	6.9	0.9
19	San Salvador, 1986	569	National Geografical Inst	5.8	3.7
20	Livermore-01, 1980	212	Del Valle Dam (Toe)	5.8	23
21	Landers', 1992	881	Morongo Valley	7.28	17.3
22	Spitak- Armenia, 1988	730	Gukasian	6.77	24
23	Chi-Chi- Taiwan, 1999	1194	CHY025	7.62	19.1

Target spectrum is the design spectrum of ASCE7 (ASCE, 2010) and the parameters S_{DS} and S_{D1} are chosen as 1.5 and 0.6, respectively (Fig.1). For matching, the period interval is between the values of $0.2T_1$ and $1.5T_1$ where T_1 is 1s.

First record set consists of the records with record numbers of {1,2,...,7}, second record set consists of that of {2,3,...,8} and for the last set, numbers of the records used are {17,18,...23}. Although the scale factors are determined for best matching before, the mean value of the spectral accelerations of the scaled records in a set may fall under the target spectrum. If such a situation happens, all the scaled records are multiplied with an additional factor in order to make the mean spectrum equal or higher than the target spectrum for the specified period interval between $0.2T_1$ and $1.5T_1$. Resultant scale factors of the records for different sets are given in Table.2. It is known that scaling may create bias (Luco and Bazzurro, 2007). In order to make it bounded and uniform for all the sets as possible as can be, the maximum scale factor is chosen as 2.5 during the scaling procedure.

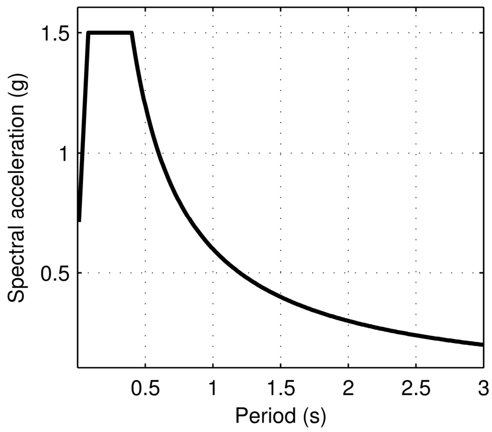

Figure 1. Target design spectrum

Table 2. Scale factors for the records used to construct 17 number of record sets

Record num.	Set-1	Set-2	Set-3	Set-4	Set-5	Set-6	Set-7	Set-8	Set-9	Set-10
1...10	1.04	2.50	2.34	2.50	2.50	1.94	2.50	2.01	2.50	2.11
2...11	2.50	2.16	2.50	2.50	2.02	2.50	1.91	2.50	2.32	2.50
3...12	2.00	2.50	2.50	1.94	2.50	2.25	2.50	1.59	2.50	2.50
4...13	2.50	2.50	2.02	2.50	2.35	2.50	1.51	2.50	2.50	2.50
5...14	2.50	1.87	2.50	2.25	2.50	1.78	2.50	2.43	2.50	1.56
6..15	1.73	2.50	2.34	2.50	1.86	2.50	2.30	2.15	1.72	2.50
7...16	2.50	2.16	2.50	1.78	2.50	2.50	2.04	1.18	2.50	1.75

Table 2 (continued). Scale factors for the records used to construct 17 number of record sets

Record num.	Set-11	Set-12	Set-13	Set-14	Set-15	Set-16	Set-17
11...17	1.04	2.50	2.34	2.50	2.50	1.94	2.50
12...18	2.50	2.16	2.50	2.50	2.02	2.50	1.91
13...19	2.00	2.50	2.50	1.94	2.50	2.25	2.50
14...20	2.50	2.50	2.02	2.50	2.35	2.50	1.51
15...21	2.50	1.87	2.50	2.25	2.50	1.78	2.50
16...22	1.73	2.50	2.34	2.50	1.86	2.50	2.30
17...23	2.50	2.16	2.50	1.78	2.50	2.50	2.04

DISPERSION OF THE SPECTRA

Although the scale factors are investigated for the best matching to the target elastic acceleration spectrum, MSE error of the records increase with increasing record numbers (1-23) provided in Table 2. This is because since they are sorted in this way. Therefore, spectra of the sets containing records with higher record numbers will possess higher dispersion, generally. By this way different dispersion values are obtained for different sets. Elastic spectral acceleration spectra of the sets and the target spectrum are given in Fig.2.

Ductility demand spectra are also calculated for each set for the constant strength reduction factor of 3 (R_μ=3) and are given in Fig.3. Before talking about the dispersion it should be noted that the mean ductility demands for the period of 0.2s are 6.6 and 26.5 for the sets 1 and 17, respectively. There might be much difference with regard to record selection for lower periods. However this calculations should be repeated with different strength reduction factors. Regarding the dispersion, similar tendency of the acceleration spectra of having higher dispersion with increasing number of record set is also obtained for the ductility demand spectra.

Coefficient of variation values of elastic spectra (COVE) and inelastic spectra (COVIN) are calculated and 17 number of data points are obtained for each of the period values of 0.2s and 1s.

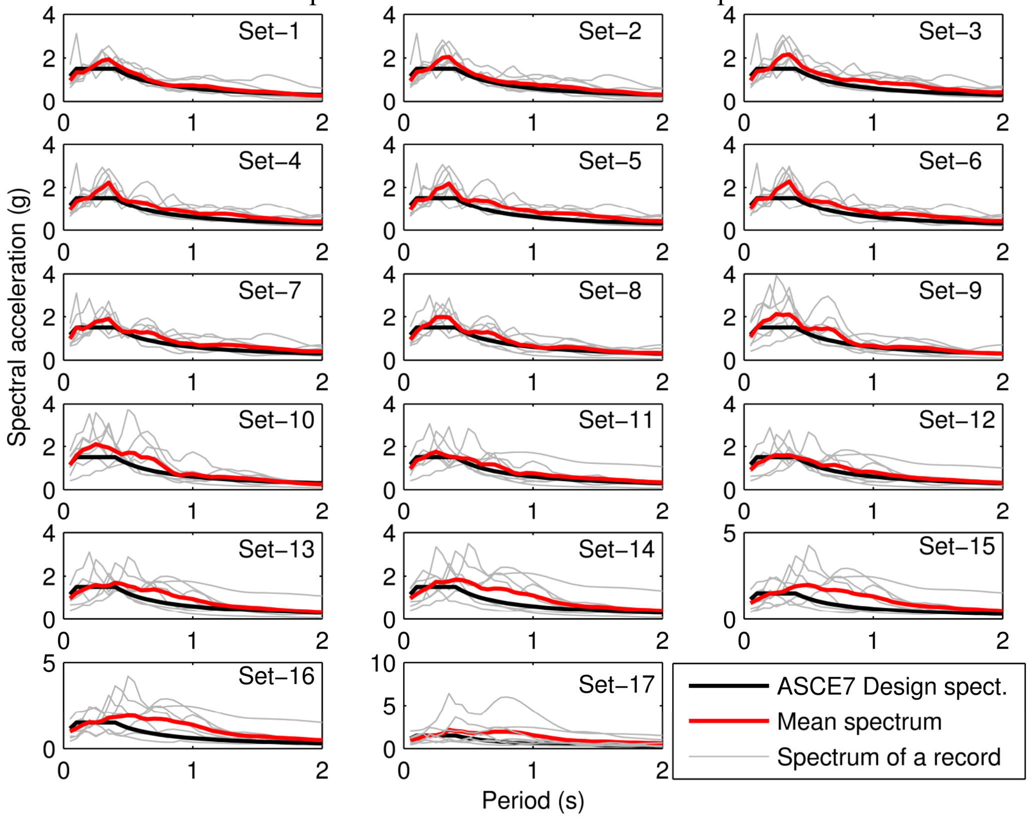

Figure 2. ASCE7 design spectrum, response acceleration spectra and their mean

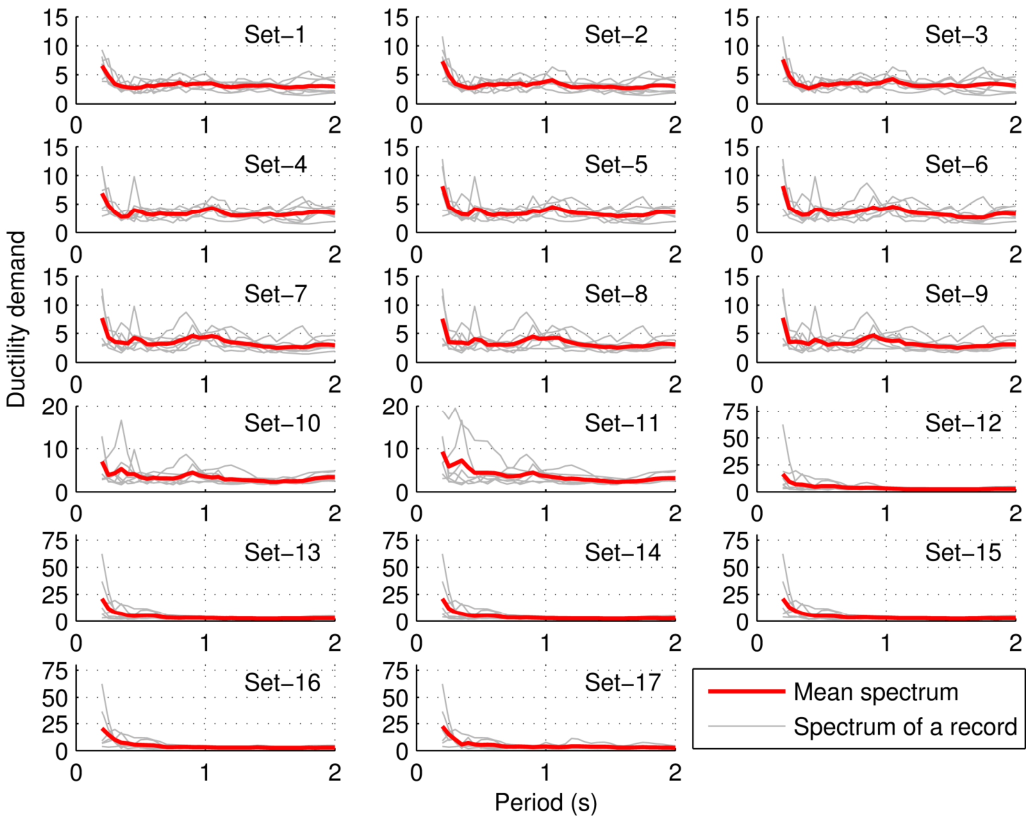

Figure 3. Ductility demand spectra for constant strength reduction factor of 3 and their mean

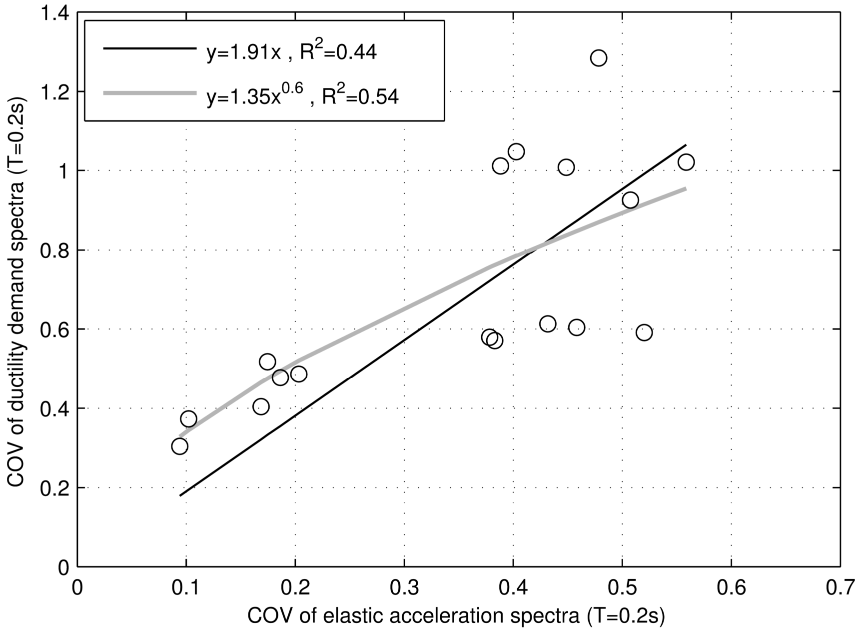

Figure 4. Relationships between the COV values of the elastic and inelastic spectra for period value of 0.2s

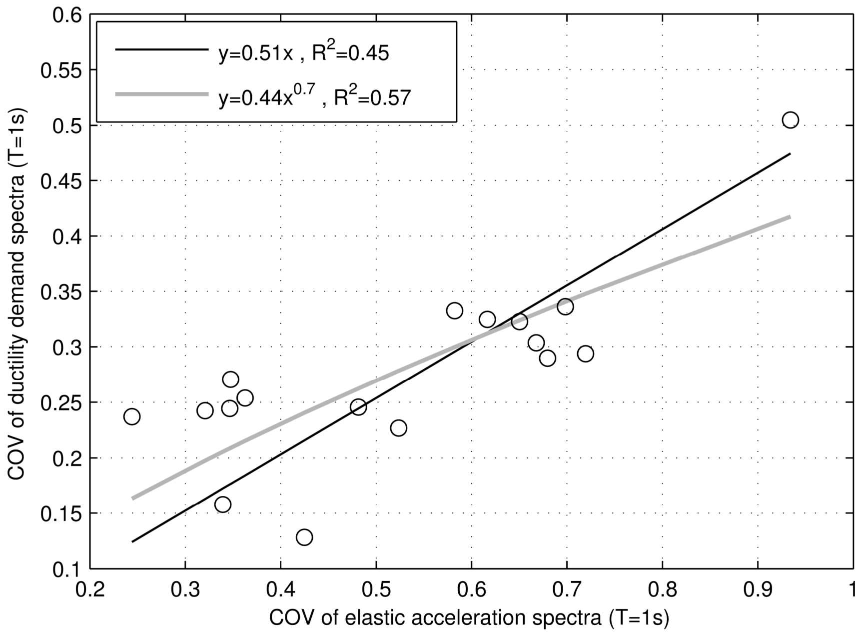

Figure 5. Relationships between the COV values of the elastic and inelastic spectra for period value of 1s

Graphics of COVE versus COVIN are given in Figs.4,5 for the period values of 0.2s and 1s, respectively. Like mean values COV values are also higher for the period of 0.2s.

Linear regression with and without nonlinear terms are also performed. For the values of COVE higher than 0.3 considerably higher COVIN values can be obtained for the period of 0.2s. Maximum COVIN value for the period of 1s was 0.5. Accordingly, lower slope values are obtained for 1s period. This is because epistemic uncertainty reduces for higher period values of inelastic displacement demand spectra, generally.

Linear regression between COVE and COVIN with linear terms gives lower R^2 values of 0.44 and 0.45 than 0.54 and 0.57 which the regression with nonlinear terms gives for the periods of 0.2s and 1s, respectively. The relationship for 1s period is slightly better. If the range of COVE values is divided into two interval such as the intervals of lower than and higher than 0.3, better results can be obtained for the period of 0.2s. For the period of 1s, if higher COVE values are excluded from the regression such as the value of 0.9 better results can be obtained too.

CONCLUSIONS

Relationships between the aleatory and epistemic uncertainties such as the uncertainty in hazard and structural response parameters used to determine damage can give information about the level of the epistemic uncertainty before performing inelastic dynamic analyses. Today the differences between the dispersion of selected earthquake sets matching to the same target spectrum may be high although the matching rules of design codes are satisfied for all the selected sets. In this study relationships between the COV values of elastic spectra and the COV values of the ductility demands values obtained by inelastic dynamic analyses of single degree of freedom systems under the considered record sets are provided by linear regressions with and without linear terms. Higher dispersion values can be seen from the provided figures without any inelastic dynamic analyses conducted. However, the study should be expanded and repeated with more specified record sets such as far filed records and near fault records with and without pulses. Different strength reduction factors with different period values should also be considered.

It should also be noted that a new attempt in the 2010 version of ASCE7 (ASCE, 2010) is to change the practice of design by providing a uniform margin against collapse instead of uniform hazard for all the structures. This kind of information like in this study can add to the knowledge of this new practice.

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