AN EFFECTIVE METHOD FOR SELECTION AND MODIFICATION OF GROUND MOTIONS FOR DYNAMIC TIME HISTORY ANALYSIS

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ABSTRACT

In this study, first a three-step screening process is presented for selection of consistent earthquake records in which number of suitable earthquakes is quickly screened and reduced from a few thousands to a handful number for practical use in the time history analysis. Records that remain at the end of this screening process are the most appropriate for the studied structures meaning that they considerably reduce the dispersion of structural responses. Then, an effective method is presented for spectral matching and modification of the selected records. A number of commonly available methods for scaling of records are examined comparatively. Dispersion of structural responses is explored using different statistical measures for each scaling procedure. It is shown that the Uniform Design Method, presented in this study for scaling of earthquake records, results in most cases in the least dispersion measure.

1. INTRODUCTION

Procedures suggested for the ground motion selection can generally be categorized in three groups regarding their level of complexity. In the first group simply the general seismicity and seismotectonic characteristics of the region are considered. Parameters such as the fault mechanism, earthquake magnitude, distance to the causative fault, etc., have been used for sorting of earthquakes. This approach has been adopted mainly by the public databases of earthquake records on the Internet, such as the PEER NGA strong motion data bank (PEER., 2009).

In the second group, similarity of spectral shapes is the basis of selection. For this purpose, the response spectrum of the record at hand is compared with the design spectrum. If enough similarity is satisfied, the record is selected for dynamic analysis. As the basis of comparison, the code-based constant-shape design spectrum can be used among other choices. To determine how similar a response spectrum is to a basis spectrum, many options are available. When using the design spectrum as the basis, the average of deviations from the basis spectrum between two certain periods can be calculated and compared.

The criteria used in the third group are generally called the advanced intensity measures. They usually combine the spectral characteristics of a ground motion with certain nonlinear responses of multi-story structures. After computing the above intensity measure (IM) for many records, those with IM's nearer to the average IM are selected.

When a record is scaled, the main idea is to minimize deviation of its response spectrum from the target (basis) spectrum in a certain period range. The period range can be defined using T_1, the period of the first mode of vibration. It is usually taken to be extending from 0.2 T_1 to 1.5 T_1 to include both the effects of higher modes and the nonlinear response of structure (ASCE/SEI 7-10., 2010). In the CMS method (Baker, J. W., 2011), derivation of the scale factor is targeted at equalizing sum of the spectral amplitudes in the required period range from the CMS to that of the response spectrum.

Scaling of records can also be accomplished using code-based prescribed procedures. ASCE7-10 requires that the scale factor be determined such that the average response spectrum of the suit of records does not fall below the design spectrum in the mentioned period range (ASCE/SEI 7-10., 2010).

The aim of this research is to sort out a suitable methodology for earthquake record selection and modification. The main criterion for recognizing the suitability of the method is chosen to be having a minimum scatter in nonlinear structural responses.

2. THE PROPOSED METHOD FOR SELECTION OF GROUND MOTIONS

In this study, a three-stage procedure for screening of earthquake records is presented. During the stages, the selection criteria become more strict and number of records that pass each screen sharply decreases. The three stages are called loose, medium and tight screens.

2.1. THE LOOSE SCREEN

In stage 1, some global characteristics of earthquakes are utilized as the basis of record selection. These are: earthquake magnitude (M), distance to the fault (R), soil type or the shear wave velocity (V_s), and peak acceleration at the ground surface (PGA).

For illustration, the following values are chosen to get forward with the next stages:

$6 \leq M \leq 8$, $10 \leq R \leq 90\ Km$, $375 \leq Vs \leq 750\ {}^{m}/_{s}$, $0.2 \leq PGA \leq 1.2\ g$.

Use of the above search criteria within the PEER ground motion database (PEER., 2009), results in 47 earthquakes.

2.2. THE MEDIUM SCREEN

For the medium screen, the more promising options, after testing several procedures, seemed to be the following two methods:

-The CMS approach; selection based on the spectral shape factor ε.

The ε factor is determined using Eq. (1):

$$\varepsilon(T) = \frac{\ln Sa(T) - \mu_{\ln sa}(M,R,T)}{\sigma_{\ln Sa}(M,R,T)} \tag{1}$$

where $\ln Sa(T)$ is the natural logarithm of the spectral acceleration of the record, $\mu_{\ln sa}(M,R,T)$ is the average of $\ln Sa(T)$ for the records of the ground motion suit, and $\sigma_{\ln sa}(M,R,T)$ is their standard deviation; all calculated at the fundamental period of building. The records with smaller ε's are less deviated from the average and are deemed more suitable for analysis.

-The spectral intensity approach.

In this method the records with spectral intensities nearer to that of the design spectrum are picked up for the next screen. The spectral intensity, SI, is calculated using Eq. (2):

$$SI = \int_{0.1}^{2.5} S_V\, dT \tag{2}$$

in which S_V is the spectral velocity. This method only needs the response velocity spectrum of each earthquake and the design velocity spectrum and therefore is simpler then the above method based on ε. Moreover, numerical analysis in this study has shown that selecting based on SI results in less scattering of structural responses compared with ε (Talebi, M., 2014). Therefore only the earthquakes selected based on SI are introduced here. For selection of earthquakes in this stage, the ratios of spectral intensities of the records at hand to that of the design spectrum are calculated. The earthquakes with ratios nearer to unity are selected. The design spectrum, S_a, used for this analysis is that of ASCE7-10.

Based on Eq. (2), 20 earthquakes with spectral intensity ratios closer to unity are selected.

2.3. THE TIGHT SCREEN

Among the methods suitable for a tight screen, referred to in Sec.1, the CMS method is selected for analysis. Of course use of more advanced intensity measures is possible too, but they have been left aside after examining, for their unwanted complexity (Talebi, M., 2014).

The CMS method needs a design spectrum and involves constructing a mean spectrum with the condition that it intersects with the design curve at a certain period. This period is taken to be the fundamental period of the buildings under study. The structures designed for the purposes of this study, are 2, 4, 6, 8 and 10 story two-way steel moment resisting frames. There are three bays each way spanning 5 m between columns. The floor-to-floor heights of stories are uniformly 3 m. The fundamental periods of 2 to 10-story buildings are determined to be 0.42, 0.79, 1.07, 1.23 and 1.52 sec, respectively.

The CMS must be constructed for each building. It is determined as follows (Talebi, M., 2014):

1) Calculation of the mean, $\mu(Ln\,S_a)$ and standard deviation, $\sigma(LnS_a)$, of the natural logarithm of the spectral accelerations. For the 20 earthquakes selected out the medium screen, $\mu(Ln\,S_a)$ and $\sigma(Ln\,S_a)$ are calculated at each period T as follows:

$$\mu_{\ln \mathrm{Sa}}(\mathrm{M,R,T}) = (1/20)\sum_{i=1}^{20} lnSa(T)_i \tag{3}$$

$$\sigma_{\ln \mathrm{Sa}}(\mathrm{T}) = \sqrt{1/20 \sum_{\mathrm{i}=1}^{20}(\ln \mathrm{Sa(T)} - \mu_{\ln \mathrm{Sa}}(\mathrm{M,R,T}))\text{^}2} \tag{4}$$

2) Determination of ε and the correlation factor ρ.

The spectral shape parameter ε is calculated using Eq. (1) at the fundamental period T. The ρ factor is determined using Eq. (5):

$$\rho(\mathrm{T}_{min}, \mathrm{T}_{max}) = 1 - \cos\left(\frac{\pi}{2} - \left(0.359 + 0.163 \mathrm{I}_{\mathrm{T}_{min}<0.189} \ln\frac{\mathrm{T}_{min}}{0.189}\right)\ln\frac{\mathrm{T}_{max}}{\mathrm{T}_{min}}\right) \tag{5}$$

where I equals unity for $T_{min} < 0.189$ and zero elsewhere. Also, for periods less than T, T_{min} is the desired period and $T_{max} = T$. For periods larger than T, The above definition is reversed.

3) Calculation of CMS.

The conditional mean spectrum is calculated using Eq. (6):

$$\mathrm{CMS}\ (\mathrm{T_L}) = \mathrm{Exp}\{\mu_{\ln \mathrm{Sa}}(\mathrm{M,R,T_i}) + \rho(\mathrm{T}_i, \mathrm{T}^*)\varepsilon(\mathrm{T}^*)\sigma_{\ln \mathrm{Sa}}(\mathrm{T}_i)\} \tag{6}$$

where (T_i) is the desired period. Similarity of each response spectrum to the CMS is measured in this method using the SSE and SF indices, introduced as follows:

$$\mathrm{SSE} = \sum_{j=1}^{n}\left(\ln \mathrm{Sa}(\mathrm{T_j}) - \ln \mathrm{Sa_{CMS}}(\mathrm{T_j})\right)^2 \tag{7}$$

$$\text{Scale Factor} = \frac{\sum_{\mathrm{j}=1}^{\mathrm{n}} \mathrm{Sa_{CMS}}(\mathrm{T_j})}{\sum_{\mathrm{j}=1}^{\mathrm{n}} \mathrm{Sa}(\mathrm{T_j})} \tag{8}$$

where $\mathrm{Sa}(\mathrm{T_j})$ is the value of the response spectrum at the descried period T_i and S_{aCMS} the CMS value at the same period. Then, 10 records with smaller SSE's and with SF's closer to unity are finally picked up for structural analysis. Table 1 lists the final earthquakes selected after the tight screen. Also, the response spectra of the selected earthquakes are shown in Fig. 1, as an example.

Table 1. Final earthquakes selected after the tight screen stage.

Row	2-story	4-story	6-story	8-story	10-story
1	NGA 0265	NGA 0265	NGA 0265	NGA 0265	NGA 0755
2	NGA 0755	NGA 0755	NGA 0755	NGA 0755	NGA 0787
3	NGA 0787	NGA 0787	NGA 0787	NGA 0787	NGA 0864
4	NGA 0864	NGA 0864	NGA 0864	NGA 0864	NGA 0952
5	NGA 1010	NGA 1010	NGA 1010	NGA 0952	NGA 1010
6	NGA 1198	NGA 1198	NGA 1198	NGA 1010	NGA 1202
7	NGA 1202	NGA 1487	NGA 1485	NGA 1198	NGA 1485
8	NGA 1487	NGA 1506	NGA 1487	NGA 1485	NGA 1487
9	NGA 1787	NGA 1787	NGA 1506	NGA 1487	NGA 1787
10	NGA 2627	NGA 2627	NGA 2627	NGA 2627	NGA 2627

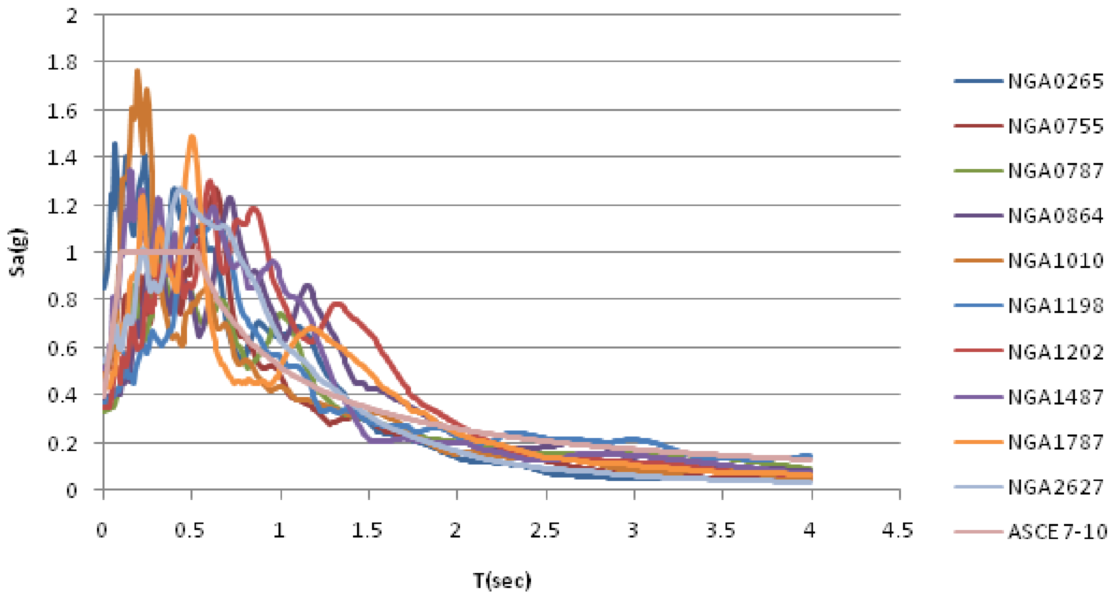

Figure. 1. Response spectra of the earthquakes selected for nonlinear analysis of the 2-story building.

3. SCALING OF THE SELECTED EARTHQUAKES

In this study a new scaling method is presented and evaluated for discrepancy. The quality of ASCE7-10 scaling is evaluated with two versions. If the individual response spectra are used, it is called the separative ASCE method, but if the mean response spectrum is utilized, the method will be called the combinatorial ASCE. In CMS, the scale factor is determined by Eq. (8).

The new method presented in this study for modification or scaling of the selected ground motions is called the Uniform Design Method (UDM). This method is presented in two versions, called separative and combinatorial. In the separative version, first the building under study is designed for the response spectrum of the original earthquake record along with other loads. The fundamental period of the designed structure is called T_1^e. The same building is again designed but this time using the design spectrum of the building code. The fundamental period in this case is called T_1^{code}. In order to arrive at a uniform design both with the response and the design spectra, similarity of design forces (spectral accelerations) resulting in similar lateral stiffnesses and similar fundamental periods is considered. Since stiffness is proportional to square of period, a scale factor is proposed as follows:

$$\text{Scale Factor} = \left({T_1^e}/{T_1^{code}}\right)^2 \tag{9}$$

The separative UDM has the drawback that it is too lengthy because each building must be designed once for each original record. The combinatorial UDM overcomes this difficulty with using the mean response spectrum of the original records for design. Therefore in this method the building is once designed using the mean response spectrum of the original records, with the resulting period T_1^e, and once with the design spectrum, resulting in period T_1^{code}. The scale factor is calculated using Eq. (9).

The scale factors using the methods mentioned above have been calculated for the records mentioned in Table 3, corresponding to the buildings introduced in Sec.2.3.1. They are proved to be between 0.75 and 2.5.

4. NONLINEAR DYNAMIC ANALYSIS

Quality of the scaling methods mentioned in Sec. 3 is evaluated in this section with determination of the structural responses by a nonlinear dynamic analysis under each scaled earthquake and calculating the scattering of results.

The analysis is implemented within Opensees (Silvia Mazzoni et al., 2007). The structural steel members are modeled with nonlinear hinges to be concentrated at their ends. For this purpose, the Steel02 material of Opensees for a St37 standard steel, accounting for the strain hardening and Bauschinger effects, is used.

In the nonlinear analysis, scattering of story drifts is calculated among earthquakes. In this study, four more widespreadly used measures are utilized for the same purpose (NIST GCR 10-917-9).

They are the coefficient of variation (COV), the logarithmic standard deviation (σ), relative difference of the averages (DA), and average of the 84 and 16 logarithmic percentiles of the responses (PA), based on Eqs. 10-13:

$$\mathrm{COV}=\frac{\sigma}{\mu} \tag{10}$$

$$\sigma=\exp\left\{\sqrt{\frac{1}{N-1}}\sum_{i=1}^{N}(x_i-\bar{x})^2\right\} \tag{11}$$

$$DA=\frac{\mathrm{MEAN}_{50}-\mathrm{MEAN}_{10}}{\mathrm{MEAN}_{50}} \tag{12}$$

$$PA=\frac{\ln X_{84}-\ln X_{16}}{2} \tag{13}$$

where MEAN50, refers to mean of response for 50 scaled records (5 scaling methods for 10 records), and MEAN10 refers to mean of responses under 10 records for each scaling method. Also, X is the response considered, being the story drift in this study. The scattering measures introduced in Eqs. 10-13 are calculated for each method of scaling, as of Sec. 3, for each building and each story response parameter. The results are mentioned in Tables 2-6 where in each column the method resulting in the least scatter, associated with the smallest value of the measure is highlighted in dark color.

Table 2. Values of the scatter in measures for different scaling methods, story drifts, 2-story building.

	Modification Method	First Floor	Second Floor
C.O.V	Combinatorial ASCE	0.510663	0.457848
	Separative ASCE	0.732088	0.664811
	CMS	0.435066	0.422985
	Combinatorial UDM	0.374488	0.365207
	Separative UDM	0.619847	0.572101
σ	Combinatorial ASCE	0.590142	0.539423
	Separative ASCE	0.863172	0.787591
	CMS	0.5788	0.558377
	Combinatorial UDM	0.434614	0.401285
	Separative UDM	0.758051	0.738098
D.A	Combinatorial ASCE	0.147169	0.11795
	Separative ASCE	0.193625	0.148596
	CMS	0.421838	0.381921
	Combinatorial UDM	0.14276	0.120268
	Separative UDM	0.232621	0.231007
P.A	Combinatorial ASCE	0.472563	0.393128
	Separative ASCE	0.696995	0.629484
	CMS	0.403995	0.386545
	Combinatorial UDM	0.306268	0.299182
	Separative UDM	0.612571	0.557937

Table 3. Values of the scatter in measures for different scaling methods, story drifts, 4-story building.

	Modification Method	First Floor	Second Floor	Third Floor	Forth Floor
C.O.V	Combinatorial ASCE	0.48102	0.54528	0.56453	0.57758
	Separative ASCE	0.58354	0.6038	0.6365	0.65131
	CMS	0.54988	0.60749	0.70486	0.62702
	Combinatorial UDM	0.4588	0.5191	0.4948	0.4694
	Separative UDM	0.619847	0.54778	0.62073	0.57758
σ	Combinatorial ASCE	0.45114	0.51301	0.50965	0.52434
	Separative ASCE	0.48654	0.50982	0.52532	0.53524
	CMS	0.43765	0.47893	0.50985	0.47143
	Combinatorial UDM	0.4957	0.5461	0.5857	0.5483
	Separative UDM	0.43022	0.48283	0.5095	0.52021
D.A	Combinatorial ASCE	0.0849	0.0984	0.1733	0.287
	Separative ASCE	0.2474	0.2317	0.1545	0.0437
	CMS	0.274	0.2825	0.3244	0.4053
	Combinatorial UDM	0.0695	0.0413	0.183	0.6262
	Separative UDM	0.181	0.1905	0.1602	0.0225
P.A	Combinatorial ASCE	0.44717	0.44696	0.41045	0.37781
	Separative ASCE	0.46399	0.47994	0.48504	0.48945
	CMS	0.4432	0.41639	0.48707	0.40474
	Combinatorial UDM	0.3803	0.4502	0.4025	0.386
	Separative UDM	0.52063	0.56546	0.5755	0.57673

Table 4. Values of the scatter in measures for different scaling methods, story drifts, 6-story building.

	Modification Method	First Floor	Second Floor	Third Floor	Forth Floor	Fifth Floor	Sixth Floor
C.O.V	Combinatorial ASCE	0.578051	0.59524	0.645508	0.672463	0.67667	0.585778
	Separative ASCE	0.482146	0.513191	0.561925	0.604147	0.620382	0.503735
	CMS	0.52915	0.532508	0.551593	0.579823	0.576912	0.534585
	Combinatorial UDM	0.6964	0.6658	0.6515	0.6599	0.6192	0.5637
	Separative UDM	0.487625	0.513186	0.556399	0.576198	0.60491	0.50588
σ	Combinatorial ASCE	0.980698	1.103367	1.157842	1.209592	1.118799	0.936966
	Separative ASCE	0.623626	0.66425	0.759885	0.884929	1.188992	0.663252
	CMS	0.805176	0.795466	0.865939	0.973753	1.034004	0.738307
	Combinatorial UDM	0.7182	0.7936	0.8537	0.8626	0.8263	0.6815
	Separative UDM	0.575085	0.677172	0.846612	0.806236	0.783091	0.516186
D.A	Combinatorial ASCE	0.1744	0.1524	0.1959	0.2131	0.2545	0.3209
	Separative ASCE	0.0213	0.0024	0.0007	0.008	0.0171	0.0909
	CMS	0.3342	0.3113	0.3638	0.4366	0.4288	0.4064
	Combinatorial UDM	0.1984	0.1858	0.2759	0.3472	0.4503	0.6096
	Separative UDM	0.3316	0.2755	0.2831	0.3105	0.25	0.2086
P.A	Combinatorial ASCE	0.698372	0.701612	0.749281	0.767174	0.683147	0.540955
	Separative ASCE	0.602578	0.630746	0.721779	0.745358	0.771463	0.596023
	CMS	0.754043	0.70824	0.714906	0.742751	0.679246	0.579779
	Combinatorial UDM	0.5578	0.6675	0.733	0.7607	0.7261	0.6221
	Separative UDM	0.503402	0.633369	0.705311	0.678121	0.660438	0.40581

Table 5. Values of the scatter in measures for different scaling methods, story drifts, 8-story building.

	Modification Method	First Floor	Second Floor	Third Floor	Forth Floor	Fifth Floor	Sixth Floor	Seventh Floor	Eight Floor
C.O.V	Combinatorial ASCE	0.46151	0.48975	0.57587	0.67939	0.84564	0.90208	0.69752	0.54622
	Separative ASCE	0.44021	0.48109	0.53303	0.63298	0.78064	0.77209	0.7402	0.53735
	CMS	0.46758	0.46070	0.50912	0.60892	0.74362	0.79640	0.61533	0.525
	Combinatorial UDM	0.5028	0.5226	0.569	0.6227	0.6651	0.6576	0.5669	0.5073
	Separative UDM	0.43583	0.42416	0.50873	0.55350	0.74553	0.70085	0.67109	0.49400
σ	Combinatorial ASCE	0.59746	0.56973	0.65520	0.67928	0.80079	1.11742	0.84399	0.68479
	Separative ASCE	0.52979	0.59256	0.63045	0.69022	0.75533	1.02047	0.91327	0.68727
	CMS	0.7030	0.61825	0.62515	0.72859	0.80456	1.20768	0.87039	0.63095
	Combinatorial UDM	0.6588	0.6301	0.6805	0.6799	0.7448	0.7502	0.698	0.6394
	Separative UDM	0.46605	0.45622	0.52842	0.54663	0.73956	0.90754	0.77356	0.61237
D.A	Combinatorial ASCE	0.0535	0.0639	0.0866	0.1191	0.1385	0.1939	0.1321	0.1905
	Separative ASCE	0.0802	0.0768	0.0592	0.0277	0.0093	0.0046	0.0582	0.0556
	CMS	0.2984	0.3128	0.3439	0.3666	0.4215	0.4435	0.3812	0.4259
	Combinatorial UDM	0.0802	0.1364	0.1878	0.3003	0.4696	0.5232	0.536	0.7116
	Separative UDM	0.1915	0.1634	0.1835	0.1577	0.0811	0.1188	0.0355	0.0397
P.A	Combinatorial ASCE	0.47744	0.53626	0.5985	0.68020	0.79234	1.16821	0.89198	0.67689
	Separative ASCE	0.45667	0.50177	0.5839	0.73629	0.75076	0.86944	0.97657	0.69541
	CMS	0.45581	0.49629	0.5844	0.65859	0.78379	1.33904	0.81926	0.61968
	Combinatorial UDM	0.5075	0.5373	0.6328	0.6742	0.7636	0.7128	0.5986	0.5375
	Separative UDM	0.316093	0.34857	0.454	0.603938	0.706468	0.777229	0.803832	0.540002

Table 6. Values of the scatter in measures for different scaling methods, story drifts, 10-story building.

	Modification Method	First Floor	Second Floor	Third Floor	Forth Floor	Fifth Floor	Sixth Floor	Seventh Floor	Eight Floor	Ninth Floor	Tenth Floor
C.O.V	Combinatorial ASCE	0.484	0.458	0.468	0.51289	0.6437	0.7315	0.7897	0.7206	0.6764	0.448
	Separative ASCE	0.513	0.471	0.473	0.4896	0.6435	0.7109	0.7146	0.7085	0.6177	0.363
	CMS	0.481	0.497	0.490	0.48269	0.5958	0.6552	0.6644	0.6660	0.6626	0.566
	Combinatorial UDM	0.507	0.509	0.505	0.5019	0.5936	0.6295	0.6164	0.5834	0.5018	0.430
	Separative UDM	0.398	0.394	0.435	0.47483	0.6421	0.7339	0.8133	0.7741	0.5968	0.478
σ	Combinatorial ASCE	0.745	0.724	0.854	0.84046	0.9198	0.9407	0.9541	1.0865	1.2482	0.511
	Separative ASCE	0.793	0.719	0.901	0.7952	0.9486	0.9189	0.9587	1.0137	0.7908	0.509
	CMS	0.710	0.879	0.911	0.7993	0.9493	0.8855	1.0384	1.0606	1.0486	0.839
	Combinatorial UDM	0.646	0.657	0.722	0.7529	0.7984	0.8234	0.8134	0.7676	0.6898	0.608
	Separative UDM	0.602	0.595	0.764	0.69633	0.8395	0.8752	0.9011	0.9602	0.7823	0.608
D.A	Combinatorial ASCE	0.021	0.000	0.003	0.0141	0.0286	0.0582	0.09	0.1047	0.1223	0.125
	Separative ASCE	0.162	0.168	0.172	0.1519	0.0735	0.0471	0.0209	0.0117	0.0596	0.067
	CMS	0.197	0.211	0.250	0.2827	0.2678	0.3186	0.331	0.3147	0.2672	0.254
	Combinatorial UDM	0.059	0.072	0.046	0.0106	0.1173	0.1856	0.2968	0.405	0.4538	0.550
	Separative UDM	0.116	0.115	0.121	0.1343	0.1056	0.144	0.1034	0.0262	0.0047	0.102
P.A	Combinatorial ASCE	0.363	0.393	0.466	0.62261	0.7199	0.8866	0.8541	1.0951	0.9674	0.405
	Separative ASCE	0.499	0.492	0.474	0.5392	0.748	0.909	0.8615	0.9374	0.6695	0.231
	CMS	0.362	0.416	0.487	0.50739	0.6982	0.8673	0.7405	1.0286	1.0429	0.728
	Combinatorial UDM	0.473	0.469	0.523	0.5556	0.634	0.7005	0.7018	0.6389	0.5263	0.407
	Separative UDM	0.315	0.360	0.396	0.8445	0.76	0.9287	0.8445	1.0499	0.6936	0.315

Values of the scatter measures as mentioned in Tables 2-6 clearly show that the combinatorial uniform design method have resulted in the least scattering of nonlinear structural responses. The separative UDM, and the combinational ASCE rank the next levels. Overall, the scaling method of CMS has performed inferior to other methods. While the combinatorial UDM associates with the least scatter of responses, it is very simple to use as mentioned in Sec. 3.2. Therefore it can be a practical and accurate enough alternative for scaling of earthquake records.

3. CONCLUSIONS

In this paper a three-stage method for selection of earthquake ground motions suitable for nonlinear dynamic analysis of structures, along with a new scaling method for modification of the selected records were presented. The selection method uses the general characteristics of earthquakes as used in online databases for an initial selection. Then it uses two stricter measures for finally picking up the suitable records. It is a fast method. It has the advantage that the stricter measures are used with a far less number of records. In the presented scaling method it was aimed to equalize the fundamental period of the studied building designed under the scaled response spectrum of the record and under the design spectrum. With calculation of four different scatter measures for nonlinear responses of five steel structures ranging from 2 to 10 stories under the 10 selected and scaled earthquake records, it was shown that the proposed method resulted in the least scatter in most cases. The quality of the ASCE and CMS scaling methods were shown to be ranked afterwards.

4. REFERENCES

ASCE Standard ASCE/SEI 7-10.2010. Minimum design loads for buildings and other structures. ISBN 978-0-7844-1085-1

Baker JW (2011) "Conditional Mean Spectrum: A tool for ground motion selection."Journal of Structural Engineering, 137(3), 322-331

Effect of Ground Motion Selection and Scaling on Engineering Demand Parameter Dispersion. NIST GCR 10-917-9.

Pacific Earthquake Engineering Research Center (PEER) (2009) Evaluation of Ground Motion Selection and Modification Methods: Predicting Median Interstory Drift Response of Buildings

Silvia Mazzoni, Frank McKenna, Michael H. Scott, Gregory L. Fenves et al (July 2007) Open System for Earthquake Engineering Simulation (OpenSees)

Talebi M (2014) Selection and Modification of Ground Motions for Nonlinear Dynamic Analysis of Structures. M.Sc. thesis, Department of Civil Engineering, Science and Research Branch, Islamic Azad University, Isfahan, Iran