COMPARISION OF DUAL SCALING WITH AMPLITUDE SCALING OF EARTHQUAKE RECORDS FOR TIME HISTORY ANALYSIS

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ABSTRACT

The main objective of this paper is to compare the response spectra estimated when using simple amplitude and dual scaling criteria. Three structures with T=0.1, 0.3 and 1.0 are considered for representing the effect of different fundamental periods. These structures are considered on soil type II, medium soil, and the selection of records is based on a region with very high seismic risk. The methodology for selecting the real time histories is applied to find seven pairs of horizontal component of real earthquake records. In case of amplitude scaling , the accelerograms are scaled by spectral acceleration and further by the correction method of Standard 2800.For dual scaling the amplitude scaling is done to match the Housner intensity of the target specturum.

In terms of the stability of the goodness of fit observed between the mean response spectrum and the design spectrum for different periods of the structure under analysis, it is concluded that the use of dual scaling offers an attractive tool to obtain sensible estimates of dynamic time-history analysis.

INTRODUCTION

Recently, time-history analysis is becoming more common in seismic analysis and design of structures. An important issue of such analysis is the selection of acceleration time histories to satisfy design code requirements and soil type at a specific site. One popular option is to use natural accelerograms which must be selected and scaled to match as close as possible all the seismological parameters affecting the target design spectrum, including the geology of the site, distance to seismic source and even the type of faulting. Further refinements for earthquake ground motion scaling criteria account for the period of the structure under analysis or even a combination of both the period and the inelastic strength of the structure (Martinez-Rueda;1998)

The dynamic analysis of structures according to seismic code regulations requires the selection and scaling of sets of accelerograms complying with certain relevance criteria. Iranian code for seismic design of structures (2800 ver3) requires that for recorded accelerograms, selection criteria concern the adequacy to the seismologic features of the sources. Tectonically and geotechnical aspects and specially the soil conditions must be match the site. Real records must also consider the magnitude, distance and earthquake mechanism.

Selected records must have strong ground motion duration at least 10 seconds or three times the fundamental period of the structure in consideration.

The first step to scale the records is scaling of their values to their peak ground acceleration, so all the records have a peak ground acceleration equal to “g”. In this process there is no role for duration of strong motions and the scaling is based on intensity scaling. At least three pair of recorded accelerograms must be used. For each pair the values of response spectra must be combined by SRSS method to give the combined spectra. Then these three combined spectra must be averaged.

There are requirements concerning the maximum allowed differences between the standard spectra provided by the code and the mean spectrum calculated for all accelerograms in the set. For example, Iranian code (2800 ver3) requires that in the range of periods between 0.2T1 and 1.5T1, where T1 is the fundamental period of the structure in the direction where the accelerogram will be applied; no value of the mean 5% damping elastic spectrum, calculated from all time histories, should be less than 1.4 times the corresponding value of the 5% damping standard spectrum.

ASCE standard SEI/ASCE 7 uses the same procedure but ‘*Each pair of motions shall be scaled such that the average value of the SRSS spectra from all horizontal component pairs is not less than 1.3 times the 5% damped design response spectrum*.’ . ASCE does not mention the number of required records for this procedure.

In this study, a proposed method (Martinez Rueda 2006) for scaling real accelerograms to obtain sets of code-compliant records is assessed. The method, which uses combined time and amplitude scaling, corroborated with an imposed value of Housner intensity.

OBJECTIVE AND SCOPE

The main objective of this paper is to compare the response spectra estimated when using simple amplitude and dual scaling criteria. Three structures are considered for representing the effect of different fundamental periods. These structures are considered on soil type II, medium soil, and the selection of records is based on a region with very high seismic risk. The methodology for selecting the real time histories is applied to find seven pairs of horizontal component of real earthquake records.

Given a recorded accelerogram with known seismological parameters (*i.e. Mw, d,* seismic site and style of faulting), Martinez_Rueda(2012) demonstrates that one can resort to modifying the accelerogram by amplitude-scaling to reflect changes in distance to source. On the other hand, if one needs to reflect a change in magnitude, a modification of the frequency content is also necessary and hence one can resort to the dual scaling (*i.e*. time-scaling + amplitude-scaling) of the accelerogram.

In dual scaling method we need to find a combination of a time-scaling factor SFt and an amplitude-scaling factor SFa that modifies the real selected records to estimate an accelerogram on medium soil. In this article an accelerogram under scaling is visualized as a time-series in which each term of the series consists of a point with time and amplitude coordinates (t,$\ddot{u}_g(t)$), Where t = time and $\ddot{u}_g(t)$ = ground acceleration. Accordingly, each point of the accelerogram subjected to dual scaling has as modified coordinates $(SF_t.t, SF_a.\ddot{u}_g(t))$; where SFt is the time-scaling factor and SFa is the amplitude-scaling factor.

AMPLITUDE SCALING FACTOR

The usual method for amplitude scaling is by spectral acceleration, ‘SA’. The amplitude scaling factor is the maximum value of the 1.4*standard spectra for the given soil type and seismic risk divided by the average of combined spectra for each pair of records. over the range of 0.2T to 1.5T.

A better option to define amplitude scaling factor is based on the comparison of an overall measure of the earthquake ground motion intensities involved. In fact, as illustrated in Figure 1, the study of Martinez-Rueda and Vlachos (2010) reveals that the degree of association (assessed by the coefficient of determination *R2*) between Housner intensity *SIH* and ductility demand is greater and far more stable over a wider range of periods and strengths than that between *SA* and ductility demand. Furthermore, Figure 1 indicates that this fact is also true when the effectiveness of *SIH* is compared with other ground motion parameters, such as

PGA, Arias Intensity *IA*, and Cumulative Absolute Velocity *CAV*. These observations are meaningful as the objective of the proposed scaling procedure is to estimate earthquake ground motions for nonlinear inelastic time-history analysis; hence, within the context of seismic structural design, a ground motion parameters well associated with ductility demand is what is desirable to guide amplitude-scaling.

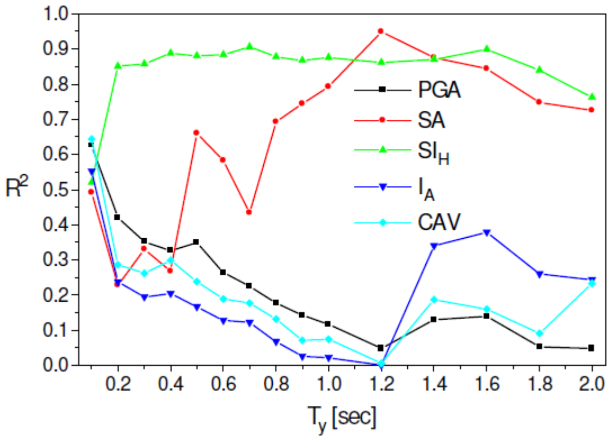


Figure 1. Comparison of GMPs performance for a family of inelastic structures with *Ty* between 0.1 and 2.0 sec and with *Cy* = 0.1(Martinez_Rueda and Vlachos, 2010)

TIME SCALING FACTOR

For practical purposes one could assume that the normalised spectrum shape is virtually the same irrespective of the distance to the source. (Martinez-Rueda; 2012).In consequence, irrespective of *d*, the distribution of the frequency content is virtually the same in each of the spectrum of the family. In fact, the period range at which *SA* exceeds *PGA* remains fairly constant for all the family of spectra. This period range is referred to in this study as the *amplification band*, which is characterised by the period *Tamp.*

If the spectra are normalised with respect to *PGA* then it is not realistic to assign a common *Tamp* for the family of spectra. Nevertheless, it is important to note that the overall shape of the spectra seem to be preserved. In the interest of simplicity, one could argue that, observing the spectra

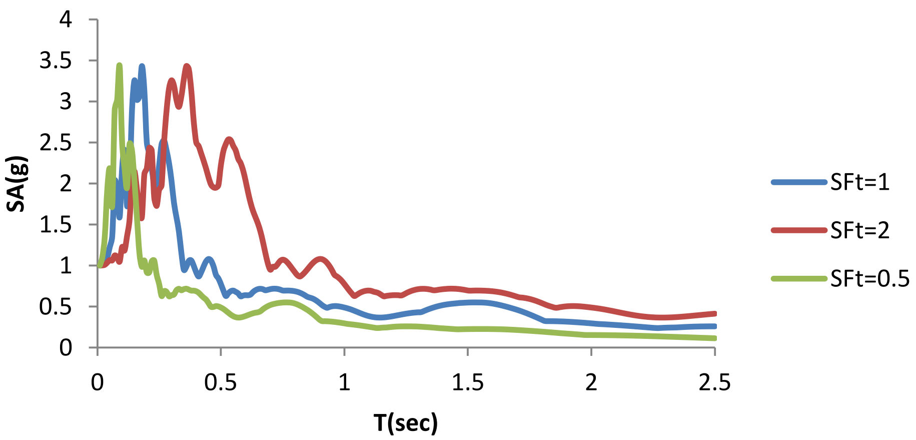


Figure 2. Effect of time scaling on the spectral shape of Varzagan record 5579-01/T

in the normalised space, the main effect of increasing earthquake magnitude (while keeping the other seismologic parameters constant) consists of a widening of the normalised spectrum shape (*i.e.* a widening of the amplification band assessed by *Tamp*) with an overall preservation of the relative amplitude of the spectral ordinates. On the other hand, a decrease of earthquake magnitude leads to a narrowing of the normalised spectrum. These trends are confirmed in the response spectra of Fig.2 for record 5579-01/T which shows that by using a time scaling factor more than 1.0, the shape of spectrum widened.

SELECTED EARTHQUAKE GROUND MOTIONS

The site of interest is assumed to be medium soil, soil type II of 2800 standard with shear velocity between 375 to 750 m/sec. By this criterion only the accelerogarms which had recorded on this soil type are chosen. Seven pairs of accelerograms of two horizontal components are considered. They relate to five earthquakes events with a magnitude more than 5.9 which recorded after 2002.Selected accelerograms are listed in Table 1.

Table 1.Natural accelerograms selected for the study.

Earthquake name	date	time	FD	M_w	Station name	Record number	distance	Record time		PGA (g)	Significant duration
AVAJ	2002/06/22	2:58:20	10	6.5	Kabodar ahang	2754-01	55.6	18	L	0.087	17.90
									T	0.166	16.19
BAM	2003/12/26	1:56:56	10	6.5	Mohamadabad	3162-01	44.2	75	L	0.124	13.96
									T	0.071	22.30
BAM	2003/12/26	1:56:56	10	6.5	bam	3168-02	10.2	66	L	0.799	8.01
									T	0.636	9.69
SILAKHOR	2006/03/31	1:17:02	----	5.9	Chalan cholan	4027-08	8.8	91	L	0.432	13.74
									T	0.357	10.99
VARZAGAN1	2012/08/11	12:23:16	12	6.1	varzagan	5579-01	19.2	85	L	0.427	5.58
									T	0.372	8.24
VARZAGAN2	2012/08/11	12:34:34	-----	6.2	ahar	5520-04	27.0	83	L	0.239	8.60
									T	0.422	6.62
VARZAGAN2	2012/08/11	12:34:34	-----	6.2	varzagan	5579-04	11.5	82	L	0.532	6.81
									T	0.530	5.90

The target design spectrum is the horizontal elastic response spectrum of standard 2800 for soil Type II ,for 5% damping multiplied by 1.4. For this type of soil the standard spectra for all seismic reigns is the same and could be computed as :

$T \le 0.1$:$B=1+15T$
$0.1 \le T \le 0.5$:$B=2.5$
$T \ge 0.5$:$B=2.5(0.5/T)^{(2/3)}$

SCALING PROCEDURES

Two scaling criteria for the seismic input were selected (Martinez-Rueda and Hamedi; 2014):

1- Amplitude scaling by spectral acceleration.

In this method the steps of standard 2800 have been used to obtain the combined (SRSS) of each pair of records and then the average of these records compared with the 1.4* standard spectra over the desired period range. In this study three structures with T=0.1 , 0.3 and 1.0 seconds and %5 damping are considered.

2- Dual scaling by appling time and amplitude scaling.

In first step the spectrum for each accelerogram are obtained and T_{amp} is calculated.
By the equation for SF_t (Martinez-Rueda ;2012) this parameter is determined for each records.

$$SF_t = \frac{T_{amp}(target)}{T_{amp}(record)}$$

Then the time intervals are multiplied by SF_t and a new time- scaled accelerogram is obtained. The Housner Intensity of each time-scaled accelerogram is calculated.

$$SI_H = \int_{0.1}^{2.5} PSV(T).dT$$

and SF_a by the equation(Martinez-Rueda; 2012):

$$SF_a = \frac{SI_H(target)}{SI_H(record)}$$

The amplitude of each time-scaled record is then multiplied by this factor and a dual-scaled accelerogram is obtained.

RESULTS

Figure 3 shows the combined(SRSS) spectra for seven pair of accelerograms , standard and

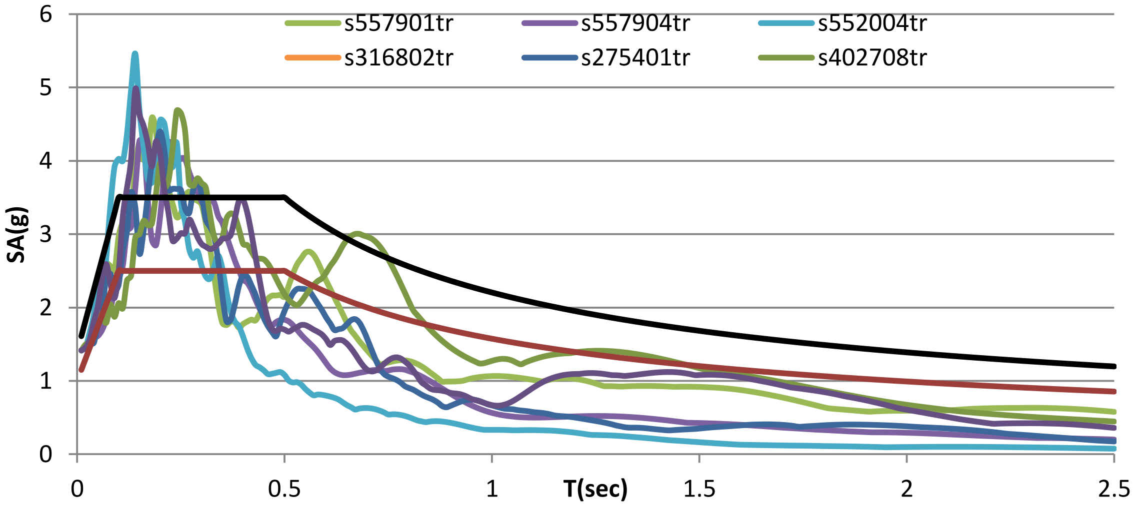
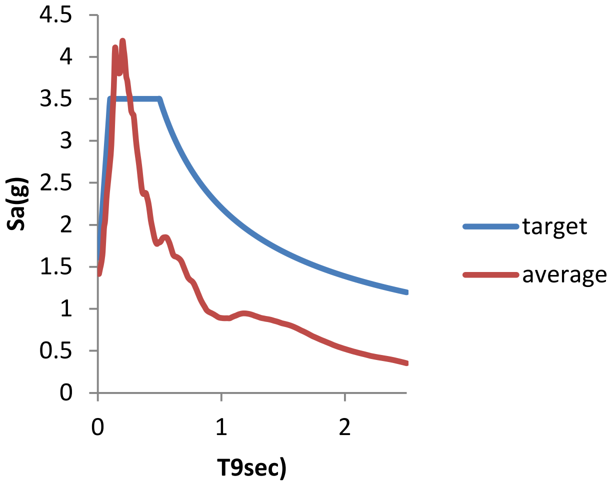
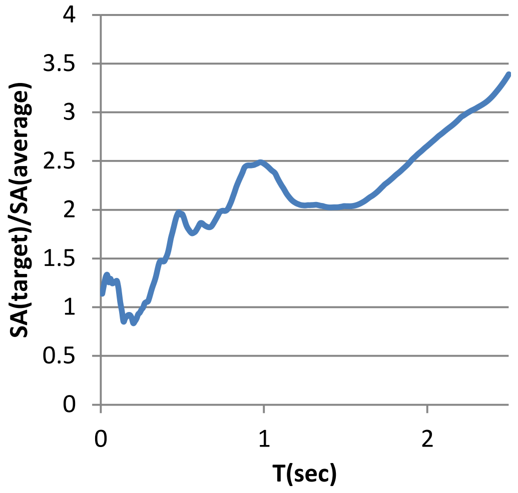


Figure 3.combined spectra of seven pair of accelerograms with standard and target spectra

1.4* standard (target) spectra. As one could mentioned the combined spectra are narrower than the target one so the criteria of dual scaling seems reasonable. Figure 4.a shows the average of the seven combined spectra and the target spectrum, and b) represent the ratio of spectral acceleration of target spectrum to the average one. The amplitude scaling factor is the maximum of this ratio over the periods 0.2T to 1.5T. By this Figure one could find the scaling factor as 1.333 for the structure with T=0.1, and 1.769 and 2.488 for structures with T=0.3 and T=1.0 respectively.



(a)



(b)

Figure 4.Amplitude scaling results: a)average of seven pairs and the target spectra b) ratio between SA of target to average spectra.

Figure 5 shows the combined spectra of the accelerograms which are scaled to accommodate a structure with T=0.1. For the range of periods between 0.02 and 0.15 sec the average spectra is over the 1.4*standard spectra. In this case multiplying the amplitude of natural records by a factor of 1.333 causes high values for SA in some accelerograms as for 5520-04.

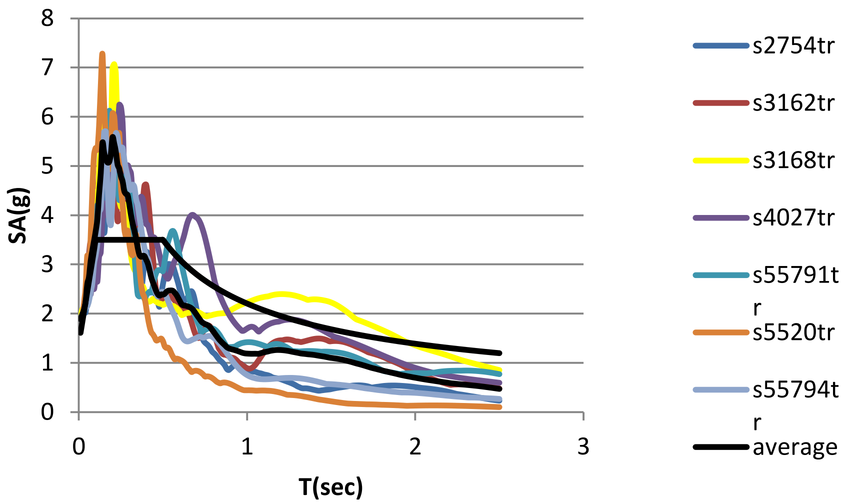


Figure5. Family of response spectra of earthquake ground motions scaled by spectral acceleration for structures with T=0.1.

Figure 6 shows the set of spectra for amplitude-scaled accelerograms with a scale factor of 2.488 which refers to a structure with T=1 sec. For these structures this high value of amplitude scale factor causes very high spectral acceleration in the structure which seems not logic.
As expected, when the records are scaled by *SA* the plots of Figure 5 and 6 shows a perfect match between the mean response spectrum and the design spectrum exactly at the two values of *T* considered in the study it means 0.1 and 1.0 sec. It is observed that this scaling criterion leads to significantly different mean response spectra depending on the structure under analysis.

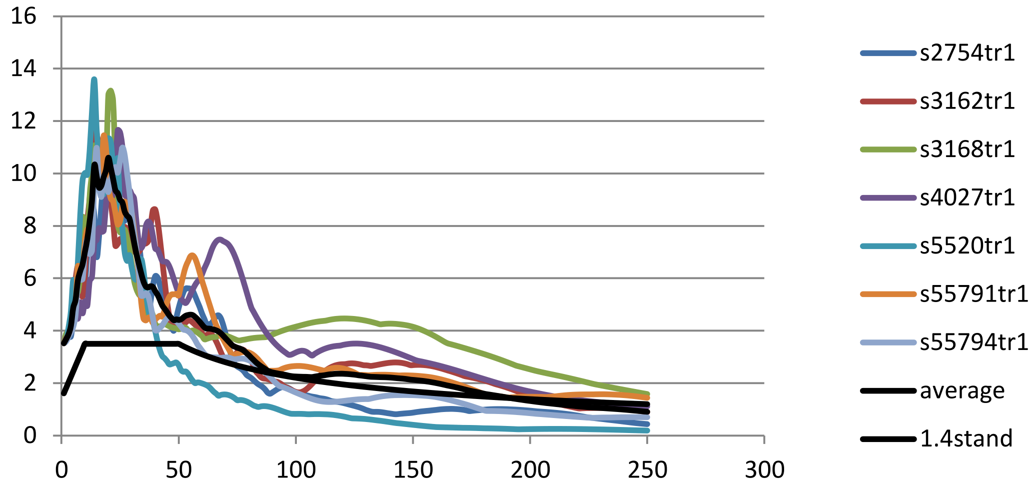


Figure6. Family of response spectra of earthquake ground motions scaled by amplitude spectral acceleration for structures with T=1.0.

Results of dual scaling are shown on figure 7. In this case the average spectrum is much wider comparing to amplitude scaling of Figure 4 and so more compatible with the target spectrum. Figure 7.b shows the ratio of SA for 1.4*standard spectrum to this value for average spectrum. one could see that the factors are smaller comparing with amplitude spectra and we expect not that high SA value in this case. For three structures under consideration, it means structures with T=0.1, 0.3 and 1.0 the scaling factor for dual scaling is 1.459, 1.459 and 1.097 respectively.

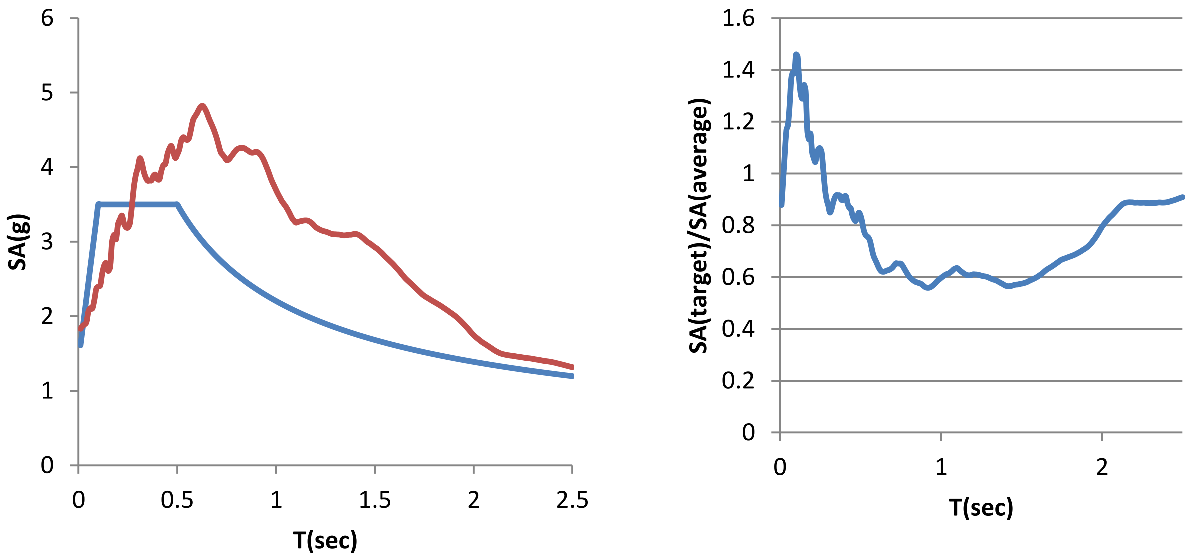


Figure 7.Dual scaling results: a)average of seven pairs and the target spectra b) ratio between SA of target to average spectra.

Figure 8 reveals that when dual scaling is adopted, both the mean response spectrum shape and the order of magnitude of its ordinates are less sensitive to the period T of the structure under analysis. It is also important to note that, in comparison with Figures 6 the goodness of fit of the mean response spectrum is largely improved. These findings suggest that dual scaling provides more stable results when compared with amplitude scaling.

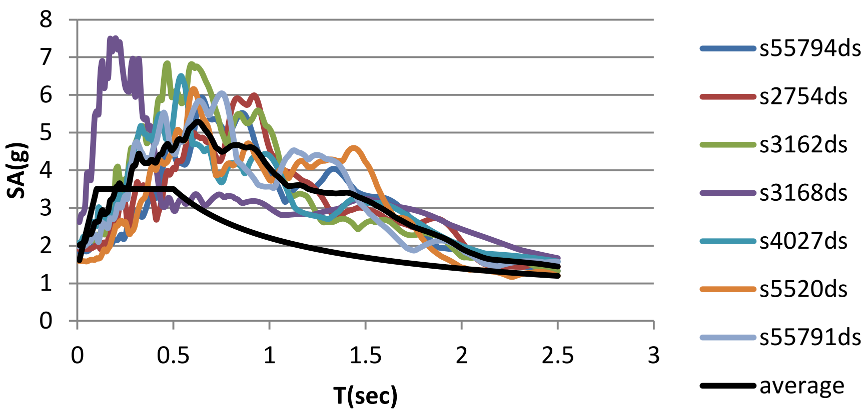


Figure 8. Family of response spectra of earthquake ground motions scaled by dual scaling for structures with T=1.0.

CONCLUSIONS

This paper has compared the method of amplitude *scaling with* dual scaling criteria for the scaling of earthquake groung motions in terms of their ability to lead to stable mean spectra shapes and realistic ductility demands. Two criteria based on amplitude scaling by spectral acceleration, and on dual scaling , both amplitude and time scaling, were first considered.

The scaling factors of the primary criteria were then further amplified to comply with the Standard (2800) constraints. This code does not permit that the mean response spectrum locates beneath the target spectrum over the period interval 0.2*T* to 1.5*T*.

In terms of the stability of the goodness of fit observed between the mean response spectrum and the design spectrum for different periods of the structure under analysis, it is concluded that the use of dual scaling offers an attractive tool to obtain sensible estimates of nonlinear inelastic time-history analysis.

For the structures and the earthquake ground motions considered in this paper, the correction of the scaling factors of the primary scaling criteria to comply with the standard 2800 constraint lead to poorer fit between the mean response spectrum and the target spectrum.

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