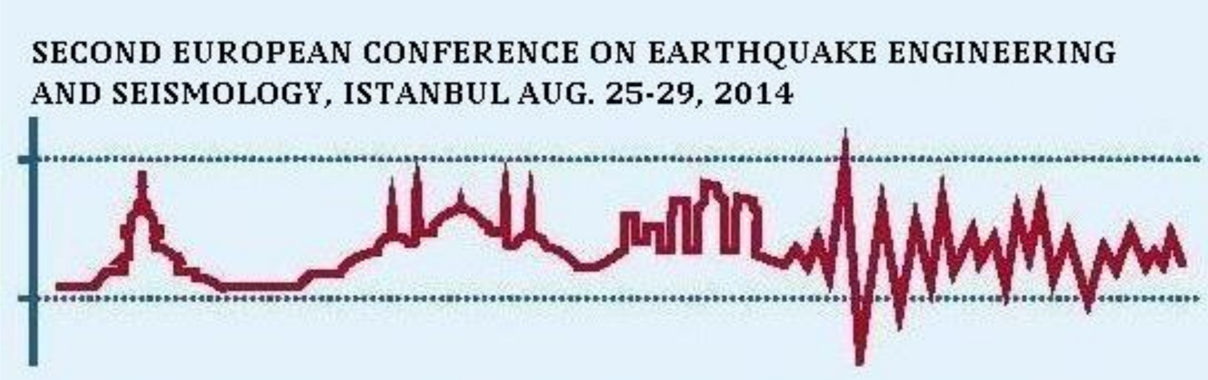

STUDY ON THE EFFECTS OF DIFFERENT METHODS FOR SELECTING ACCELEROGRAMS ON SEISMIC RESPONSE OF CONCRETE MOMENT RESISTING FRAMES

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ABSTRACT

Choosing accelerograms have always been one of the important challenges which Structural Engineers face for using in non-linear dynamic analysis for studying the performance of structures. Different methods for choosing accelerograms have been proposed till now each having its own advantages and disadvantages. In this research record selection is done by using the criteria as magnitude, site-to-source distance, soil profile, and fundamental period spectral acceleration for structure and epsilon parameter. The structures used in this research are the frames of 4 stories reinforced concrete with 20 and 30 feet bay width which are studied based on Incremental dynamic analysis method. The results show that code methods have non-conservative responses in comparison to other methods and also using scaling factors in code methods are against the safety. It is also observed that frames having space lateral load bearing system have higher resistance compared with perimeter frames against the earthquake.

INTRODUCTION

Earthquake has always been one of the most destructive natural disasters which causes lots of life and financial losses each year around the world. Today, by the progress of knowledge and science and increase in the computing power of computers, different methods are invented to analyse the power resulted from earthquake and to design the buildings against these powers. One of these methods is non-linear dynamic analysis. Non-linear time history analysis is the only analysis which can precisely predict total and local structural demand. But one of the key problems in non-linear dynamic analysis is selecting a proper seismic input, which can provide a suitable estimation of structure seismic operation, based on the seismic hazard analysis that the structure is located in it.

Since earthquake magnitude (M) and distance (R) (in km) of the rupture zone from the site of interest are the most common parameters related to a seismic event, it is evident that the simplest selection procedure involves identifying these characteristic (M, R) pairs. Shome et al. (1998) formed sets of real accelerograms in order to assess the non-linear seismic response of a five-story building.

A selection criterion complementing both earthquake magnitude and distance in the search window is the actual soil profile (S) at the site of interest, leading to (M, R, S) record sets (Youngs et al., 2006 & Kurama and Farrow 2003). The geotechnical profile is known to influence seismic motions by modifying both their amplitude and the computed response spectra. In order to introduce the soil profile into the selection process, site classification and strong-motions recording sites must be known with a high degree of confidence. Generally speaking, shear-wave velocity at the uppermost 30m

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(V_{s30}) can be used as a suitable metric for site classification, although there are cases where deeper soil structure can also exert a strong influence.

For an assessment of structural performance, the ground motion IM customarily adopted is spectral acceleration near the fundamental period of the structure with a damping ratio of 5%. It is clear that S_a is related to both structural and seismic motion characteristics; while the PGA of a record which constituted a commonly used IM in the past, accounts only for strong motion features. In principle, Sa (T_1) is an attractive intensity measure for record selection, but among records with similar values of S_a, there is significant variability in the level of structural response in a MDOF non-linear model. In order to reduce this remaining record-to-record variability to increase the accuracy and efficiency of the structural response calculations, Baker and Cornell (2005) proposed an improved IM, which besides Sa (T_1) includes the ε (epsilon) parameter associated with ground motions. This particular IM is termed vector-valued because it comprises two parameters, as opposed to the traditional scalar IMs.

Archetype moment frames

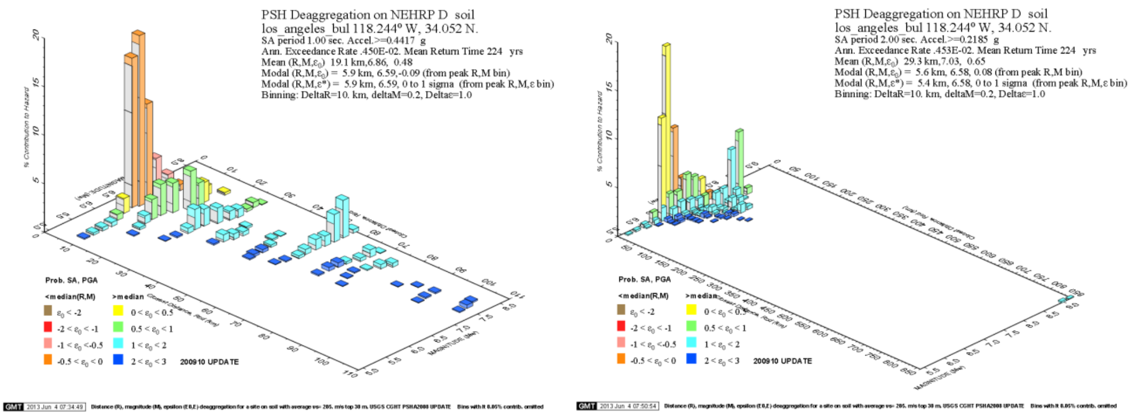
Precise modeling of structural components in addition to careful selection of ground motion records leads to better quantification of structural performance and collapse potential of structures. Therefore, a set of four story three bay reinforced concrete moment resisting frames are selected which are representatives of mid-rise structures. These frames are designed based on ACI 318-05 design code and modeled as plastic hinge model in order to capture the strength and stiffness deterioration (ACI Standard 2005). They are two dimensional, modeled with elastic elements and rotational springs at each end part of the elements as plastic hinges. The plastic hinges behave based on the model developed by Ibarra. This model contains four modes of cyclic degradation: strength deterioration of the inelastic strain hardening branch, strength deterioration of the post-peak strain softening branch, accelerated reloading stiffness deterioration and unloading stiffness deterioration (Ibara and Krawinkler 2005). The frames have the average period of 1 second and it is assumed that entering the non-linear region increases it to 2 second. Comprehensive characteristics of these frames are provided in the study by Haselton (2006) which Table.1 presents a brief description of them. All of the frames are modeled using OpenSees open source program (Opensees 2011).

Table 1. Design information of archetype frames used in this study

Design Number	Design ID Number in Haselton's study	Period (Sec)	No. of stories	Bay Width (ft)	Lateral Load Bearing System
1	1003	1.12	4	20	Perimeter
2	1004	1.11			Perimeter
3	1008	0.94			Space
4	1009	1.16		30	Perimeter
5	1010	0.86			Space

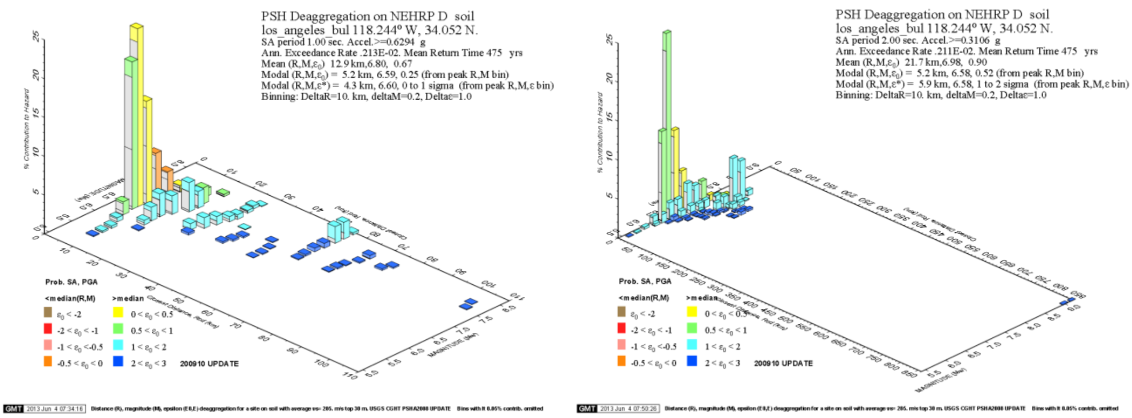
Disaggregation Analysis

This section describes how we can choose an appropriate value for epsilon in order to consider this parameter in the record selection process. Generally, earthquake hazard consists of different faults in the region and broad range of probable events. Therefore, disaggregation analysis utilizes Bayes' rule in order to incorporate all seismic sources of the region which leads to presenting particular contribution scenarios for a specific hazard level. One of the outputs of this analysis is a mean value for epsilon. There are two approaches for conducting this analysis with just slight differences. First approach which is developed by Bazzurro and Cornell (1999) disaggregates the hazard in a way that the S_a exceeding the S_a level of interest (i.e. $S_a \geq S_{a0}$). McGuire (1995) proposed the second approach which is conditioned on the S_a being equal to the S_a level of interest (i.e. $S_a = S_{a0}$). This study uses the USGS (2008) online tool which is based on McGuire's approach for performing disaggregation analysis. Results of this analysis is usually illustrated in 4D plots. Disaggregation analysis has been conducted in this study for Los Angeles Bulk Mail site with geographic coordination of (Latitude/Longitude=34.052°/-118.244°), mean shear wave velocity V_{s30}=285 m/s (soil type D based on NEHRP). 4D results are illustrated in Figs 2, 3 and 4. As this study tries to investigate the effect of spectral shape, disaggregation analyses have been conducted for three hazard levels of 224, 475 and 2475 years.



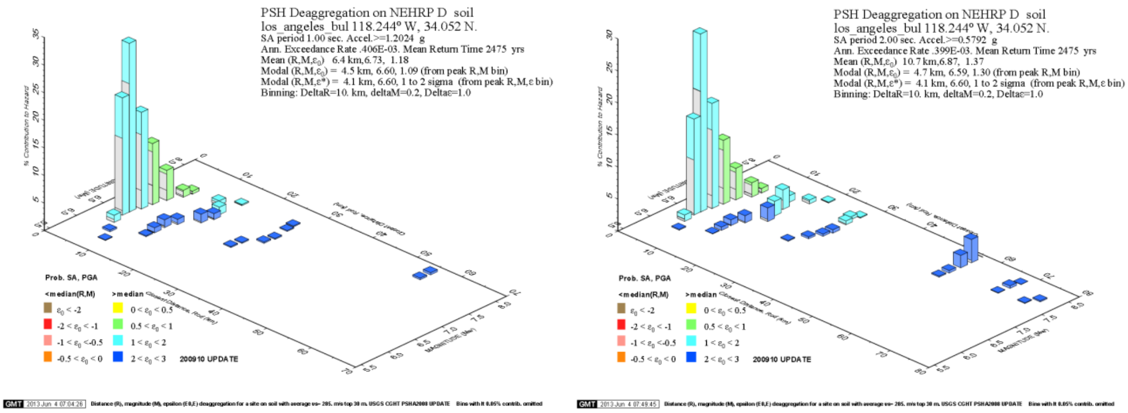
(a) (b)

Figure 1. Disaggregation analysis for 224 year hazard level (a) Period=1 sec. (b) Period=2 sec



(a) (b)

Figure 2. Disaggregation analysis for 475 year hazard level (a) Period=1 sec. (b) Period=2 sec



(a) (b)

Figure 3. Disaggregation analysis for 2475 year hazard level (a) Period=1sec. (b) Period=2sec

Methods of selecting accelerograms

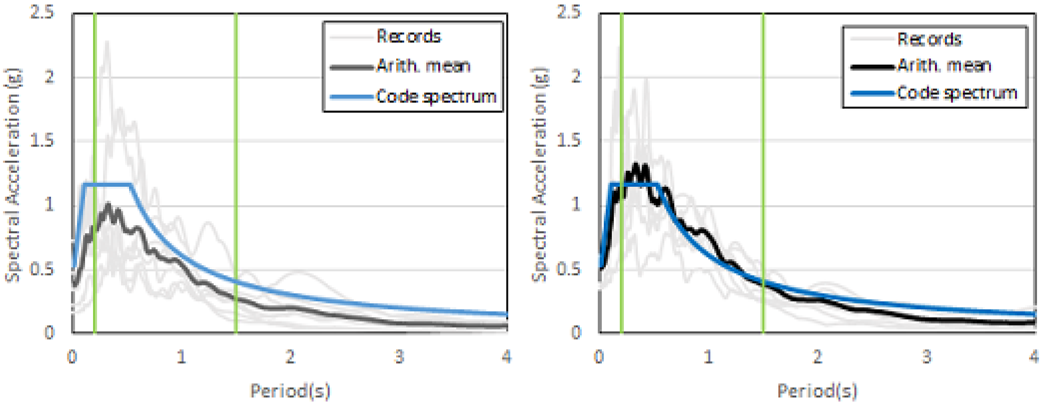
In this research, 6 methods of selecting accelerogram is investigated and compared. In the first method, selection is based on earthquake magnitude, site-to-source distance, soil profile and epsilon parameter associated with period at one second.

In the second method instead of epsilon at one second, the amount of epsilon is associated with periods at one and two seconds. The reason is that when the structure enters the non-linear step, the first-mode period increases by member yield and the spectrum acceleration in periods greater than the period in the first-mode will get importance. Because of this, in the researches done by Haselton (2006), Baker and Cornell (2006), the epsilon parameter is investigated in a period twice the primary amount of the fundamental period of structure.

In third method, selection is based on earthquake magnitude, site-to-source distance, soil profile and rupture mechanism. And it was tried to select the accelerograms in a way that it has the most compatibility with the code target spectrum. Here it is needed to mention the considered Code for calculating the design spectrum is ASCE-07.

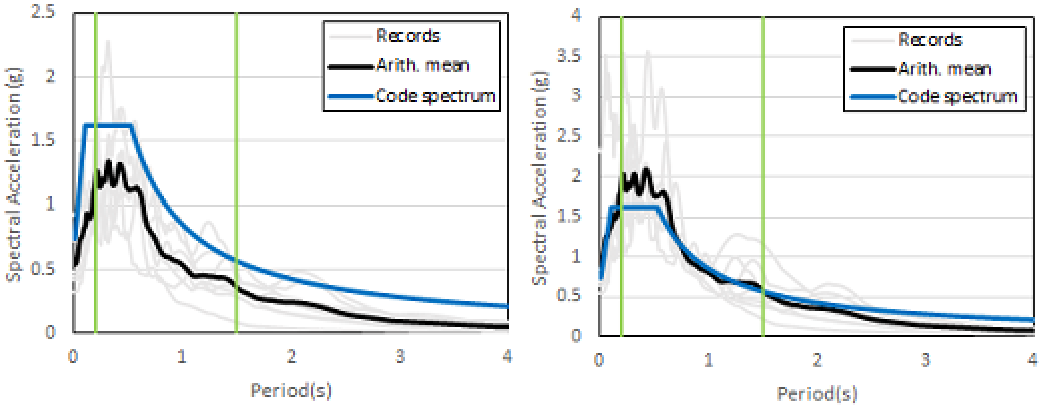
In fourth method, the selection parameters are the same as the parameters in third method with a difference that in fourth method, the code scaling method is used in order to better matching with the code target spectrum.

Looking at Fig.4 to Fig.6, it can be understood to what extend the scaling of accelerograms have been effective and have caused a better matching of average spectrum of each set with code target spectrum. As it is shown in these figures, the more the return period of earthquake increases, the more the distance of average spectrum of the set from code target will increase as well. The reason is that finding such earthquakes with such spectral acceleration amounts becomes more limited and difficult.



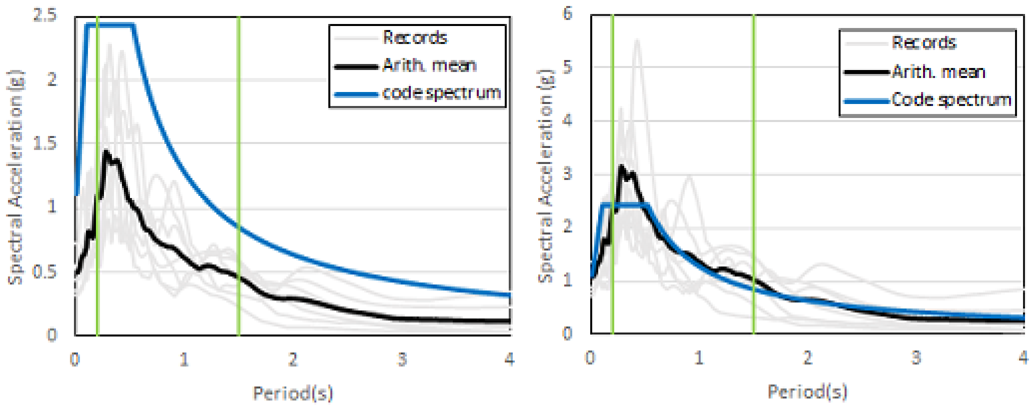
(a) (b)

Figure 4. Accelerogram spectrum along with the average spectrum and Code Target Spectrum with 224years return period (a) before scaling (b) after scaling



(a) (b)

Figure 5. Accelerogram spectrum along with the average spectrum and Code Target Spectrum with 475years return period (a) before scaling (b) after scaling



(a) (b)

Figure 6. Accelerogram spectrum along with the average spectrum and Code Target Spectrum with 2475years return period (a) before scaling (b) after scaling

It should be considered that 475years spectrum is the same as ASCE-07 code design spectrum. About 2475 years' spectrum, code maximum spectrum is considered. According to the explanations provided by this code, the maximum spectrum is considered 1.5 times larger than 475years design spectrum. In order to calculate the code spectrum related to 224years return period, the procedure becomes more complicated. According to the explanations in 1.6.1.3.2 section of ASCE 41-06 code, for events with occurrence probability greater than 10% in 50 years (475 years return period) when spectral response acceleration parameter in low periods belongs to the area larger than 1.5, the amounts of response acceleration parameters should be revised by Eq.(1).

$$S_i = S_{i10/50}\left(P_R / 475 \right)^n \tag{1}$$

In above relation, P_R is the return period of the earthquake under study, $S_{i10/50}$ is the amount of correspondent spectral acceleration with 475years return period and n is the exponent obtained from Table.2 (Table 3.1 of ASCE 41-06 code).

Table 2. Amounts of n for determining the response acceleration parameters in events by occurrence probability greater than 10% in 50years.

area	n	
	S_S	S_1
California	0.44	0.44
Pacific Northwest	0.89	0.96
Intermountain	0.54	0.59
Central U.S.	0.89	0.89
Eastern U.S.	1.25	1.25

As far as the area under study is located in California, so the amount for n will be 0.44. By putting this amount in Eq.(1) the factor will be 0.718 which is in fact the result of dividing 224years code spectrum into 475years design code spectrum.

In fifth method, beside the considered parameters in third method, a ±50% dispersion criterion is considered around the code target spectrum and it was tried to select the accelerograms in a way that they would be placed in this area.

In sixth method, offered by Riahi and Estekanchi (2007) known as the Minimization Method, the primary selection was done based on earthquake magnitude, site-to-source distance, soil profile and rupture mechanism. In the next step, a set consisting of 20 best accelerograms matching the code target spectrum~~,~~ and scaling factor amounts for each of these spectrums were separately calculated in a way that F becomes minimum in Eq.(2).

$$\min F = \sqrt{\frac{\sum_{T_{min}}^{T_{max}} \left[SF \times RS(t_i) - TRS(t_i) \right]^2}{n}} \tag{2}$$

In the above equation, SF is scaling factor, RS (t_i) is the amount of spectral response acceleration in different periods, TRS (t_i) is the amount of spectral acceleration resulted from code target spectrum in different periods and n is the number of considered time steps.

Then, from these accelerograms, seven accelerograms which have scaling factor between 0.5 and 2.5 were selected and in the last step, it was tried to minimize the distance between target spectrum and mean spectrum of these 7 accelerograms. Therefore, the new scaling factors were considered as the final scaling factors.

Because a wide range of scale factors make problems in non-linear dynamic analysis, a limitation for the values of scale factors between 0.5 and 2.5 is considered. Luco and Bazzurro (2004) showed that depending on the vibration period and strength of the SDOF structure, scaling earthquake records up and down can result in non-linear structural responses that are biased high. The magnitude of this bias depends on the value of scale factor. It also depends on the characteristics (e.g. M_w and R_{close}) of the earthquake records that are scaled.

Comparison of results

The amounts of response acceleration and peak drift of all stories corresponding with mean spectral acceleration and code spectral acceleration were resulted. Comparison of the resulted amounts of these six methods is represented as diagrams in Fig.7 and Fig.8 for return period of 224 years.

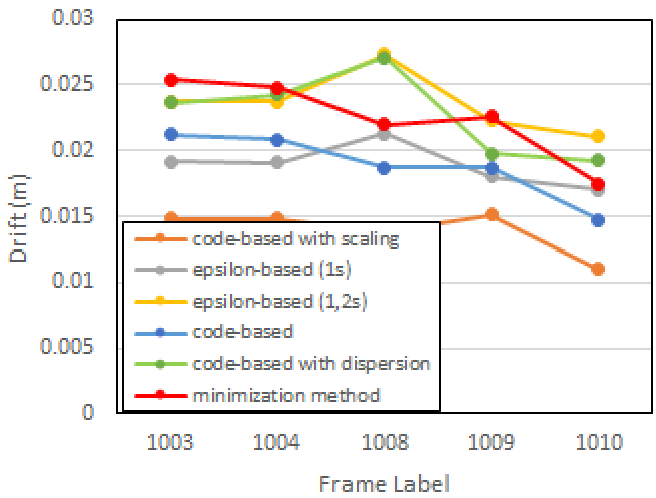


Figure 7. Distribution of peak drift amounts for different frames corresponding with mean spectral acceleration

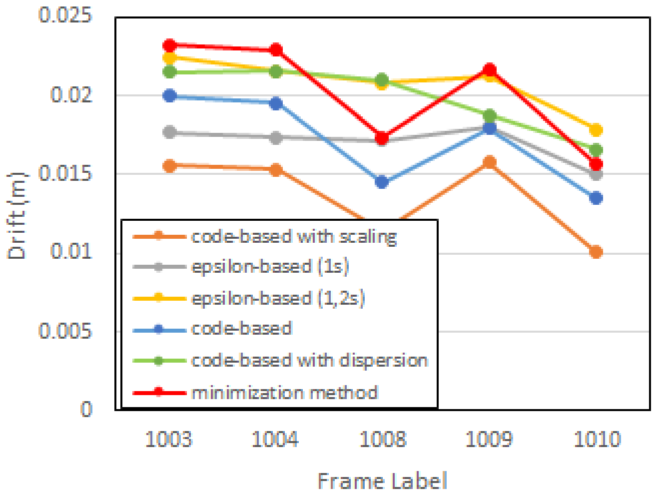
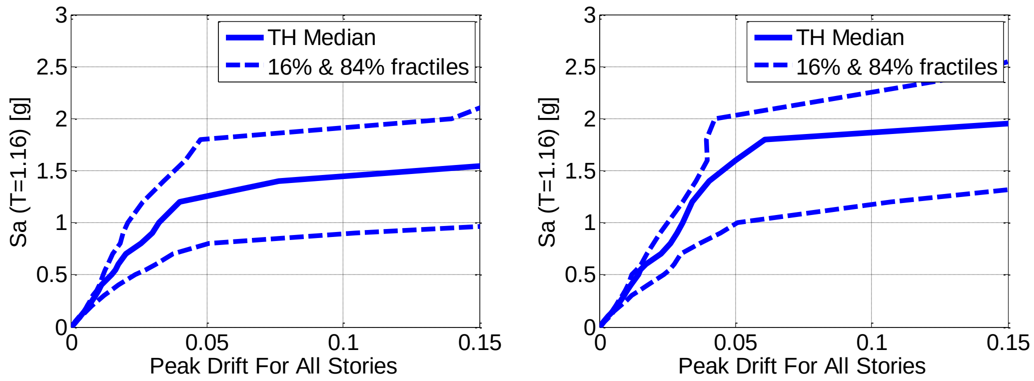


Figure 8. Distribution of peak drift amounts for different frames corresponding with code spectral acceleration

As it is shown in Fig.7 and Fig.8 minimization method has the most drift. Selection method corresponding with one and two seconds' epsilon is placed after it and the selection method with dispersion criterion is placed at the end. The notable point in this problem is that all applied methods have the higher response amount from the code methods. This indicates the non-conservativeness of code methods.

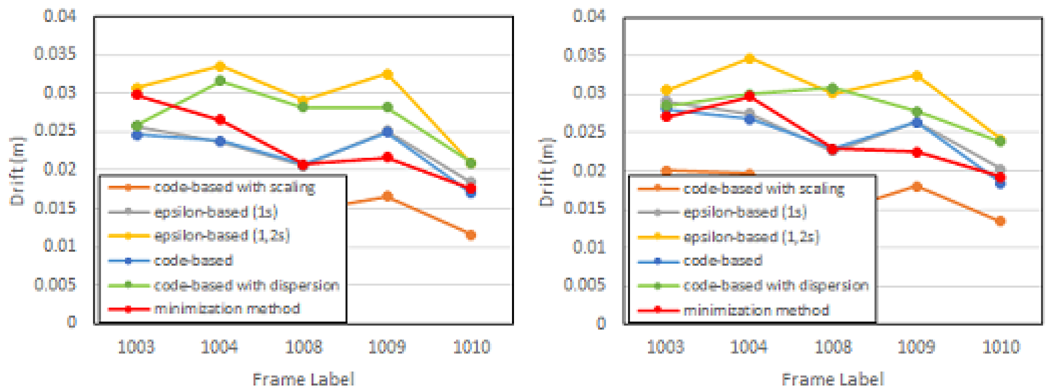
Also as it is shown in Fig.7 and Fig.8, using scaling factors in Code method causes the lowering of response amounts in comparison with the non-scaling method. This means that using scaling factors in code method is counter-direction of certainty. This procedure is also exactly considered about the earthquakes with return period of 475 years and 2475 years. Figures are shown in below. The only difference between average amounts in Fig.8 and code amounts in Fig.7 is that non-scaling code method is placed lower in comparison with the selection method based on the epsilon of one second in 1009 frame. The reason of this is clarified in Fig.9. As it is shown in spectral acceleration 0.549g the amount of drift of the second method is more but by decreasing spectral acceleration to Code amount (Spectral acceleration is 0.527g), drift amount decreases in this frame and finally results in placing the Code method diagram in comparison to the correspondence with one second method, because the slope of the code diagram is steeper and also in correspondence with one second epsilon method, there is concavity at this point.



(a) (b)

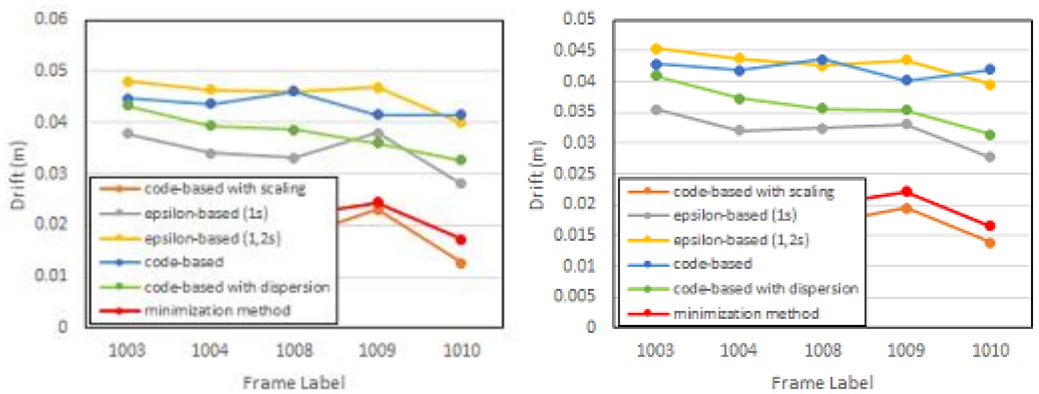
Figure 9. The median of the earthquake response curve for 1009 frame (a) selection based on one second epsilon (b) selection based on non-scaling Code method

Now, if the diagrams are drawn for drift amounts for return periods of 475 years and 2475 years, it can be seen that in these figures Code method along with scaling has the lowest response which as mentioned, this implies the non-conservativeness of code scaling methods. Also in Fig.7, 8, 10 & 11 it is shown that the method correspondent with one and two second epsilon has higher responses in comparison to one second epsilon; so considering the one second epsilon will be non-conservative.



(a) (b)

Figure 10. Distribution of peak drift amounts for different frames correspondent with (a) mean spectral acceleration (b) code spectral acceleration for return period of 475 years

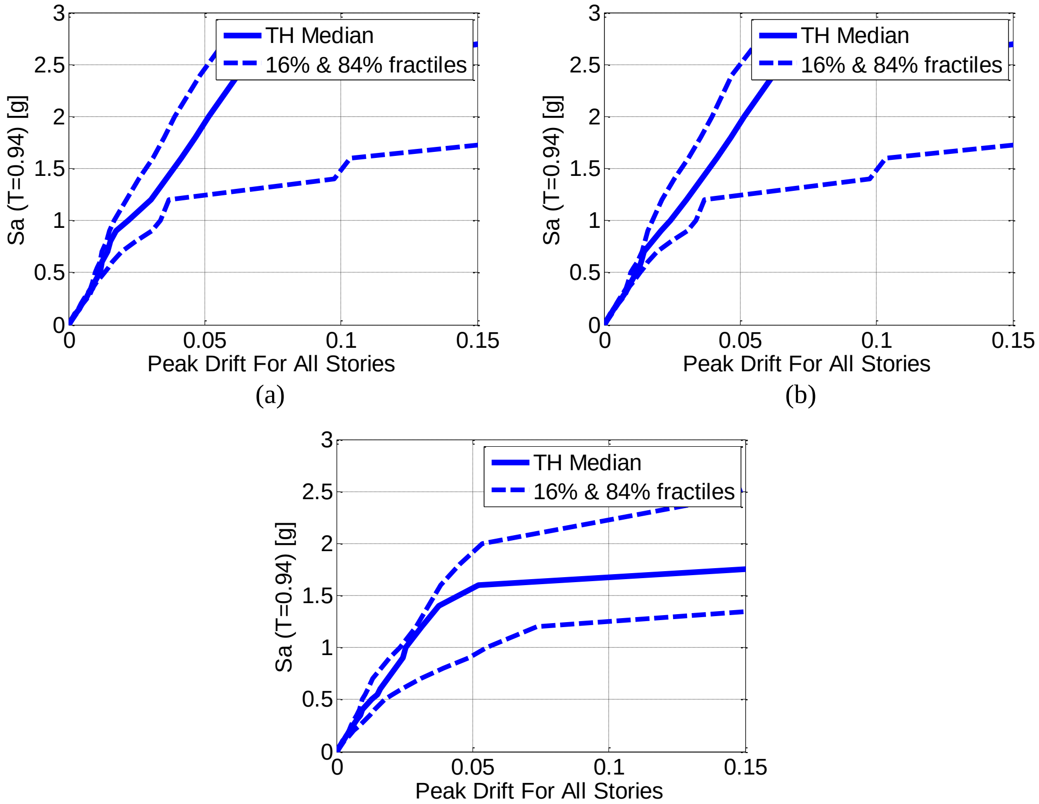


(a) (b)

Figure 11. Distribution of peak drift amounts for different frames correspondent with (a) mean spectral acceleration (b) code spectral acceleration for return period of 2475 years

By observing the figures relative to the distribution of drift amounts for different frames in three investigated return periods, another interesting point is also perceived and this point is that drift amount of 1008 frame is lower in comparison to the 1003 and 1004 frames which have equal bay width. In fact this is because of the more resistance of space system compared with the perimeter system against lateral loads. This procedure is also repeated in frames with the same bay width 1009 and 1010 which have perimeter lateral load bearing system and space lateral load bearing system respectively.

The 1008 frame compared with 1003 and 1004 frames has a higher relative displacement only in a number of cases; the same as what is observed for non-scaling code selection method in Fig.11, the reason of it is understood in Fig.12. In Fig.12, the median of response curve related to non-scaling code method is drawn for three risk levels of 224 years, 475 years and 2475 years. In Fig.12.a, the diagram has a steep slope in acceleration range of 0.65g – 0.8g and this also exists in Fig.12.b in acceleration range of 0.85g-0.9g; but in Fig.12.c, the diagram has a low slope in acceleration range of 1.35g-1.46g. This procedure has caused to have a large increase in relative displacement when having a little increase in spectral acceleration and this case has caused the more relative displacement of 1008 frame in return period of 2475 years compared with 1003 and 1004 frames.



(a) (b) (c)

Figure 12. The median of earthquake response curve for 1008 frame for 3 return periods (a) 224 years, (b) 475 years and (c) 2475 years based on non-scaling code selection method

CONCLUSIONS

In this research record selection is done by using the criteria as magnitude, site-to-source distance, soil profile, Code design spectrum, fundamental period spectral acceleration for structure and epsilon parameter. Here, there is a limitation for the values of scale factors between 0.5 and 2.5, because a wide range of scale factors make problems in non-linear dynamic analysis. Depending on the vibration period and strength of the SDOF structure, scaling earthquake records up and down can result in non-linear structural responses that are biased high. The magnitude of this bias depends on the value of scale factor. It also depends on the characteristics (e.g. M_w and R_{close}) of the earthquake records that are scaled. The structures used in this research are the frames of 4 stories reinforced concrete with 20 and 30 feet bay width which are studied based on Incremental dynamic analysis method. The results show that Code methods have non-conservative responses in comparison to other methods and also using scaling factors in Code methods are against the safety. It is also observed that frames having space lateral load bearing system have higher resistance compared with perimeter frames against the earthquake.

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