EVALUATION OF THE EFFICIENCY OF GROUND MOTION SELECTION METHODS IN ASSESSMENT OFTHE SEISMIC DEMANDS WITH SIGNIFICANT HIGHER MODE EFFECTS

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ABSTRACT

An important step for the Nonlinear Time History Analysis (NLTHA) of structures is to select a reliable set of ground motions. An effective selection can reduce the possible scatter in the results due to the intrinsic uncertainties of recorded Strong Ground Motions (SGMs). Following the described purpose to achieve a more reliable estimation of the seismic behaviour of structures; Different SGM selection and modification methods have been proposed.

In this paper the "structure-specific" selection, is evaluated quantitatively. Two proposed selection methods based on the spectral shape and the ability of reliable prediction of dynamic collapse capacity of group structures are chosen and the sensitivity of response characteristics to the selected SGMs in case of MDOF systems is investigated.

Selection methods are based on some simplifying assumptions that may not be true in case of complex structures. Also, most of proposed selection and scaling methods are claimed to be efficient in case of building structures, while many researchers in the field of earthquake engineering are interested in the seismic evaluation of soil systems or special non-typical structures. MDOF systems including a 3-story steel frame, a 12-story steel frame and two typical soil profiles are modelled. The features of frames and soil profiles are selected such that the efficiency of methods can be compared both for "soft" and "stiff" dynamic systems.

The results show that when the selection method consider only the spectral shape at the first mode of vibration, significant reduction in the reliability of EDPs is possible. To resolve the mentioned problem it is suggested that new scaling and selecting methods be designed in which the role of higher modes of vibration and more complex mechanisms of failure as a part of selection problem is considered.

INTRODUCTION

First step in the Nonlinear Time History Analysis (NLTHA) of structures is to select a reliable set of ground motions (Ghafory-Ashtiany et al., 2012). In probabilistic seismic demand analysis of structures based on the Pacific Earthquake Engineering Research (PEER) centre framework, one of the key points to ensure the reliability of results is to reduce the dispersion in calculated Engineering Demand Parameters (EDPs). An effective selection can reduce the possible scatter in the results due to the intrinsic uncertainties of recorded Strong Ground Motions (SGMs).

Different SGM selection and modification methods have been proposed (Haselton et al., 2009). Some traditional approaches such as "site-specific" methods, suggest the application of seismological criteria to determine appropriate ground motions. Code-based procedures highlight the spectral compatibility with the Uniform Hazard Spectrum (UHS). Successful scaling or structure-specific selection is directly related to the application of best possible Intensity Measure (IM) which shows an acceptable correlation with the target EDPs. There is a variety of proposed modern IMs to increase the reliability in the response estimation process (Ghafory-Ashtiany et al., 2012).

It is observed that the spectral shape corresponding to the ground motion has a significant role in the seismic behaviour of dynamic systems under ground motion excitation (Baker and Cornell, 2005). To quantify the concept of the spectral shape, the epsilon (ε), introduced by Eq.(1), for the (pseudo) spectral acceleration at the natural period of structure and a specific damping ratio e.g. Sa(T1,5%) is selected. Epsilon measures the deviation of Sa(T1,5%) for a ground motion from the geometric mean Sa(T1,5%) computed from a ground motion prediction equation. In other words, it is defined as the difference between the natural logarithms of two Sa(T1,5%) normalized by the standard deviation obtained from an attenuation relationship.

$$\varepsilon = \frac{\ln Sa_{Mean} - \ln Sa}{\sigma_{\ln Sa}} \tag{1}$$

Baker and Cornell have shown that different epsilon values, as a proxy over average spectral shape, can cause different inelastic structural response (Ghafory-Ashtiany et al., 2012). This advantage of epsilon and the acceptable correlation with the structural response is used for structure-specific ground motion selection (Baker, 2011). Recently, it is shown that a small number of subsets of SGMs can be selected from a general set of SGMR's such that each can predict the nonlinear response of a particular group of structures, i.e. of SDOF systems representing a typical behavior (Ghafory-Ashtiany et al., 2011).

In the next sections, after a brief description of the mentioned selection methods, we compare the efficiency of methods in case of some MDOF nonlinear systems.

SELECTION METHODS

As it is mentioned in the introduction, two structure-specific ground motion selection methodologies are selected for more investigation:

EPSILON-BASED SELECTION (BAKER, 2011)

The method is based on the calculation of conditional mean spectrum (CMS) for a target seismic scenario i.e. the target magnitude, soil type, distance and epsilon. The main steps of selection process are:

- Specify a target scenario. In this paper, a typical sever event, which is originally introduced. by (Ghafory-Ashtiany , 2011), is selected. The moment magnitude, closest distance to the rupture and shear wave velocity at the site are 7, 10 and 360m/s respectively. To compute the epsilon values a new world wide ground motion prediction equation for shallow crustal events is used (Arian Moghaddam et al. 2015). The target epsilon value in each case is assumed equal to the mean prediction corresponding to the first modal period of MDOF system.
- Compute the CMS spectrum and find proposed ground motions with the best spectral compatibility. In this step, the PEER NGA selection engine is used.
- Check the seismological features of selected SGMs and select the final 8 ground motions.

Record selection for group-structures (Ghafory-Ashtiany et al.,2011)

The goal of this approach is to select from a general databank of SGMR's, a limited number of SGM subsets such that each can be used for the reliable prediction of nonlinear response of a particular group of structures. Fig.1 depicts the general scheme of proposed method, while readers can refer to (GhaforyAshtiany et al.,2011) for more detailed information.

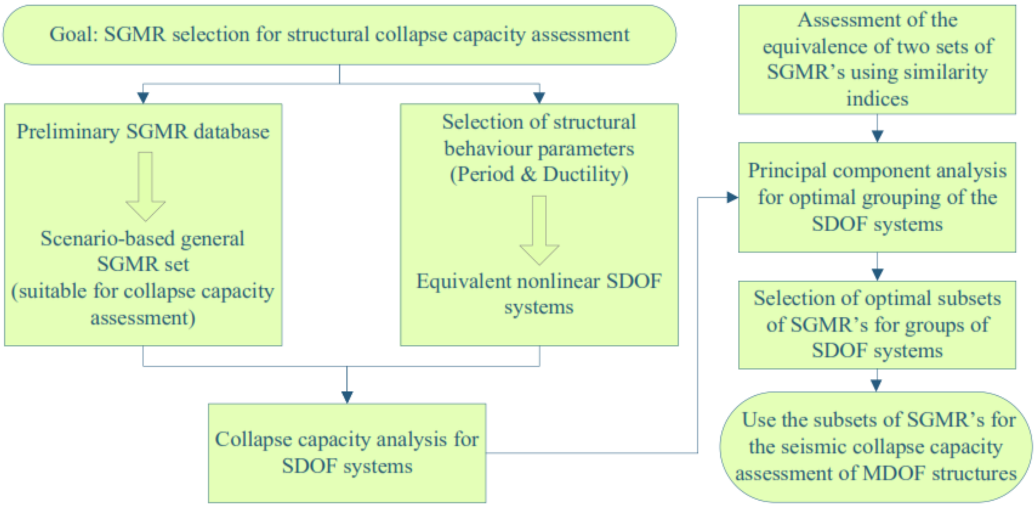

Figure 1. Schematic steps of record selection for group-structures (Ghafory-Ashtiany et al.,2011)

MDOF SYSTEMS

To investigate the efficiency of the selection methods in case of MDOF systems, two 2-D steel moment resistant frames (MRF) are modelled in OpenSees finite element program(Mazzoni ET AL., 2006) : a 3-story frame representing structures with short period of vibration and another 12-story frame as the representative of flexible long period structures. These frames are selected from a large database of structural systems introduced in (Dimopoulos et al., 2011), which are originally used to predict the structural displacements under seismic excitation. Gravity load on the beams equal to 27.5kN/m (dead plus live loads) is considered. To investigate more complex systems, two typical soil profiles are modelled using the software SHAKE (Schnabel et al., 1972). The behaviour of soil profiles can be affected by the contribution of several modes all in elastic range. Also, the profile can experience high level of nonlinearity due to the sever induced strains at different height levels. Table1 presents general characteristics of MDOF models, while the details of soft soil profiles are depicted in Fig.2 and 3. The general characteristics of soil and structures are changed such that the first modal period of vibration approximately equals to that of 12-story frame. The same conditions are assumed for stiff soil profile and the 3-story frame.

METHODOLOGY

"First set" of ground motions (F1 to F8) consists of 8 accelerograms proposed by (GhaforyAshtiany et al.,2011) and the "Second set" are 8 accelerograms (S1 to S8) as the output of an epsilon-based selection using the PEER NGA search engine. Incremental dynamic analyses (IDA) are carried out to compare the ability of the selection methods in prediction of the seismic behavior of steel frames.

Intensity levels are controlled at each step by scaling up the spectral response at first mode of vibration Sa(T1,5%) to a predefined value. Scale factor is increased using 0.05g steps until the maximum Inter-Story Drift Ratio (IDR) of 0.2 is observed or structural instability occurs.

Table 1. characteristics of structural models

story	bay	Column: (IPB) - Beams: (IPE)	Period(sec)		
			mode 1	mode2	mode3
3	3	260-330(1-3)	0.37	0.23	0.07
12	3	450-360(1)+450-400(2-3)+450-450(4-5)+400-450(6-7)+360-400(8-9) +360-360(10)+ 360-330(11-12)	1.15	0.42	0.24

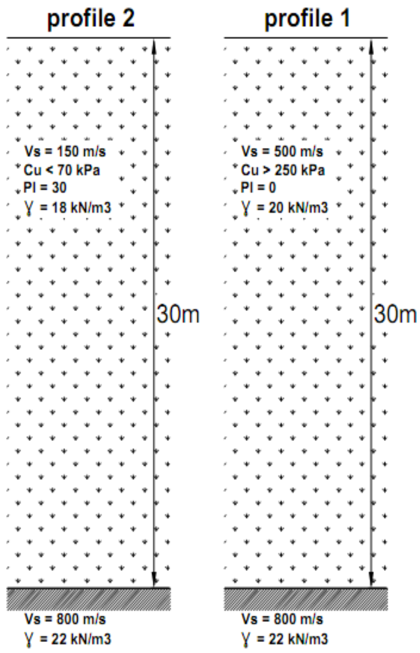

Figure 2. Typical Soil profiles: soft soil (left) and stiff soil (right) (Schnabel et al.,1972)

For two soil profiles, peak acceleration, velocity and displacement at the top of profile is recorded under seismic excitation by selected SGMs, which are denoted as Acc, Vel and Disp, respectively. It is worth noting that the efficiency of methods are defined as the lower dispersion in the results, while the deviation of EDPs from exact values cannot be measured unless a comprehensive Response History Analysis (RHA) is done using a large dataset of SGMs. Therefore, to compare the statistical dispersion in the results the Coefficient of Variation (C.O.V) is used. Eq.2 presents the definition of C.O.V:

$$C.O.V = \frac{EDP_{Mean}}{\sigma_{EDP}} \qquad (2)$$

In case of IDA results, the C.O.V for the Sa(T1,5%) at the IDR corresponding to the collapse(in this study IDR_{Max} equal to 0.05 is selected) is reported.

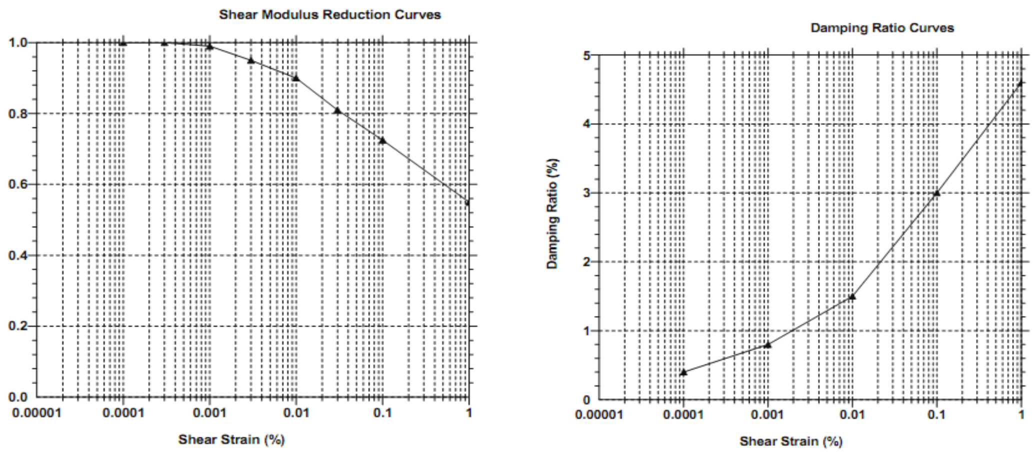

Figure 3. Nonlinear behaviour assumed for stiff soil (Schnabel et al.,1972)

RESULTS

The results of IDA analyses are depicted in Fig.4 for 3-story steel MRF and Fig.5 for 12-story steel MRF. IDA curves in Figures have been normalized to a target value computed from a design response spectrum (Iranian Code of Practice for Seismic Resistant Design of Buildings, standard no. 2800, third edition). Target Sa(T1,5%) is computed based on the selected scenario for epsilon-based selection.

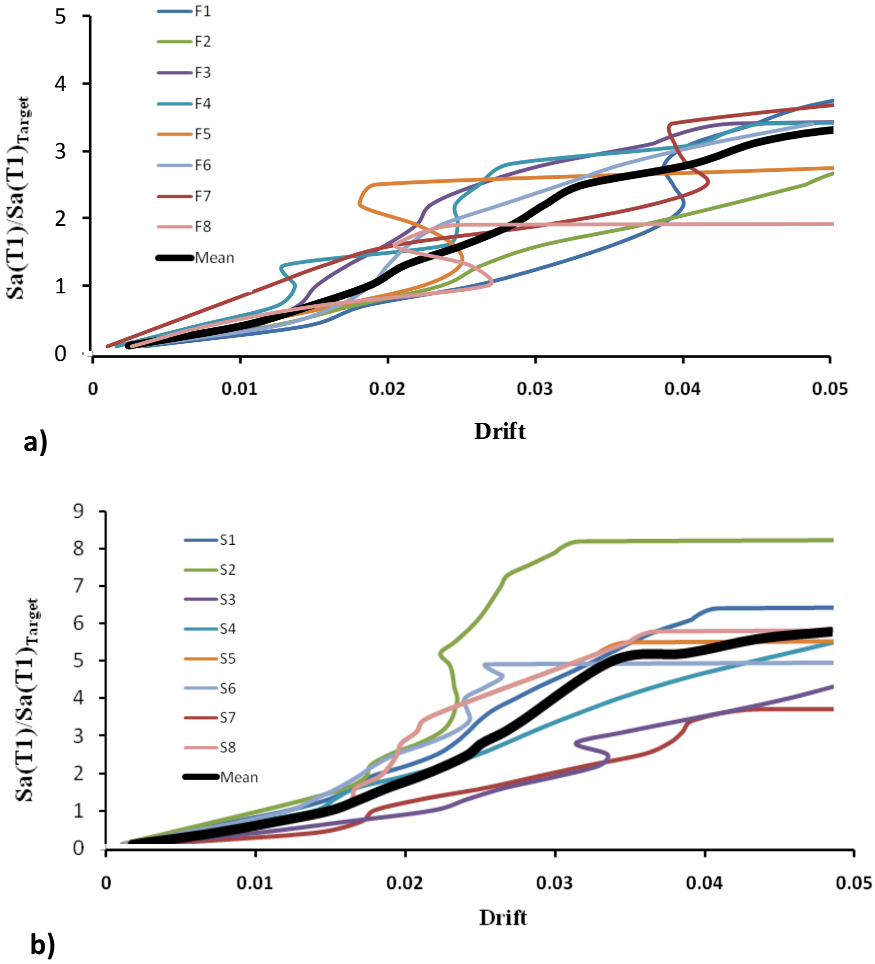

Figure 4. IDA curves for 3-story steel frame: a) First set of SGMs (Group of structures) and b) Second set of SGMs (ε-Based)

It should be noted that for NLTHA of soil profiles, the selected SGMs in both methods are scaled to these target Sa(T1,5%) values. Fig.6 and Fig.7 summarize the computed EDPs at the top of soil profiles. The original values are normalised to the target spectral responses. In other words, figures present maximum top acceleration divided by $Sa(T1,5\%)_{Target}$, maximum velocity divided by $SV(T1,5\%)_{Mean}$ and maximum displacement divided by $SD(T1,5\%)_{Mean}$, while SV and SD are the mean spectral velocity and displacement computed over all 16 SGMs.

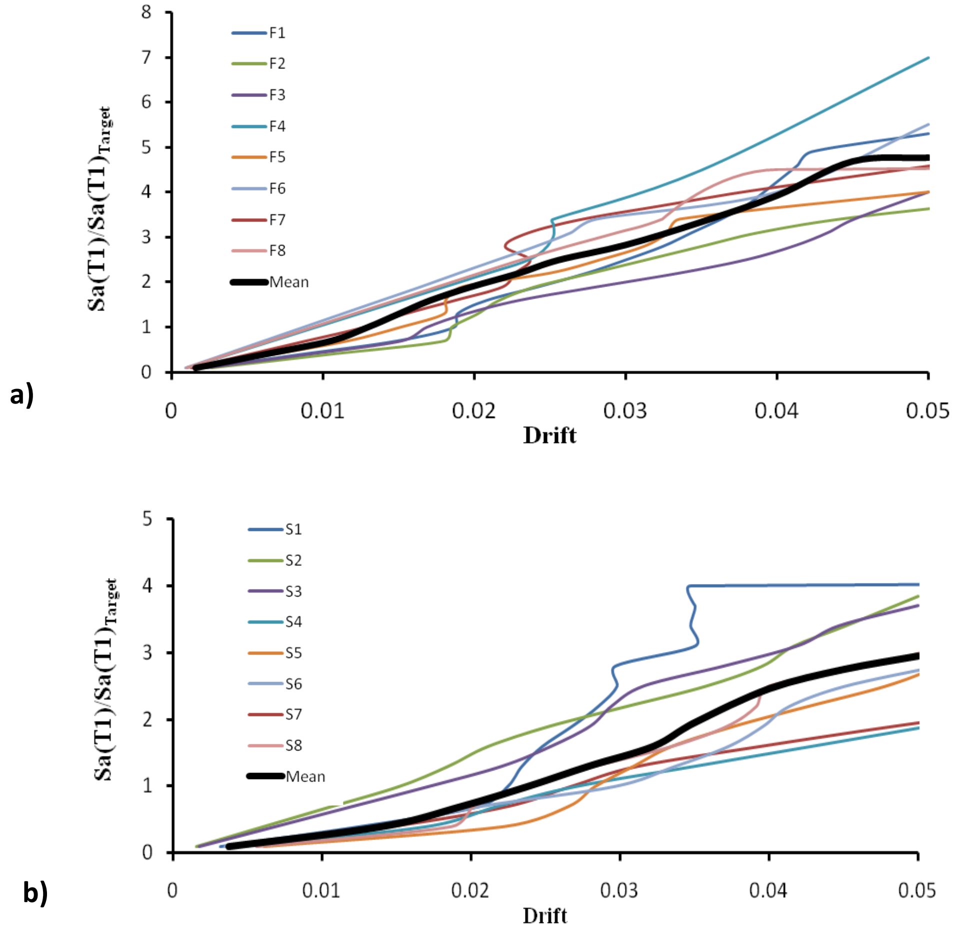

Figure 5. IDA curves for 12-story steel frame: a) ε-Based SGMs and b) SGMs for group of structures

According to figure Fig. 4 and Fig. 5, variation in the IDA curves at lower IDRs corresponding to the elastic behaviour of frames can be contributed to the effect of higher modes of vibration. This trend is more sever for 3-story frame which the second modal period is more close to the first one. For both 3 and 12-story frames, epsilon-based selection estimates a lower mean IDA curve while the trend is more sever at the higher IDR values. However, the deviation of EDPs from exact values cannot be measured unless a comprehensive Response History Analysis (RHA) is done using a large dataset of SGMs. As it is clear inFig.7, The efficiency of both methods in the estimation of top displacements for soil profiles is reduced dramatically. It can be understood from large C.O.V values that the behaviour of a displacement-control soil system cannot easily be approximated by regular patterns obtained for building structures.

In the case of steel frames, selection process based on the spectral shape in term of epsilon yields more dispersion in the IDA results. The results of NLTHA for stiff soil profile are in general agreement with the results of IDA curves. In other words, the record selection for the group of structures can still yield more reliable results, while the mean values of EDPs are greater than epsilon-based SGMs.

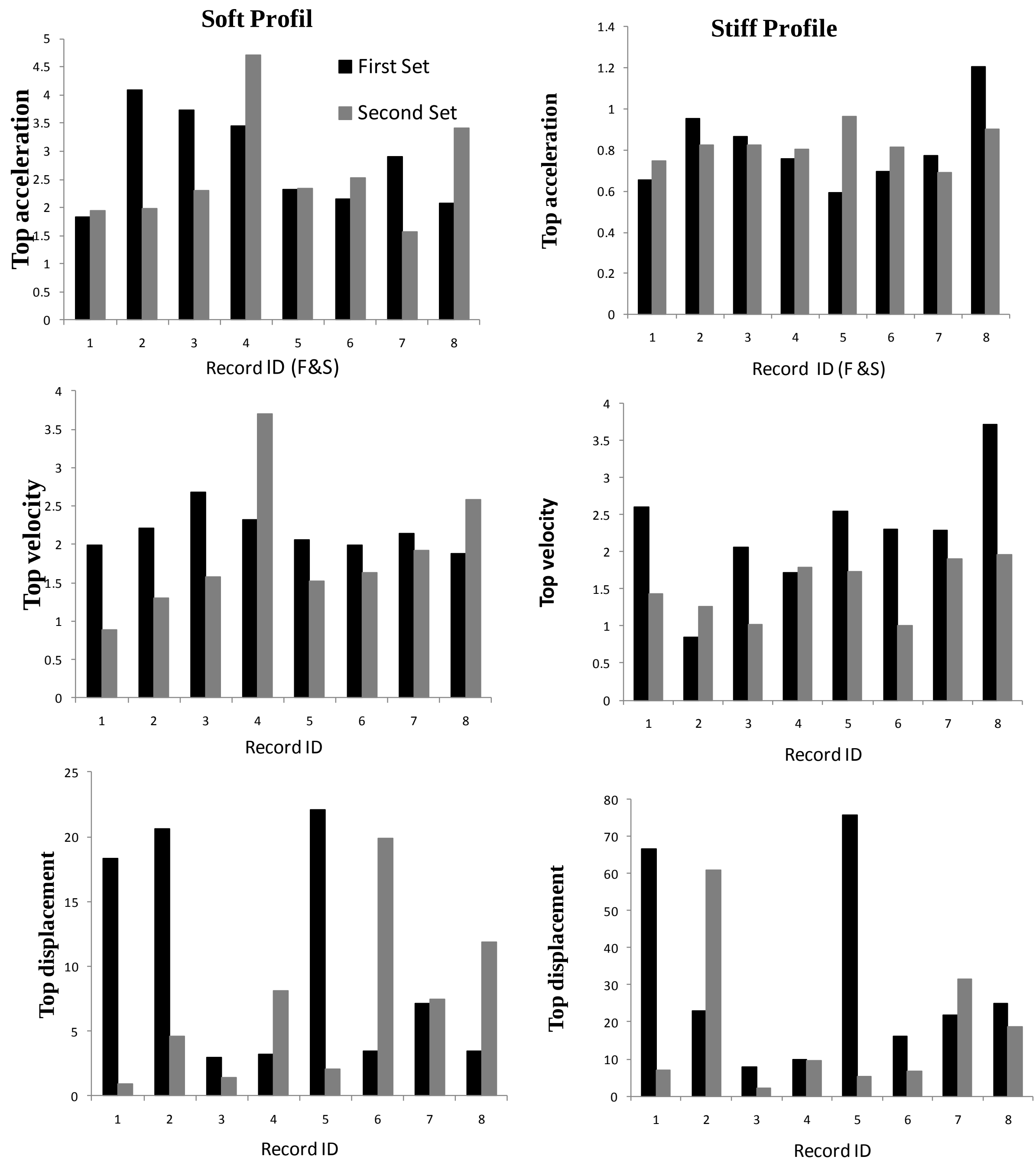

Figure 6. Computed EDPs for soil profiles: Soft soil (left) and Stiff soil (right)

CONCLUSIONS

Two structure-specific ground motion selection approaches are studied and compared quantitatively in this paper. Four MDOF systems including two soil profiles and two steel frames are considered to represent two types of seismic behaviour: soft and stiff. Dynamic capacity curves are obtained using IDA analysis for steel frames, while maximum responses at the top of soil profiles is used as the monitored EDPs.

It can be concluded from the results that the generalization of proposed structure-specific record selection methods for more complex and irregular systems needs more wide investigations. It is suggested that new scaling and selecting methods be designed in which the significant role of higher modes of vibration and possible mechanisms of failure is considered as a part of selection problem.

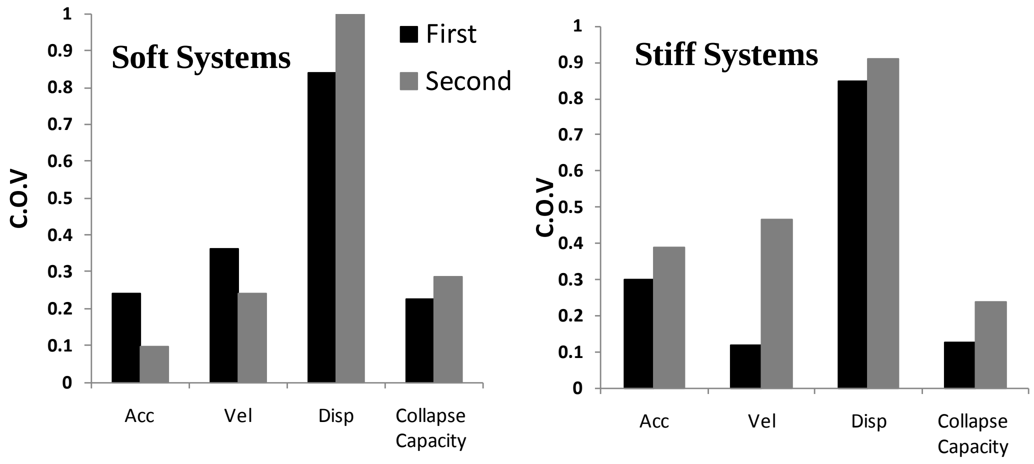

Figure 7. Comparison of the dispersion in the results: soft soil and 12-story frame (left) and stiff soil and 3-story frame (right)

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