THE CODE-BASED SELECTION OF GROUND MOTION RECORDS FOR NONLINEAR TIME-HISTORY ANALYSIS

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ABSTRACT :

The seismic resistance design codes recommend the selection of at least three or seven ground motion records, for the time-history analysis purposes, which shall be compatible to the design spectrum. On the other hand, the spectrum compatible records may change the structural response because of the different characteristics in comparison with the real ground motion records. It is important to propose a methodology that selects a limited number of real ground motion records, instead of the spectrum compatible records, to predict the best estimate of the response, since the design purposes are usually constrained by using of a few number of ground motion records. This paper presents the results of a statistical nonlinear response analysis of a test structure (three-storey reinforced concrete building) calculated using: (1) a selected set of thirty free-field real ground motion records presented an earthquake scenario; (2) two sets of three spectrum compatible records based on the common codes recommendation; and (3) a limited set of real ground motion records based on a precedence list of ground motion records. The structural demand and capacity are computed and compared based on the three pre-scribed methods. It is assumed that the first method result is the best prediction of the structural response. It has been shown that the second method (commonly used in the codes) predicts the structural response so conservative; hence, it is always in the safe side. However, the proposed method (third method) is able to predict the median response within an acceptable accuracy, based on the thirty ground motion records, which needs much less computation efforts in comparison with the first method.

KEYWORDS: Performance assessment, Ground motion selection, Record selection, IDA analysis, Seismic response, Nonlinear time history analysis

1. INTRODUCTION

The dispersion in the seismic response of structure, which defines the seismic demand and capacity, is usually high even if a large number of real ground motion records being used. That is, the time-history analysis for the design purposes shall be performed based on an appropriate suite of ground motion records. The common design codes recommend selecting at least three or seven records in a way that the mean spectral acceleration (the SRSS of both components) covers the design spectrum. The record selection becomes, by this criterion, a little difficult, at least if the real records being of interest. For clarify of exposition, four different methods have been reviewed to satisfy the common codes requirements which are as follows:
1) To scale up all acceleration values of the selected record to ensure that the record spectral acceleration is above the values of the design spectrum in the interest region. This method is practically impossible to use, because it will increase the spectrum amplitude significantly and the design will not be economic.
2) To select a set of records from a record database in a way that their mean response spectrum have a good compatibility with the design spectrum [1]. This method is obviously an optimization process which needs a relatively large records database for its input. However, this method may not work due to the limitations of the earthquake catalogue, if the scenario-based record selection is of interest.
3) To use the spectrum compatible or synthetic records. The spectrum compatible records are based on some modifications on the real records characteristics. The synthetic records are usually produced based on the sinusoidal motions [2]. The disadvantages of using the compatible or synthetic records are reported in the literature [3].
4) To use a limited number of real ground motion records to predict the median response of structure. This method needs a precedence list of ground motion records to be established before the time-history analysis is performed [4]. The main advantage of this method is that the selection of a few real ground motion records is possible based on a scenario earthquake.
In this paper the disadvantages of using the spectrum compatible records (which are commonly used for the design purposes) are reviewed and the results are compared to the median response of the structure based on the real records. It is concluded that using of compatible sets of records may result to a conservative prediction of the structural response.

2. GROUND MOTION RECORDS

A set of thirty ground motion records, as used by other researchers (e.g. [8]), has selected from the PEER Strong Ground Motion Database [9]. The earthquake moment magnitudes M_w for the selected records, which are relatively large, ranged from 6.5 to 6.9. The selected ground motion records were recorded on firm soil [10], with no marks of directivity effects. The list of records is presented in Table 1.

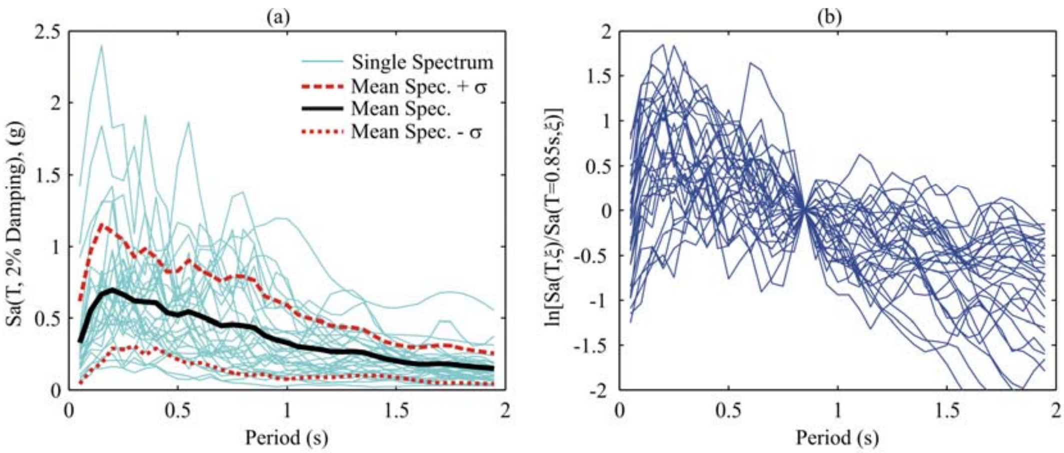

Figure 1. (a) The 2%-damped elastic acceleration spectra for thirty ground motion records, (b) The 2%-damped elastic acceleration spectra normalized to the spectral acceleration at the period of 0.85 second.

Table 1. The selected set of ground motion records.

Event, Year, M_W^*	ID	Station	$\phi^{\circ\dagger}$	$Soil^{\pm}$	$R^{\hbar}$	PGA
Loma Prieta, 1989, 6.9	1	Agnews State Hospital	090	C,D	28.2	0.159
	2	Hollister Diff. Array	255	-,D	25.8	0.279
	3	Anderson dam Downstrm	270	B,D	21.4	0.244
	4	Coyote Lake Dam Downstrm	289	B,D	22.3	0.179
	5	Sunnyvale Colton Ave	270	C,D	28.8	0.207
	6	Anderson dam Downstrm	360	B,D	21.4	0.24
	7	Hollister South & Pine	000	-,D	28.8	0.371
	8	Sunnyvale Colton Ave	360	C,D	28.8	0.209
	9	Halls Valley	090	C,C	31.6	0.103
	10	WAHO	000	-,D	16.9	0.37
	11	Hollister Diff. Array	165	-,D	25.8	0.269
	12	WAHO	090	-,D	16.9	0.638
Northridge, 1994, 6.7	13	LA, Baldwin Hills	090	B,B	31.3	0.239
	14	LA, Hollywood Storage FF	360	C,D	25.5	0.358
Imperial Valley, 1979, 6.5	15	Computertas	285	C,D	32.6	0.147
	16	Plaster City	135	C,D	31.7	0.057
	17	El Centro Array # 12	140	C,D	18.2	0.143
	18	Cucapah	085	C,D	23.6	0.309
	19	Chihuahua	012	C,D	28.7	0.27
	20	El Centro Array # 13	140	C,D	21.9	0.117
	21	Westmoreland Fire Station	090	C,D	15.1	0.074
	22	Chihuahua	282	C,D	28.7	0.254
	23	El Centro Array # 13	230	C,D	21.9	0.139
	24	Westmoreland Fire Station	180	C,D	15.1	0.11
	25	Computertas	015	C,D	32.6	0.186
	26	Plaster City	045	C,D	31.7	0.042
San Fernando, 1971, 6.6	27	LA, Hollywood Stor. Lot	180	C,D	21.2	0.174
	28	LA, Hollywood Stor. Lot	090	C,D	21.2	0.21
Superstition Hills, 1987, 6.7	29	Wildlife Liquefaction Array	090	C,D	24.4	0.18
	30	Wildlife Liquefaction Array	360	C,D	24.4	0.2

* Moment magnitude, † Component, $^\pm$ USGS, Geomatrix soil class, $^\hbar$ Closest distance to fault rupture expressed in kilometer.

The 2%-damped acceleration elastic response spectra of the set of ground motion records are presented in Figure 1a. The large dispersion is observed although the ground motion records were selected within a fairly limited interval of magnitude and fault distance (Table 1). The natural logarithm of the spectral acceleration (Figure 1a), normalized to the spectral acceleration at the period of 0.85s is shown in Figure 1b. Clearly the dispersion for a SDOF model with the period of 0.85s is equal to zero. However, the dispersion is still high for the periods beyond the period of the SDOF system, as shown in Figure 1b, which more clarifies the importance of the record selection.

3. TEST STRUCTURE

The test structure (referred as the SPEAR building) is a three-storey asymmetric reinforced concrete frame building, for which a pseudo-dynamic experiment was performed at full scale at the ELSA Laboratory, within the European research project SPEAR ("Seismic Performance Assessment and Rehabilitation of Existing Buildings") [5]. The elevation, the plan view and the reinforcement details of the beams and columns of the SPEAR building, which had been designed for gravity loads only, are shown in Figure 2. The so-called post-test mathematical model [6] created within the OpenSees program [7] was employed for the analyses performed in this study. This mathematical model consists of beam and column elements whose flexural behaviour was modeled by one-component lumped plasticity elements, consisting of an elastic beam and two inelastic rotational hinges (defined by the moment-rotation relationship). A more detailed explanation of the model and a comparison with the experimental results can be found in [6].
For reasons of simplicity, the nonlinear dynamic analyses were performed by subjecting the structure to loads

in the weak X direction only (Figure 2). For this direction the ratio between the maximum base shear and the weight of the building amounted to only about 0.1.

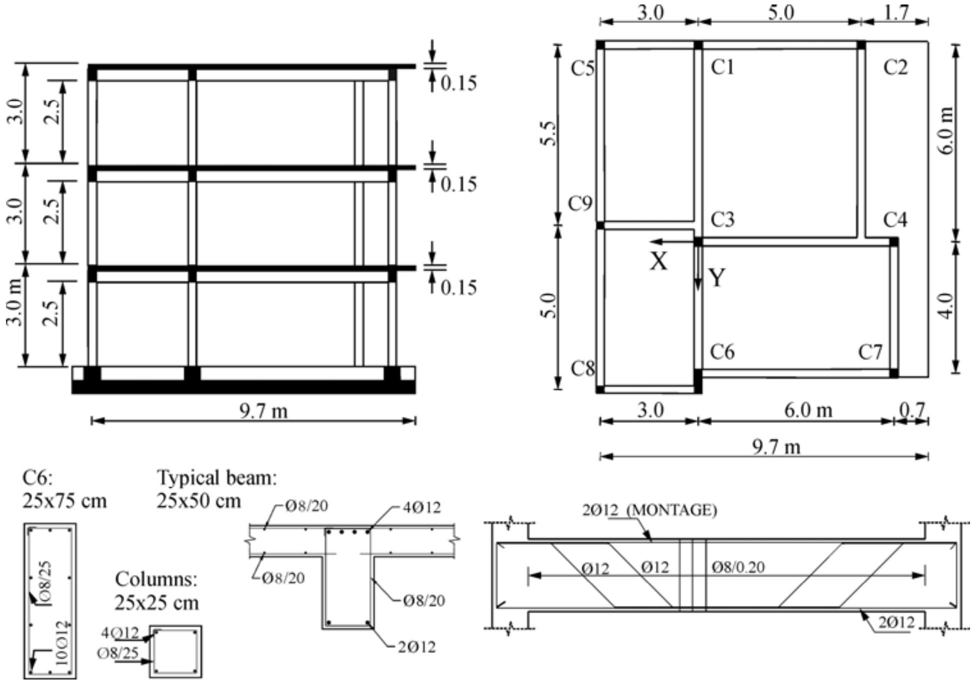

Figure 2. Elevation and plan view of the SPEAR building, showing typical reinforcement details.

4. INCREMENTAL DYNAMIC ANALYSIS (IDA) FOR THE REAL AND SPECTRUM COMPATIBLE RECORDS

The IDA analyses are performed for the test structure using Hunt and Fill tracing algorithm [8]. The IDA analysis results for the selected real records (Table 1) are shown in Figure 3. The three (No. 7, No.10 and No.14 in Table 1) real ground motion records, as recommended by the UBC97 code [11], which are corresponding to the three highest capacities in the IDA curves as shown in Figure 3, are selected for the design time history analysis. The three selected ground motion records are scaled (to become spectrum compatible) to the UBC97 design spectrum, as seen in Figure 4, by using the SYNTTH software [12] for the soil type B and $Z = 0.4$. Figure 3 shows the IDA curves for the three spectrum compatible records in comparison with the IDA curves that have been obtained based on the thirty real ground motion records shown in Table 1. The IDA curves for the three spectrum compatible records, are usually (at least in the context of this example) are lower than the IDA curves of the real ground motion records. The Intensity Measure (IM) corresponding to the worst (the lowest) capacity point of the three spectrum compatible records is 0.22g which can be compared to 0.51g which is the IM corresponding to the median IDA curve based on the thirty real ground motion records. Hence; by following the code procedure, the IM of the capacity equal to 0.22g shall be used for the design purposes. In other words, the S_a(0.85,5%), in the case of this example, is 0.47g based on the UBC97 code spectrum and the global instability (flat line in the IDA curve) is not reached at S_a(0.85,5%)=0.47g for the median IDA curve based on the thirty real ground motions; but all of the three IDA curves for the spectrum compatible records show the instability below this level of IM. This means the IM corresponding to the global capacity of the structure is predicted conservative using the spectrum compatible records.

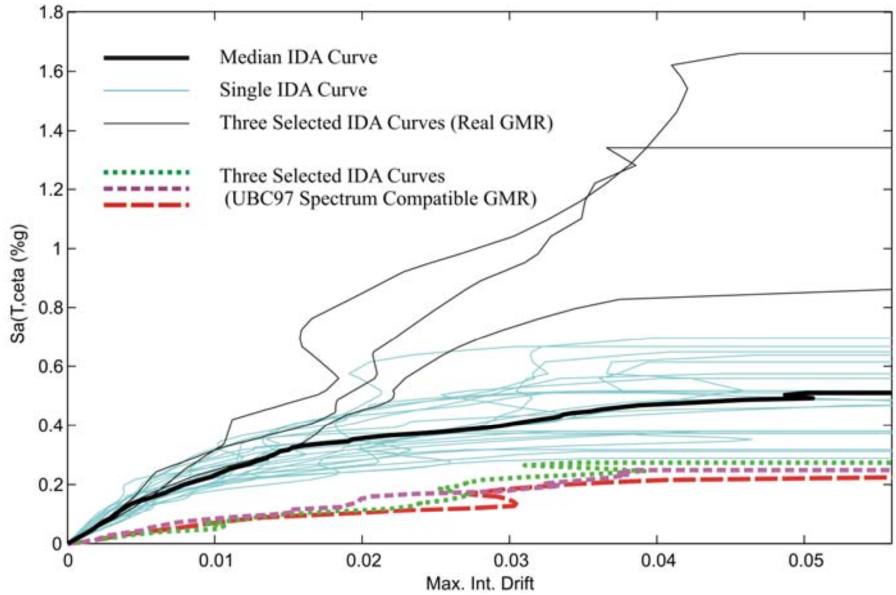

Figure 3. The thirty IDA curves and the corresponding median IDA curve compared to the three IDA curves (No. 7, 10 and 14) which are compatible to the UBC97 design spectrum.

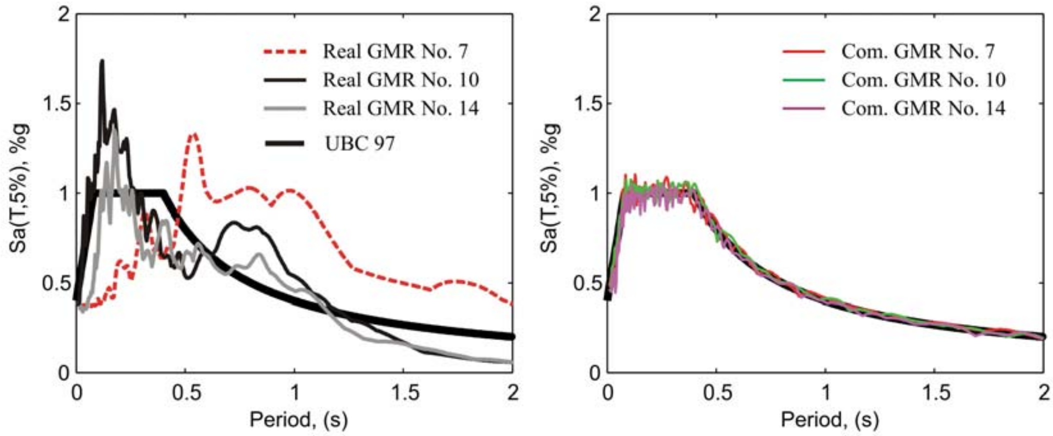

Figure 4. The 5% damped spectra for the three selected real ground motion records (No. 7, No.10 and No.14 in Table 1) compared to the UBC97 spectrum (left); The 5% damped spectra for the corresponding three compatible ground motion records compared to the UBC97 spectrum (right).

These significant changes in the IDA curves as well as in the capacity point IMs, obviously, come from the process of producing spectrum compatible records. Figure 5 shows the 5% damped spectrum for the UBC97 code as well as the real and compatible spectra for the three selected ground motion records, which are normalized to the S_a(0.85s,5%). The figure shows the significant changes in the records spectra generated to be compatible with the UBC97 code spectrum. The spectrum values for the periods beyond 0.85s are larger for the spectrum compatible records (influencing the nonlinearity effect), and, for the periods less than 0.85s the spectrum values are amplified significantly for the spectrum compatible records (influencing the higher modes effect). In general, it can be concluded that, although using of the code procedure reduces the response dispersion (which is intuitively obvious in Figure 3), but, this methodology is so conservative for the prediction of the median response.

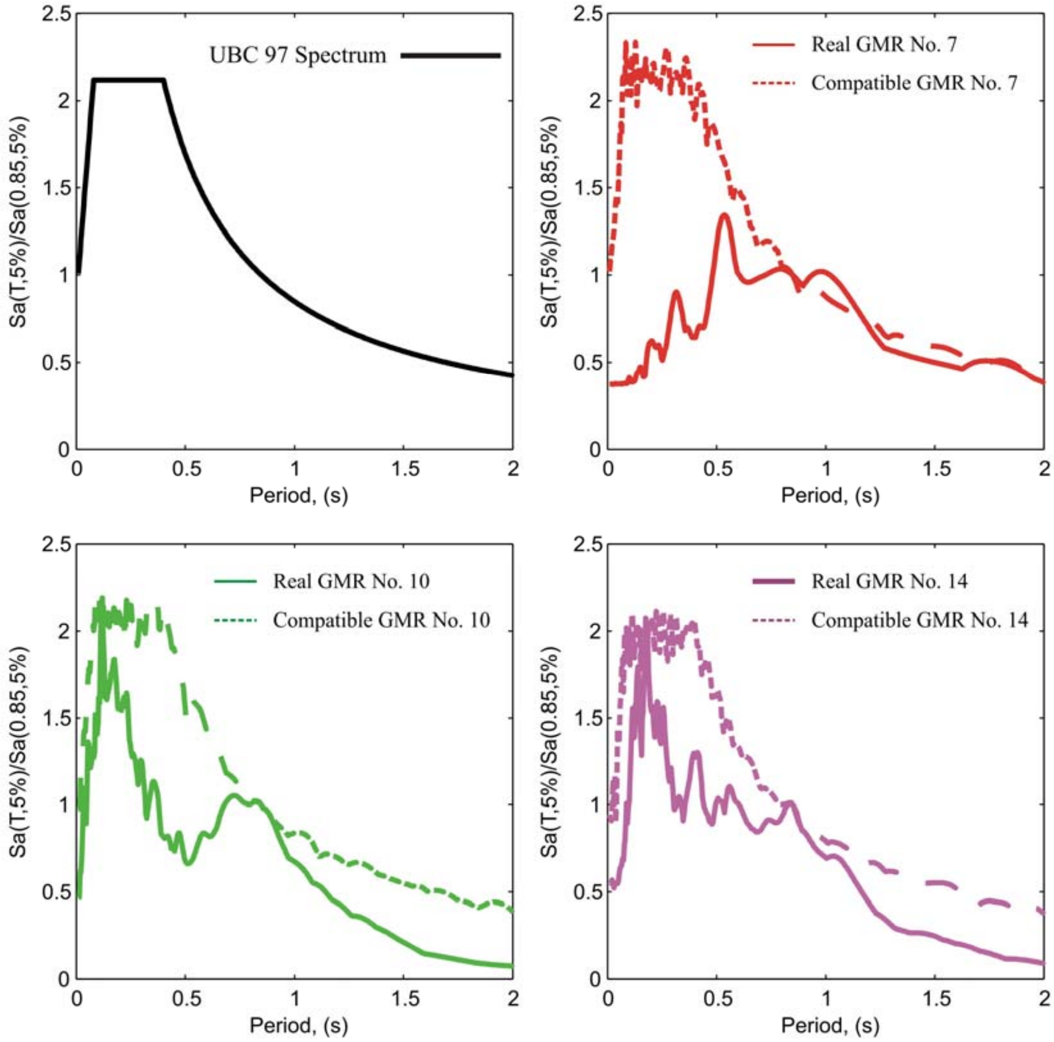

Figure 5. The 5% damped spectrum for the UBC97 code as well as the real and compatible spectra for the three selected ground motion records normalized to the S_a(0.85s,5%).

For further elaboration of the code method, another three real ground motion records which are corresponding to the three lowest capacities in the IDA curves (records No. 5, 24 and 30 in Table 1) have been selected based on UBC97 code [11] recommendation. The same process has been applied on these three ground motion records for the IDA calculations and the results are shown in Figure 6. The IDA curves for the three spectrum compatible records are calculated and compared, as seen in Figure 6, to the IDA curves based on the thirty real ground motion records as described in Table 1. The IDA curves for these three spectrum compatible records are again under the IDA curves based on the real ground motion records. The IM corresponding to the worst capacity point of the three spectrum compatible records is 0.28g and can be compared to 0.51g which is the IM corresponding to the median IDA curve based on the thirty real ground motion records. It is again confirmed that the code methodology gives conservative result in comparison with the result based on the real ground motion records.

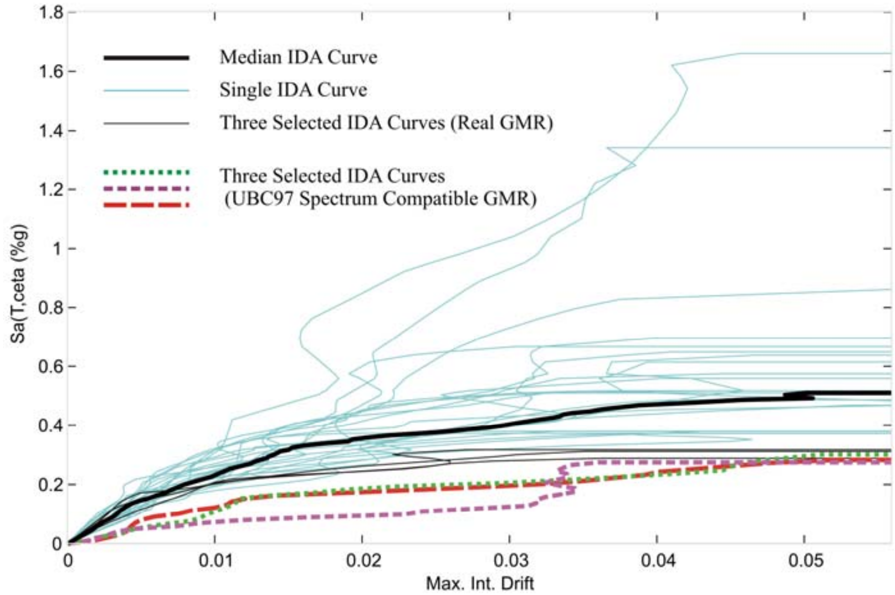

Figure 6. The thirty IDA curves and the corresponding median IDA curve compared to the three IDA curves (No. 5, 24 and 30) which are compatible to the UBC97 spectrum.

5. PRECEDENCE LIST OF GROUND MOTION RECORDS

It is shown in the previous section that the spectrum compatible records may enter a bias in to the structural response computation because of the different characteristics in comparison with the real ground motion records. Since the design procedures are usually constrained by the number of ground motion records, it is important to propose a methodology (e.g. [4]) to select the real records, instead of the use of spectrum compatible records, to predict the best estimate of the response. Recently, the concept of the precedence list of ground motion records is introduced [4]. It provides the advantage of a simple mathematical model, which is not computationally demanding, and it is defined as an optimization problem, which can be solved by means of a genetic algorithm or a proposed simple procedure. Once the precedence list of ground motion records is known, the response of the structure can be computed progressively, starting from the first ground motion record in the precedence list. When the required tolerance in the prediction of the seismic response is achieved, the analysis can be terminated, although the single-record IDA curves are computed only for a few number of ground motion records from a set.

Using the precedence list of ground motion records, will result to significant reduction in the time-history analysis [4] for the structural design or assessment purposes. The median IDA curve (the bold black curve in Figure 3 and Figure 6) can be predicted by only four ground motion records selected from the top of the precedence list. By using this approach the capacity and the demand for the structure would be based on the 30 real ground motion records; hence the design will be more economic. Interested reader can find more information regarding the precedence list of ground motion records in [4].

6. RESULTS AND CONLUSIONS

The effect of the code-based input ground motion selection has been investigated on the test structure (SPEAR building) using the IDA analysis. The IDA analysis are performed for a suite of 30 real ground motion records and the median IDA curve is calculated. Two different sets of records, each containing three records out of the selected 30 ground motion records, are selected. The selected records are changed to be compatible with the design spectrum. The IDA analysis is done for the two sets of spectrum compatible records. It is shown that the structure response based on the spectrum compatible records is significantly greater than the median response based on the 30 real ground motion records. Although the structural response based on the spectrum compatible records is always in the safe side, but, it is conservative.

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