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# COMPARISON OF STRUCTURAL SEISMIC RESPONSE BASED ON REAL AND SPECTRUM COMPATIBLE NEAR-SOURCE GROUND MOTION RECORDS

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**Keywords:** IDA analysis, SDOF system, Bias, Spectrum compatible ground motion record, Intensity measure, Displacement ductility.

**Abstract.** *A relatively large set of single-degree-of-freedom systems, for different period, damping and backbone curves, are selected and subjected to two different sets of ground motion records. The first set of ground motion records is consisting of 31 near-source strike-normal ground motion components recorded under forward directivity conditions from four different earthquakes. The 31 prescribed real records are used as "seeds" to generate the second set of ground motion records which are compatible to the median response spectrum of the first set of records. The single-degree-of-freedom systems response is calculated, then, for the two prescribed sets of ground motion records in different levels of ground motion intensities. Recently, this kind of nonlinear analysis, which is called Incremental Dynamic Analysis (IDA), is widely used by many researchers. The nonlinear structural seismic response, for the two sets of ground motion records, is statistically compared to identify the differences which are made from the spectrum matching process into the structural seismic response. The results show that the seismic structural capacity in terms of intensity measure based on the spectrum compatible records is biased. On the other hand, the seismic structural capacity in terms of displacement ductility is statistically un-biased.*

## 1 INTRODUCTION

The dispersion in the seismic response of structures, 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 response 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 records 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 a relatively large set of single-degree-of-freedom systems, for different period, damping and backbone curves, are selected and subjected to two different sets of ground motion records to investigate more about using spectrum compatible records.

## 2 SELECTION OF SDOF SYSTEMS

In the study, the seismic response database was established for the SDOF system, which is intended to simulate the seismic response of reinforced concrete buildings. For this purpose a piecewise four-linear backbone curve was chosen to mimic the static pushover curve of both the MDOF and the equivalent SDOF system. A typical four-linear backbone curve (see Figure 1a) starts elastically up to the cracking point (LS1), yields at ductility $\mu$=1 (LS2), remains fully plastic up to the ductility $\mu_u$ (LS3), and then starts to degrade with a slope $\alpha$ $k_0$ until the zero strength. Four parameters control the shape of the backbone curve. With a suitable variation of the four parameters the idealized curve can be fitted to almost any pushover curve. Additional structural input parameters are period and damping, which were assumed to be mass proportional. The parameter $\beta$, which describes the unloading stiffness of the Takeda's hysteretic rules [5], was assumed constant (0.5).

The SDOF-IDA curves were calculated for eleven periods (0.1, 0.2, 0.3, 0.4, 0.5, 0.75, 1.0, 1.25, 1.5, 1.75 and 2.0 seconds, respectively), for three different damping ratios (1, 3 and 5% mass proportional damping), for eleven different combinations of $F_{cr}/F_y$ and $\mu_{cr}/\mu_y$ (see Figure 1b), for seven different ductilities (2, 3, 4, 5, 6, 7 and 8), and for three different slopes $\alpha$ k0 of the degrading strength (-0.05, -0.25 and -0.5, respectively). Note that any of the relations

$F_{cr}/F_y = \mu_{cr}/\mu_y$ (Figure 1) corresponds to the usual bi-linear idealization of the section 0–LS3 which is commonly used in earthquake engineering. Using all combinations of the defined structural input parameter of the SDOF system, it is necessary to calculate 7623 SDOF-IDA curves for each selected ground motion record. All nonlinear dynamic analyses were performed by OpenSees [6].

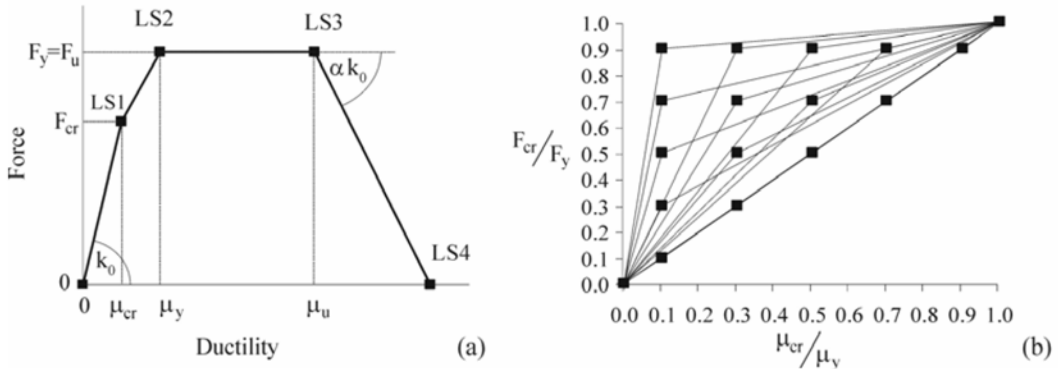


Figure -1. (a) Definition of the backbone curve with six controlling parameters (b) all different possible combination of the backbone curves for the ratios Fcr/Fy and μcr/μy between 0 and 1.

## 3 EARTHQUAKE GROUND MOTION RECORDS

A set of 31 near-source (closest source-to-site distance, $R_{close}$, less than 16 km), strike-normal ground motion components recorded under forward directivity conditions from four different earthquakes is considered. All the ground motions were recorded on NEHRP $S_D$ or $S_C$ sites, e.g. [7], and were uniformly processed by Walter Silva for the PEER Strong Ground Motion Database (http://peer.berkeley.edu/smcat/). The characteristics of the records are summarized in Table 1 and the 5% damped elastic response spectra are presented in Figure 2. The prescribed real records (Table 1) were also used as "seeds" for a spectrum matching exercise with the median response spectrum from Figure 2 as the smooth target. The matching has performed by Dr. Norman Abrahamson using the program RSPMATCH [8].

Table -1. Near-field earthquake ground motion records.

| Earthquake Location | Year | $M_w$ | Source Mech. | Station | $R_{close}$ (km) | PGA (%g) |
|---|---|---|---|---|---|---|
| (1) Imperial Valley | 1979 | 6.5 | SS | Brawley Airport | 8.5 | 0.158 |
| (2) | | | | EC County Center FF | 7.6 | 0.180 |
| (3) | | | | EC Meloland Overpass FF | 0.5 | 0.378 |
| (4) | | | | El Centro Array #1 | 15.5 | 0.138 |
| (5) | | | | El Centro Array #4 | 4.2 | 0.357 |
| (6) | | | | El Centro Array #5 | 1.0 | 0.375 |
| (7) | | | | El Centro Array #6 | 1.0 | 0.442 |
| (8) | | | | El Centro Array #7 | 0.6 | 0.462 |
| (9) | | | | El Centro Array #8 | 3.8 | 0.468 |
| (10) | | | | El Centro Array #10 | 8.6 | 0.176 |
| (11) | | | | El Centro Array #11 | 12.6 | 0.370 |
| (12) | | | | El Centro Differential Array | 5.3 | 0.417 |
| (13) | | | | Westmorland Fire Sta | 15.1 | 0.077 |
| (14) | | | | Parachute Test Site | 14.2 | 0.135 |
| (15) Superstition Hills (B) | 1987 | 6.7 | SS | El Centro Imp. Co. Cent | 13.9 | 0.308 |
| (16) | | | | Westmorland Fire Sta | 13.3 | 0.210 |

| | | | | | | |
|---|---|---|---|---|---|---|
| (17) | | | | Parachute Test site | 0.7 | 0.419 |
| (18) Loma Prieta | 1989 | 6.9 | RV/OB | Saratoga - W Valley Coll. | 13.7 | 0.403 |
| (19) Northridge | 1994 | 6.7 | TH | Canyon Country - W Lost Cany | 13.0 | 0.466 |
| (20) | | | | Jensen Filter Plant # | 6.2 | 0.393 |
| (21) | | | | Newhall -Fire Sta # | 7.1 | 0.724 |
| (22) | | | | Rinaldi Receiving Sta # | 7.1 | 0.887 |
| (23) | | | | Sepulveda VA # | 8.9 | 0.722 |
| (24) | | | | Sun Valley - Roscoe Blvd | 12.3 | 0.298 |
| (25) | | | | Sylmar - Converter Sta # | 6.2 | 0.594 |
| (26) | | | | Sylmar - Converter Sta East # | 6.1 | 0.839 |
| (27) | | | | Sylmar - Olive View Med FF # | 6.4 | 0.733 |
| (28) | | | | Arleta - Nordhoff Fire Sta # | 9.2 | 0.237 |
| (29) | | | | Newhall - W. Pico Canyon Rd. | 7.1 | 0.426 |
| (30) | | | | Pacoima Dam (downstr) # | 8.0 | 0.499 |
| (31) | | | | Pacoima Kagel Canyon # | 8.2 | 0.527 |

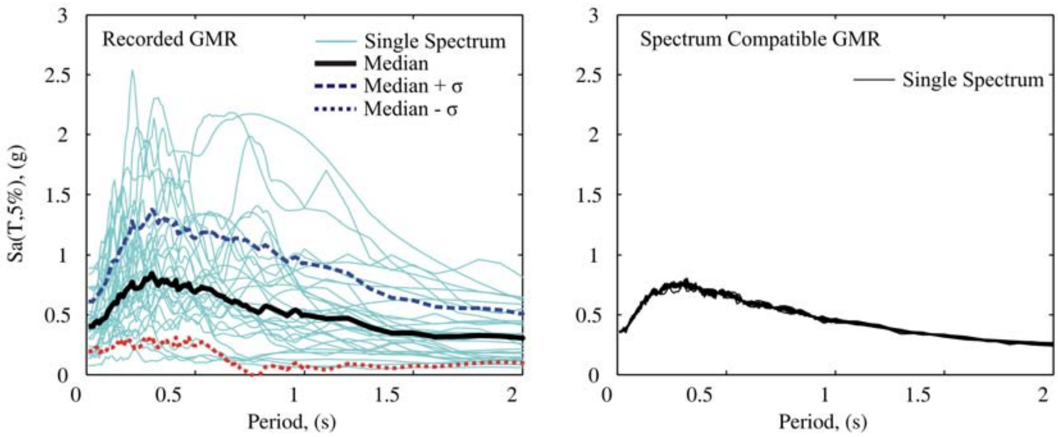


Figure -2. The 5% damped elastic response spectra for the 31 recorded (left) and spectrum compatible (right) ground motion records.

## 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 [9]. All IDA curves are containing of twenty points where each point is calculated form a nonlinear time-history analysis for a particular SDOF system (Figure 1). The IDA curves are calculated first for the peak ground acceleration (PGA), as an intensity measure (IM), which can simply be transformed to any further new linear IMs, e.g. the spectral acceleration at the period of the SDOF system with 5% damping ratio, $S_a(T_1, 5\%)$.

## 5 THE SDOF SEISMIC CAPACITY BIAS

This study is focused on the bias which may introduce from the spectrum compatible records into the structural seismic capacity points. The structural seismic capacity points are corresponding to the LS4 in Figure 1. The bias in terms of IM, which is either PGA or $S_a(T_1, 5\%)$ in this case, is calculated as the ratio between 'median of IMs corresponding to the capacity points for 31 real records' and 'median of IMs corresponding to the capacity points for 31 spectrum compatible records' for a specific SDOF system. The bias in terms of damage measure (DM), which is the displacement ductility (equal to nonlinear displacement divided by $\mu_y$) in this case, is calculated as the ratio between 'median of DMs corresponding to the capacity points for 31 real records' and 'median of DMs corresponding to the capacity points for 31 spectrum compatible records' for a specific SDOF system. The bias in terms of IM is shown in Figure 3 to Figure 5 for different period, damping and backbone controlling parameters and for PGA as well as $S_a(T_1, 5\%)$ as an IM. The bias in terms of DM is shown in Figure 6 for different period, damping and backbone controlling parameters. The Durbin-Watson test [10] is performed to test if the residuals (from a linear regression) are independent, against the alternative that there is autocorrelation among them. The results show that the estimation of the median IM for the structural seismic capacity is biased. The maximum bias can be around 1.5, as shown in Figure 3 to Figure 5, which means the median IM for the seismic capacity points is predicted with 50 percent conservation based on the spectrum compatible records. Fortunately, the bias is statistically more than one which means the design based on the spectrum compatible records is conservative. On the other hand, the estimation of the median DM for the structural seismic capacity, as shown in Figure 6, is statistically un-biased which is a promising result.

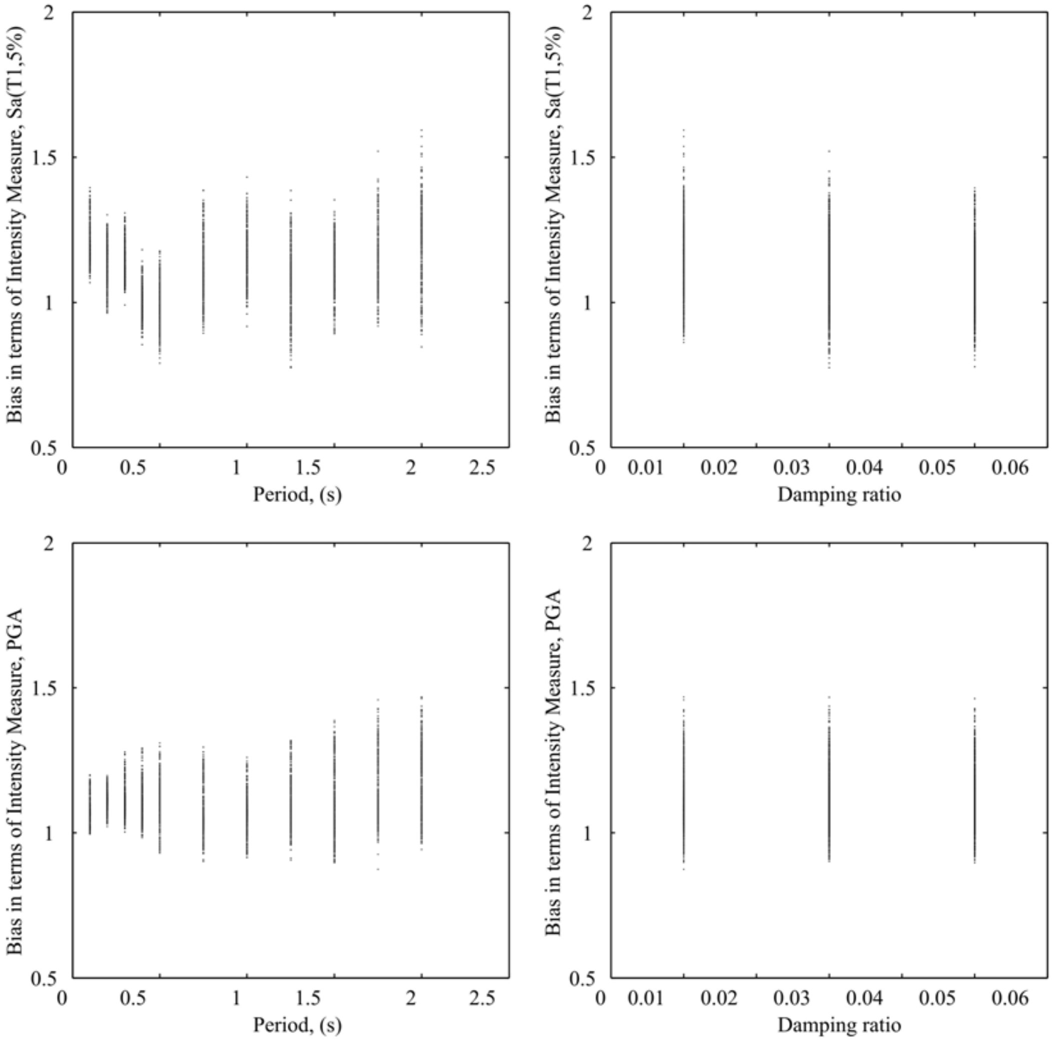


Figure -3. The bias in the SDOF seismic capacity points in terms of intensity measure versus period and damping ratio. The alternatives for the IM are PGA and $S_a(T_1, 5\%)$.

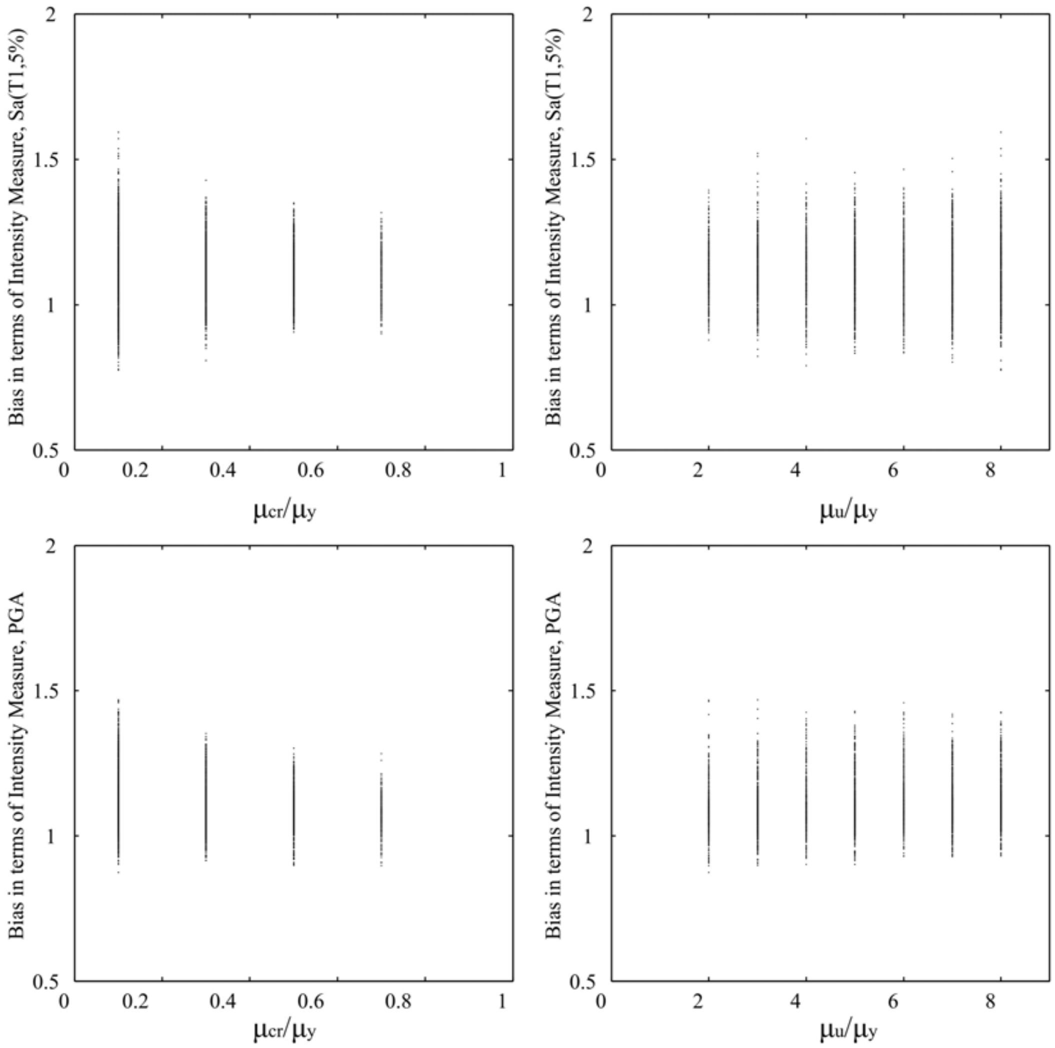


Figure -4. The bias in the SDOF seismic capacity points in terms of intensity measure versus $\mu_{cr}/\mu_y$ and $\mu_u/\mu_y$. The alternatives for the IM are PGA and $S_a(T_1, 5\%)$.

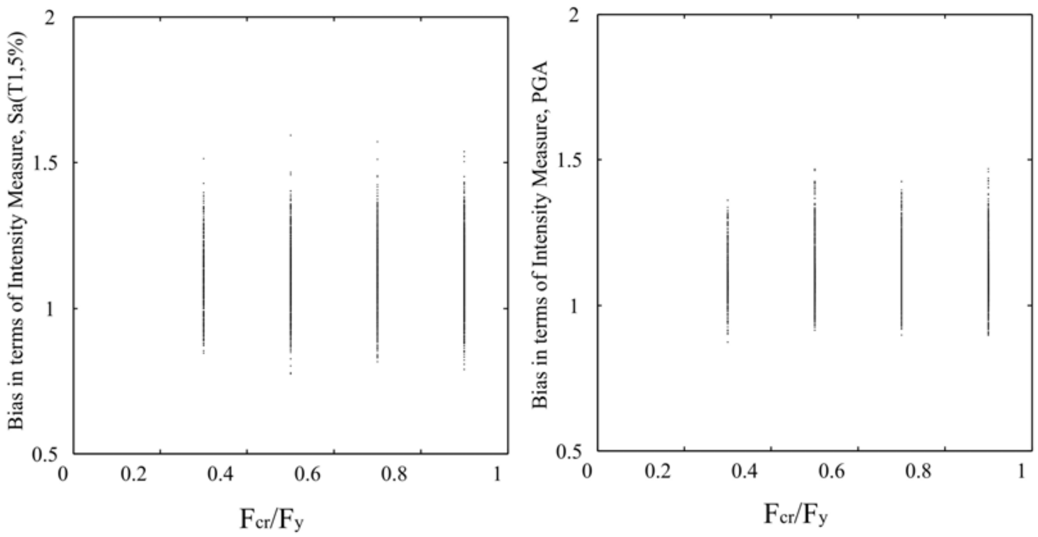


Figure -5. The bias in the SDOF seismic capacity points in terms of intensity measure versus $F_{cr}/F_y$. The alternatives for the IM are PGA and $S_a(T_1, 5\%)$.

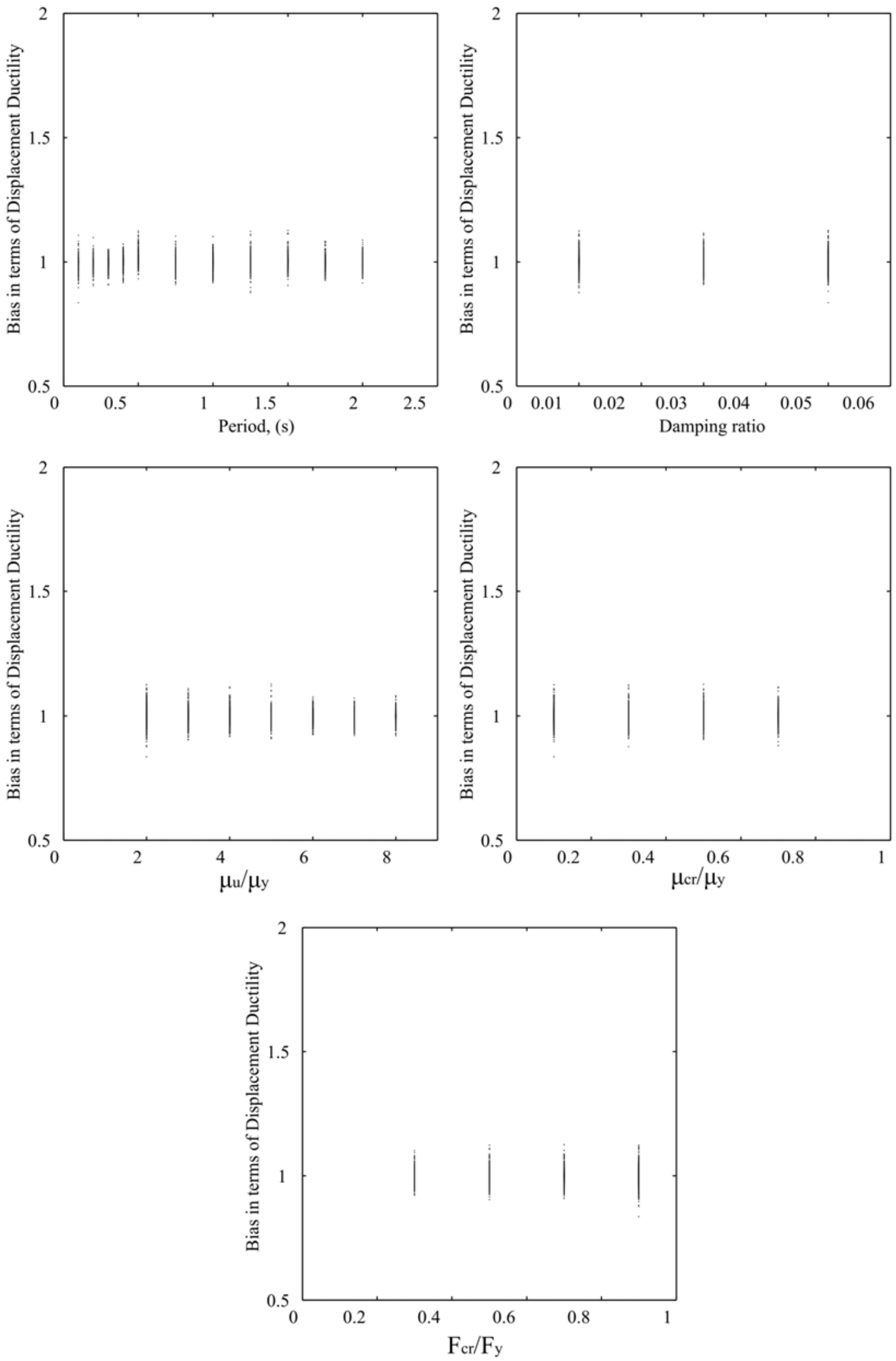


Figure -6. The bias in the SDOF seismic capacity points in terms of displacement ductility versus period, damping and backbone controlling parameters (see Figure 1).

## 6 CONCLUSIONS

The effect of using the spectrum compatible records on the estimation of the structural seismic capacities has been investigated for a huge set of SDOF systems using the IDA analysis. The IDA analyses are performed for a suite of 31 real ground motion records as well as 31 spectrum compatible ground motion records and the median IM and DM for the capacity points are calculated. It is shown that the median IM corresponding to the structural capacities is estimated conservatively based on the spectrum compatible records. On the other hand, the median DM corresponding to the structural capacities is estimated statistically un-biased. It should be noted that all the results are concluded from a huge set of SDOF systems which can be interpreted for first mode dominated structures. For the multi-degree-of-freedom (MDOF) structures, other characteristics such as higher mode effects, distribution of the nonlinear hinges or failure mechanisms can change the results.

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## REFERENCES

[1] F. Naeim, A. Alimoradi, S. Pezeshk, Selection and Scaling of Ground motion Earthquakes for Structural Design Using Genetic Algorithms. *Earthquake Spectra*, **20**(2), 413-426, 2004.

[2] J.J. Bommer, A.B. Acevedo. The use of real accelerograms as input to dynamic analysis. *Journal of Earthquake Engineering,* **8**(1) 43-91, 2004.

[3] F. Naeim, M. Lew, On the use of design spectrum compatible time histories. *Earthquake Spectra*, **11**(1), 111-127, 1995.

[4] A. Azarbakht, M. Dolšek, Prediction of the median IDA curve by employing a limited number of ground motion records. *Earthquake Engineering & Structural Dynamics*, **36**, 2401-2421, 2007.

[5] T. Takeda, M.A. Sozen, N.N. Nilsen, Reinforced concrete response to simulate earthquake. *Journal of Structural Division*, **96**(2), 2557-2573, 1970.

[6] F. McKenna, G.L. Fenves, M.H. Scott, An object-oriented software for earthquake engineering simulation. Univ. of California, Berkeley, California, 2000. ⟨http://opensees.berkeley.edu/⟩

[7] FEMA. The 2000 NEHRP recommended provisions for new buildings and other structures. *Report No. FEMA-368*, SAC Joint Venture, Federal Emergency Management Agency, Washington, DC, 2002.

[8] N.A. Abrahamson, *Non-Stationary Spectral Matching Program RSPMATCH*, User Manual, 1993.

[9] D. Vamvatsikos, C.A. Cornell, Incremental Dynamic Analysis. *Earthquake Engineering and Structural Dynamics*, **31**(3):491-514, 2002.

[10] MATLAB, the language of technical computing, version 7.0.0.19920(R14), May 06, 2004. http://mathworks.com.