Quantification of Effectiveness of Indices for Selection of Design Ground Motions by using Mutual Information

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Introduction

Selection of design ground motion (GM) for nonlinear dynamic analysis is a difficult task because of its unpredictability and sensitivity to various uncertain parameters. Authors have proposed a scheme based on indices for selection of design GMs [1,2]. In these situations indices are objected to quantify the damaging capabilities of GMs.

One index is able to consider limited aspects of GM characteristics, and another index may be effective to cope with different aspects of GM characteristics. Therefore, total seismic damage experienced by the structure is accessed differently by different indices. Combination of indices can represent the structural damage more appropriately because diverse characteristics of GMs are considered. In order to select appropriate indices, we need to quantitatively evaluate the efficiency of an index or combination of indices to represent the severity of structural damage due to a GM.

Objectives

It is required to set a mean for the selection of index or a combination of indices, which is relatively efficient to represent the damaging capabilities of GM, considering stochastic nature of structural characteristics and complexity of nonlinear response. We proposed to use mutual information (MI) and compare its performance with conventional covariance.

Evaluation of performance of indices for the selection of GMs

(1) Coefficient of Covariance

Conventionally, a higher value of coefficient of covariance between the index value and the probability of structural damage validate the superiority of index or combination of indices. This is helpful when a linear relationship exist between the index value and the probability of structural damage, but due to complexity of nonlinear response and variety of combinations of indices, the linear relationship is not the *most likely* option. In such generalized scenarios, it is not possible to evaluate the correlation between the indices values and probability of structural damage by covariance.

(2) Selection of Indices Based on Mutual Information

MI is a measure of information shared between two independent variables. Let I be MI value between an index k and probability of structural damage P, then I quantifies the amount of information that k have about the P. Hence it is expected that indices with higher MI value will be more appropriate to evaluate the probability of structural damage. In combination of indices the amount of information is enhanced due to inclusion of different aspect of structural damaging capabilities of GM, so combination of indices yield superior results as compared to a single index. In that context, we proposed to use the MI to quantitatively evaluate the effective of indices.

As compared to covariance, MI value will be appropriate regardless of type of correlation between k and P. The advantage of using MI value over conventional approach is elaborated by a numerical simulation.

Numerical Simulations

Two dimensional, three bay, five-story concrete frame is exposed to a set of 450 GMs selected from K-net and factored to peak acceleration of 6 to 8 m/sec^2. Uncertainty of structural properties is incorporated by considering stochastic nature of material properties. OPENSEE [3] is used to conduct the nonlinear analysis. Let us assume that a GM, say GM1, is more damaging than another GM, or GM2, if the number of damage components due to GM1 is more than that by GM2. By means of that definition of structural damage, percentiles of GMs based on damage of MDOF is calculated. Percentiles of GMs are also calculated by using index values, while joint probability is used to calculate the percentile for the case of multiple indices. Percentile of a GM indicates the rank of GM in the set of GMs. Distribution of aforementioned percentile for the case when displacement response of SDOF corresponding to first mode is used as an index, are plotted in Fig.1. From this distribution, MI value is calculated to show the goodness of an index. For comparison, coefficient of covariance is also calculated.

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Eight indices and their twenty eight combinations are used to evaluate percentile of GMs. Based on similar nature of indices, indices and their combinations are categorized into five groups (Table-1). Group of indices are sorted in ascending order of expected performance of indices, e.g. indices related to response of SDOF corresponding to first mode (group-3) are expected to superior then second mode indices (group-1) and combination of them (group-2).

Simulation Results

The MI value between the percentile of GM based on damage of MDOF system and percentile of GM accessed by the indices are plotted in Fig.2 (a). Fig.2 (b) shows the corresponding coefficient of covariance values. The MI value is higher for the indices which were expected to perform more appropriately. Increasing trend of average value of MI for each group in Fig.2 (a) more clearly depicts that MI increases due to inclusion of more informative indices, while covariance coefficient is nearly same for indices of all groups. Hence, MI is efficient to evaluate the effectiveness of indices, higher the value of MI batter the index or combination of indices will be.

It is important to note that, MI value is less for group-2 as compared to group-3. Conventionally, group of indices is more effective than a single index. The results show that consideration of an informative index is better than an uninformative combination of indices. MI value attain highest value for group-5, because information are accumulated due to combination of indices from both first and second mode responses, but covariance coefficient is insensitive to the aforementioned aspects, and covariance coefficient is similar for indices of group-3, 4 and 5.

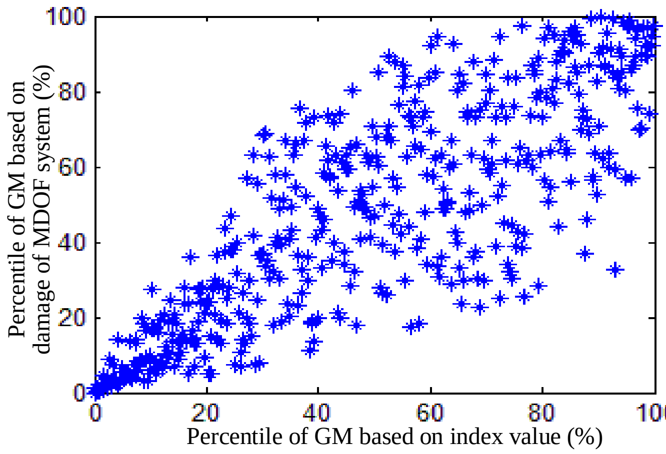

Fig.1 Distribution of percentile of GM based on damage of MDOF and based on index values.

Table-1 Indices based on SDOF corresponding to first and second mode of MDOF system

Group-1	Disp. Vel. Acc. Dissipated Energy of SDOF second mode.
Group-2	Combinations of Disp. Vel. Acc. Dissipated Energy of SDOF second mode.
Group-3	Disp. Vel. Acc. Dissipated Energy of SDOF first mode.
Group-4	Combinations of Disp. Vel. Acc. Dissipated Energy of SDOF first mode.
Group-5	Combinations of Disp. Vel. Acc. Dissipated Energy of SDOF first and second mode.

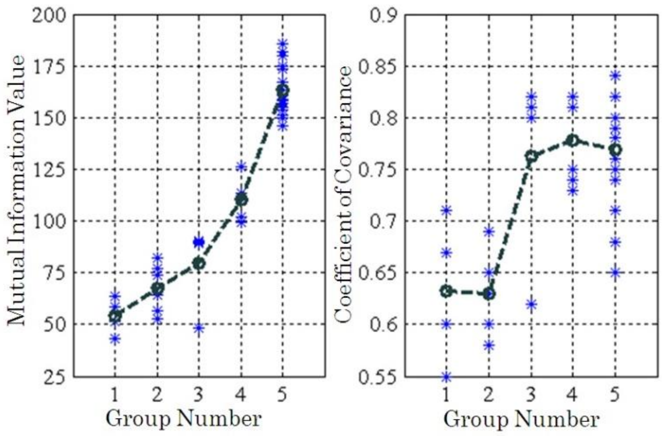

Fig.2 (a) Mutual information and (b) Coefficient of covariance between the percentile of GM based on probability of damage and percentile of GM from indices.

Conclusions

Quantification of effectiveness of indices to depict the damage capabilities of GM is a crucial issue of earthquake engineering and it requires a detailed investigation. Authors proposed to use MI for the quantification of effectiveness of indices, as MI is a measure of amount of information which is shared by two independent quantities. With the help of numerical simulations, it is shown that MI is efficient to quantify the effectiveness of indices for selection of design GM.

References

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