ENHANCEMENT OF EFFECTIVENESS OF INDICES FOR DESIGN GROUND MOTION SELECTION TO CONSIDER NONLINEAR STRUCTURAL RESPONSE

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1. INTRODUCTION

Nonlinear dynamic analysis of structure is one of the most effective ways to look into the performance of structure in nonlinear range. Meanwhile, selection of design ground motions (GM) out of a large number of possible GMs is difficult due to complexity and unpredictability of nonlinear response.

It is important to formulate the suite of possible GMs for dynamic analysis of the structure under consideration to enhance the reliability of seismic performance of structures. Uncertain fault parameters and uncertainty of seismic activity result with huge number of possible GMs. Thus, a GM is required which can represent the suite of possible GMs so that designing the structure against the representative GM is equivalent to design the structure considering the suite of possible GMs.

In literature, a good number of procedures are proposed for selection of design GMs by using indices, such as peak acceleration, duration of GM signal. Some indices consider the effect of response of structure, but since indices are simple, indices cannot circumscribe the complexity and unpredictability of nonlinear response. Indices that can reflect complexity of nonlinear response in selection/synthesis of design GMs is required.

2. OBJECTIVES

Considering the background described above, the objective of this study is set to enhance the effectiveness of indices for selection of design ground motion by considering the effect of nonlinear response of structure. Performance of a proposed method of synthesis of design GMs is verified by numerical simulations.

3. NUMERICAL MODEL AND SUITE OF POSSIBLE GROUND MOTIONS

Design GMs are selected for a two dimensional five-story moment resisting concrete frame. Material properties of moment resisting frame are considered as stochastic variables to reflect the uncertainty of structural characteristics.

In the presented work we focus on reliability of selection/synthesis of representative GM of suite of GMs, assuming that suite of possible GMs is known. Here GMs are intentionally selected without considering site conditions etc, because we want to have our suite include wide range of GMs. As a suite of possible GMs, 2,000 time histories of real earthquake events are obtained from K-NET and factored to peak acceleration of 600 to 800 cm/sec^2 to constitute the suite of possible GMs. Dynamic nonlinear analysis is conducted by using OpenSees (OpenSees)

4. FEATURE INDICES BASED DESIGN GROUND MOTION SELECTION/SYNTHESIS CONSIDERING COMPLEXITY OF NONLINEAR RESPONSE

Authors have presented the concept of damage mechanism based indices to select appropriate indices (Ahmed and Honda, 2011). According to that concept, influential damaging mechanisms are accessed and accordingly indices are selected.

In our simulation, same strength columns are used for all the floors (because columns have the same size and reinforcement), the damage will be contributed at lower part of structure due to maximum bending moments. Utilizing the concept of damage mechanism based indices, response of a bilinear single degree of freedom system (SDOF) is adopted as an appropriate index for the concrete moment resisting frame under consideration.

This index is a response of a spring mass system, and it cannot circumscribe the complexity of nonlinear response of concert structure. Meanwhile, we cannot quantitatively consider the aforementioned uncertainties and complexities of nonlinear response in selection/synthesis of design GM. Thus, we propose to consider fluctuation to the parameters of indices. This will be helpful to consider a verity of aspect of ground motion in context of structure under consideration, which we may not know if we use a single spring mass system.

To study the effect of aforementioned aspect, design GMs are selected assuming three different conditions as discussed in the following.

4.1 Simulation Conditions

Displacement response of SDOF system (D1) is used as index to select the GM representing the suite of possible GMs. We compare three conditions as:

Case-I: GM is selected with deterministic parameters of SDOF. Natural period and yielding force of SDOF system is fixed and set identical with the target structure.

Case-II: GM is selected with the same index, but we give fluctuation to the parameters of SDOF.

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Case-III: GM is synthesized in an iterative process by considering index with fluctuation in structural parameters. In the iterative process, the GM is modified slightly so that it becomes tough for the target structure.

Quantification of structural damage: The structural damage is judged by comparing the strain of steel bars of ground floor columns. A GM, say GM1 is more damaging than another GM, or GM2, if strain at first floor columns caused by GM1 is more than that by GM2. Strain of first floor columns is compared, because damage will occur at the first floor for this structure. Based on this definition, probability of structural damage (P_d) is formulated.

Condition to be design GM: We assume that a GM with 10% exceedance probability in terms of structural damage (strain at the first floor) should be the design GM. Thus, a GM which shows 10 % exceedance probability in terms of feature indices would be the design GM.

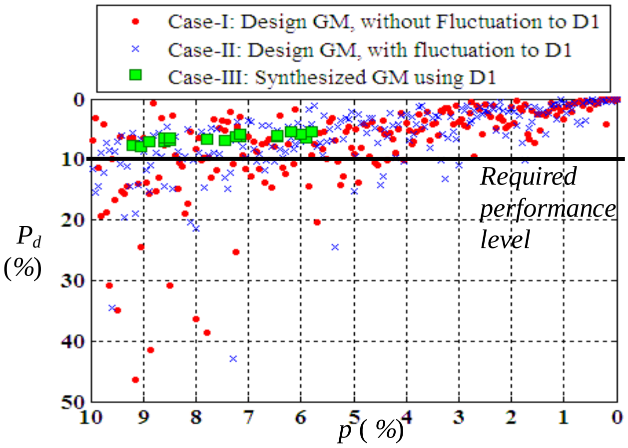

Fig.1 Distribution of exceedance probability of structural damage (P_d) against exceedance probability in terms of indices (p) for design GMs from three different approaches.

4.2 Simulation Results and Discussion

Case-I: Deterministic parameters of SDOF are used and the GM showing 10 % exceedance probability in terms of index D1 are selected as design ground motions. The responses of selected design GMs are plotted in Fig. 1. Along horizontal axis exceedance probability in terms of index D1 (p) is plotted, while on vertical axis exceedance probability of structural damage (P_d) is plotted. The required performance level is marked by horizontal solid line. Selected design GMs are expected to be above the required performance level. But some GMs lie below the target level.

To show the goodness of indices, the percentage of GMs showing the required performance for full scale structure to the GMs conforming the condition to be design GM are calculated and termed as reliability. For this case, reliability is 75.1%, it means if we randomly select a GM, which conform the required condition then there is 25% chances that the selected design GM do not show promising response for full scale structure.

The reason is that the index used to represent the set of possible GMs is very simple as compared to complexity of nonlinear response. Thus, reliability of having required design GM is low.

Case-II: To consider the effect of nonlinear response of structure in feature indices to represent the suite of possible GMs, we consider fluctuation in the parameters of SDOF and average of 20 SDOF is used to formulate the exceedanace probability in terms of index (D1) of suite of GMs. Similar to the Case-1, exceedaing probabilities in terms of index (D1) and structural damage are calculated and shown in Fig.1. To make comparison on the same bases, we calculated the reliability similar to Case-I. The reliability of having required design GM is 81.0%. This shows that reliability of having the required design GMs is increased as compared to Case-I.

The reason is that, due to consideration of fluctuation to the parameters of indices, we can evaluate verity of aspect of GMs which are influential in nonlinear analysis. While if we consider deterministic parameters of SDOF (as in case-I), then we may not effectively evaluate the GMs. This approach fairly works for the structure under consideration.

Case-III: The reliability of having the required GMs is increased in case-II as compared to case-I, yet the reliability is not reached to maximum level. We must admit the reliability of having required design GM is limited due to uncertainty and unpredictability of nonlinear response. This leads to the requirement of synthesis of design ground of required performance. Here we synthesize a GM by modifying the time frequency characteristics of a randomly selected GM. The iterative modification process is explained and verified by the authors (Honda and Ahmed, 2011). The GMs are synthesized considering the effect of nonlinear response. Similar to the previous two cases the performance of the synthesized GMs is produce on Fig.1. Fig.1 shows that the reliability of synthesized GMs is fairly up to saturation level.

5. CONCLUSIONS

Selection of representative GM is an important aspect of nonlinear analysis. Complexity and unpredictability of nonlinear response complicate the selection of appropriate representative GM. Consideration of complexity of nonlinear response in selection of representative GM is a difficult task. We propose and verify by numerical simulation that if we consider fluctuation in parameters of indices, the efficiency of indices is increased, because it help us to consider a verity of influential aspect of ground motions, which cannot be considered if parameters of indices are deterministic. As a future study, it is required to discuss the applicability of the proposed approach for more complicated structures.

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OpenSees (Open System for Earthquake Engineering Simulation): http://opensees.berkeley.edu/ Visited on 4th Apr. 2012.