Seismic Vulnerability Assessment of RC Frames via IDA

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***Abstract*—**A capacity spectrum method (CSM), one of methodologies to evaluate seismic fragilities of building structures, has been long recognized as the most convenient method, even if it contains several limitations to predict the seismic response of structures of interest. This paper proposes the procedure to estimate seismic fragility curves using an incremental dynamic analysis (IDA) rather than the method adopting a CSM. To achieve the research purpose, this study compares the seismic fragility curves of a 5-story reinforced concrete (RC) moment frame obtained from both methods; an IDA method and aCSM. Both seismic fragility curves are similar in slight and moderate damage states whereas the fragility curve obtained from the IDA method presents less variation (or uncertainties) in extensive and complete damage states. This is due to the fact that the IDA method can properly capture the structural response beyond yielding rather than the CSM and can directly calculate higher mode effects. From these observations, the CSM could overestimate seismic vulnerabilities of the studied structure in extensive or complete damage states.

***Keywords*—**Seismic fragility curve, Incremental dynamic analysis, Capacity spectrum method, Reinforced concrete moment frame.

I. Introduction

THE seismic fragility curves predict probabilities of reaching or exceeding specific damage states for a given level of earthquake response. Researches on the seismic fragility curves has carried out since 1980's and has been increased according to develop analysis techniques [1]-[3]. A capacity spectrum method (CSM) has generally regarded as a convenient methodology even if it contains the limitations on predicting the seismic response of structures. To overcome the limitations, this paper proposes the procedure to estimate seismic fragility curves based on Incremental Dynamic Analysis (IDA) rather than a CSM since the IDA are generally known to provide more reliable seismic response of a structure than the CSM. This study comparatively investigates the seismic fragility curves obtained from the IDA method and the CSM for a 5-story reinforced concrete moment frame.

II. Structural Analysis of Prototype Building

A. Description of Prototype Building

A 5-story reinforced concrete (RC) framed building shown in Fig. 1 is selected as a prototype structure and is seismically designed according to the current Korean seismic design code, KBC2009. It is assumed that the prototype building is located in Seoul, Korea and its site class is assigned to S_D. Seismic design parameter including response amplification factor, R, a deflection amplification factor C_d, an over-strength factor Ω_O, and in important factor I for the prototype building are S_{DS}=0.499, S_{D1}=0.287, R=5, Ω_O=3, C_d=4.5, I=1.0.

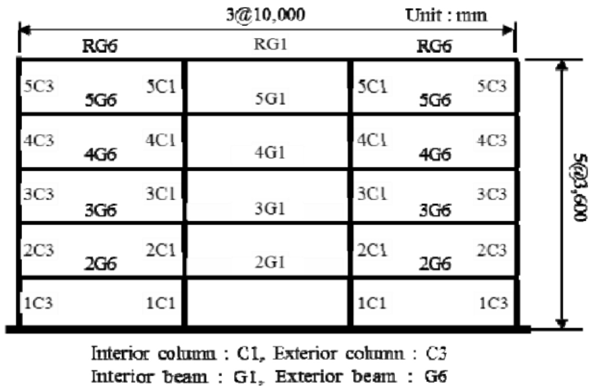

Fig. 1 Elevation and frame plan of prototype building

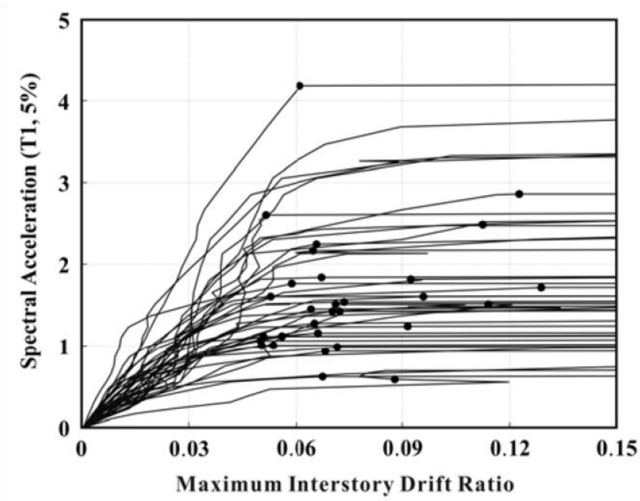

Fig. 2 Result of incremental dynamic analysis

For an analytic model, the earthquake engineering simulation software, Ruaumoko2D [4], is used. Forty recorded ground motion records provided by the FEMA-P695 [5] are imposed to the prototype building. Scaling of the seismic waves is carried out to meet the seismic intensities of the building site.

B. Result of Incremental Dynamic Analysis

An IDA method suggested by [6] is used to evaluate the seismic performance of building structures. As shown in Fig. 2, IDA results are presented as the relation between the elastic acceleration response spectrum and maximum inter-story drifts. Building collapse points are determined rules suggested by [6] that the last point on an IDA curve with tangent slope equal to 20% of the initial slope could become the collapse point.

III. Evaluation of Seismic Fragility

A. Analysis Method of Seismic Fragility

The seismic fragility curve of a building is defined as a lognormal function that describes the probability of being in or exceeding a given damage state for any earthquake intensity. The conditional probability / of being in, or exceeding, a particular damage state, *ds*, given the spectral displacement,
 is defined by

$$P \quad | \quad \Phi \quad \ln \, \underline{\quad} \qquad (1)$$

where Φ · is a function representing a probability obtaining from a standard normal distribution table, is the lognormal standard deviation of spectral displacements for the given damage state, *ds* and , is the median value of spectral displacements at which the building reaches the criteria of damage state, *ds*.

Damage states describe structural damage states for seismic loads and are classified into Slight, Moderate, Extensive, and Complete states. A capacity spectrum method is generally used to evaluate the spectral displacement, of a building. This method employs a capacity curve representing the seismic performance of a building coupled with a demand curve which expresses the seismic hazard of its site. The building response expecting under the given seismic hazard is calculated by an intersecting point of these two curves, called as the performance point.

TABLE I
Typical Drift Ratios Used to Define Median Values of Structural Damage for the RCMRFs

Drift ratio at the threshold of structural damage			
Slight	Moderate	Extensive	Complete
0.0063	0.01	0.02	0.04

B. Construction of Seismic fragility Curves Using an IDA Methodology

In this paper, seismic fragility curves are determined from the process shown in Fig. 3. Criteria of damage states (Slight, Moderate, Extensive, Complete) are decided by [7]. For a low and mid-rise reinforced concrete moment frame, damage states are classified based on inter-story drifts as shown in the Table I. The seismic fragility curves for ground motion intensities (GMIs) of 50, 100, 200, 250, 500, 1000, 2400,4800 -year return periods in Korea are evaluated to achieve the purpose of this paper. A four-step process illustrated in Fig. 3 is briefly described as follow [8].

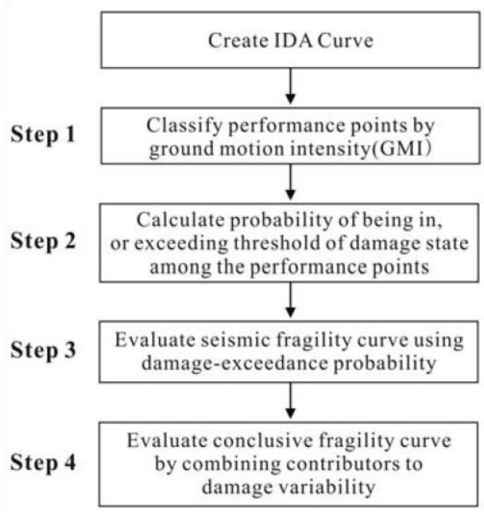

Fig. 3 Flowchart of procedure for calculating seismic fragility curve using IDA method

The performance points defining the maximum inter-story drift for each GMI are first grouped from IDA curves, as shown in Fig. 4. The classified performance points can be then reformatted into a histogram, as shown in Fig. 5. The lines drawn parallel to the y-axis represent the prescribed damage states of a prototype building. The probability of exceeding each damage state is calculated by counting cases where the performance points are exceeding each damage state. From the counts, the probability of exceeding each damage state for each GMI can be represented as Fig. 6. The points on the graph are equal to exceeding probability for four damage states and eight GMIs and are used for the fitting curves, eventually becoming seismic fragility curves. A median value of each fragility curve is equal to the inter-story drift which is most probable displacement demand for each damage state. An optimized standard deviation of a fragility curve following the lognormal cumulative distribution is calculated from the median value and points scattered on the graph. The calculated standard deviations of the studied prototype building are 0.50, 0.45, 0.34 and 0.38 for the slight, moderate, extensive and complete damage states. Finally, other variances related to uncertainties of structural modeling, estimated structural response, and determination of threshold of structural damage states should be computed to define a fragility curve. In this study, the variances are calculated from the same way adopting in the HAZUS [7]. However, the most influencing uncertainty occurring from seismic hazard is directly considered in this paper by employing the IDA methodology, which is unique and improved process over the HAZUS process using a certain value as a variance of ground motion intensities. It is noted that the IDA method is based on structural analysis results using multiple earthquake records so that the variability of ground motions has already applied to seismic fragility curve using IDA method. Variances related to a capacity curve are influenced from an analytical model, which is designed many components affecting building performance such as structural types and using the seismic design of a building. Large amount of analytical models should be required in order to consider these variances. For this reason, a lot of computation time and resources are required to exactly evaluate the variances in the IDA method. Please note that in evaluating the variance, this study adopts the same way as the HAZUS to avoid such excessive computation time and resources.

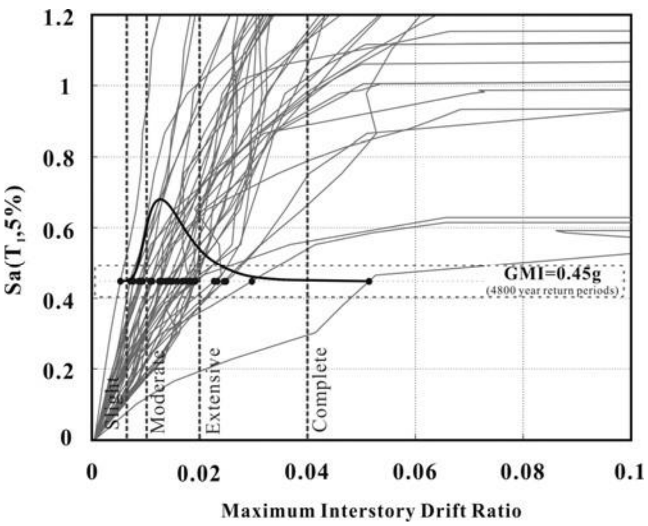

Fig. 4 Classification of performance points based on GMI

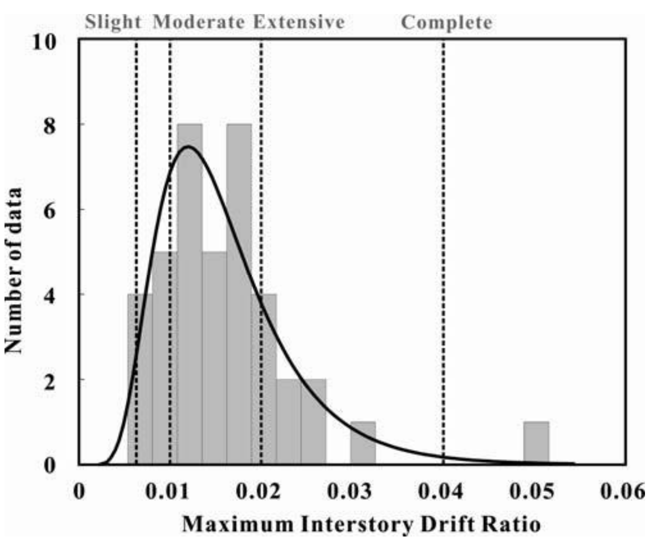

Fig. 5 Histogram of performance points in GMI=0.45g

C. Results and Discussions

In order to verify adequacy using the IDA method, the seismic fragility of the prototype building is evaluated using the CSM. The comparative results are shown in Fig. 7. The fragility curves have the same median values because both methods use the same damage criteria. However, they have different standard deviations. The standard deviations estimated by the IDA method are 0.68, 0.65, 0.58, and 0.60 while those estimated by the CSM are 0.51, 0.62, 0.65, and 0.72 for the slight, moderate, extensive and complete damage states. The reason of different standard deviations is due to the fact that the strength and stiffness degradation resulting from component damage is not specifically included in the CSM. Furthermore, the IDA method considers several realistic earthquake responses of the prototype building, such as post-yielding behavior of a building, characteristics under each mode of a building, energy dissipation capacities etc.

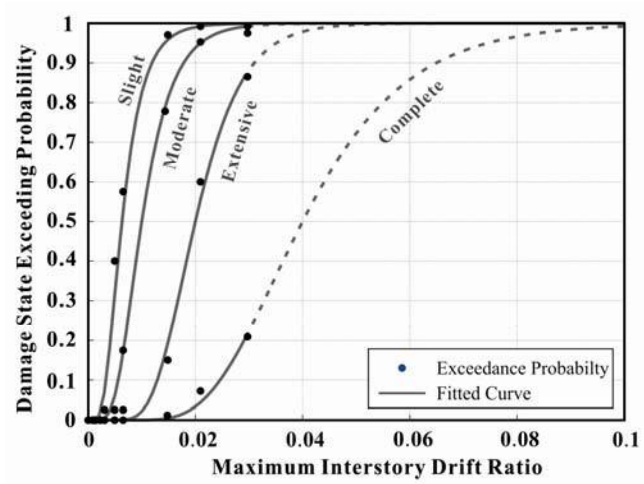

Fig. 6 Seismic fragility curve of a prototype frame

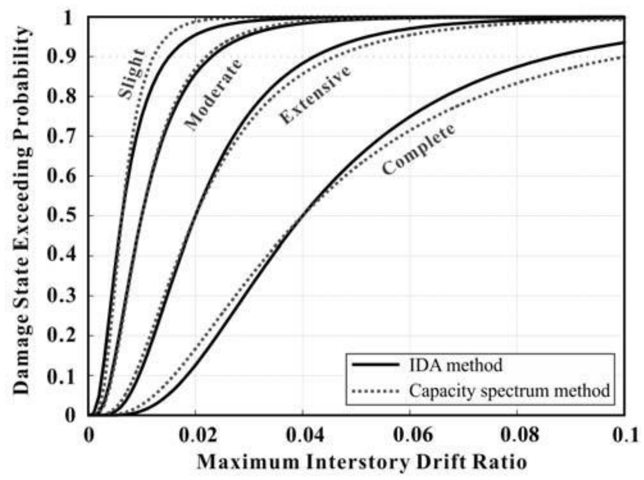

Fig. 7 Comparison of seismic fragility curve with analysis methods

IV. Conclusion

This paper proposes a procedure that can estimate the seismic fragility curves of structures based on the IDA method and comparatively investigates the seismic fragility curves using both the IDA method and the CSM. The shapes of both seismic fragility curves are similar in slight, moderate and extensive damage states. However, the fragility curves for complete damage states are different in that the IDA method presents sleeper sloped fragility curve than the CSM.

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