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Fragility curves construction for an RC frame

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ABSTRACT

The Seismic fragility curve is mainly applied to evaluate the planning of pre-earthquake disaster and recovery from post-earthquake. It provides the conditional probability of structural response to earthquake loads as a function of ground motion intensity. The traditional methods of generating fragility curves include a large number of computational models that represents the analysis of earthquake time history and inherent variation in the properties of materials of a particular building type. There are several Response surface methods available in which HDMR i.e. High Dimensional Model Representation which can express input-output relation of complex computational models.

This input-output relation can minimize the procedures of the expensive computations in problems like development of fragility curve. This technique was first applied by Unnikrishnan et al. (2012) in fragility evaluations and he demonstrated its computational efficacy compared to Monte Carlo method which is computationally intense. In this study, an HDMR response surface method is used to develop the fragility curve of an RC Frame. There are many simplified approaches which are quite easy on computational terms for fragility development of curve. Cornell et al (2002) offered such method that assumes a law model between the earthquake's intensity and damage parameters. The study showcases the Fragility Curves assessment by using HDMR and its computational efficacy with reference to one of the methods used by Cornell et al (2002).

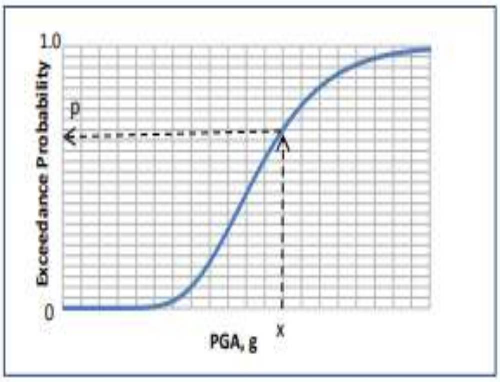
Keywords: *HDMR, Fragility Curve, Cornell's Method, Latin Hypercube Sampling, MCS, Probability of exceedance.*

1. INTRODUCTION

1.1 Fragility Curves

The vulnerability assessment of buildings is generally carried out to check the strengthening requirements of building in case of any earthquake. This assessment is done prior to the earthquake and to accomplish this the Fragility Curve Assessment is the most suitable method. It epitomizes the conditional probability which is a response to a particular structure may exceed the performance limit at a given ground motion intensity. These curves are valuable tools for the valuation of the probability of structural damage due to earthquakes as a function of ground motion indices otherwise design parameters.

Fragility curves - show the probability of failure verse us peak ground acceleration. Fig 1.1 shows a typical fragility curve with PGA along the x-axis and probability of failure along the y-axis. A point in the curve represents the probability of exceeding of the damage parameter, which can be lateral drift, storey drift, base shear etc., over the limiting value mentioned, at a given ground motion intensity parameter.



1.2 METHODS OF DEVELOPMENTS OF FRGILITY CURVES

Conventional methods for computing building fragilities are:

- Monte Carlo simulation (MCS)
- Cornell *et al.* (2002)
- Response Surface Method
- ATC-63

The most accurate solutions that can be expressed mathematically are produced by a procedure called Monte Carlo Simulation (MCS) Procedure. It a statistical simulation method that employs a sequence of random numbers to complete the simulation. The MCS procedure is quite time-consuming and expensive as it requires a large number of models to obtain a reliable evaluation of fragilities. Comell et al (2002) proposed a methodology proposed a methodology to characterize the fragility function as the probability of exceedance of the designated Engineering Demand Parameter (EDP) for a selected physical limit state (DS) for a particular ground motion intensity quota (IM). Fragility curve reaching a specified damage state or more is represented as a function of that particular demand.

1.3 OBJECTIVES OF THE STUDY

The main objectives of the current study have been quoted as follows:

- Using High Dimensional Model Representation (HDMR) response surface method to develop fragility function for a typical RC frame.
- To develop fragility functions as per the method proposed by Cornell *et al.* (2002) for the same frame.
- Studying the Fragility curves development using HDMR and its computational efficiency with reference to the one using the method suggested by Cornell *et al* (2002).

1.4 SCOPE OF WORK

The present study is limited to a single RC plane frame without a shear wall, basement, and plinth beam. The stiffness and strength of Infill walls are not considered. The Soil structure interface effects are not taken into account in the study. The flexibility of floor diaphragms is ignored and is considered as a stiff diaphragm. The column bases are assumed to be fixed in the study. Open Sees platform (McKenna *et al.,* 2000) is used in the present study to implement the simulation of a large number of computational models for fragility evaluation. The nonlinearity in the material properties is modeled using fiber models available in Open Sees platform.

This study is related to RC Plane Frame without shear wall and plinth beam. The Soil-Structure Interface effects and wall's stiffness and strength infill are not considered. Also, the flexibility of floor diaphragm is considered as the stiff diaphragm and the bases of columns assumed to be fixed. Open Sees platform (McKenna *et al.,* 2000) is used in the study to implement the simulation of a large number of computational models for fragility evaluation. The nonlinearity in the material properties is modeled using fiber models available in Open Sees platform.

2. LITERATURE REVIEW

2.1 INTRODUCTION

The study implies a detailed literature review on various conventional methods which are involved in fragility curve development like Monte Carlo Simulation, method proposed by Cornell *et al.* (2002), Response Surface Method Latin Hypercube Sampling, etc. In the latter part, a general review of High Dimensional Model Representation HDMR technique and its application in Fragility curve evaluation are also discussed.

2.2 FRAGILITY ANALYSIS

Tantala and Deodatis (2002) considered a reinforced 25 storey moment resisting structure with three bays. The time histories of scholastic procedures were used and the Fragility curves are developed for a wide series of ground motion intensities. The nonlinear analysis was done by taking into account the P-Δ effects and ignoring soil-structure collaboration. The nonlinearity in the material properties in the model was achieved with nonlinear rotational springs. For Ground motion Monte Carlo Simulation is used and the duration for simulations was done at 2^{nd}, 7^{th} and 12^{th} seconds in order to observe the effects. DRAIN-2D used as a dynamic analysis tool with in elastic time history data. The arbitrary material strengths for every beam and column were simulated using Latin Hypercube sampling.

2.3 Methodology of HDMR in Fragility Evaluation

The principal step in the computation of the seismic fragility curves using HDMR is the definition of the input and output variables. Seismic intensity parameter is also defined and used as an input variable. To recognize the damage states, depending upon the type of structure being considered, Base Shear, Maximum Roof displacement, Peak interstorey drift, Damage indices, Ductility ratio and Energy dissipation capacity can be used.

In the above study by Unnikrishnan *et al.* (2012) two cases namely Spring-Mass system and RC plane frame were considered and fragility curves were obtained. In the Spring-Mass system stiffness, Mass and Sa (spectral acceleration) were considered as input variables. For the RC plane frame Compressive strength and Modulus of elasticity of concrete, Yield strength of steel and Sa were the input variables.

Various combinations of input variables were generated, which represents different earthquake-structure circumstances and the sampling points of the HDMR.

The definition of input and output variables is the principle step in the computation of seismic fragility curves using HDMR wherein the Seismic intensity parameter is also defined. Depending upon the type of structure, Base Shear, Maximum Roof displacement, Peak interstorey drift, Damage indices, Ductility ratio and Energy dissipation capacity can be used to recognize the damage states.

Unnikrishnan *et al.* (2012), in relation to the above study, considered two cases viz. Spring-Mass system and RC plane frame and obtained the fragility curves. In the Spring-Mass system stiffness, Mass and Sa (spectral acceleration) were considered as input variables. For the RC plane frame Compressive strength and Modulus of elasticity of concrete, Yield strength of steel and Sa were the input variables. Numerous combinations of input variables were generated, that represents different earthquake-structure circumstances and the sampling points of the HDMR.

3. DEVELOPMENT OF FRAGILITY CURVES USING HDMR

3.1 GENERAL

In this chapter, the main focus is on the development of Fragility curves using the HDMR methodology. The study considers the ground motion data, limit states, uncertainties in material properties and finally fragility evaluation. For the study, the peak ground acceleration is taken as the seismic intensity measure and the roof displacement is considered as the engineering demand parameter for generation of fragility curves for different performance levels

3.2 DESCRIPTION OF THE STRUCTURE

An RC frame having six stories and three bays is considered in this study. It is designed according to IS 456-2000 using M20 concrete and Fe415 steel. In Figure 3.1 we can find the details of the building elevation and reinforcement details of beams and columns. The frame is having a storey height of 3.6 m and bay width of 5 m. The base of the frame is considered as fixed. In addition to self-weights of beams and columns, the dead load (due to slabs and infill walls) and live loads prescribed for all beams are 35 kN/m and 15 kN/m respectively.

3.3 EARTHQUAKE GROUND MOTIONS

By using 44 scaled earthquake records the Randomness in ground motion is taken into account. The ground motion data is taken from the work done by Haselton *et al. (*2007) a general far-field ground motion set was established for use in structural analyses and performance valuation. 22 pairs of motions that cover the FEMA P695 (ATC-63) far-field ground motion set details of which are given in Table 3.2. This 22 pairs (44 components) of ground motions are used in this study.

Table 3.2 Details of Earthquake records considered as per FEMA P695 (ATC-63)

Sl No	Magnitude	Year	Event	Fault type	Station name	Vs_30 (m/s)
1	6.7	1994	Northridge	Blind thrust	Beverly Hills - 14145 Mulhol	356
2	6.7	1994	Northridge	Blind thrust	Canyon Country - W Lost Cany	309
3	7.1	1999	Duzce, Turkey	Strike-slip	Bolu	326
4	7.1	1999	Hector Mine	Strike-slip	Hector	685
5	6.5	1979	Imperial Valley	Strike-slip	Delta	275
6	6.5	1979	Imperial Valley	Strike-slip	El Centro Array #11	196
7	6.9	1995	Kobe, Japan	Strike-slip	Nishi-Akashi	609
8	6.9	1995	Kobe, Japan	Strike-slip	Shin-Osaka	256
9	7.5	1999	Kocaeli, Turkey	Strike-slip	Duzce	276
10	7.5	1999	Kocaeli, Turkey	Strike-slip	Arcelik	523
11	7.3	1992	Landers	Strike-slip	Yermo Fire Station	354
12	7.3	1992	Landers	Strike-slip	Coolwater	271
13	6.9	1989	Loma Prieta	Strike-slip	Capitola	289
14	6.9	1989	Loma Prieta	Strike-slip	Gilroy Array #3	350
15	7.4	1990	Manjil, Iran	Strike-slip	Abbar	724
16	6.5	1987	Superstition Hills	Strike-slip	El Centro Imp. Co. Cent	192
17	6.5	1987	Superstition Hills	Strike-slip	Poe Road (temp)	208
18	7	1992	Cape Mendocino	Thrust	Rio Dell Overpass - FF	312
19	7.6	1999	Chi-Chi, Taiwan	Thrust	CHY101	259
20	7.6	1999	Chi-Chi, Taiwan	Thrust	TCU045	705
21	6.6	1971	San Fernando	Thrust	LA - Hollywood Stor FF	316
22	6.5	1976	Friuli, Italy	Thrust-part blind	Tolmezzo	425

3.4 FAILURE CRITERIA AND PERFORMANCE LIMITS

The roof displacement as often preferred by many researchers to be taken as criteria of failure because of ease and convenience associated with its evaluation. The limit states considered are in accordance with Federal Emergency Management Agency (FEMA) 356. The limit states associated with various performance levels of reinforced concrete frames is given in Figure 3.2 and Table 3.3 (FEMA 356, 2000).

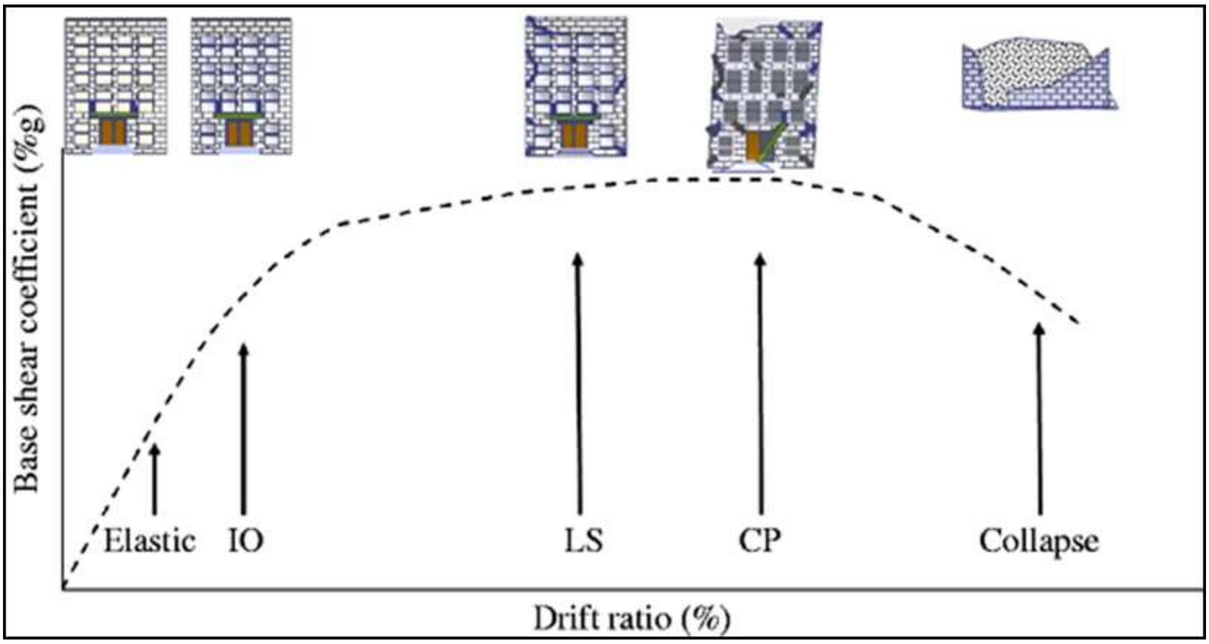


Figure 3.4 Damage states of a representative building pushed to failure (FEMA356)

3.5.1 Convergence Study

The determination of an optimum number of simulations to yield a reasonably accurate probability of failure in MCS is carried out by estimating the probability of exceedance for various numbers of simulations ranging from 10 to 100000. This procedure is repeated for arbitrary PGA values such as 0.2g, 0.55g, and 1g. The variation of a number of simulations and the probability of exceedance for these cases are shown in Figures 3.4a, 3.4b, and 3.4c. It is found that 10000 simulations are appropriate for the convergence.

3.5.2 Monte Carlo Simulation of the Metamodel

The corresponding response (roof displacement) is calculated on the basis of Monte Carlo simulation which is performed successively on the overall Metamodel, by arbitrarily generating 10000 values for input variables and the probability of exceedance for each PGA is calculated by dividing the number of cases exceeding the limiting response value by the total number of simulations (10000). The fragility curve is obtained by joining the points represented by the probability of exceedance for each PGA. This procedure is repeated for all the limit states values given in Table 3.2.

4. SUMMARY AND CONCLUSIONS

4.1 SUMMARY

Fragility curves are a useful representation of the conditional probability of structural response when subjected to earthquake loads as a function of ground motion intensity. It plays a significant role in the pre-and post-earthquake damage and assessment of loss to the design makers. Fragility Generation curves in conventional methods include earthquake simulation of a large number of computational models that represent the inherent variation in the material properties of a particular building type to obtain an accurate and reliable estimate of the probability of exceedance of the chosen damage parameter. The method that can express input-output relations of complex computational models is High Dimensional Model Representation (HDMR) method. This input-output relation can reduce the number of iterations of expensive computations especially in problems like fragility curve development. Unnikrishnan *et al.* (2011) was the first scholar to implement this HDMR method in Fragility curve development. In this study, fragility curve of an RC frame is developed using three-point sampling HDMR response surface method considering the first two terms of the generalized HDMR input-output relation. Cornell *et.al.* (2002) proposed the most popular and simplified approaches for fragility curve development. This method assumes a power law model between the damage parameter and intensity measure of the earthquake. The aim of the present study is to develop the fragility curve for an RC frame applying HDMR expansion and study the relative computational efficiency and accuracy with reference to the one proposed by Cornell (2002). The conclusions obtained from the study, limitations of the present work and the future scopes of this research are quoted in this chapter.

4.2 CONCLUSIONS

The following are the major conclusions that are reached from the studies conducted:

4.2.1 HDMR method of Fragility Evaluation

- Computational efficiency with reference to Monte Carlo Simulation
- Time History analysis of one model for 44 earthquake data takes about 5 hours for the considered plane frame.
- If Monte Carlo simulation is used for the evaluation of fragility curve a minimum of 10,000-time history analysis is to be performed.
- In HDMR 3-point sampling method, only 9 Time History analysis was done to obtain the metamodel, on which Monte Carlo simulation was done using the metamodel (generating 10,000 random values for the input variables), which takes only a few minutes.
- The time consumption is reduced by about 99.9% compared to MCS when HDMR is used.
- The metamodel is a polynomial function that relates roof displacement (damage parameter) with the random variables defining the frame. The metamodel provides the dependency of damage parameter on each of the random variables. Higher the value of the coefficient of the random variable higher will be.