DEVELOPMENT OF ANALYTICAL FRAGILITY CURVE – A REVIEW

Rony Joy[1], Dr. CK Prasad Varma Thampan.[2]

[1]PG Student, Department of Civil Engineering, NSS College of Engineering, Palakkad, India
[2]Professor, Department of Civil Engineering, NSS College of Engineering, Palakkad, India

---

Abstract - *In recent years, substantial quantity of study has been carried out so as to evaluate vulnerability of building during a seismic event. Seismic vulnerability analysis is a fertile area of research which needs a lot of input from seismologists and engineers. Fragility curve is a statistical tool developed for the vulnerability assessment in several field .The seismic fragility of a structure is the probability of failure for a given seismic hazard level. It's measured as the probability of exceedance of a specific limit state of the selected (DM) damage measure for a given (IM) intensity measure. Over the last couple of years, the incremental dynamic analysis or 'IDA' has become the popular alternative for developing the seismic fragility curves for a given structure. An IDA consists of a series of nonlinear time-history analysis of the mathematical model of a structure subjected to incremented intensity measures of a ground acceleration data. A multi-IDA, where a large number of ground acceleration records are used to obtain multiple IM vs. DM 'IDA curves', are generally used in a seismic fragility analysis. For a specific IM, the variation in DM are treated as random samples in calculating fragility. Typically, log-normal distributions are used to model the distribution of DM at every hazard level. The parameters of those lognormal distributions vary over hazard levels. Fragility curves are obtained from the multi-IDA data, using the traditional fitting technique.*

Key Words: Fragility Curve, Incremental Dynamic Analysis, Vulnerability Assessment, Non Linear Response History Analysis, Intensity Measure, Damage Measure.

1 INTRODUCTION

Recent studies shows that structural performance of Reinforced Concrete (RC) buildings always play crucial roles in terms of earthquake losses. Structures already built are vulnerable to future earthquakes. Damage to structures cause deaths, injuries, economic losses. Earthquake risk is associated with seismic hazard, vulnerability of building, exposure. Seismic risk measures the likely ground movement that can happen at site. Tools specifically defined for crisis administration and seismic danger moderation arrangements must be defined. Vulnerability Index and Fragility Curves are two such tools which are used, to study the vulnerability and possible retrofitting for building typologies.

Vulnerability assessment reveals the damageability of a structure under varying ground motion intensities. Vulnerability can be outlined as the sensitivity of the exposure to seismic hazard. The vulnerability of an element is usually expressed as a percent loss for a given seismic intensity level. The aim of a vulnerability assessment is to obtain the probability of a given level of damage for a given building type due to scenario earthquake. Vulnerability of structures to ground motion effects is usually expressed in terms of fragility curves or damage functions that take into account the uncertainties in the seismic demand and structures capacity. Fragility curve is a statistical tool developed for the vulnerability assessment in different field. The outcome of this assessment can be used in loss estimation which is essential in disaster mitigation emergency preparedness.

The main objectives of this paper is to review the step by step procedure to develop the analytical fragility curve to evaluate the seismic vulnerability of a structure. Additionally this paper is meant to give an insight into the Incremental Dynamic Analysis which help in predicting seismic structural capacity level of structure and better understanding of the structural behavior under strong ground motion levels.

2 THEORETICAL BACKGROUND

Earthquakes cause economic losses apart from the torturous pain of loss of lives. Seismic risk assessment is the first step within the disaster prevention strategy and in reducing the associated risks of infrastructures. The comprehensive study of seismic risk are often divided into 3 components- Hazard, Vulnerability and Exposure. Hazard is that the event capable of inflicting harm whereas Vulnerability represents the degree of loss of a component ensuing from a hazard. Exposure is that the amount of parts (population, the economic activities, and therefore the constructions and structures) exposed to a hazard. It's well understood that it's not the earthquake that kills however the failure of the buildings exposed to those earthquakes. So understanding the behaviour of the buildings throughout Earthquake may be a growing space of research. Assessing the vulnerability of the structures as seismic performance are often useful for risk mitigation and emergency response coming up with.

2.1 Fragility Curve

A fragility analysis is an effective tool for vulnerability assessment of structural systems. The fragility curve, which is developed from the behavior model of structure, capacity and a suite of ground motions, is a graphical representation of the seismic vulnerability of a structure. Fragility curves can be developed either for a specific system or component for a class of systems and components. Fragility curves provide the likelihood of surpassing a given damage state as a function of an engineering demand parameter that represents the ground motion. That is, it is the graph of intensity measure (IM on X axis) and % of damage on Y axis. In this work, the maximum inter-story drift ratio of the structure has been considered as a damage measure (DM) and 5% damped first mode spectral acceleration as an intensity measure (IM).

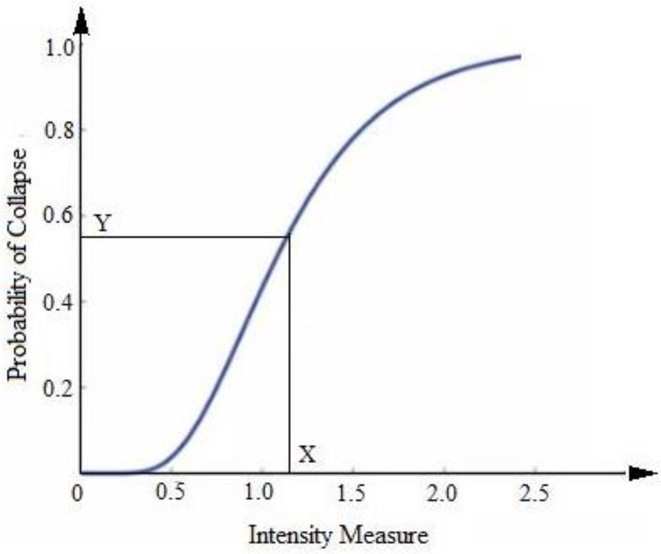

Fig. 1. Fragility Curve

Fragility curves are functions that describe the probability of failure, conditioned on the full range of loads to which structure might be exposed. Fig 1 shows a typical fragility curve with IM along the x-axis and probability of failure along y-axis. Each point in the curve represents the probability of exceedance of the damage parameter, which can be storey drift, lateral drift, base shear, etc., over the predefined limiting value, at a given ground motion intensity parameter. For an IM of say = x, the fragility curve gives the corresponding probability of exceedance of limiting damage parameter as = p%'. It can be interpreted that if 100 earthquakes of IM = x occur, p times the damage parameter will exceed the limiting value for which the fragility curve is developed. The information can be used to analyze, evaluate and improve the seismic performance of both non-structural and structural elements.

2.2 Analysis

To develop the analytical fragility curve it is required to carry out Incremental Dynamic Analysis (IDA). Incremental Dynamic Analysis (IDA) is a parametric structural analysis approach that has proposed to predict seismic behavior of structures under strong ground motion. IDA is able to estimate limit-state capacity and seismic demand by executing a series of nonlinear time history analyses under a suite of multiple scaled ground motion records. Selected ground motion intensity, for evaluating seismic capacity, is incrementally increased until structural capacity reach to the global collapse. Vamvatsikos (2002) states that IDA has significant potential and is not just a solution for performance based earthquake engineering. In other words, it has the capability to extend far beyond that and give more accurate prediction about structural behavior under seismic load to researchers. IDA method basically takes the old concept of scaling ground motion records and develops it into a way to accurately describe the full range of structural behavior, from elasticity to collapse. IDA is widely applicable method and a multi-purpose tool for assessing structural performance which can accurately predict the responses of structures under a wide range of intensities.

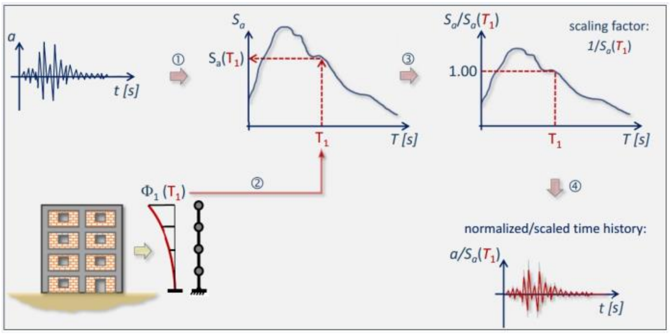

Fig. 2: IDA – Procedure (NORSAR)

IDA is one of the well-known approaches to evaluate the structural performance level under a suite of seismic ground motions. IDA is able to estimate limit-state capacity and seismic demand by performing a series of nonlinear time history analyses under a suite of multiple scaled accelerogram records of earthquake ground motion acceleration. In IDA method, the intensity of selected ground motion is incrementally increased until the intended limit state seismic capacity of the global structural system is achieved. Besides, it contains plotting an intensity measure (i.e. first mode spectral acceleration, Sa) versus a damage measure (maximum inter-story drift ratio). Moreover, fragility curves can be derived by IDA method which the demonstrate expected damage in terms of Collapse Prevention, Life Safety and immediate occupancy as a function of the chosen ground motion intensity.

The main objectives of IDA method are summarized below,

- Better understanding of the structural behavior under strong ground motion levels.
- Predicting the seismic structural capacity level of the structure.
- Understanding the range of response or demands against the range of potential levels of a ground motion record.
- Illustrate the dispersion of the structural response nature within increasing of seismic ground motion intensity.
- Derive a multi-record IDA curve to demonstrate stability and variability of different seismic ground motion records.

3 LITERATURE REVIEW

Various literature reviewed on fragility assessment is presented in this section. A number of works have been performed on seismic vulnerability assessment A review of literatures is presented in brief summarizing the work done by different scholars and researchers on development of fragility curves for building structures.

Shome N, Cornell C. A. (2000), in their conference paper presented the criteria for selection of earthquake. Also suggested different technique for normalizing or scaling the accelerograms data for nonlinear time history analysis. Scaling can be done based on PGA or based on Ist mode pseudospectral acceleration for damping equal to 5% and it was concluded that the latter is an efficient choice for the medium-rise structures since it provides a proper estimate of seismic demand and capacity of the building, and minimizes the scatter in the results. Minimum no of earthquake required to carry out nonlinear time history analysis effects the stability capacity estimates. These ideas were clearly explained in this paper. Recorded motions are selected from a bin of recorded motions such as the Pacific Earthquake Engineering Research center (PEER NGA database), Consortium of organization for Strong Motion Observation System (COSMOS) or K-NET.

FEMA-356 (2000) is intended to serve as a nationally applicable tool for design professionals, code officials, and building owners undertaking the seismic repair and rehabilitation of existing buildings. The procedures contained in this standard are specifically applicable to the rehabilitation of existing buildings and are, in general, more appropriate for that purpose than are new building codes. Advancement of present-generation performance-based seismic design procedures is widely recognized in the earthquake engineering community as an essential next step in the nation's drive to develop resilient, loss-resistant communities. This document provides different Seismic performance levels of buildings for structural and Non-structural components in detail. The performance levels like Immediate Occupancy, Life Safety, and Collapse Prevention are clearly outlined in this document. It also gives different analysis procedures used for Seismic rehabilitation of buildings.

Vamvatsikos D, & Cornell, C. A (2002) explained the importance of incremental dynamic analysis and procedure to conduct the same. IDA is a method that estimates the seismic behavior of structure by specifying performance limit-states for a specified structure at a selected site. It fundamentally takes the old concept of scaling accelerogram records and use it in such a way that estimate precisely the full range of structural behavior, from elasticity to collapse. This method helps in predicting the seismic structural capacity level of the structure. This method was further developed and was used for seismic vulnerability assessment of the structures and the procedure for the same was also presented in the paper.

Murat and Polat et al. (2006) established the fragility curves for mid-rise RC frame buildings located in Istanbul and investigated the effect due to the number of stories of the building on fragility constraints. To study this effect buildings with 3, 5 and 7 story were designed according to the Turkish seismic design code. IDA using twelve artificial ground motions were applied to these sample building and fragility curves were developed considering a lognormal distribution for the IDA result. Also the regression analysis was carried out between fragility parameters and the number of stories of the building. It was found that fragility parameters change widely due to the number of stories of the building. Finally, the maximum allowable inter-story drift ratio and spectral displacement values that satisfy the immediate occupancy and collapse prevention performance level requirements were estimated using obtained fragility curves and statistical methods

Guneyisi and Altay (2008) detected the behaviour of already existing Reinforced Concrete (RC) office structures through fragility plots considering the circumstances as before and after retrofitted by liquid viscous (VS) dampers The 3- dimensional analytical model of the RC building was created in ETABS version 7.2 Structural Analysis Program for the analysis. The seismic reaction of the buildings was obtained by the nonlinear dynamic analysis with pushover investigation. The fragility curves were made for four damage conditions which are slight, moderate, major, and collapse states. The fragility curve produced for the structure showed that the chance of failure on building has found to be minimized with the aid of retrofitting.

Jack W Baker (2011) presented the methodology to develop the observed and the theoretical fragility curves. This paper put forward a maximum likelihood estimation technique, as a statistically rigorous method for fitting collapse fragility function from multiple stripe analysis or incremental dynamic analysis. This facilitate efficient estimation of collapse fragility function while limiting the required number of ground motion and structural analysis. Thus this technique can reduce the time required in this entire process. The fragility fitting technique is easily implemented in Matlab or Excel and example codes using both software packages are provided.

Aiswarya S and Nandita Mohan (2014) conducted study on the flat slab system subjected to different ground motions and developed the fragility curve based on the pre-defined damage state. Twenty five artificial ground motions were selected from the PEER ground motion database and were applied to these sample building. Fragility curves were developed by considering the damage states from FEMA 356(2000).From this they concluded that flat slab systems are more vulnerable to seismic hazard because of their insufficient lateral resistance and undesired performance at high levels of seismic demand. Based on this they proposed the retrofitting technique like inclusion of shear wall. The fragility curve developed for retrofitted building was then compared with that of the unretrofitted building and concluded that the addition of shear wall has improved the seismic response of the building.

Suraj V. Borele (2015). This paper dictates the methodology for the generation of fragility curve which is the graphical representation of the seismic risk of a structure. In this study the fragility curves were developed based on the, guidelines given by HAZUS technical manual. Two and four storey RC frame building was selected for the case study and their seismic behaviour with and without infill was taken into consideration. The infill wall was modeled as an equivalent diagonal strut and the width of the struts for each infill panel is evaluated by using the guidelines given in FEMA 356. The RC buildings was modelled and analyzed using SAP2000 v14 and the design was based on IS 456:2000 and IS 1893(Part 1):2002. Static Non-linear analysis or Pushover analysis of the building models was carried out capacity curves were developed from this. The results of the capacity curve were used to plot the fragility curve. The fragility curves developed from this study were used to compare the seismic performance of the building models

Vazurkar U. Y and Chaudhari, D. J (2016). This paper details the vulnerability assessment of reinforced concrete buildings using fragility curves. Fragility curve describes the probability of damage being exceeded a particular damage state. In this study the fragility curves were developed based on the, guidelines given by HAZUS technical manual. The RC buildings was modelled and analyzed using SAP2000 v14. Non-linear static analysis procedure is used for the analysis of RC buildings. The pushover analysis was carried out as per the guidelines given in ATC40. Pushover analysis was conducted and the capacity curve was plotted. Results obtained from pushover analysis are used for plotting the fragility curves. For plotting the Fragility Curves Spectral Displacement were considered as the ground motion parameter. The damage states were described as per the HAZUS technical manual. Finally, based on the obtained fragility curves the spectral displacement values that satisfy the predefined performance level requirements were estimated. These plotted fragility curves were used to study the seismic performance of building models.

4 SUMMARY AND CONCLUSION

A brief review of several literatures presented shows that fragility curve proves to be efficient tool for studying the vulnerability of the structure. Seismic fragility analysis of structures using data from multi-IDA provides a very practical approach. Since the proposed method involves more computation for multiple limit states based fragility estimations, a modified version can thus be a area for further study. The modified method, while reducing computational costs to the level of the method practiced currently, should provide better estimates of fragility at all limit states. There is future scope for further study in this area

REFERENCES

[1] FEMA. *Prestandard and commentary for the seismic rehabilitation of buildings*. *Report No. FEMA-356*, SAC Joint Venture, Federal Emergency Management Agency, Washington DC, 2000

[2] Marco Vona, " Fragility Curves of Existing reinforced concrete Buildings Based on Specific Structural Performance Levels" *Open Journal of Civil Engineering*, pp. , 120-134, August 2014

[3] PEER. (2010). *Technical Report for the Ground Motion Database web.* California Pacific Earthquake Engineering Research Center.

http://peer.berkeley.edu/peerground_motion_database

[4] S Aiswarya, Nandita Mohan, "Vulnerability analysis by the development of fragility curves," *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE),* pp. 33-40, May 2014

[5] Shome N, Cornell CA. Normalization and scaling accelerograms for nonlinear structural analysis. *Proceedings of the 6th U.S. National Conference on Earthquake Engineering*, paper 243. EERI, El Cerrito, CA: Seattle, Washington 1998; 1–12

[6] Shome, N., & Cornell, C. A. (1999). Probabilistic seismic demand analysis of nonlinear structures. *Report No. RMS-35, RMS Program, Stanford University, Stanford*,

http://pitch.stanford.edu/rmsweb/Thesis/NileshShom.pdf..

[7] Suraj V. Borele, "Damage assessment of structural system using fragility curves" *Journal of Civil Engineering and Environmental Technology,* vol 2, pp. 72- 76, June 2015

[8] Vazurkar U. Y and Chaudhari, D. J, "Development of Fragility Curves for RC Buildings" *International Journal of Engineering Research,* vol 5, pp. 591- 594, February 2016

[9] Vamvatsikos, D., & Cornell, C. (2002). Incremental dynamic analysis. Submitted to Earthquake Engineering and Structural Dynamics, John Wiley & Sons, Ltd