A REVIEW ON EARTHQUAKE VULNERABILITY ASSESSMENT

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Abstract – *Majority of human beings live in earthquake prone areas. Earthquake causes significant loss of life and damage of property every year. It is required to identify the damage of a structure caused due to varying ground motion intensities. This identification results will help an engineer to take necessary action against the after-effects of an earthquake. The vulnerability of a structure has to be found out under various ground motion intensity measures (IM) such as Peak Ground Acceleration (PGA). From this, fragility curves can be developed. Fragility analysis is a probabilistic approach, which is commonly used now-a-days. As per this method, different Damage states (DS) have to be defined and then probable damage of the structure in connection with the IM can be found. Fragility curves are generated from multiple Incremental Dynamic Analysis or IDA curves with the help of traditional curve fitting technique.*

*Key Words***:** Fragility curve, Incremental Dynamic Analysis, Base isolation, Non linear dynamic analysis, Damage state.

1. INTRODUCTION

Earthquakes are one of the most hazardous natural disasters that attack human and cause large damages especially in regions which is defined as high-seismic zone by geologists. Majority of human beings live in earthquake prone areas. Various seismic analysis approaches were proposed including both static and dynamic methods. Although seismology has been continuously advancing during the century, it is impossible to predict future earthquakes' severity and time of attacking. Therefore previous earthquake data are still widely used to analyze buildings resulting in buildings for future earthquakes. Already constructed buildings may collapse under future earthquakes.

Due to the difficulties in predicting earthquakes and its random nature, various probabilistic analyses were proposed in analyzing building seismic responses. In addition to uncertainties in seismic loads, uncertainties associated with building material, design process, building geometry, and construction will also lead to the use of probability to predict building responses.

Fragility analysis is a probabilistic method which shows the probability of exceeding a certain damage level. This technique is commonly used in order to evaluate the earthquake vulnerability assessment of various structures. Fragility curve is a statistical tool used for the vulnerability

assessment and it gives the probability of building damage level under different ground motion intensities. This assessment is generally used in disaster mitigation fields.

The main objective of this paper is to review the development of fragility curve, especially analytical, to study earthquake vulnerability of a structure. Also this paper gives an overview about IDA which is used to analyze the behavior of structure under various ground motion intensities.

2. THEORETICAL BACKGROUND

Earthquake effects of general type buildings are predicted with the help of some functions such as loss and damage functions. But these functions may not be useful for some kind of specific buildings. The development of the above mentioned functions are easy only if the user is an engineer experienced in non- linear analysis field. In disaster mitigation field, user must create various functions that can be used for both specific and individual type buildings.

2.1 Fragility Curve

A fragility analysis is widely used for hazard assessment and earthquake vulnerability assessment of various structures . The fragility curve is a statistical tool showing the probability of exceeding certain damage state as a function of intensity measure(IM). It is developed from multiple IDA curves. Commonly used IMs are Spectral acceleration (Sa), Spectral displacement (Sd), Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV) etc. Figure 1 shows a typical fragility curve with PGA along x-axis and probability of failure along y-axis. A point in the curve represents the exceeding probability of damage state at a given intensity measure. These damage states can be lateral drift, base shear, story drift etc. The function, which is used to generate fragility curve for a building, is generally found to be log-normal functions.

2.2 Incremental Dynamic Analysis (IDA)

IDA is a computational analysis method of earthquake engineering to study the behavior of structure under seismic loads. Simulated building seismic responses obtained from IDA are represented by IDA curves that require a series of non- linear time history analysis with a suite of ground motions, during which the ground motion
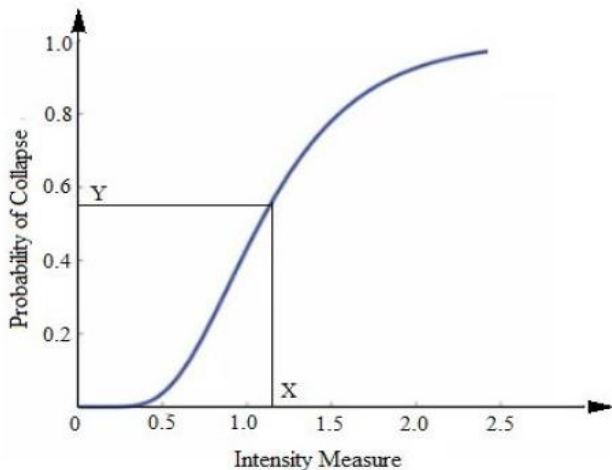
Fig. 1: Fragility Curve

intensities are increased using a specified scale factors. Therefore, IDA provides the building's seismic behaviour for the whole range from elastic to collapse.

Three steps were used to perform IDA and develop IDA curves, namely, pre- process, process and post- process as described below.

Pre- process:

1. Create a dynamic structural model for RC buildings.
2. Select a suite of ground motion records.
3. Scale all ground motion records to a defined design spectrum for a location where structure is located to yield comparable IDA curves.
4. Choose an incremental scale factor step.

Process:

1. Perform non- linear time history analysis for each ground motion multiplied by first step of scale factor.
2. Increase ground motion intensity through scale factor.
3. Analysis is repeated until the structure has collapsed.

Post- process:

1. Choose IM and DS.
2. Plot IDA curve by interpolating the results of IM and DS for each ground motion.
3. Define different limit states for each IDA curve.
4. Plot fragility curve for all determined limit states in order to calculate probability of reaching specific limit states.

3. LITERATURE REVIEW

Few studies have been conducted in the field of earthquake vulnerability assessment and base isolation. A brief review of those papers is presented here.

Vamvatsikos. D & Cornell C. A (2002) explained the need of incremental dynamic analysis in the field of vulnerability assessment and its procedure. IDA is a parametric analysis which predicts complete structural responses and performances. In this analysis, a properly defined structural model is subjected to a suite of ground motion records and the intensity of these ground motions are gradually increased using scale factors. In the end, a number of curves depicting the parameterized responses versus the ground motion intensity levels are produced. IDA performs a huge number of non-linear time history analyses. For example, a complete IDA may have 20 or more ground motion pairs and each is scaled to 12 levels leading to 20x12 = 240 times non-linear time history analyses. Although it takes a long time to perform IDA, it can provide the whole range of structural responses from elastic to collapse. IDA is mainly used for finding out the seismic structural capacity of a building.

Murat Serdar Kircil & Zekeriya Polat (2006) explained the analysis of fragility on a mid-rise RC frame buildings situated in Istanbul. Turkish seismic design code is used to design the sample buildings. Sample buildings include 3, 5 and 7 story buildings. 12 artificial ground motions were considered for doing Incremental dynamic analyses. After the analysis, both yielding and collapse capacity of those sample buildings were found out. With the help of above mentioned capacities, fragility curves were developed. Then the maximum allowable inter-story drift ratio and spectral displacement were estimated which satisfy the "immediate occupancy" and "collapse prevention" requirements. A better relation is obtained between number of stories and spectral displacement in the case of collapse prevention performance level. However, the same observation is not valid for the immediate occupancy level.

Nikolay & Ryan (2008) carried out a concept demonstration of friction pendulum bearing system with the help of lab setups. Single degrees of freedom systems with and without base isolation are considered for the study. The free and forced vibrations responses are noted using the accelerometers. The testing is carried out on a Shake Table. The results showed that the model with Friction Pendulum Bearing system had a drastic lowering in lateral acceleration due to varying lateral forces. In general, the base isolated system's dynamic response is found to be much better than the other.

Amiri Hormozak. E (2013) explained different methodologies developed to show fragility relationship between IM and the building responses. These methodologies are classified into four types which are experiential, analytical, empirical, and hybrid fragility curves. The experiential fragility curves are developed based on the opinion or expert data collected from people when there was not sufficient data to predict the probability of the building damage due to earthquake. Empirical fragility curves are constructed based on field observations. The process for developing an empirical fragility curve starts after an earthquake and then damage data are collected. With these data and shake map which shows ground motion intensity distribution, damage probability matrices can be developed.

Analytical fragility curve is more common than the other curves which use numerical simulation to predict damage distributions. For complex buildings, analytical method is adopted to create fragility curves. Hybrid fragility curve is developed based on a combination of experiential, empirical and analytical method and it gives more realistic fragility curve.

Luigi Petti et al (2013) investigated seismic behavior of base isolated structures with friction pendulum slide bearings devices subjected to near fault events characterized by significant vertical ground motion components. They have studied the effects of vertical components on seismic response using non-linear dynamic analysis by considering two near-fault seismic events. The results showed that the base shear increases linearly with vertical seismic motion. But the relative displacements are not highly influenced by the vertical ground motion.

Chandak. N. R (2013) was presented a work related to the effect of base isolation on the response of RC Building. The six storey building is analyzed with rubber isolating device and by providing friction pendulum isolation device at its base. The analysis was done by using response spectrum analysis. Here, the design spectra recommended by Indian Standard Code IS 1893-2002 (part-I) and Euro Code 8 are considered for comparison. The main objective of this study is to investigate the differences caused by the use of different codes in the dynamic analysis of multistoried RC building along with fixed and isolated base condition. Two different floor plans that are symmetric (SB) and unsymmetric (UB) with torsional irregularity are taken as sample building. To evaluate the seismic response of the buildings, elastic analysis is performed using the computer program SAP2000. Results obtained from the work showed that there is reduction of base shear, storey drift, storey shear, torque and increment in the storey displacement. It is also observed from the comparative study that the building response with isolated base is very less to that of building with fixed base in all the cases and IS code depict higher values in all the cases with and without isolation, when compared to that of Euro code.

Bhatti. A. Q, Varum. H & Zeeshan Alam (2013) investigated seismic vulnerability assessment and evaluation on a high rise building in Islamabad in order to propose basic guidelines and suggestions for Pakistan Code. It is aimed that the document will work as a guideline source for the seismic evaluation, calculation and assessment of strength, behavior and expected performance and also the safety of already existing buildings. Modal analysis was carried out using ETABS. Different mode shapes for different time periods, T, for the existing building was analyzed. At last, the paper concluded that the Dynamic analysis generally gives lower forces hence the computation is rewarded by accurate result. The response is more sensitive to individual characteristics of strong motion record hence as more as possible number of records shall be used for time history analysis.

Shah. N. N & Tande. S. N (2014) showed that all the seismic analysis approaches cannot analyze all buildings except for the detailed non-linear dynamic analysis. For instance, ELF is only suitable for determine seismic forces of regular buildings up to 90 m high and located in seismic zone I and II, while dynamic analyses such as nonlinear time history analysis can be applied to both regular and irregular buildings in the seismic zone IV and V.

Bakhshi. A & Mostafavi. S.A. (2014) explained the usefulness to assess the effect of base isolation systems on the structural performance of RC structure through probabilistic methods such as developing fragility curves. They considered three 2-D reinforced concrete moment-resisting frame structures with different heights such as 3, 7, 12 stories. The structures were rehabilitated using Lead Rubber Bearing (LRB) isolators based on FEMA 356 instructions. Seismic and structural uncertainties were taken into account through modeling different material properties as random variables. By comparing these fragility curves it was concluded that isolators are a good retrofit method that can decrease the vulnerability of RC buildings. In addition by assessing the effect of being the earthquake near to source it was found that these were more vulnerable for isolated buildings whereas for far-field events, it was found to be zero.

Ashish. R. Akhare & Tejas. R.Wankhade (2014) considered a G+12 story hospital building and conducted a comparison on the effect of earthquake using various base isolation systems on these building. They have considered High density rubber bearing (HDRB) and friction pendulum as isolation devices. The non-linear time history analysis is carried out by considering El-Centro time history data. Comparison between the fixed base and the base isolated structure is carried out and the parameters such as base shear, mode period, storey displacement, storey drift and storey acceleration are compared using SAP2000. The results of the research show that the response of the structure can be reduced by the use of High Density Rubber Bearing (HDRB) and Friction Pendulum System (FPS) isolators. Thus base isolation technique has proved to be a reliable method of earthquake resistant design.

Dhawade. S. M (2014) conducted a comparative study for seismic performance of base isolated & fixed based RC Frame Structure. A G+14 storied frame structure is taken to compare the seismic effect of fixed base structure with respect to isolated structure. The G+14 storied frame structure is design with base isolation by using the ETAB software. High Damping Rubber Bearing (HDRB) is used as an isolator having efficient results for frame structure over the fixed base structure than any other isolation system. The report concluded that the very less values come for lateral loads by using High Damping Rubber Bearing. It has high flexibility and energy absorbing capacity, so that during an earthquake, when the ground vibrates strongly then only moderate motions are induced within the structure itself. It is also observed that when increasing the number of stories the variation of maximum displacement of stories will be somehow considerable. And thus it is concluded that the performance of isolated structure is efficient in the earthquake prone areas.

Marco Vona (2014) explained a procedure to develop analytical fragility curves for Moment Resisting Frame

Reinforced Concrete buildings. The investigated buildings can be considered low-engineered buildings, using no seismic codes or old seismic codes. The seismic capacity of the selected models representing the existing RC buildings has been evaluated through non-linear dynamic simulations. Seismic response has been analyzed, considering various response parameters, such as ductility demands and Inter-storey Drift Ratio (IDR). It is concluded that defining an accurate tool for seismic reduction strategies is essential for accurate structural performance analysis.

Aiswarya S & Nandita Mohan (2014) conducted a study on the generation of fragility curves for a five-story reinforced concrete (RC) flat-slab building structure. For the development of fragility curves a set of earthquake records were selected from PEER data base. Inelastic time history analysis was performed to analyze the structure subjected to the earthquake records in terms of spectral acceleration in ETABS. The fragility curves developed from this study were used to compare the seismic performance of retrofitted and un-retrofitted structure. From the study, they concluded that the 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 and studied its effect using the fragility curve.

Tarannum Yasmin et al (2015) reviewed the importance of fragility analysis using existing methodologies and focuses on their key features highlighting the limitations. The paper suggests the way for selection of appropriate assessment method for seismic vulnerability assessment of existing buildings. Through the review it is observed that in most of the vulnerability assessment methods, significance of elements such as staircases and lift shafts has not been considered. Therefore, there is need for further research required to develop experimental methods considering the changes in stiffness and overall resistance of buildings. The document outlined that while selecting a particular methodology one should taken into account the type of building/structure, availability of expertise, availability of ground motion data, and availability of previous earthquake damage records etc.

Sumit. A. Patel et al (2016) conducted a fragility analysis of high-rise building structures using ETABS software. They have developed fragility curves for the building with X-bracing, V-bracing. The fragility curves developed in terms of PGA for Limit state: slight, Moderate, major and collapse in lognormal distribution. Results showed that the probabilities of damage of structure for repairable, damage state in medium soil consider decreases as we shift from the Bare to X-bracing structure and further increase from X-bracing to V-bracing structure in various stories. From Non-linear static analysis, generations of hinges in X-bracing are less than V-bracing and Bare structure. So, X- bracing works very effectively in earthquake loading.

4. SUMMERY AND CONCLUSIONS

After reviewing some of the literature works done by different scholars and researchers in the development of fragility curves, it is understood that fragility curve is found to be an efficient tool for studying the vulnerability of a structure under various strong ground motions. While in the development of fragility curves, analytical approach is most common and thus widely used in various studies. Also fragility curves are generated from multiple Incremental Dynamic Analysis or IDA curves with the help of traditional curve fitting technique. Since it is a tedious and time consuming process, further studies are recommended in this area.

Also while analyzing the papers, it is noticed that major studies were done only up to mid-rise buildings and a limited number of studies were conducted on high- rise buildings. Thus a study in the field of vulnerability assessment on a high-rise building is highly recommended.

Installation of different base isolators helps to safe guard the building when different ground motion intensities hit the building. The papers outlined that Friction Pendulum Bearing System (FPS)reduces the storey drift of the building under varying ground intensity motions, especially when the number of storeys increases.

While keeping all those in mind, an effective study can be done mainly concentrating on earthquake vulnerability assessment of a high- rise RC building with Friction Pendulum System (FPS) as the main base isolator.

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