SSRG International Journal of Civil Engineering
ISSN: 2348 - 8352 /doi:10.14445/23488352/IJCE-V7I5P101

Volume 7 Issue 5, 1-9, May 2020
©2020 Seventh Sense Research Group®

Seismic Risk Assessment of Asymmetric Frame Buildings using Fragility Curves

Upasana R. Rana[#1], Snehal V. Mevada[#2] and Vishal B. Patel[#3]

[#1] *PG Research Scholar, Structural Engineering Department, Birla Vishvakarma Mahavidyalaya Engineering College, Vallabh Vidyanagar, Anand, Gujarat, India,*

[#2, #3] *Assistant Professor, Structural Engineering Department, Birla Vishvakarma Mahavidyalaya Engineering College, Vallabh Vidyanagar, Anand, Gujarat, India*

Received Date: 10 April 2020
Revised Date: 22 May 2020
Accepted Date:27 May 2020

Abstract

Risk assessment is a useful tool for determining ultimate behavior of structures subjected to highly unpredictable and uncertain dynamic forces produced from earthquakes. Fragility curves are the best representation of risk assessment. In the present study, risk assessment and fragility analysis of asymmetric structures subjected to seismic loading are evaluated. Further, the effects of various eccentricities on seismic risk assessment are also studied. The fragility curves are developed for different cases of eccentricities and various structural configurations of 5 storied RCC bare frame building. The considered buildings are subjected to ground motions of past recorded earthquakes. Incremental Dynamic Analyses carried out to evaluate the responses of the considered buildings subjected to earthquake excitations. Considering various performance levels as per ATC-40, Monte Carlo is the method used to develop fragility curves. It is observed that for immediate occupancy failure criteria, the probability of failure is increased constantly with increasing the percentage of structural eccentricity. Further, very less variation is observed in the probability of failure under life safety and collapse prevention failure stages.

Key Words — *Risk Assessment, Fragility Curves, Seismic load, Incremental Dynamic Analysis*

I. INTRODUCTION

Risk Assessment of structures implies estimation of the limit state probabilities to evaluate the performance and determine the overall capacity of structure under seismic loading. The behavior of structure subjected to uncertain parameters is highly unpredictable. Risk assessment is useful to determine the behavior of structure subjected to uncertain parameters. There are three types of uncertainty present in the structure; a) random ground excitation; b) statistical uncertainty; and c) model uncertainty [2]. The most uncertain parameter which causes maximum damage to structure is random ground excitation called an earthquake. The structure is always vulnerable to the earthquake, so risk assessment of structure subjected seismic loading will become important to study. Accuracy of the reliability analysis depends upon how accurately all the uncertainties account in the analysis. The most important aspect of the reliability analysis is the consideration of uncertainties that make structures vulnerable to failure for a predefined limit state. Risk assessment is extension of reliability analysis by considering the consequences of failure [1]. Application of risk assessment is to determine the capacity of structure, damage states estimation, loss estimation, retrofitting and requirement of strengthening [3].

In the past, many researchers have investigated seismic vulnerability, risk assessment, probabilistic seismic demand analysis (PSDA), multi-hazard risk associated with collapse limit state and develop the fragility curves by regression analysis or simulation based methods. Celik and Ellingwood [4] studied on seismic vulnerability & risk assessment by simulation based reliability analysis and determine seismic fragility curves and damage states. Mojiri et. al. [5] studied on seismic probability risk assessment & probabilistic seismic demand analysis (PSDA), RC models using excitation generated by experimental shake tables and determine seismic demand levels and fragility curves. Arabzadeh and Galal [6] studied on sensitivity & effect of Fiber Reinforced Polymer (FRP) retrofitting on seismic collapse of the system for different tensional effects and found the effective strengthening layout by FRP and develop fragility curves. Faghihmaleki et.al. [7] studied on a probabilistic framework for multi-hazard risk associated with collapse limit state of G+8 RC moment frame with shear wall using software Seismostruct under the blast and seismic loading condition and develop fragility curves. Huang et.al. [8] studied on probability density evaluation method (PDEM) of analysis, which is a method of dynamic reliability & seismic fragility analysis for development of fragility curves.

Fragility analysis is the analysis to determine the behavior of structure with the constant increase in Peak Ground Acceleration. It is aimed to determine fragility curves. The fragility curve is half a bell shape curve with normal probabilistic distribution of damage state. Fragility curves are the best representation of risk assessment. Fragility curve shows the continuous relationship between ground motion intensity measure and probability of exceeding predefine damage state for specified structure. Peck ground acceleration (PGA), peck ground velocity or spectral acceleration considered as a ground motion Intensity Measure (IM) and base shear, storied drift or lateral displacement can be considered as predefine Damage State (DS) [3].

It is very obvious that symmetric structure is not possible each time because of variation in site of structure, architectural demand and structural demand as well. Therefore, asymmetricity of the structure cannot be avoided and to study the effect of eccentricity in seismic risk assessment will become important. The variation in capacity and performance of structure with varying eccentricity can studied by application of risk assessment & determine fragility curve.

The main objective of this study is to evaluate the seismic risk of reinforced concrete structure by determining the fragility curve. Further, the effects of various eccentricities on seismic risk assessment of structure are also studied.

II. FRAGILITY ANALYSIS

A. Monte Carlo method

Fragility analysis can be done by analytical methods or by simulation method. From previous researches it is proved that the Monte Carlo method of simulation is the most effective method of simulation. The Monte Carlo method is based on integration of a given problem by mean value interpretation using stochastic experiment which gives a central estimation of the value of integral [2]. Monte Carlo method is a technique that involves using random numbers and probability to solve the problems. It calculates a set of random values of the probability functions. Depending upon number of uncertainties and the ranges specified for them, a Monte Carlo simulation performed until convergence of both input & output variables to their mean is reached & value of standard deviation becomes stable [1]. Monte Carlo simulation produces a distribution of possible outcome values.

The probability of failure P_f is obtained as [1]

$$P_f = \iint \dots \int_{g(x)\leq 0} Fx(X) \quad dx \tag{1}$$

in which $Fx(X)$ is the joint density function of variables $x_1;\ x_2;\ .\ .\ .\ x_n$ and dx stands for $dx_1;\ dx_2;\ dx_{3;\dots\dots};\ dx_n$ [1].

This Monte Carlo simulation of basic variables according to their probabilistic characteristics and then feeding them in the limit state function, the equation of probability of failure for function g (X) < 0 will become [1]:

$$P_f = N_f / N \tag{2}$$

in which N = total number of simulation cycles and

N_f = number of failed cycles

For accuracy of the estimated probability of failure, it is better to approximately compute the variance of the estimated probability of failure, which is done by assuming each simulation cycle to constitute a Bernoulli trial [1]. Therefore, N_f in N trials can be considered to follow a binomial distribution. The variance of the estimated probability of failure can be computed approximately as [1]:

$$var\ (P_f) = (1 - P_f)\ (P_f) / N \tag{3}$$

The statistical accuracy of the estimated P_f is measured by the coefficient of variation given by:

$$cov\ (Pf)\ \cong \frac{\left[\frac{\sqrt{((1-Pf)(Pf))}}{\sqrt{N}}\right]}{Pf} \tag{4}$$

The smaller the coefficient of variation, the better the accuracy is. Accordingly, N is decided.

B. Method for Determining Fragility Curve

The first step to determine fragility curve is modeling of structure. Modeling is done by various available software tools like Seismostruct or OpenSEES. RC frame or steel structure with a load transfer mechanism needs to define, which requires number of stories and bays, grade of concrete and yield strength of steel, reinforcement details of beams and columns and all other data which are necessary to define the model. Next step is to define of uncertainties which are classified as randomness and variability of ground excitation in terms of earthquake records (time histories); statistical uncertainty in terms of material uncertainties like modulus of elasticity of concrete(E_c), yield strength of steel (f_y) and compressive strength of concrete (f_{ck}) and model uncertainty, which arises due to imperfection of mathematical modeling which are considered.

After define the uncertainty, it is necessary to determine failure criteria and performance limit. The threshold values derived from performance limit of ATC 40 chord rotations and capacity curve of each model using nonlinear method of analysis. These values are used as boundary value of Immediate

Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP) failure criteria for the development of fragility curves.

Incremental Dynamic Analysis is carried out, collect the results in terms of uncertain parameters vs failure criteria which called Response Clouds. Application of Monte Carlo method on results of Incremental Dynamic Analysis gives fragility curves.

III. NUMERICAL STUDY

A. Details of Building

In the present research work, a 5 storied RCC frame building is considered for development of fragility curve. ETABS software tool is used to check the safety and stability of structure. The isometric view and plan of 5 storied RCC frame building is shown in figure 1. The physical properties and seismic properties of the building is as shown in Table1.

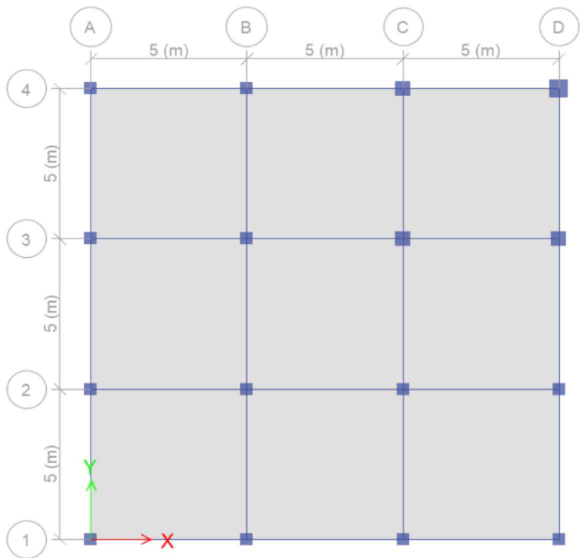

Figure 1 Plan of Building

Table I Properties of Building

Parameter	Value
Concrete Grade	M25
Steel Grade	Fe415
Storey Height	3.5m
Total Height of Building	17.5m
C/C Bay Distance	5m
Beam Size	230mm x 460mm
Column Size	400mm x 400mm
Slab Thickness	120mm
Wall Thickness	230mm
Seismic Zone	5
Importance Factor (I)	1
Response Reduction Factor (R)	5
Soil Type	Hard
Live Load	2 kN/m^2

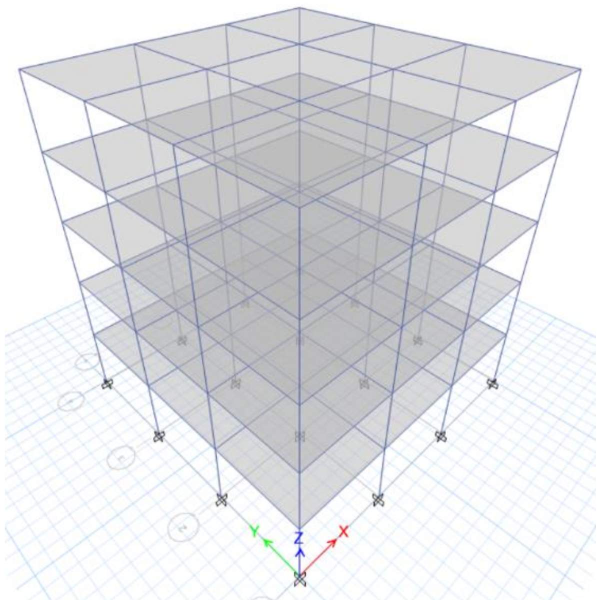

Figure 2 Isometric View of Building

B. Details of Time Histories used for IDA

Table II Time Histories used in IDA

Earthquake	PGA (m/sec^2)
Imperial Valley, 1940	0.312
Loma Prieta, 1989	0.966
North Ridge, 1994	0.897
Kobe, 1995	0.821

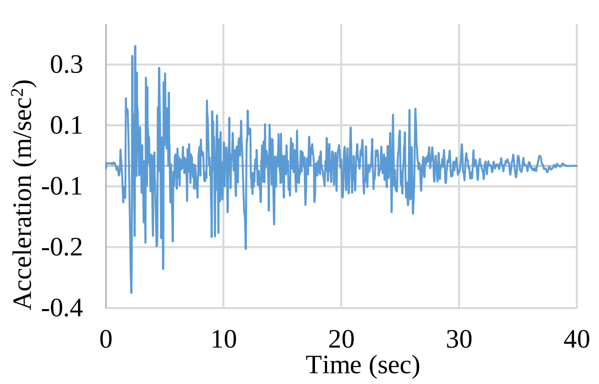

Figure 3 Time History of Imperial Valley, 1940

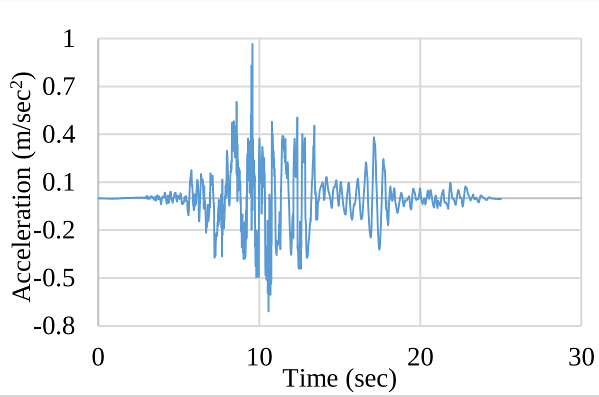

Figure 4 Time History for Loma Prieta, 1989

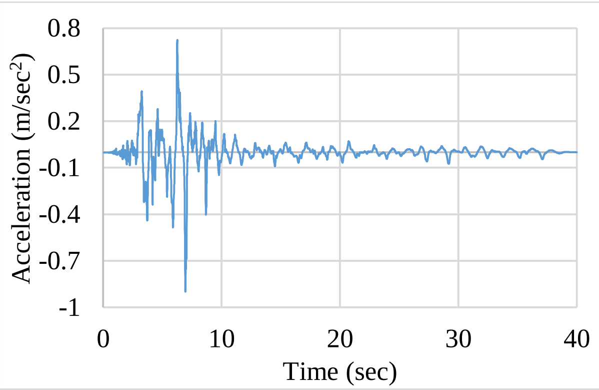

Figure 5 Time History for North Ridge, 1994

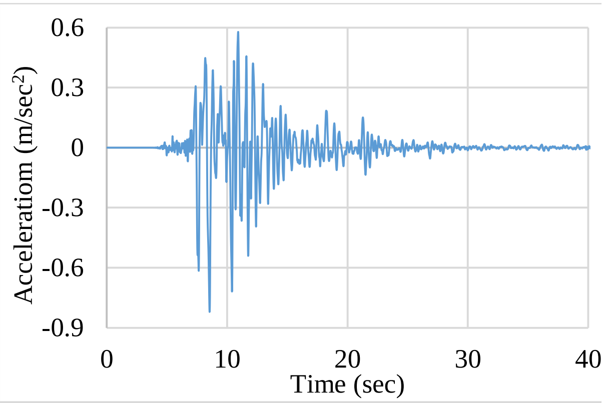

Figure 6 Time History of Kobe, 1995

C. Consideration of Asymmetricity

Four models are considered with eccentricity ranges between 0 to 5%, 5 to 10%, 10 to 15% and 15 to 20% which are 0%, 7.50%, 13.25% and 17.70%. The eccentricity developed by shifting the center of stiffness which is done by varying column dimensions as shown in figure 7. The dimension of three columns which are indicated as ‘1’ and one corner column which is indicated as ‘2’ in figure 7 are required to increase for increasing the eccentricity. Because of that, center of stiffness is shifted towards upper right corner which is highlighted in figure 7. The dimensions of these columns for various cases are shown in Table 3. The dimension of remaining all columns is 400mm x 400mm.

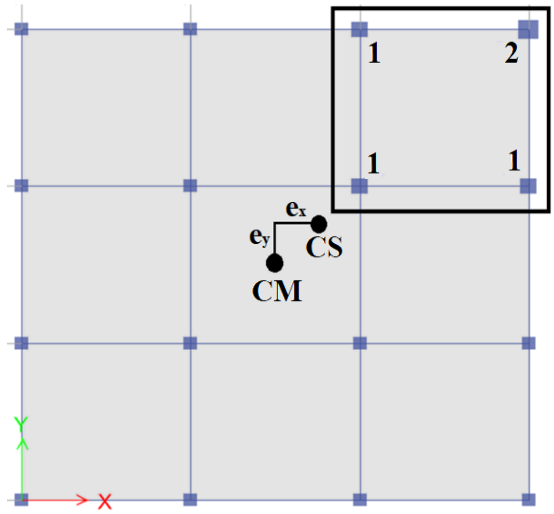

Figure 7 Plan of RCC Building with Eccentricity

Table III Dimensions of corner Columns for various eccentricity cases

Model	Eccentricity	Column ‘1’	Column ‘2’
1	0%	400 mm X 400 mm	400 mm X 400 mm
2	7.5%	450 mm X 450 mm	525 mm X 525 mm
3	13.25%	500 mm X 500 mm	600 mm X 600 mm
4	17.70%	600 mm X 600 mm	625 mm X 625 mm

IV. RESULTS AND DISCUSSION

A. Results of Incremental Dynamic Analysis (IDA)

Incremental dynamic analysis (IDA) has been done by Seismostruct software using scale factor 0.2 to 3 with increment of 0.2 to evaluate the complete behavior of the structure and to determine fragility curve. Incremental dynamic analysis is also known as dynamic pushover analysis. In IDA constant scale factor is multiplied with intensity of ground motion to create monotonically scaled time history. The structure is analyzed under these monotonically scaled time histories, behavior of structure noticed and results are collected. The results of IDA are plotted in terms of Intensity Measure (IM) vs Damage State (DS) called response clouds. The response clouds of various frame building models are shown in figures 8 to 11.

From the figures 8 to 11 it is noticed that IDA gives the total behavior of structure in terms of required failure criteria (top drift) vs required acceleration. The trend line in the graph gives linear regression of obtaining results. The pattern between increment in failure of a structure (top drift) and the uncertain parameter (PGA) can identify from this trend line.

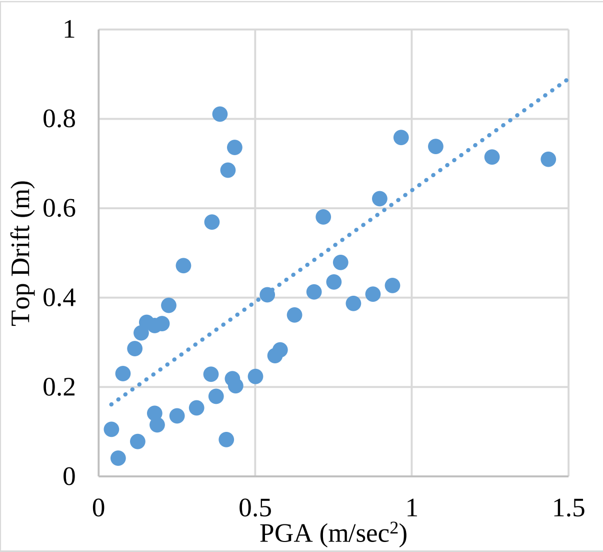

Figure 8 Response Cloud (0% eccentricity case)

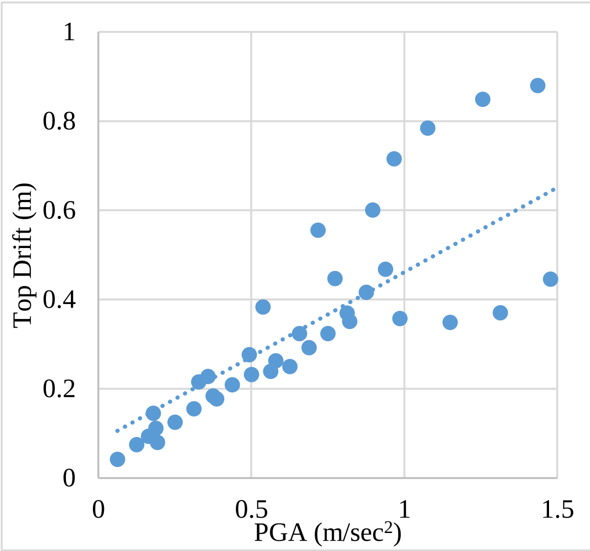

Figure 9 Response Cloud (7.5% eccentricity case)

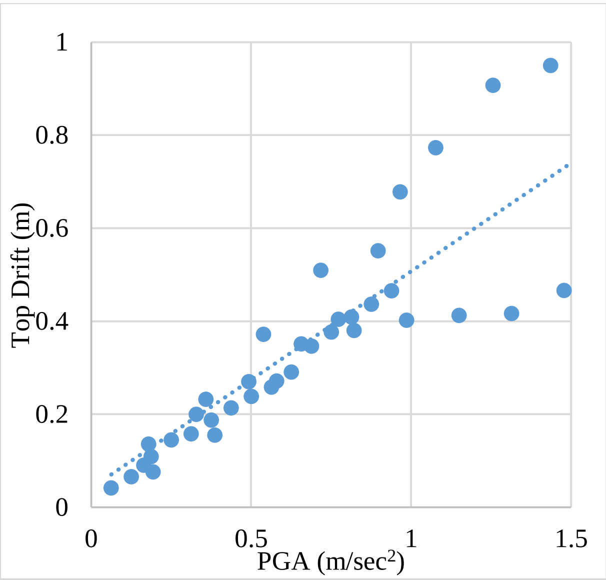

Figure 10 Response Cloud (13.5% eccentricity case)

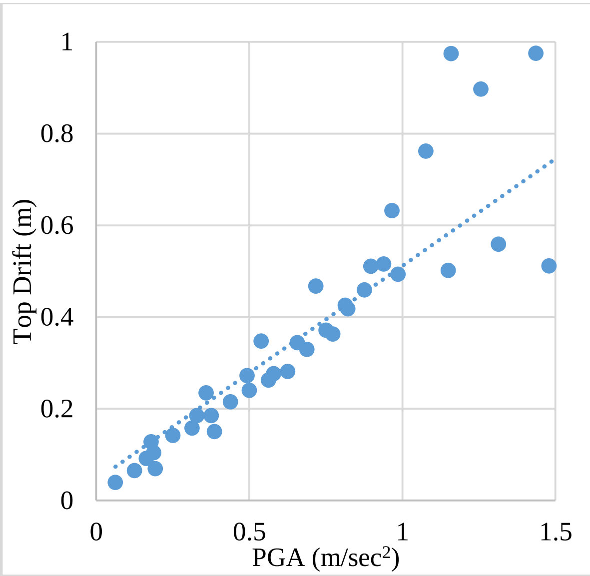

Figure 11 Response Cloud (17.5% eccentricity case)

B. Failure Criteria and Performance Limits

The damage states are considered as per ATC-40 and fragility curve plotted for three failure criteria which are Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP). The static pushover analysis gives failure criteria limits. The results of pushover analysis are represented by pushover curves which is plotted between Displacement Vs Base shear. The Pushover Curves for frame building are shown in figures 12 to 15.

Immediate Occupancy means the post-earthquake damage state in which only very limited structural damage has occurred. The basic vertical- and lateral-force-resisting systems of the building retains nearly all of their pre-earthquake characteristics and capacities. The risk of life-threatening injury as a result of structural failure is negligible, and building should be safe for unlimited egress, ingress and occupancy [3]. Life Safety means the post-earthquake damage state in which significant damage to the structure has occurred, but some margin against either partial or total structural collapse remains. The level of damage is lower than that for the Structural Stability Level. Major components have not dislodged or fallen, threatening life safety either within or outside the building. Injuries might occur during the earthquake; however, the overall risk of life-threatening injury as a result of structural damage is expected to be very low. It should be possible to repair the structure [3]. Collapse Prevention means the post-earthquake damage state in which significant damage to the structural elements and total collapse of the structure has occurred.

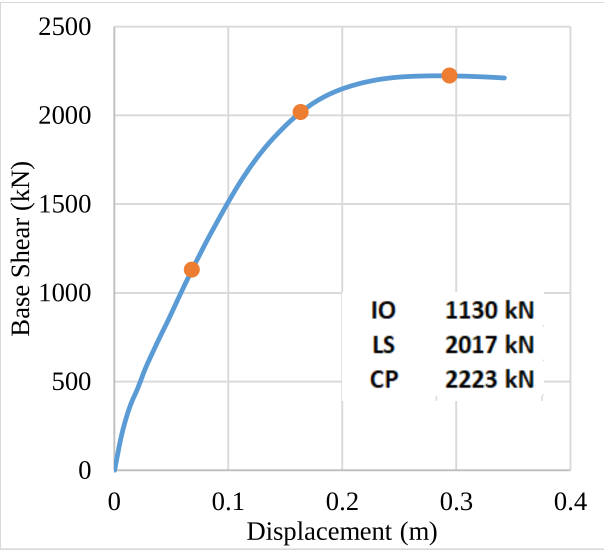

Figure 12 Pushover curve of 0% eccentricity building

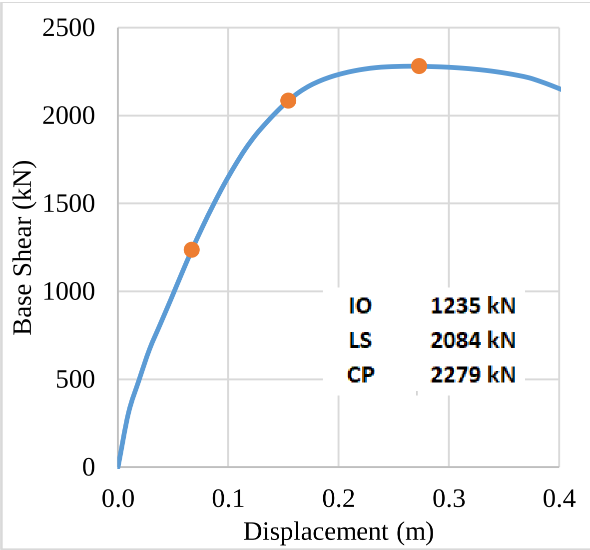

Figure 13 Pushover curve of 7.5% eccentricity building

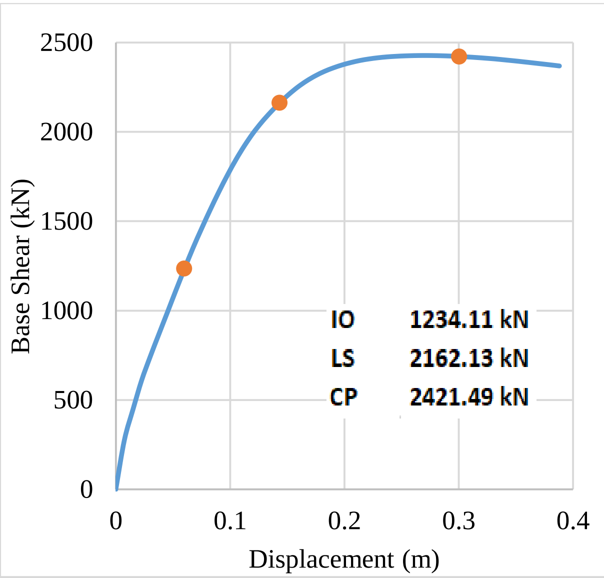

Figure 14 Pushover curve of 13.5% eccentricity building

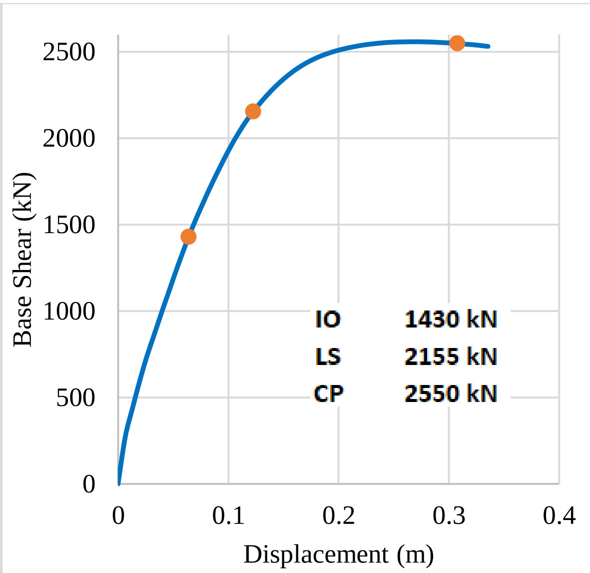

Figure 15 Pushover curve of 17.5% eccentricity building

From figure 12, it is noticed that the when the load applied to the structure (0% eccentricity case), it starts to deform. For the very first its obey the Hook's low and gives the linear pushover curve. The structure gives non-linear behavior with further application of the load and finally reached ultimate non-linearity limit. Further application of load gives total collapse of the structure.

This structure will fail at 1130 kN for immediate occupancy failure criteria, at 2017 kN for life safety failure criteria and at 2223 kN for collapse prevision failure criteria. Similarly, the figures 13 to 15 are also understood.

C. Development of Fragility Curve

The fragility curves of 5 storied RCC frame building for various eccentricities are determined by using Monte Carlo method. Figures 16 to 19, represent the fragility curves which is plotted between PGA (m/sec^2) as an uncertain parameter to the probability of failure as considered damage state (top drift). It states that probability of exceeding the top drift from its predefine failure limit. It is noted that increment in PGA increases the probability of failure. As PGA of CP condition is higher as compared to LS & PGA of LS condition is higher as compared to IO, building fails at smaller excitation in LS & even smaller excitation in the IO.

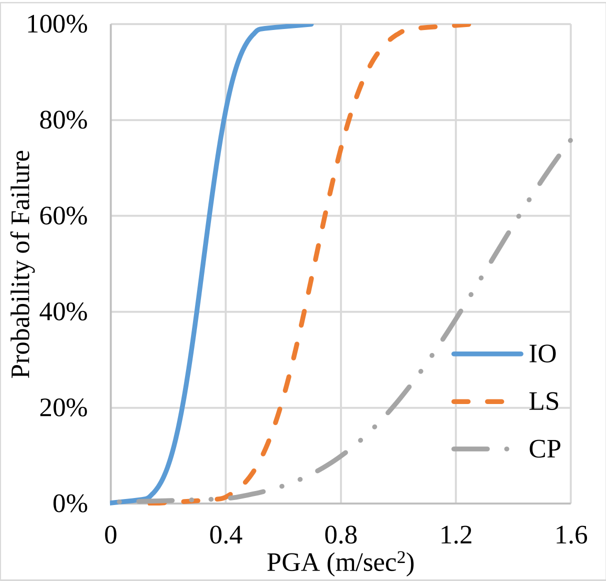

Figure 16 Fragility curve of 0% eccentricity building

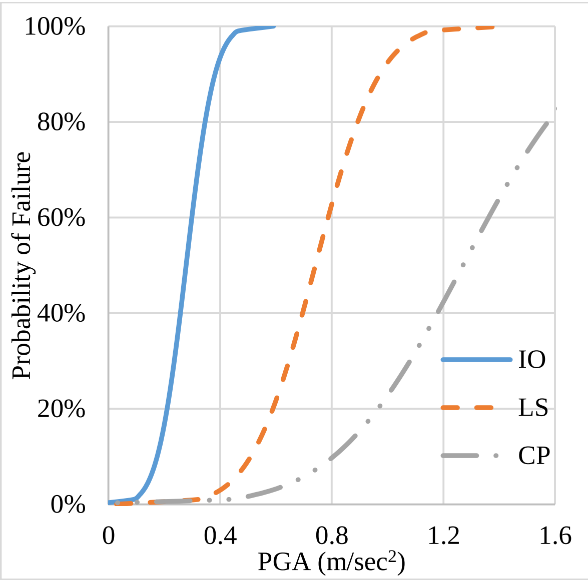

Figure 17 Fragility curve of 7.5% eccentricity building

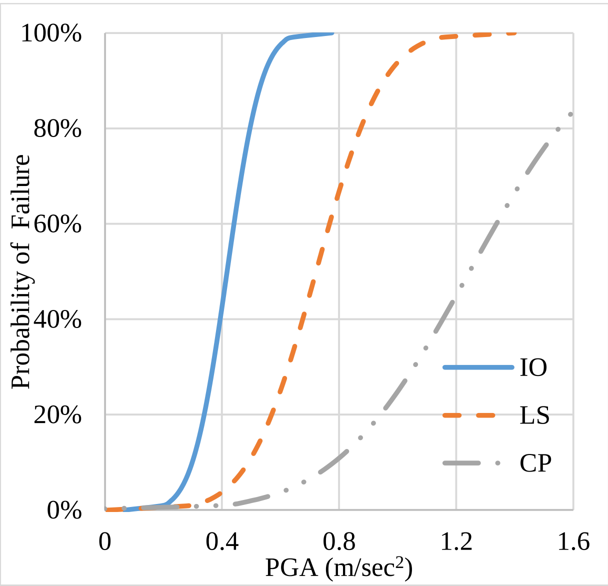

Figure 18 Fragility curve of 13.5% eccentricity building

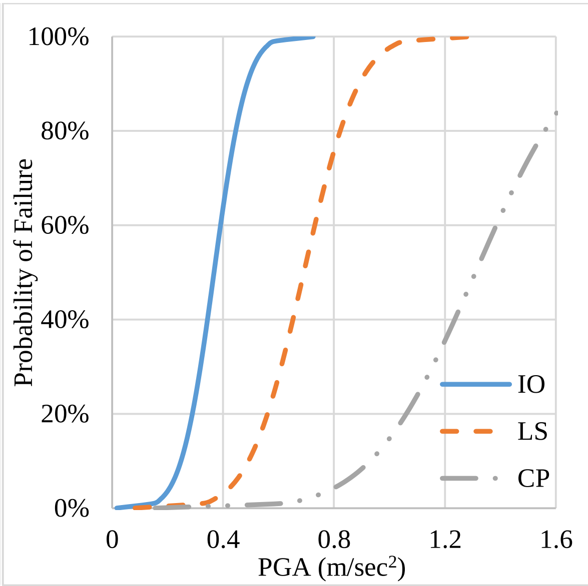

Figure 19 Fragility curve of 17.5% eccentricity building

V. COMPARISON OF FRAGILITY CURVE FOR VARIOUS ECCENTRICITY

After determination of fragility curve, to know the behavior of structure with constant increasing eccentricity the comparison is required. Therefore, comparison of all cases of RCC frame building is carried out with different failure criteria IO, LS and CP which shown in figure 19 to 21.

It is observed from figure 20, for immediate occupancy failure criteria; with the increased in the eccentricity from 0 to 7.5%, the probability of failure increases by 10%; by an increment in the eccentricity from 7.50 to 13.25%, the probability of failure increases to 10%; by an increment in the eccentricity, from 13.25% to 17.70%, the probability of failure increases to 10%. The average increment in the probability of failure is 10% observed.

It is observed from figure 21, for life safety failure criteria; with an increment in the eccentricity, from 0 to 7.5%, the probability of failure increases to 3.00%; by an increment in the eccentricity from 7.50 to 13.25%, the probability of failure increases to 1.64%; by an increment in the eccentricity from 13.25 to 17.70%, the probability of failure increases to 3.26%. The average increment is 2.63% in the probability of failure is observed.

It is observed from figure 22, for collapse prevention failure criteria; with an increment in the eccentricity from 0 to 7.5%, the probability of failure increases to 3.46%; by an increment in the eccentricity from 7.50 to 13.25%, the probability of failure increases to 3.65%; by an increment in the eccentricity from 13.25 to 17.70%, the probability of failure increases to 2.15%. The average increment is 3.08% in the probability of failure is observed.

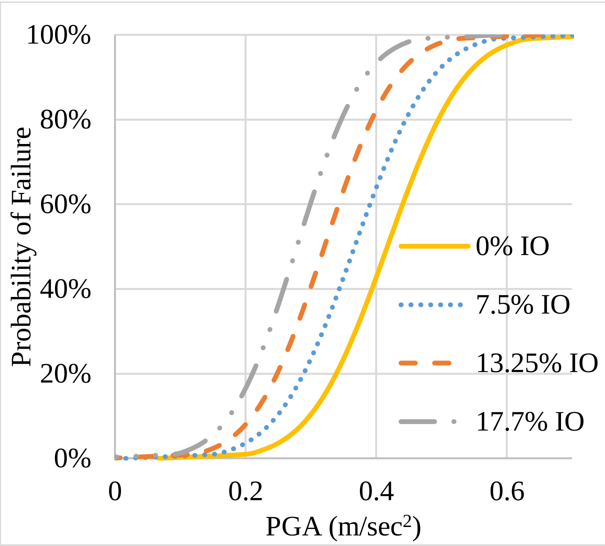

Figure 20 Comparison of fragility curves IO

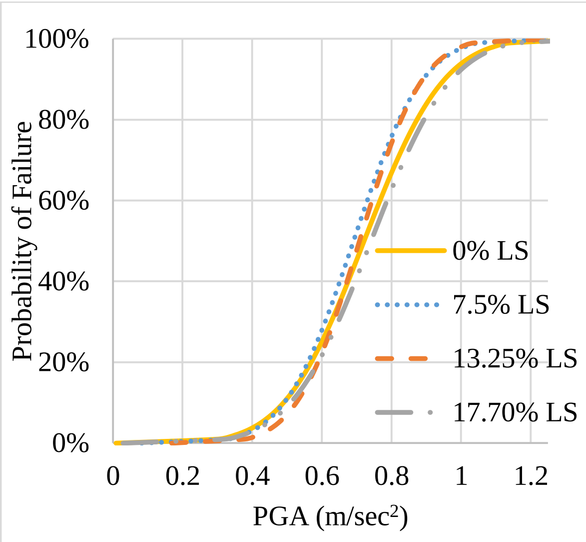

Figure 21 Comparison of fragility curves LS

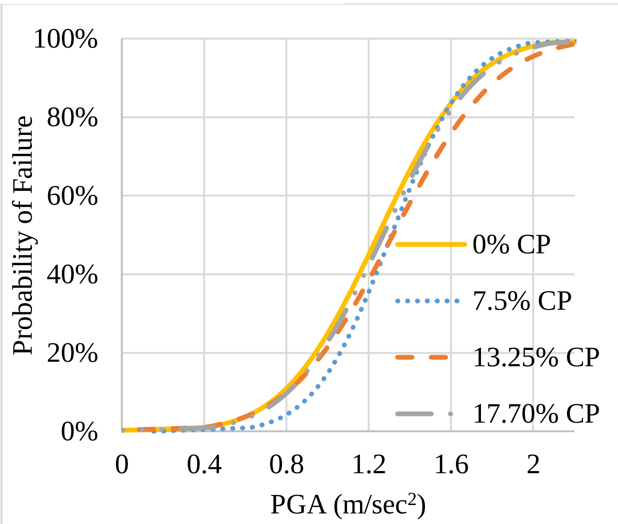

Figure 22 Comparison of fragility curves CP

VI. CONCLUSIONS

In the present paper, asymmetric frame building with various eccentricities is analyzed and design. Performance evaluation and determination of failure limits of various buildings is done by Incremental Dynamic analysis and static pushover analysis. By using Monte Carlo method, fragility curves for 5 storied asymmetric frame building with eccentricity ranges of 0 to 5%, 5 to 10%, 10 to 15% & 15 to 20% are determined considering failure criteria in terms of immediate occupancy, life safety and collapse prevention.

From the research work carried out herein, the following conclusions can be drawn.

1. With the increase in peak ground acceleration, the probability of failure increases in all the failure criterias namely immediate occupancy, life safety and collapse prevention.
2. For the same value of peak ground acceleration, the probability of failure in immediate occupancy criteria is higher than life safety criteria. Similarly, for the same value of peak ground acceleration, the probability of failure in life safety criteria is higher than collapse prevention criteria for asymmetric buildings.
3. The probability of failure is high corresponding to lower values of peak ground acceleration in immediate occupancy criteria. Whereas, for the same probability of failure the peak ground acceleration requirement is higher in collapse prevention criteria as compared to life safety criteria.
4. For immediate occupancy criteria, significant increment of 10% in the probability of failure is noticed with the increase in eccentricity.
5. For life safety and collapse prevention criterias, very negligible increment in probability of failure of about 2 to 4% is noticed with the increase in eccentricity.

REFERENCES

[1] Datta T K (2010), 'Seismic Analysis of Structures', John Wiley & Sons (Asia) Pte Ltd.

[2] Ditlevsen O. and Madsen H.O. (2005), 'Structural Reliability Methods' John Wiley & Sons Ltd, Chichester.

[3] Sheth & Desai (2018) 'Performance Evaluation of RC Moment Resisting Frames by Development of Fragility Curves', 16th Symposium on Earthquake Engineering December 20-22, 2018 IIT Roorkee, India Paper No. 11

[4] Celik, O. C., & Ellingwood, B. R. (2009) 'Seismic risk assessment of gravity load designed reinforced concrete frames subjected to mid-America ground motions', Journal of Structural Engineering, Vol. 135, No. 4, pp. 414-424.

[5] Mojiri, S., El-Dakhakhni, W. W., & Tait, M. J. (2015) 'Seismic fragility evaluation of lightly reinforced concrete-block shear walls for probabilistic risk assessment', Journal of Structural Engineering, Vol. 141, No. 4, pp 04014116-1 to 04014116-13.

[6] Arabzadeh, H., & Galal, K. (2017) 'Seismic Collapse Risk Assessment and FRP Retrofitting of RC Coupled C-Shaped Core Walls Using the FEMA P695 Methodology', Journal of Structural Engineering, Vol. 143, No. 9, pp 04017096-1 to 04017096-20.

[7] Faghihmaleki, H., (2017) 'An evaluation of multi-hazard risk subjected to blast and earthquake loads in RC moment frame with shear wall', Journal of Engineering Science and Technology, Vol. 12, pp 1-12.

[8] Huang, Y., Hu, H., & Xiong, M. (2018) 'Performance-based seismic fragility analysis of retaining walls based on the probability density evolution method', Structure and Infrastructure Engineering, Vol. 15, pp 1-10.