Seismic Fragility Assessment of Regular and Vertical Setback RC Frame Buildings

[1]Priyanka M. Patil, [2] Prof. Shrirang Tande.
[1]M. Tech Student, [2]Assistant Professor.
[1]Walchand College of Engineering, Sangli, Maharashtra, India,
[2]Walchand College of Engineering, Sangli, Maharashtra, India,

Abstract: Earthquake is one of the most natural disaster which causes loss of human life and structural collapse. The performance of multi-storey framed building during earthquake depends on the distribution of mass, strength and stiffness in both horizontal and vertical planes of the building. Based on this there are two types of irregularities: vertical and horizontal irregularity. A common type of vertical irregularity is vertical setback building which is used in modern constructions.

Present study shows the seismic performance and behaviour of regular and vertical setback RC framed structures by Incremental Dynamic Analysis (IDA) proposed by Vamvatsikos & Cornell. For this, two types of RC moment resisting building frames are taken in this study work which are one regular and one irregular RC frame. This two building frames are modelled and analysed in SEISMOSTRUCT 2016.Ten real ground motion pairs have selected and scaled, then applied to the buildings to perform the Incremental Dynamic Analysis (IDA). Fragility curves have developed based on IDA results for the four limit states including slight damage, moderate damage, extensive damage, and complete collapse. For the development of fragility curves, guidelines given by HAZUS MH MR-4 technical manual have been used. From fragility curves probability of exceedance of certain damage level have been calculated.

***Key Words*: SEISMOSTRUCT-2016, Incremental dynamic analysis, Fragility curves, HAZUS MH MR4, Damage states, etc.**

*1.*INTRODUCTION

EARTHQUAKES are the most volatile, disturbing and unpredictable of all natural disasters, in which it is very difficult to save life and engineering properties. To overcome these problems, we need to identify the seismic performance of various buildings through various analytical procedures. This is because to make sure that the various buildings withstand during earthquake events. And hence can save as many lives as possible. During earthquake the performance of a structure depends on many factors such as stiffness, adequate lateral strength, simple and regular configurations etc. The structures with regular geometry suffer less than the structures with irregular in their mass, stiffness, setback structures. Therefore, designing and analyzing structures to resist seismic attack is essential not only for new buildings, but also for existing buildings.

We observe that real structures are frequently irregular as perfect regularity is an idealization that rarely occurs in the practice. Regarding buildings, for practical purposes, major seismic codes across the globe differentiate between irregularity in plan and in elevation, but it must be realized that irregularity in the structure is the consequence of a combination of both types. It is seen that irregular structural configurations either in plan or in elevation were often recognized as one of the major causes of collapse during precedent earthquakes. There are two types of irregularities- 1. Plan Irregularities 2. Vertical Irregularities.

Vertical Irregularities are mainly of five types-

i) Stiffness Irregularity — a) Soft Storey-A soft storey is one in which the lateral stiffness is less than 70 percent of the storey above or less than 80 percent of the average lateral stiffness of the three storey above. b) Extreme Soft Storey-An extreme soft storey is one in which the lateral stiffness is less than 60 percent of that in the storey above or less than 70 percent of the average stiffness of the three storey above.

ii) Mass Irregularity-Mass irregularity shall be considered to exist where the seismic weight of any storey is more than 200 percent of that of its adjacent story's. In case of roofs irregularity need not be considered.

iii) Vertical Geometric Irregularity- A structure is considered to be Vertical geometric irregular when the horizontal dimension of the lateral force resisting system in any storey is more than 150 percent of that in its adjacent storey.

iv) In-Plane Discontinuity in Vertical Elements Resisting Lateral Force-An in-plane offset of the lateral force resisting elements greater than the length of those elements.

v) Discontinuity in Capacity — Weak Storey-A weak storey is one in which the story lateral strength is less than 80 percent of that in the storey above.

As per IS 1893, Part 1 Linear static analysis of structures can be used for regular structures of limited height as in this process lateral forces are calculated as per code based fundamental time period of the structure. Linear dynamic analysis is an improvement over linear static analysis, as this analysis produces the effect of the higher modes of vibration and the actual distribution of forces in the elastic range in a better way. Different seismic analysis approaches have been developed to predict buildings responses when subjected to strong earthquakes. With the development of computer software, analysis methods are expanded from static to dynamic and from linear to nonlinear analysis to obtain more realistic seismic response of buildings. There are three static seismic analysis methods including Equivalent Lateral Force (ELF), the Conventional Pushover and Adaptive Pushover. Dynamic methods consist of Multi-modal spectral, Nonlinear Time history and Incremental Dynamic Analysis (IDA). Methods cannot analyse all buildings except for the detailed and linear dynamic analysis (Shah and Tande 2014).

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 (Bagheri 2012). Methods cannot analyse all buildings except for the detailed and linear dynamic analysis (Shah and Tande 2014)

1.2 Incremental Dynamic Analysis (IDA):

Incremental Dynamic Analysis (IDA) is a computational analysis method in earthquake for performing determination of the behavior of structures under seismic loads. The buildings seismic responses obtained from IDA. The response of the structure was represented by IDA curves that require a series of non-linear time history analysis with a suite of scaled ground motions, during which the ground motions' intensities are increased using a specified scale factor. IDA provides the buildings' seismic behavior for the whole range from elastic to collapse.

Bertero firstly proposed the idea of incremental dynamic analysis (IDA) in 1977 and it has been subjected to substantial development by many researchers at the end of last century and the beginning of this century. This analysis method was adopted by the Federal Emergency Management Agency (FEMA 2000a) and is considered as the state-of-the-art method to estimate the structural responses under seismic loadings. 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. The intensity continues to increase when the whole structural responses range from elastic to the nonlinear followed by structural collapse (Vamvatsikos 2002). Following figure shows the IDA curves with four damage limit states in HAZUS MH MR4 technical manual.

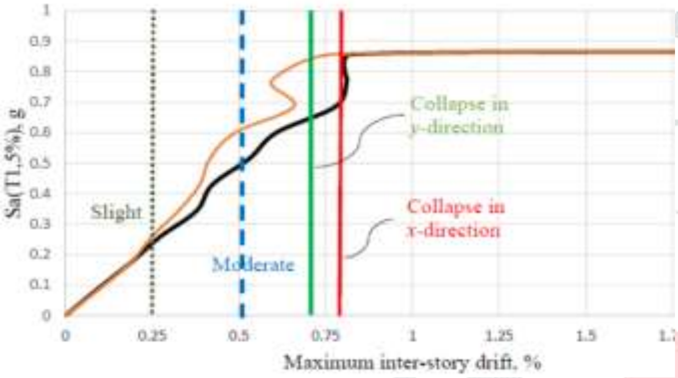


Fig.1 Median of IDA curves and inter-story drift ratio percentage for three limit states for building

1.3 Fragility curves:

Fragility curve is defined as the conditional probability which exceeds a specified limit state and evaluates seismic vulnerability of the structure. Fragility curve shows the probability of structure damage as a function of ground motion intensity measure (IM) such as Peak Ground Acceleration (PGA), spectral acceleration at the fundamental building period with 5% damping 1 (T1,5%) or any other intensity measures.

$$f_{DS}(IM) = P\,(DS/IM) \qquad \text{Eq. 5-1}$$

where,

IM = the ground motion intensity measure.

DS = the damage state.

P= the probability of exceeding a damage level.

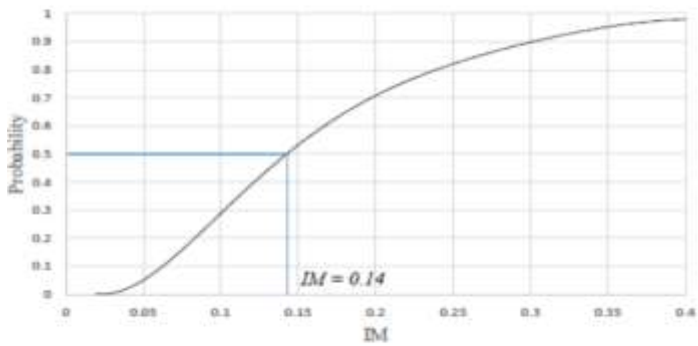


Figure 2 Fragility curve of collapse limit state shows the way of determining the probability of 50% of collapse

Figure 2-shows the probability of collapse limit state and the probability from 0% to 100% of collapse can be determined from the curve. For example, if we want to determine 50% probability of collapse, we shall determine the point on the fragility curve which has a vertical axis value equal to 0.5. Then, value on the horizontal axis representing *IM = 0.14* the ground motion intensity (i.e. IM = 0.14g) is determined which corresponds to the probability of 50% of collapse. Different methodologies were

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

Fragility curves defines the probability that the expected different damage d of a structure exceeds a given damage states

Fragility curves for Incremental Dynamic analysis:

The probability of exceeding a damage level (D) can be determined using following Eq.

$$P(\leq D) = \phi(\frac{Ln(x) - \lambda}{\zeta}) \quad \text{……………eq.2}$$

Where,

ϕ = The standard normal distribution,

x = The ground motion parameters, which is Sa (T1,5%) obtained from IDA curves, taking natural logarithm (Ln(x)),

λ= The mean of Ln(x),

ζ = The standard deviation of Ln(x).

The Fragility curves were plotted Spectral acceleration vs Probability of exceedance.

2. Description of building:

The building description is given below.

Table 1 Description of Building

No. Of Story	7
Story height	3000 mm
Soil Type	Medium (Type II)
Zone	III
Thickness of Slab	150 mm
Beam Size	230mm x 450mm
Column Size	300mm x 600mm
Number of bays	4 (X and Y direction)
Spacing Between Frames	4 m along X direction 3 m along Y direction
Grade of concrete	M25
	M30
Steel	Fe500

The loads considered for designing the frames are given in Table 2. The loads are calculated using the material properties and the element dimensions

Table 2 Loads considered for design of building

Sr No.	Load type	Value
1	Floor finish	1 kN/m^2
2	Live Load	3kN/m^2

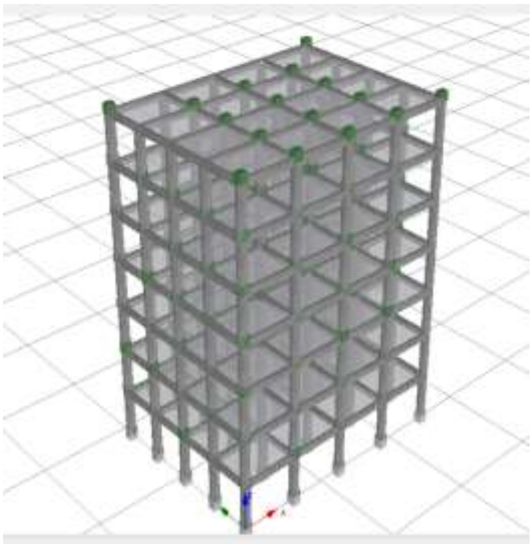


Fig. 3(a) Elevation of Regular building

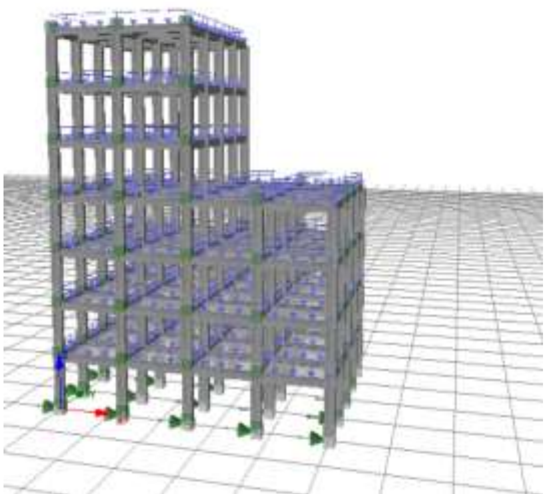


Fig.3(b) Elevation of Irregular building

3.Results and Discussion:

The building has modelled in SEISMOSTRUCT-2016.Modal analysis has done on both structures to calculate fundamental natural period of the building. The results are as given below,

Sr. No.	Building	T(sec)
1	Regular Building	0.785
2	Vertical Setback Building	0.82

This shows fundamental natural period of the building is increased for vertical setback building i.e. building becomes flexible due to setback.

Incremental dynamic analysis has done in SEISMOSTRUCT-2016 using ten scaled ground motions. Following figure shows the IDA curves for regular and irregular building. Maximum Interstory drift ratio is used as damage measure on x axis and first mode spectral acceleration (5% damped) is used as intensity measure on y axis.

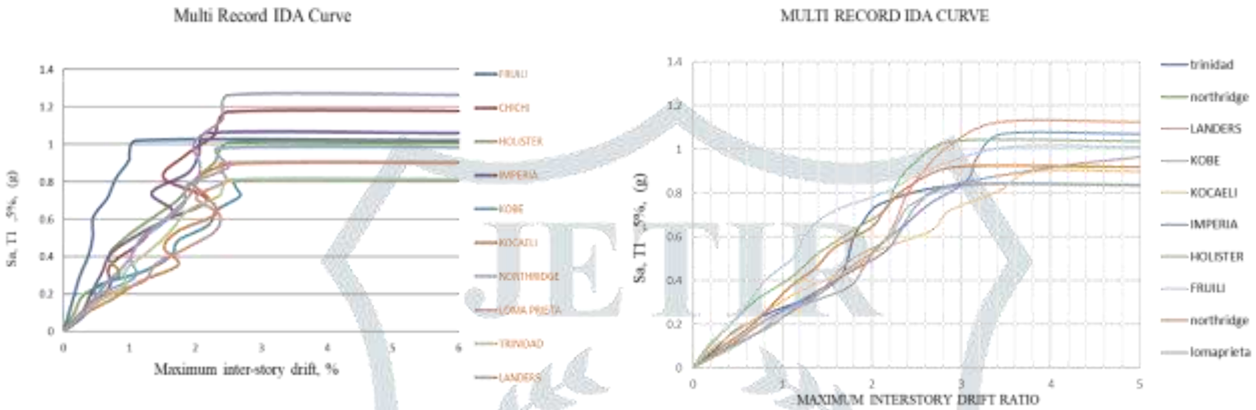


Fig.4 IDA curves for regular building and vertical setback building

Fragility curves were plotted for slight damage, moderate damage, Extensive damage and collapse damage limit states from HAZUS MR4 Technical Manual. Structural fragility curves parameters- Moderate code seismic design level taken from HAZUS MR4 Technical manual.

Table-5 Fragility curves Parameters

Damage State	Interstory drift at Threshold Damage state
Slight	0.0025
Moderate	0.0043
Extensive	0.0117
Complete	0.0300

From using Equation no.2 discussed in IDA, Probability of exceedance is calculated for plotting Fragility curves. Following figure shows the Fragility curves obtained from IDA curves for both the structu

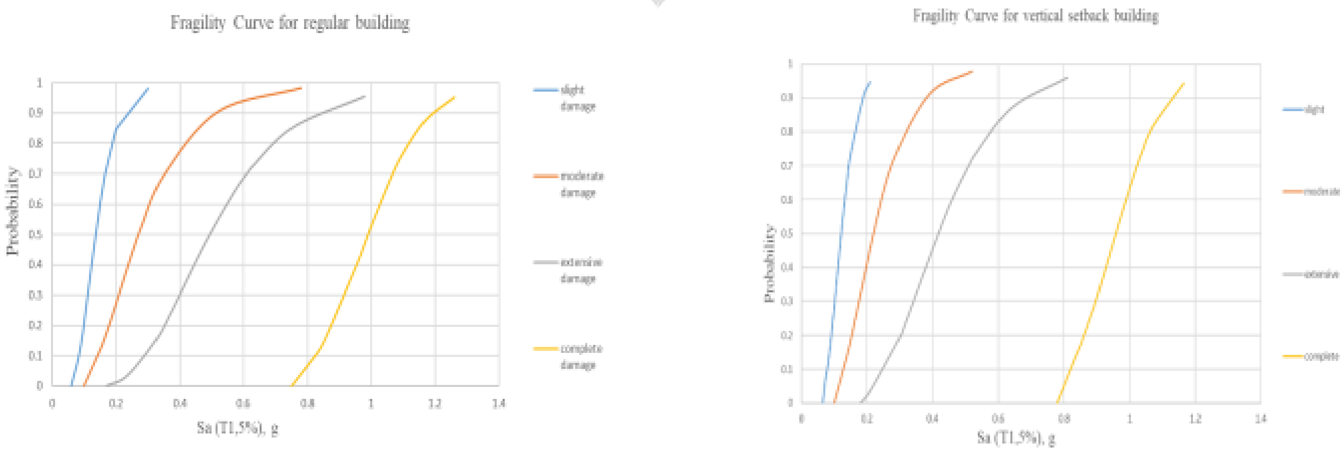
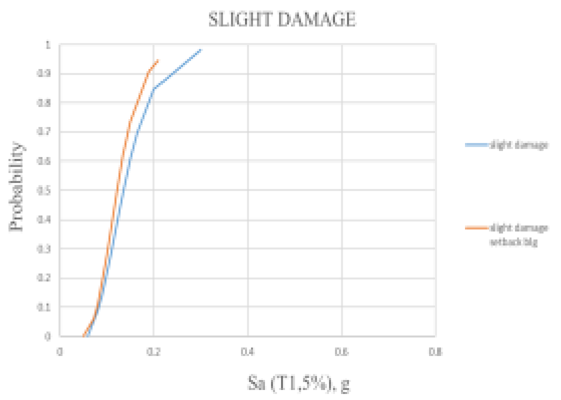
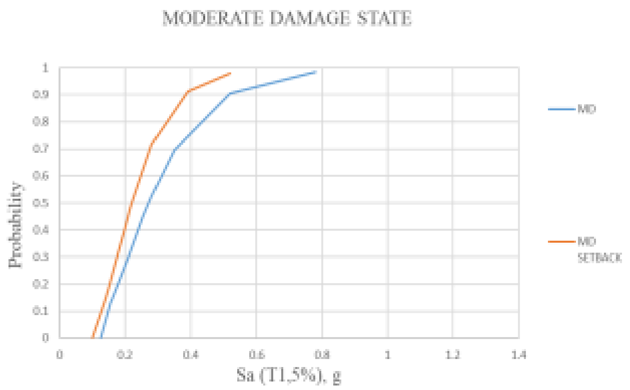


Fig.5 Fragility curves for regular building and vertical setback building

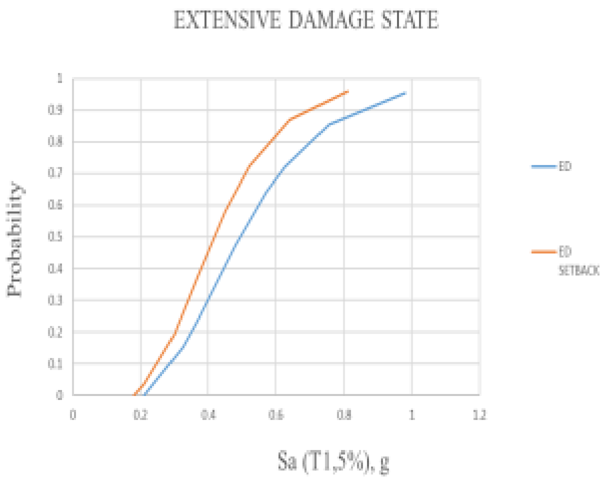
Fragility curves of the same limit state of both building models were plotted on the same graph to compare their seismic performances.



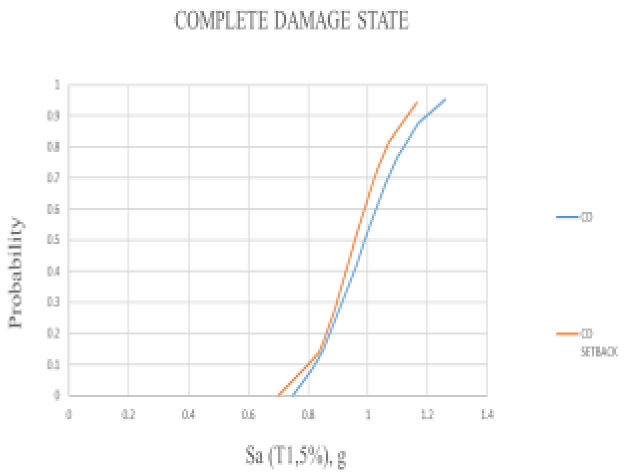
(a)



(b)



(b)



(d)

Fig.6 Fragility curves comparison of (a) Slight Damage, (b) Moderate Damage, (c) Extensive Damage, (d) Complete Damage for regular building and vertical setback building

Based on fragility curve comparison for all damage limit states shown in fig.6, regular building requires high earthquake intensity for exceedance of all damage limit states than vertical setback building. So setback building is more vulnerable during earthquake.

4. CONCLUSIONS

The main objective of this study is to demonstrate the effect of vertical setback on dynamic response of building. To complete this objective, one regular and one vertical setback building were modelled, designed and analyzed in SEISMOSTRUCT 2016.Their seismic performances were compared using probabilistic method which was fragility curve analysis. Two building have same height. Vertical setback building has setback on 4th floor so both the buildings have same plan dimensions for four floors. Four damage limit states were identified for both the buildings and fragility curves of all damage limit states were compared for both the buildings. corresponding irregular frames in all damage limit states.

From the results discussed above, it is concluded that-

I) Fundamental period of vertical setback structure is more than regular building of same no. of story due to decreased stiffness. This is due to decrease in stiffness of building frames due to setbacks i.e. Vertical setback building is more flexible than regular building. Thus there is need for providing more reinforcement for vertical setback building.

II) Regular building requires high earthquake intensity for exceedance of all damage limit states than vertical setback building. So, vertical setback building is more vulnerable to seismic attack.

Thus,The seismic performance of regular frame R is found to be better than vertical setback building in all damage limit states. Therefore, it should be constructed to minimize the seismic effects.

REFERENCES

- 1) Murat Serdar Kirc¸il∗, Zekeriya Polat, (2006), "Fragility analysis of mid-rise R/C frame buildings", Engineering Structures 28, pp 1335–1345.
- 2) Shan-suo Zheng, Wen-bo Li,b, Qian Li1,c and Fan Wang,(2012)," Seismic Fragility Analysis of SRC Frame Structures", Applied Mechanics and Materials Vols. 166-169 (2012) pp 2042-2045
- 3) P. Rajeev a , S. Tesfamariam,(2012)," Seismic fragilities for reinforced concrete buildings with consideration of irregularities", Dept. of Civil Engineering, Faculty of Engineering, Monash University, Clayton Campus, Vic 3800, Australia.
- 4) A.Habibi1 and K. Asadi,(2013),"Seismic Performance of RC Frames Irregular in Elevation Designed Based on Iranian Seismic Code", Journal of Rehabilitation in Civil Engineering 1-2 ,40-55.
- 5) Lee, S.W., Yi, W.H. and Kim, H.J. (2014), "Seismic Fragility Functions for RC Moment Resisting Frames using Incremental Dynamic Analyses", World Academy of Science, Engineering and Technology International Journal of Civil, Structural, Construction and Architectural Engineering Vol:9, No:2, 2015.
- 7) F. Behnamfar , M. Banizadeh,(2015)," Effects of soil–structure interaction on distribution of seismic vulnerability in RC structures", Department of Civil Engineering, Isfahan University of Technology, Esfahan 8415683111, Iran
- 8) Ravindra N. Shelke, U. S. Ansari, (2017)," SEISMIC ANALYSIS OF VERTICALLY IRREGULAR RC BUILDING FRAMES", International Journal of Civil Engineering and Technology (IJCIET) Volume 8, Issue 1, January 2017, pp. 155–169.
- 9) National Institute of Building Sciences (2004). Multi-hazard loss estimation methodology earthquake model: HAZUS MH-MR1 Technical manual. Washington, DC: Federal Emergency Management Agency.
- 10) IS:1893 Indian standard criteria for earthquake resistant design of Structures, part 1 general provision and building. New Delhi: Indian standards Institution;2002.
- 11) FEMA (2009), Federal Emergency Management Agency, "Quantification of Building Seismic Performance Factors", Report FEMA P695, Washington, D.C. (US).
- 12) Vamvatsikos, D., & Fragiadakis, M. (2010). Incremental dynamic analysis for estimating seismic performance sensitivity and uncertainty. Earthquake engineering & structural dynamics, 39(2), 141-163.
- 13) National Institute of Building Sciences (2004). Multi-hazard loss estimation methodology earthquake model: HAZUS-MR4 Technical manual. Washington, DC: Federal Emergency Management Agency.
- 14) IS 800:2007" code of practice for general construction of steel"
- 15) IS 456:2000"code of practice for Plane & Reinforced concrete"
- 16)Lagaros, N. D. (2008). Probabilistic fragility analysis: A tool for assessing design rules of RC buildings. Earthquake Engineering and Engineering Vibration, 7 (1), 45-56.
- 17)IS:1893Indian standard criteria for earthquake resistant design of Structures, part 1 general provision and building. New Delhi: Indian standards Institution;2002.