# To Develop Fragility Curve For Rc Building Under Seismic Load With Plan And Vertical Irregularities

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*Abstract* - **The significant damage has been observed repeatedly to structures with structural irregularities in their plans during many past earthquakes, great research has been undertaken to assess their seismic vulnerability. While most of the previous studies used simple conceptual representations such as one-dimensional or two-dimensional templates in the study of fragility of abnormal design systems. A HAZUZ methodology is provided here for deriving fragility curves for systems with design abnormalities. A spatial damage index is formulated and used as a damage characterization measure to characterize the damage state of irregular structures. The procedure is illustrated through a reference derivation of fragility curves for an irregular RC building. Fragility analysis is used to develop the different damage grades based on HAZUS methodology. Damage probability matrices for quality point as per ATC-40 were developed to assess the damage condition for each hazard level**

*keywords* - **Fragility curve, Damage Index, Irregularity, HAZUZ methodology**

## I. INTRODUCTION

Earthquake can be described as shaking the Earth's surface, resulting from the Earth's lithosphere's sudden release of energy th at generates seismic waves. Usually, during an earthquake, it is not the trembling ground itself that takes lives. It is the resulting devastation of buildings made by man and the instigation of other natural disasters such as tsunamis, avalanches and landslides. Earthquake damage often depends on their size and form of fault.

In the past, we have seen the devastating earthquake in 2005 Kashmir earthquake. which occurred at a magnitude of 7.6 moments and was located centred near the city of Muzaffarabad, and also affected Pakistan's Khyber Pakhtunkhwa province and Indian-administered Jammu and Kashmir. Kashmir lies in the Eurasian and Indian tectonic plate collision zone. The geological activity arising from this impact, which is also responsible for the formation of the Himalayan peaks, is the source of extreme seismicity in the area.

We have already experienced disastrous effects of the earthquake, especially in India. For example, Bhuj Earthquake, calculated at 7.7 on the Richter scale in 2001, was Gujarat's most destructive experience of earthquake in history. There is a very strong probability of such an earthquake occurring in the future.

In 2016, the sixth update of the seismic design code IS 1893 was released with some major design methodology improvements. It suggests a decrease in moment of inertia (Ig) for structural elements such as a beam / column, while IS 1893:2002 is quiet about it and suggested taking Gross section properties. Thanks to cracking resulting in improvements in the flexural stability (EI) will be significantly reduced. Most geologists agree that one of the causes for heightened seismic activity is global warming. According to their research, melting glaciers and rising sea levels disrupt the balance of pressure on Earth's tectonic plates, resulting in increased earthquake frequency and intensity.

## II. FRAGILITY CURVE

Fragility curves are defined as the probability of reaching or exceeding a specific damage state under earthquake excitation. Fragility curves provide the conditional probability of structural response when subjected to earthquake loads as a function of ground motion intensity or other design parameters. The fragility curves are established to provide a prediction of potential damage during an earthquake.

The fragility function is also directly used to reduce damage cost and loss of life during a seismic event. Fragility curves - show the probability of failure verse us peak ground acceleration. typical fragility curve with PGA along the x-axis and probability of failure along y-axis. A point in the curve represents the probability of exceedance of the damage parameter.[12]

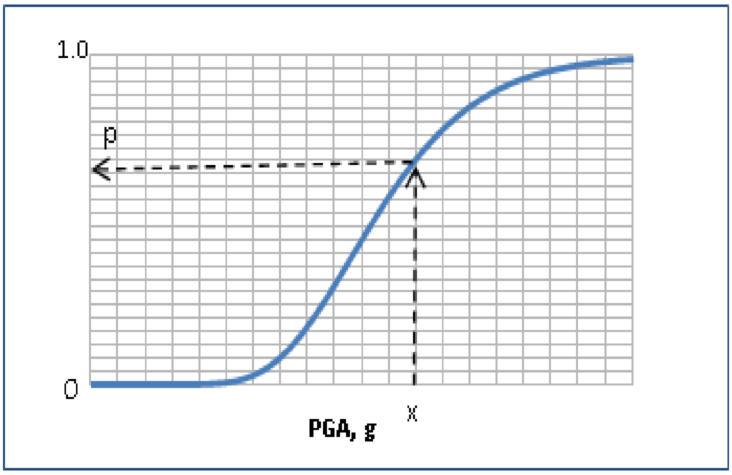


Figure 2.1 Typical Fragility Curve showing PGA vs. Probability of exceedance

Fig 2.1 shows typical fragility curves for different limiting values for damage parameter. The intensity measure here is the spectral displacement of the earthquake. As the limiting value increases the curve shifts towards right and becomes more flat. From the figure it can be seen that at weak shaking the probability of exceedance for the limit state corresponding to slight damage is high. For strong earthquakes probability of exceedance is 100% for the first curve, which means slight damage is sure, moderate and extensive damages are likely to occur. But probability that complete damage will occur is low. Regions of various damage states such as slight, moderate, Extensive and complete damages are marked between each fragility curves. With the severity of damage, the parameter defining the limit state of damage increases, and the exceedance probability decreases.[8]

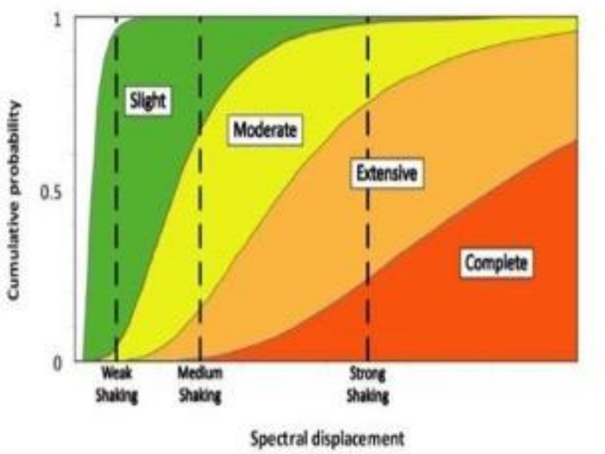


Figure 2.2 Fragility Curves For 4 Different Limit States

For an earthquake with spectral intensity corresponding to weak shaking, the exceedance probability for the slight damage is quite high and the levels defined by higher damage states such as moderate, Extensive, complete are very negligible. Whereas if there is an earthquake of strong intensity the building is more likely to be crossed the damage states of slight and moderate. The exceedance probability for the extensive damage state is more than that of complete damage state. [8]

### 2.1 Types of Irregularities

The irregularity in the building structure may be due to irregular distribution in their mass, strength and stiffness along the height of building. When such building are constructed in high seismic zone, the analysis and design becomes more complicated. [9]
There are two type of irregularities :-

1. **Plan irregularities**
2. **Vertical irregularities**

Vertical irregularities are one of the major reasons of failure of structure during earthquakes. Vertical irregularities are mainly of three type:-

1) **Stiffness irregularities :-** Under stiffness irregularity the stiffness of the member in a frame are not equal and they vary according to the floor height, modulus of elasticity of concrete and moment of inertia of concrete. [9]

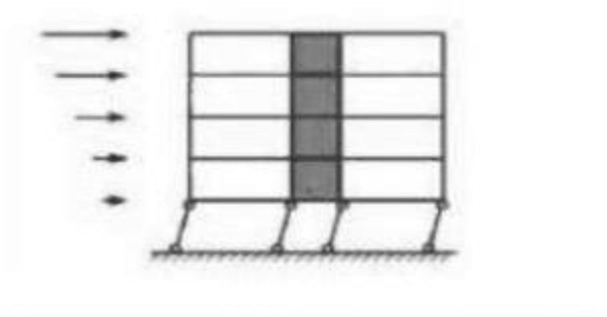

Figure 2.3 Stiffness Irregularities

2) **Mass irregularities :-** mass irregularity shall be considered to exist where the seismic weight of any storey is more than 200 percent of that of its adjacent storeys. In case of roof irregularities need not be considered. [9]

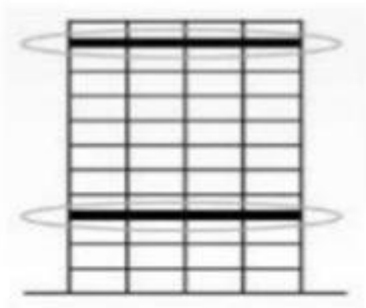

Figure 2.4 Mass Irregularities

3) **Vertical geometric irregular :-** A structure is considered to be vertical geometric irregular when the horizontal dimension of lateral force resisting system in any storey is more than 200 percent of that in its adjacent storey. In case of roof irregularity need not be considered. [10]

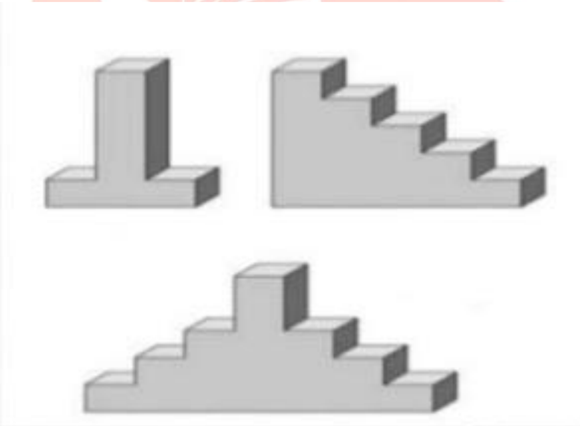

Figure 2.5 Vertical Geometric Irregular

**III. HAZUZ**

**3.1 Fragility analysis as per the HAZUZ Methodology**

Fragility curve trails the form of logarithmic standard deviation of spectral displacement and a lognormal dispersal function with mean value. It explained the probability of the structure when it gains or surpass any particular damage state as a function of seismic ground motion. In this study, spectral displacement is measured. In present study, 8-storey RC buildings follow HAZUZ procedure from the HAZUS®-MH MR5. According to HAZUZ methodology equation of probability as following equation (3.1):

$$p(ds/s_d) = \emptyset\left[\frac{1}{\beta_{ds}}\ln\left(\frac{s_d}{s_{d,ds}}\right)\right] \quad \textbf{(3.1)}$$

Where, The spectral dissplacement ($S_{d,ds}$) the building range the damage state threshold; The standard deviation of the natural logarithm of spectral displacement for damage state denoted as $\beta_{ds}$; The standard normal cumulative distribution function denoted as Φ.

**3.2 Beta**

Fragility arc scattering for the defined harm level threshold depends primarily on the lognormal volatility associated with power curve βc; The lognormal variance associated with the spectrum of demand βD; the lognormal variability associated with the discrete threshold of individually damage state (βT,ds). the already calculated damage-state beta value standards taken from the HAZUZ ® -MH MR5 shown in Table[3-1].

Table 3-1 Structural Fragility Curve Parameters for Beta(βds) – Moderate Code Seismic

| Building class | Post-yield degradation of structural system | | |
|---|---|---|---|
| | Structural systems with Moderate capacity variability $\beta_C$=0.3 | | |
| | Minor degradation | Major degradation | Extreme degradation |
| | Damage variability ($\beta_{Tds}$) | | |
| | Moderate (0.4) | Moderate (0.4) | Moderate (0.4) |
| Low-Rise (1-3 floors) | 0.80 | 0.95 | 1.05 |
| Mid -Rise (4-7 floors) | 0.75 | 0.85 | 1.00 |
| High | 0.70 | 0.80 | 1.00 |

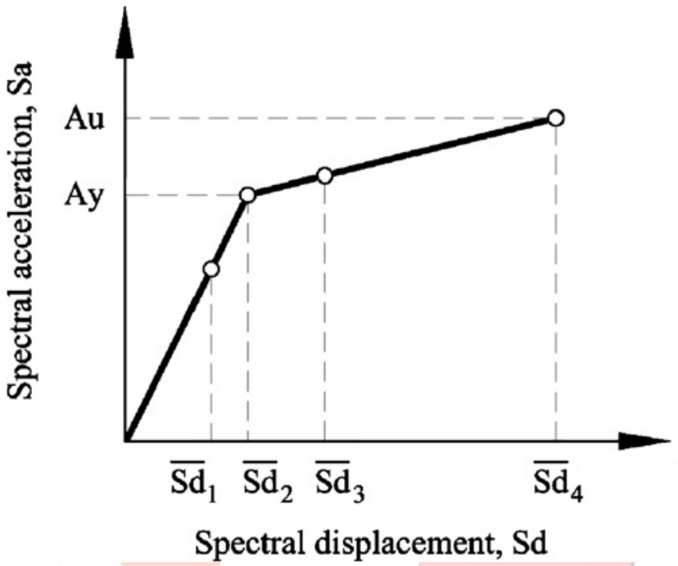


Figure 3.1 Damage State Thresholds from Capacity Spectrum

The damage states created on performances of building to defined the damage state thresholds as presented in HAZUZ®-MH MR5. Barbat et al. (2008) give a damage states threshold built with Yielding Spectral Displacement as well as Ultimate Spectral Displacement of the building shown Table [3-4]. This Sdy and Sdu found in capacity curve by bilinearization as shown in Fig. (3-1).

Table 3-2 Damage State Threshold (See Fig. 3.1)

| Damage State | Damage state | Damage state thresholds |
|---|---|---|
| DS-1 | Slight | $S_{d1}= 0.7\ S_{dy}$ |
| DS-2 | Moderate | $S_{d2} = S_{dy}$ |
| DS-3 | Extreme | $S_{d3} = S_{dy} + 0.75\ (S_{du} - S_{dy})$ |
| DS-4 | Complete | $S_{d4} = S_{du}$ |

**IV LITERATURE REVIEW**

**Do-Soo Moon et. al.**[1] presented study on fragility analysis of space reinforced concrete frame structures with structural irregularity in plan In which the three dimensional representations are used to evaluate appropriate and accurate seismic performance of space RC frame structures with structural irregularity in their plans. Author also used first order reliability method(FORM) to determine failure probability and FERUM / ZEUS-NL are selected as the reliability and structural analysis tools. Five different models of RC frame structures are studied, with varying plan irregularities from 0 to 10% with the 2.5% increment. There are 15 ground motions are used and they are considered into three groups based on the ratio of PGA to PGV. The structural capacity and earthquake demand are both considered. There are three limit states, serviceability, damage control, and collapse prevention. The corresponding values of inter storey drift ratio for each limit states are determine from a series of adoptive pushover analyses. The lognormal cumulative probability distribution is used to generate the fragility curves. From the obtained fragility curves, it is observed that seismic vulnerability is affected by the structural irregularity. By the mathematical solution it is clearly state that as the plan that the building with ME100(10% irregular building) has almost 10,15,45 % less serviceability, damage control and collapse prevention damage state of fragility curve than ME00(regular building).

**Fadzli Mohamed Nazri et.al.** [2] experimentally studied Fragility Curves of Regular and Irregular Moment-Resisting Concrete and Steel Frames. In this paper, the author considered regular and irregular moment resisting frame of different material, heights and ground motion. The height of the concrete and steel frames used in this analysis are 3,6 & 9 stories. Different types of frames are designed based on Eurocode 3 and Eurocode 2 with the use of Eurocode 8 for earthquake loading. The incremental dynamic analysis was done by using SAP2000 software. This IDA curve were compared to five level of FDMA-356, which are operational phase(OP), immediate occupancy(IO), damage control(DC), life safety and collapse prevention(CP). The fragility curve for both irregular and regular frames were developed and it is concluded that for 3 storey regular MRCF's sustainable value is 1.7g and for irregular MRCF's sustainable value is 1.8g. So the regular frame give better performance than irregular frame.

**P. Rajeev et. al.** [9] discussed about seismic fragility for reinforced concrete building with consideration of irregularities. In which the author analyse study the effect of soft storey(SS) ,construction quality(CQ) and their interaction on probabilistic seismic demand model(PSDM) and seismic fragility of RC building. Here, the different height of building such as three, five and nine storey three bay RC frame is considered for analysis and numerical model. The function of soft storey and construction quality is developed by using the response surface method. The sample structure is made to check to accuracy and sensitivity of predictive tools. The bootstrap model is use for development of confidence bond of fragilities. From the analytical work, it is shown that the structure irregularities have significant influence on the PSDM parameters. It can be also seen that the soft storey (SS) and construction quality (CQ) have significant influence on seismic fragility. The construction quality and vertical irregularities are also give an effect on seismic risk assessment.

**Seong Hoon Jeong et. al.** [1] investigated on fragility analysis of buildings with plan irregularities. In this paper, the author give methodology for the derivation of fragility curve for plan irregularities. In the derivation of fragility of curve, the structure response is determine by single quantity like dame index, top displacement and storey drift. The damage measures of irregular structure can be determine by spatial damage indices and conventional damage indices. Through the comparison b/w fragility curve determine by conventional and spatial damge indices, it is shown that for spatial responding structure the conventional damage index is unconservative. So that, this method use for deriving the fragility curve is identically useful for seismic assessment of plan irregular structure.

**T. Choudhury et. al.** [10] carried out seismic fragility of reinforced concrete frames with vertical irregularities This paper provides an investigation into the seismic fragility assessment methodologies for reinforced concrete (RC) frames with and without vertical irregularities (soft storey). Nonlinear dynamic analysis of the frames subjected to ground motions scaled-up for different PGA is develop to estimate the local and global drift demands, also known as engineering demand parameters (EDPs). This engineering demand parameter (EDP) is use in a large-scale fragility assessment of building includes peak roof or top storey displacement. Here, the global displacement or drift response of the building is entirely defined by the top storey displacement. In this paper the author found that Irregular frames show storey collapse mechanism in the weak storey, and in contrast, the regular frames show multi-storey collapse mechanism for the same seismic intensity.

**Koktong Tan et. al.** [7] performed on fragility curves of a RC frame building subjected to seismic ground motions. In which the author analysed three storey reinforced concrete frame building for different site soil condition classified as C and D of NEHRP. This soil are subjected to small number of ground motions. In this paper, the non linear time history analyses were obtain by using opensees software. The maximum inter storey drift ratio is determined by using HAZUS. After this research work, the author concluded that the soil type D give more extensive damage than type C.

**Ghada Mousa Hekal et.al.** [5] investigated on seismic fragility curves for mid rise reinforced concrete frame structure with different lateral load resisting system .The author analysed mid rise reinforced concrete framed structure with two different lateral load resisting system ,shear wall and rigid marginal beams the main aim is to investigate the influence of the location of system in the location of system in the structure ,for example level of marginal beams and arrangement of shear wall. The five performance levels are considered in this analysis collapse prevention , life safety, damages control , immediate occupancy ,operation from the study .the author observed that the best behaviour of structure as compared to exterior that the provision of rigid marginal beam in lower storey give more efficiency against lateral load resisting in structure

**Angelo's D'Ambrisi et. al.** [12] discussed about the effect of common irregularities on seismic performance of existing RC framed building. The author analysed the seismic performance of RC existing framed structure subjected to seismic action the effect of common irregularities such as asymmetric plan, irregular distribution of balcony, different live load and nonhomogeneous mechanical properties equivalent eccentricity that result by5% .the displacement of top storey is longer than 10% while the increase in first storey inter storey inter storey drift is ranging between 7 to 25 % depending on considered PGA the obtain result shows that common irregularities affect the seismic response of Rc building with concrete having poor material properties

**F. Hosseinpour et. al.** [8] presented on fragility curves for RC frames under multiple earthquakes. In which they develop fragility curves for three RC (reinforced concrete) buildings with different number of stories under multiple earthquakes. The effect of different parameters including damage from previous event, vertical earthquake component, earthquake region, number of stories, and earthquake intensity on fragility curves were considered. Here they considered four cases. The difference between fragility curves in four cases decreases with the increase of the number of stories and this can be because of the higher story displacements in taller buildings under a single event. The PGA as the intensity measurement works well for 3 story buildings. However, with the increase of the number of stories, PGA may not be a good intensity measure to derive fragility curves. The structural vulnerability increases with the increase of the number of stories. The Fragility curves are highly affected by earthquake region and so that earthquake characteristics should be determine before deriving fragility curves.

**Tathagata Roy et. al.** [11] carried out comparison of damage index and fragility curve of RC structure using different Indian standard codes. In this paper the author consider 4-storey RC moment resisting frame. From the fragility analysis, the spectral displacement at different damage states is compared against the Indian standard codes. The author also use pushover analysis in case of damage and concluded that the damage for IS-1893:1970 is maximum for a fixed value of roof displacement compared to IS-1893:1984 and IS-1893:2002, in which the damage obtained by IS-1893:2002 has the least value. It also conclude that Due to high ductility obtained by the most recent code, the pattern would follow that the maximum roof displacement will occur for IS-1893:2002, but at 0.54g PGA the maximum roof displacement for IS-1893:1984 comes out to be higher than IS-1893:2002.
irregularity increases the space RC frame structures become much vulnerable to earthquake damage. At last they give result

**literature related to IS code:-**

**IS code 1893 (Part-1):2002 and 1893 (Part-1):2016 [6]**

IS 1893 (Part 1), 2016.Criteria for earthquake resistant design of structures Part 1 General provisions and buildings, Bureau of Indian Standards (BIS) classifies RC frame buildings into Special Moment Resisting Frames (SMRF) with no change in response reduction factors 5. IS 1893 (Part-1):2002 were silent about the effective moment of inertia for structure member beam/column. However, IS 1893 (Part-1):2016 give a reduction in the moment of inertia for the structure member beam/column.

## V. CONCLUSION

This research aims to obtain more precise and appropriate seismic fragility curves for their three-dimensional models of spatial RC frame systems of different degrees of design irregularity. Once quantitative fragility curves are obtained, a structure's reaction is usually defined by a single quantity such as top displacement, inter-story drift or damage index. HAZUS methodology for the generation of fragility curves is addressed and fragility curves for low-rise RC building structures are created without taking into account infill walls. Based on the results produced, It is assumed that this approach gives an indication for estimating the level of damage of the building according to the particular value of spectral displacement. Since the HAZUS method works on non-linear static procedures, By comparing the fragility curves resulting from the spatial and conventional damage indices it is shown that using the conventional damage index for spatially responding structures is unconservative. The proposed method for deriving fragility curves is therefore highly recommended for seismic assessment of irregular plan structures.

## VI. REFERENCES


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