JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

SEISMIC RISK ASSESSMENT OF RC FRAMED VERTICALLY IRREGULAR BUILDINGS

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ABSTRACT: - Buildings with vertical irregularities are gaining a lot of attention in the seismic research field. For architectural views, many constructions have vertical irregularity. Buildings develop vertical irregularity as a result of a major change in stiffness & strength. An extreme form of vertical irregularity is the open ground story (OGS). The current study considers the predictable OGS & the graded form of deviation. The OGS building design code recommends scale factor (SF) for the construction of open floor columns. In the current study, vulnerability and reliability analyzes were used to investigate the performance of typical OGS buildings designed considering hierarchical structures with different scale factors and different geometric configurations. As intensity metric, the crucial inter-storey drift is taken into account.

OGS For the current analysis, building frames with varied MFs & stepped irregular frames with various infill configurations & heights (6, 8 & 10 storeys) are taken into consideration. Using Cornell's methods, fragility curves are created for each form of structure (2002). For each frame, PSDM models are created, & the related fragility curves are produced. The PSDM models & fragility curves are used to derive conclusions about the relative performances of each frame. It has been shown that a structure with infill walls on all storey's performs on par with an OGS-framed structure with an MF of around 1.5. As MF rises, OGS frame performance improves, but the neighboring storey becomes more exposed.

In Manipur area (Ukhraul), one of India's most susceptible locations, the study is exp&ed to include the seismic dependability of standard OGS structures with varied MFs as well as stepped type buildings with various infill configurations. The region's fragility curve & seismic hazard curve are combined to determine the dependability. The analysis completed by Pallav et al. served as the source for the seismic hazard curve for the current investigation (2012).

At an earthquake intensity of 2% likelihood of occurrence in 50 years at collapse prevention performance level, the dependability of all the frames is assessed. By contrasting the achieved reliabilities with the goal reliabilities recommended by ISO 2394, the performance of the buildings is evaluated (1998). It has been noted that frames without any infill walls were unable to meet the desired reliability standards. The structure that has infill walls installed equally throughout all storey's reaches the desired reliability levels. The performance of structures during earthquakes is significantly enhanced by the rigidity of infill walls.

Keyword: *Magnification factors (MF); Open ground storey (OGS); stepped Irregular buildings, Seismostruct; Fragility analysis, Reliability analysis, Peak Ground Acceleration (PGA), Performance levels*.

1- INTRODUCTION

Buildings with vertical irregularities are a highly typical characteristic in urban areas. Buildings typically develop irregular vertical shapes during the design stage for both architectural & functional reasons. These structures showed greater earthquake sensitivity in history. This topic has been the subject of several deterministic investigations. So, the current study's major objective is to evaluate the comparative effectiveness of typical vertically irregular structures within a probabilistic domain.

This particular sort of irregularity results from a rapid loss of stiffness or strength in a specific storey. A qualified structural engineer may find irregularities in buildings to be a significant difficulty in areas with heavy seismic activity. Modern urban infrastructures contain a significant number of vertically asymmetrical structures. Urban India has several different styles of buildings, including stepped & open ground story. Fig [1-1] depicts a Typical Open Ground Storey with a Stepped irregular framed construction.



Fig [1-1] vertically irregular buildings [i] OGS Building [ii] Stepped type building.

2- REQUIREMENT FOR VERTICAL IRREGULARITY IN BUILDINGS

No design advice, specifically for OGS frames, were made for vertical irregularity in the preceding IS 1893 specification. Nevertheless, the 2002 revision came about as a result of the Bhuj earthquake. A new design suggestion for OGS structures was added into the most recent edition of IS 1893 (2002) (part 1).

The soft storey's columns & beams must be built for 2.5 times the storey shear & moments computed under the seismic load of bare frame type structures, according to clause 7.10.3 (a). Kanitkar & Kanitkar (2001), Kaushik, & Subramanian (2004) all study the magnification factor (MF) 2.5. (2006). The "strong beam - weak column" scenario is likely to emerge from using the Magnification Factor MF 2.5 in beam design.

The following five categories of anomalies for structures are given out by the IS 1893 (2002) code:

1- A story is considered to be stiffness irregular if its lateral stiffness is less than either 70% of the story above it or 80% of mean inflexibility of the 3 levels more than it.

2- When any narrative's effective mass exceeds 150% of the effective mass of a story next to it, weight (mass) irregularity is said to occur.

3- When the flat measurement of lateral force-resisting scheme in any story exceeds 130% of to in a neighboring story, vertical geometric irregularity is said to be present.

4- When an in-plane offset of the lateral-force-resisting elements is more than the length of those elements or when there is a decrease in the stiffness of the resisting element in the narrative below, in-plane discontinuity - in vertical lateral-force-resisting elements is said to occur.

5- Discontinuity in Capacity - A weak tale is one whose lateral strength is less than 80% of the narrative's lateral strength in the story mentioned above. The sum of the lateral strengths of all seismically resistant components that share the story shear in the direction under consideration is the story lateral strength.

3- LITERATURE

The literature review that was done for this study is broken up into two parts. In the first section, design requirements according to Indian code for various structures are examined along with an overview of the fragility analysis of the present design provision of vertically irregular buildings. The dependability & seismic hazard analyses are based on different regions of India in the second section.

Afarani & Nicknam (2012) used incremental dynamic analysis to observe the behavior of the vertically irregular building under seismic stresses. They are dealing with an eight story conventional structure that has two bays that are 4 m wide in the y direction & four bays that are 3 m wide in the x direction, with a storey height of 3 m. [1]

18 ground motion recordings with Richter magnitudes of 5 to 8 on solid soil are taken from the Pacific Earthquake Engineering Research Centre (PEER) database & were recorded at far-field locations more than 10 km away from the epicentre. SeismoStruct-V5 programme models the structure as a nonlinear dynamic analysis. Elastic is modelled after steel.

According to FEMA 440, there was Perfectly Plastic (EPP) hysteresis without any evidence of local or lateral bending, & the connections failed. Incremental dynamic analysis is used to compute the maximum inter-story drift ratios & first mode spectral acceleration, & the IDA curved is plotted to determine the collapse locations. The building's examination is concentrated on the structures' ability to prevent collapse. By applying the Cumulative Distribution Function & the collapse points of the lognormal distribution, fragility curves are produce. [2]

Samoah (2012) studied non-ductile reinforced concrete (RC) frame structures' fragility behaviour in low- to medium-seismic regions, preferring Accra, the capital of Ghana in West Africa. Inelastic pushover analysis is used to examine the structural strength of the structures, while inelastic time history analysis is used to evaluate seismic demand. [3]
Ellingwood (2001) used probabilistic risk analysis techniques over a 20-year period to determine the building's seismic risk assessment. He concentrated on the reliability- & probability-based condition assessments of existing buildings. The steel frames that are welded together are planned. [4]

The same goal dependability level was examined by Sykora, M., & Holicky, M. (2011) for the evaluation of existing structures. By taking into account the various criteria, it is possible to calculate how the cost as well as the dependability index vary. The goal dependability for the building has been determined by taking into account the numerous codes, & the performance levels are assessed as a result. [5]

4- VERTICALLY IRREGULAR BUILDINGS' PERFORMANCE EVALUATION USING FRAGILITY CURVES

4.1 CONSTRUCTION OF FRAGILITY CURVES

The chance of exceeding a certain Engineering Dem& Parameter (EDP) for a chosen Structural Limit State (DS) for a particular ground motion intensity measure is represented by a fragility function (IM). These curves are cumulative probability distributions that show the likelihood, in relation to a certain dem&, that a component or system may reach a specific damage state or a more severe one. As a result of a certain dem&, the fragility curve is damaged to the specified damage state or a more severe one. For each damage state, a fragility curve may be created & stated in closed form using Eq. 1.1

$$P\,(C\text{-}D \le 0 |\, IM) = \emptyset\left(ln\frac{S_d}{S_c}\middle|\sqrt{\beta^2_{d|\,IM} + \beta^2_c}\right) \ldots\ldots\ldots\ldots 1\text{-}1$$

Where Sd is the median of the demand, Sc is the median of the selected damage state (DS), and C is the drift capacity. Dispersion in the intensity measure and capacity, or d/IM and c, respectively. For component fragilities, Eq. 3-1 can be represented as Eq. 1-2 as follows:

$$P(DS \mid IM) = \emptyset\left(\frac{\ln IM - \ln IM_m}{\beta_{comp}}\right) \ldots\ldots\ldots\ldots\ldots\ldots 1\text{-}2$$

4.2 GROUND MOTION DATA

According to ASCE 7-05, three or seven ground movements are necessary for a fair assessment of the structural reaction. ATC 58 50% draught, however, suggests a set of 11 ground motion pairings for a trustworthy estimation of the reaction amounts. 30 recorded ground vibrations are recommended by ASCE/SEI 41 (2005) to satisfy the spectrum matching requirements for NPP facilities. From Haselton and Deierlein (2007), thirty Far-Field natural Ground Motions were gathered. These are transformed using a programme called WavGen created by Mukherjee and Gupta (2002) to fit the IS 1893 (2002) spectrum. The Response spectrum for converted ground movements is shown in Fig 3-1 together with the Indian spectrum.

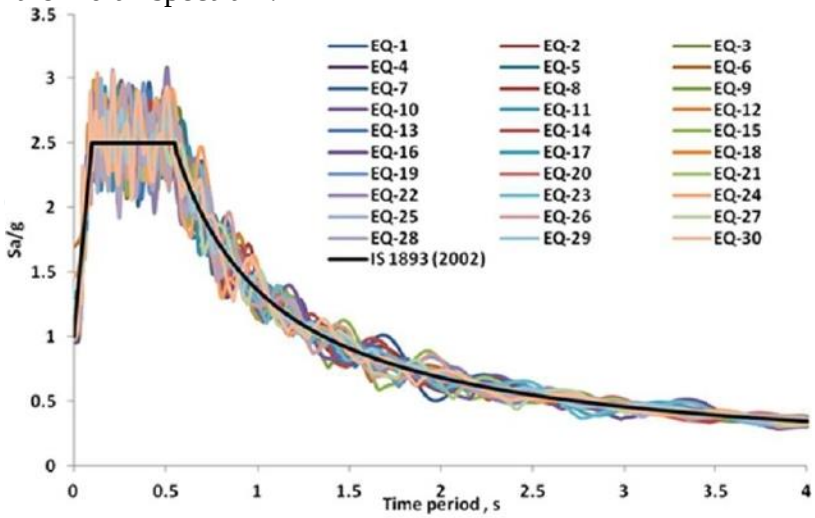

Fig [1-2] 30 transformed ground motion response spectra and the IS 1893 (2002) design spectrum

4.3 BUILDING DESIGN

The present study's building frames that were taken into account for the numerical analysis are situated in Indian seismic zone V with medium soil conditions. These frames were created as ordinary moment-resisting frames, with seismic loads calculated in accordance with IS 1893 (2002) and RC components developed in accordance with IS 456 (2000) standards**.**

S.NO.	Frame designation	Designation	Ground storey column section
1	6 to 10stories and 6 bays, Full Frame	FF	350 × 350
2	6 to10 stories and 6 bays, OGS (M.F =1)	OSG 1	350 × 350
3	6 to 10 stories and 6 bays, OGS (M.F =1.5)	OSG 1.5	450 × 450
4	6 to10 stories and 6 bays, OGS (M.F =2)	OSG 2	600 × 600
5	6 to 10 stories and 6 bays, OGS (M.F =2.5)	OSG 2.5	750 × 750

Table [1-1] Details of Open Ground Storey frames

4.4 PERFORMANCE LEVEL

Performance levels serve as indicators of the building's damage statuses in the presence of seismic loads. Fig 1-3 and table 1-2 demonstrate the performance levels for a typical building that has been pushed laterally to failure. According to FEMA356, the inter-storey drift (Sc) for these performance levels has been calculated as 1%, 2%, and 4%, respectively.

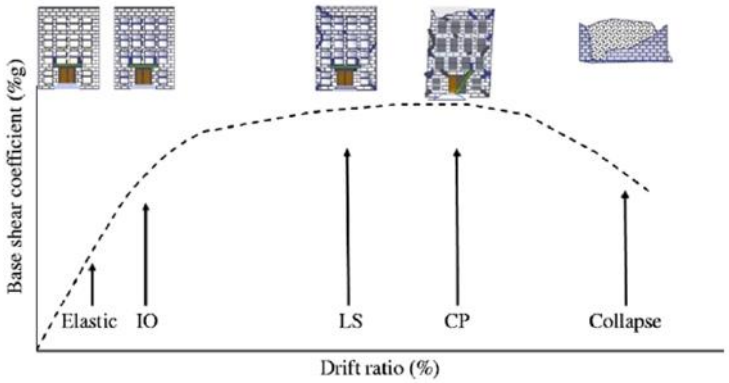

Fig [1-3] A typical building's damage stages as it approaches collapse (Courtesy, FEMA356)

Limit states designation	Performance level	Inter-storey Drifts Sc for MRF, (%)
IO	Light repairable harm	1.1
LS	Reasonable repairable harm	2.1
CP	Near Collapse	4.01

Table [1-2] Harm limitations for RC frames at various structural performance levels (FEMA356)

5- RELIABILITY ASSESMENT OF RCC FRAMES

5.1 INTRODUCTION

The inter-storey drift capacity corresponding to a given performance level will most likely be exceeded by the maximum inter-storey drift in the frames if subjected to an earthquake of a certain severity in terms of effective PGA, according to the fragility curves thus far developed. The fragility curves must be paired with the seismic hazard curve in the study zone in order to calculate the reliability, which is inversely related to the likelihood of failure, and the actual probability of failure. The seismicity of the particular location for which the structure has been constructed should be accurately depicted by the danger curve. The Manipur region's danger curves, which are in seismic zone V, were chosen for the current study. A building was also developed. Hazard curve for a location where a 1.05g earthquake would have a 2500-year return time or a 2% chance of exceeding it in 50 years. The dependability index is determined by taking the regular normal distribution and reversing it. The Target Reliability Indices requirement for each performance level (consequences of failure) for each relative cost of measures is recommended by ISO 2394 (1988). To evaluate dependability, the current study has established target reliability values based on ISO 2394: 1988.

5.2 SEISMIC RELIABILITY ANALYSIS FOR VARIOUS HAZARD SCENARIOS

The danger curve of the area for which the structure is constructed must be integrated with the fragility curves created in the preceding Chapter. The yearly probabilities of particular amounts of earthquake motion are used to represent the seismic hazard P [A = a]. The danger curve created for Manipur is used in this study. By taking into account a succession of (increasingly severe) limit states, LSi, the formula may be used to compute limit state probabilities:

$$P\{LS_i\} = \sum_a \{LS_i \mid A = a\} P\{A=a\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\{1.3\}$$

According to Cornell et al. (2002), the fragility FR(x) and the derivative of the seismic hazard curve GA(x) may be convolved to remove the acceleration-related conditioning and get a point estimate of the limit state probability for state eq 1.3

$$P\{LS_i\} = \int F_R\{x\} \frac{dG_A}{dx} dx \ldots\ldots\ldots\ldots\ldots\ldots\{1.4\}$$

Eq. 1.4 is numerically integrated to determine the likelihood of failure. Figure 1-4 provides a pictorial explanation of numerical integration. The fragility and danger curves are separated into narrow strips that run parallel to the vertical axis. For each strip, the ordinate of the fragility curve is multiplied by the slope of the hazard curve, and the sum of all the strips is then used to calculate the likelihood of failure.

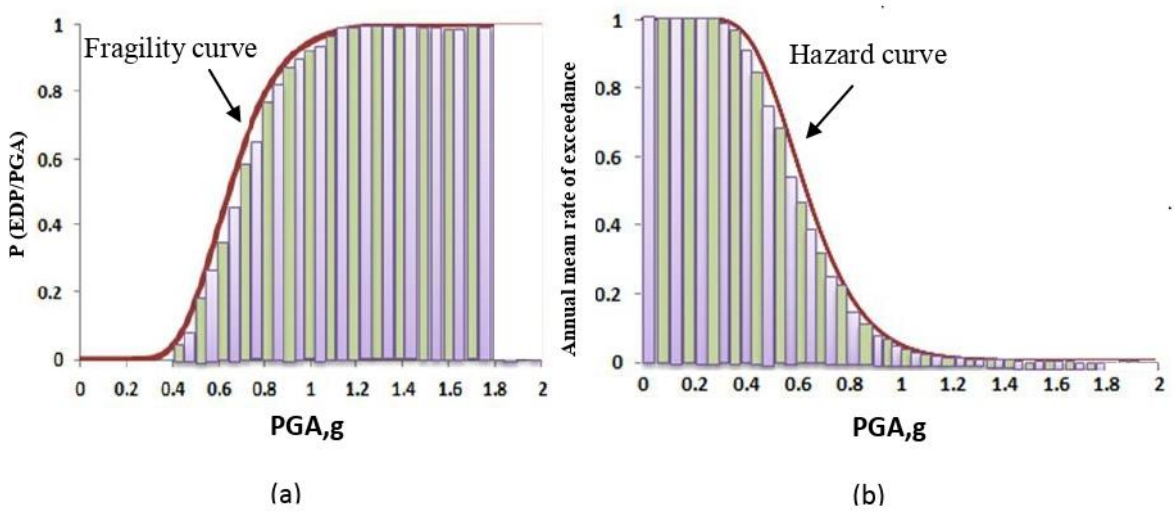

Fig [1-4] (a) fragility curve & (b) hazard curve for probability of failure

For the probability estimate to be useful, the parameters at the fragility-hazard interface must be dimensionally consistent. The following common Equation may be used to get the reliability index for the associated likelihood of failure.

$$B = -\emptyset^{-1}\{pf\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.5$$

5.3 ANALYSIS OF SEISMIC HAZARDS

A complementary cumulative distribution function (CCDF), as per, is used to visualise the seismic risk at a construction site. The annual frequency for exercise intensity x above a certain level is hazard function. Basic seismic hazard analysis shows that there is log-linear relationship b/w annual maximum seismic ground acceleration or spectral acceleration & probability, GA(a), that specifies values of acceleration are exceeded, as reference, at moderate to large values of ground acceleration. This connection means that the equation that follows describes

$$G_A\{x\} = 1\text{-}\exp\{-\{x/u\}^{-k}\} \ldots\ldots\ldots\ldots\ldots\ldots 1.6$$

The parameters of the distribution are u and k. The danger curve's slope is determined by the parameter k, which is connected to the yearly maximum peak acceleration's COV.

Pallav et al. (2012) provide an approach for the evaluation of seismic risk of building structures. The hazard analysis estimates the likelihood that a specific amount of ground motion will be exceeded in 50 years. The risk is determined by factors such as the frequency and magnitude of earthquakes, the nature of the rocks and sediments that earthquake waves pass through, etc.

The probabilistic seismic hazard curve of Manipur is chosen for the current study since it is located in the seismically active area of North East India. Pallav et al. (2012) produced the curve in question. Figure 1.5 depicts the danger curve for the Manipur area.

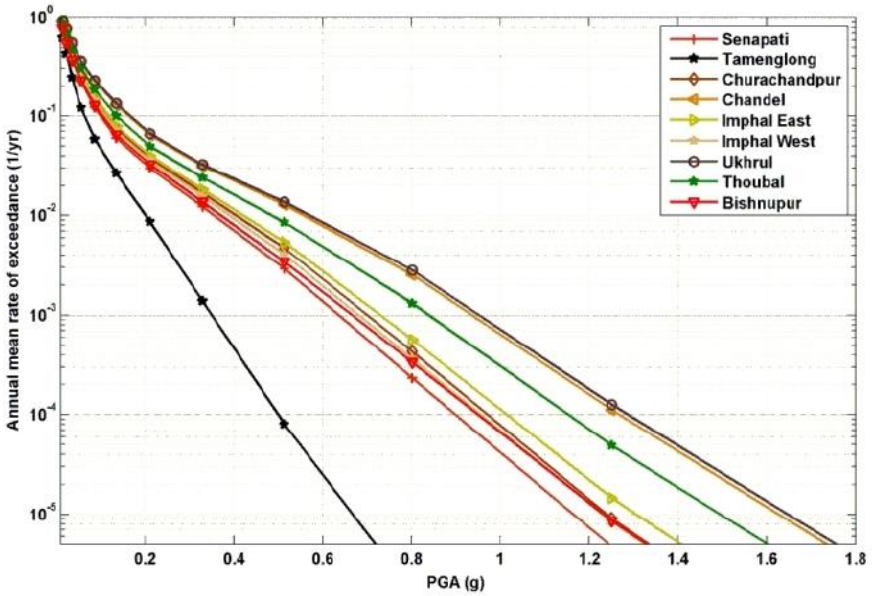

Fig [1-5] The danger curve for the Manipur area.

Fig 1-5 (Pallav et al., 2012) depicts the risk curves for the various regions in the Manipur area. The danger curve for the Ukhrul site is taken from the graph in Fig 4-2 and displayed as shown in Fig 1-6.

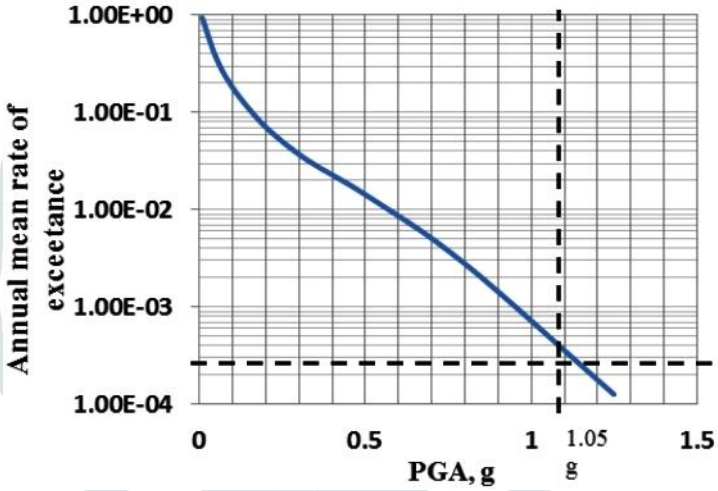

Fig 1-6 A failure probability hazard curve's numerical integration

6- CONCLUSION

The study's conclusion is divided into two categories. The behavior of OGS Buildings is detailed in the first section. The second half also discusses the performances of stepped type structures.

6.1 OSG BUILDING

- For 6, 8 & 10 storied OGS frames with different MFs at different performance levels like IO, LS & CP, the probability of exceedance & fragility curves are computed & illustrated for all the frames.

- For all of the OGS frames taken into consideration for the study, probabilistic seismic dem& models (PSDM) are created using log-log graphs. A PSDM comparison Plotted is models for every building case study with different infill wall layouts. The fragility curves are created using EDP as the ground storey's inter-storey drift. Using the three performance levels of IO, LS, & CP from the PSDM model according to the technique described in the previous sections.

- The naked frame is the most vulnerable of all the frames taken into consideration, according to the fragility curves. The inter-storey drift of bare frames (BF) is found to be much larger than that of FF & OGS frames across all structures. When an OGS frame is built for an MF of 1.5, the maximum ground storey inter-story drift

is 16% lower than it would be for an FF frame. When compared to OGS structures planned with an MF of 2.0, the inter-storey of the ground story is lowered by 51% with an MF of 2.5. Similar to this, it is discovered that the greatest inter-storey drift decrease in an OGS building planned with MF of 2.0 compared to that with MF of 1.5 is around 33%.

6.2 STEPPED BUILDING

- The fragility curves for stepped type buildings were produced using the same methodology. The inter-storey drifts for frames without infill walls (BF, ST1 & ST2) are much greater than frames with infill walls (FF, STFF1 & STFF2), according to the PSDM models of the vertically uneven structure. Only somewhat different are the inter-storey drifts of vertically uneven structures created with various stepped layouts without infill walls (ST1, ST2). Stepped frames are determined to be somewhat safer than matching regular frames, according to the fragility curves of the vertically uneven structures. The vertically asymmetrical structures (STFF1, STFF2) with infill walls exhibit the same behavior.

- Compared to FF & all other types of buildings, the vertically irregular structure with single & double stepped types & an infill wall offers more safety cases. The mass & consequently the inertia forces operating at top levels would be reduced due to the absence of some frames in the stepped structures than in an FF frame. This might be the cause of the mediocre conduct seen with vertically uneven structures.

6.3 RELIABILITY ANALYSIS

- The seismic reliability evaluation of typical vertically irregular buildings with diverse designs is another major topic of the current work. The hazard curve created by Pallav et al. (2012) is utilized for the analysis Manipur region & has been displayed by taking into account distinct regions. The observations from the reliability graph are described below.

- For 6, 8 & 10 storied OGS frames at various performance levels, such as IO, LS, & CP, the likelihood of failure & reliability indices for all the frames at PGA of 1.05g are determined.

- In contrast to full in filled frames (FF), which are able to achieve the intended dependability at all performance levels, bare frames (BF) are unable to do so. This is according to ISO 2394, 1998.

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