SEISMIC RISK ASSESSMENT OF RC FRAMED VERTICALLY IRREGULAR BUILDINGS

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ABSTRACT: ***-The area of vertically irregular type of building is now having a lot of interest in seismic research field. . Many structures are designed with vertical irregularity for architectural views. Vertical irregularity arises in the buildings due to the significant change in stiffness and strength. Open ground storey (OGS) is an example of an extreme case of vertically irregularity. The typical OGS and stepped types of irregularities are considered in the present study. For OGS buildings, the Magnification factors (MF) are suggested by the design codes, for the design of the open ground storey columns. The present study focus on the performance of typical OGS buildings designed considering various magnification factors as well as the stepped type buildings with different geometry configurations using fragility analysis and reliability analysis. The critical inter-storey drift is considered as an intensity measure.***

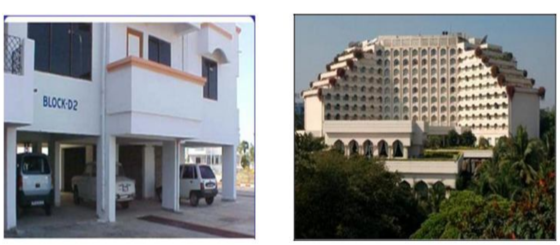
OGS Building frames designed with various MFs and stepped irregular frames with different infill configurations, and having heights (6, 8 &10 stories) are considered for the present study. Fragility curves are developed for each type of buildings as per the methodology introduced by Cornell (2002). PSDM models are developed for each frames and the corresponding fragility curves are generated. Conclusions on the relative performances of each frame are drawn from the PSDM models and fragility curves. It is observed that in terms of performance, a building with infill walls in all stories is equally comparable with an OGS framed building with MF of about 1.5. Performance of the OGS frame increases with the increase in MF, but it makes the adjacent storey vulnerable

The study is extended to the seismic reliability of typical OGS building with various MFs and also the stepped type buildings with different infill configurations in Manipur region (Ukhraul), which is one of the most vulnerable regions in India. The reliability is found out by combining a fragility curve with a seismic hazard curve of the region. The seismic hazard curve for the present study is chosen from the study conducted by Pallav et. al (2012). The reliability of all the frames is evaluated for an earthquake intensity of 2% probability of occurrence of in 50 years at collapse prevention performance level. The performance of the buildings is assessed by comparing the reliabilities achieved with the target reliabilities suggested as per ISO 2394 (1998). It is observed that the frames without any infill walls failed to achieve the target reliabilities. The building provided with infill walls throughout all stories uniformly, achieves the target reliabilities. The stiffness of infill walls is a significant factor that improves the performance of buildings during earthquake.

I.INTRODUCTION:

Vertical irregularities in buildings are very common feature in urban area. In most of situations, buildings become vertically irregular at the planning stage itself due to some architectural and functional reasons this type of buildings demonstrated more vulnerability in the past earthquakes. The topics related to of vertical irregularities have been in focus of research for a long time. Many studies have been conducted in this area in deterministic domain. Hence the focus of present study is to assess the relative performances of typical vertically irregular buildings in a Probabilistic domain.

This type of irregularities arises due to sudden reduction of stiffness or strength in a particular storey. For high seismic zone area, irregularity in building is perhaps a great challenge to a good structural engineer. A large number of vertical irregular buildings exist in modern urban infrastructures. Among them Open ground storey as well as stepped types of buildings are very common in Urban India. A typical Open Ground Storey and a Stepped irregular framed building are shown in Figure 1.1.



(a) (b)

Fig:1.1 Vertical Irregular Buildings (a) OGS Building (b) stepped Building

Open ground storey buildings are also called „open first storey buildings" or „pilotis" „stilted buildings". Because of the scarcity of land, the ground storey is kept open for parking purpose and no infill walls are provided in ground storey but the all above storey are as provided with infill walls.

STEPPED BUILDINGS:

Reduction of lateral dimension of the building along their height is categorized as "stepped building". Because of the functional and aesthetic architecture these types of buildings are preferred in modern multi-storeyed building construction. The main advantages of this type of buildings are they provide good ventilation with adequate sun lights to the lower storeys, Sarkar et.al. (2011). this type of building form also provides for compliance with building bye-law restrictions related to `floor area ratio'. Stepped buildings are used to increase the heights of masonry structures by distributing gravity loads produced by building materials such as brick stone etc. These buildings also allow the natural erosion to occur without compromising the structural integrity of the building.

A major earthquake shook cities and villages across the south Asian, several villages in Pakistan and leaving more than 1000 people feared dead. The magnitude 7.6 earthquake killed 157 people across India's Jammu and Kashmir. Scores of people were feared killed or trapped in two 12-storey apartment blocks reduced to rubble in Islamabad as Figure (a) shows.

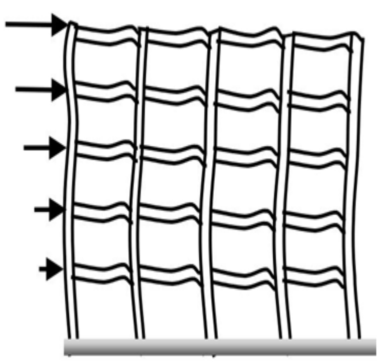
The stepped building (Time ball Station in Christchurch) at New Zealand is one of the many buildings and landmarks in the city that has been diminished to ruin because of a 6.3 magnitude of earthquake rocked New Zealand that causing widespread damage and killing at least 65 people.(Figure (b).


(a) (b)

a) A stepped type building in islamabad collapses
b) New Zeland Earthquake

BAR FRAMED BUILDINGS:

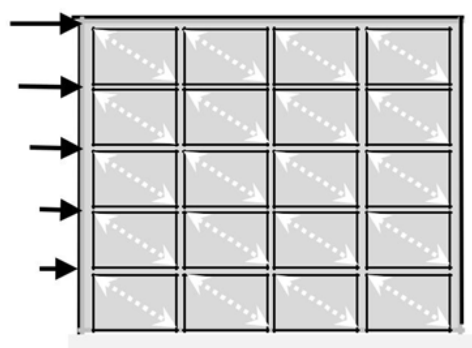
As per the Indian standard code for earthquake resistance structure designed it is mentioned that while designing a structure the contribution of infill are neglected. The buildings are designed as a bare frame that is the only design of columns and beams are taken into consideration. In the seismic point of view this is the worst case as compared to other building types where the vulnerability is more against lateral loads because of the absence of the infill.



Behavior of Bar frame under lateral loads

TYPICAL INFILLED MASONRY BUILDINGS:

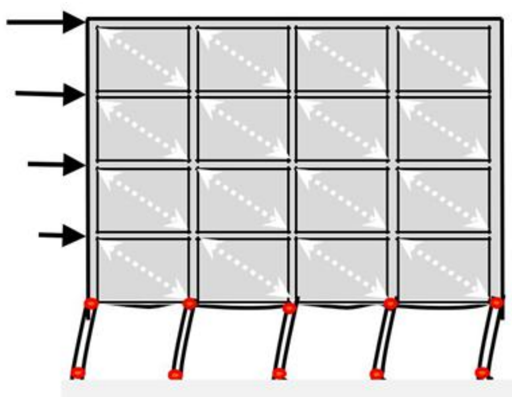
The typical infill masonry buildings are the regular buildings considering infill walls provided uniformly through the structures that enhance the strength and stiffness of the structures. The infill walls are considered as a non- structural element from the convenience design practice as per IS code. But in the actual practice the presence of infill walls create a strut compressive action acting diagonally in the direction opposite to the application of the lateral force that may try to counter act the lateral force that causes less deflection. In a bare frame, the resistance to lateral force occurs by the development of bending moments and shear forces in the various beams and columns through the rigid jointed action of the beam-column joints, but in the case of infill frame because of the strut action, contributing to reduced bending moments but increased axial forces in the beams and columns.



Behavior of fully frame under lateral load

TYPICAL OPEN GROUND STOREY(OGS) BUILDING:

Because of the absence of the infill walls at the ground storey and that of present at all the storey above, the stiffness is sudden decreases which are termed as stiffness irregularity. The base shear is registered by the ground storey columns. Because of the increase in the shear force causes the increase in bending moment and thereby higher curvature that may tends to higher inter storey drift formation at the ground storey and that enhance by the P-effect the plastic hinges are formed. The upper store will move as a single block. This type of collapse is called as soft storey collapse. Because of the decrease in the stiffness at ground storey this type of buildings are considered as the most vulnerable type from the seismic point of view. The fig shows the soft storey collapse of typical OGS buildings.



Behavior of OGS frame under lateral load

II LITERATURE REVIEW:

The Literature review conducted as part of the present study is divided into two segments. The first part deals with the overview on the fragility analysis of existing design provision of Vertically irregular buildings with regards to the design criteria as per Indian code for various buildings are discussed. In the second part, it based on the seismic hazard analysis and reliability analysis by considering different region in India.

Afarani and Nicknam (2012) observed the behaviour of the vertically irregular building under seismic loads by Incremental Dynamic Analysis. They have dealing with eight stories regular building having 2 bays with 4 m width in y direction has and 4 bays with 3 m width in x direction with 3 m storey height is considered. They considered Dead load as 2 ton/m is distributed on beams. To avoid torsional effects they considered symmetric building and steel moment resisting frames which are designed according to IBC 2006 and ANSI/AISC 360-05.

Tantala and Deodatis (2002) considered a 25 story of reinforced concrete moment resisting frame Building having three-bays. They have generated fragility curves for a wide range of ground motion intensities. They have used time histories are modelled by stochastic processes. Simulation is done by power spectrum probability and duration of earthquake by conducting 1000 simulation for each parameter. The nonlinear analysis is done by considering the P- effects and by ignoring soil-structure interaction. They have considered the nonlinearity in material properties in model with nonlinear rotational springs a bilinear moment-curvature relationship by considering the stiffness degradation through hysteretic energy dissipation capacity over successive cycles of the hysteresis. They have used Monte Carlo simulation approach for simulation of the ground motion. The simulation for the durations of strong ground motions is done at 2, 7 and 12 seconds labels to observe the effects. They considered the effects of the assumption of Gaussianity and duration. They have adopted stochastic process for modelling. The analyses were done by using DRAIN-2D as a dynamic analysis with inelastic time histories data. The random material strengths were simulated for every beam and column using Latin Hypercube sampling.

Murat and Zekeria (2006) studied the yielding and collapse behaviour of RC frame buildings in Istanbul was analysed through fragility analysis based on numerical simulation. They have studied number of stories of buildings as 3, 5 & 7 storeys designed as per Turkish seismic design code (1975).The fragility curves were constructed with the help of the results of regression analysis. They have examined with 12 artificial ground motions for the analysis. Incremental dynamic analysis (IDA) method is used for estimating structural performance under several ground motions. The Characteristic strength of concrete as 16Mpa and two different type of steel as 220Mpa & 420Mpa are used. The uncertainty due to scatter of material as well as the soil structure interaction was ignored in their design mean value of material strength was taken into consideration which was evaluated experimentally.

Davis and Menon (2004) examined the presence of masonry infill panels modifies the structural force distribution significantly in an OGS building. They considered verities of building case studies by increasing the storey heights and bays in OGS buildings to study the change in the behaviour of the performance of the buildings with the increase in the number of storey and bays as well as the storey heights. They observed that with the total storey shear force increases as the stiffness of the building increases in the presence of masonry infill at the upper floor of the building. Also, the bending moments in the ground floor columns increase and the failure is formed due to soft storey mechanism that is the formation of hinges in ground storey columns.

Scarlet (1997) identified the qualification of seismic forces of OGS buildings. A multiplication factor for base shear for OGS building was proposed. The modelling the stiffness of the infill walls in the analysis was focused. The effect of in Multiplication factor with the increase in storey height was studied. He observed the multiplication factor ranging from 1.86 to 3.28 as the number of storey increases from six to twenty.

Hashmi and Madan (2008) conducted non-linear time history and pushover analysis of OGS buildings. They concluded that the MF prescribed by IS 1893 2002 for such buildings is adequate for preventing collapse.

Sarkar et al (2009) considered the irregularity in stepped framed building by considering Regularity index.78 building frames with uniform number and bay width of 4 and 6m respectively with varying degree of stepped irregularity are considered seven numbers of buildings with different height are also included without considering step.50 modes are focused for four different cases of building. They observed by histogram that with the increases in irregularity, the first-mode participation decreases with increased participation on some higher modes. Delhi Secretariat building ten-storied office building located in New Delhi (Seismic Zone IV with designed PGA of 0:24g as per IS 1893:2002).The modelling and analysis were done by using a program SAP2000.

Pallav et al (2012) estimated the spectral acceleration of the Manipur region through the probabilistic seismic hazard analysis (PSHA). The area considered for the analysis is divided into different zones. By consideration of past earthquake data the earthquake recurrence relations are evaluated for the analysis Seenapati, tamenglong, churachandpur, chandel, imphal east, Imphal west, Ukhrul, Thoubal and Bishnupur places belongs to that region are considered for the analysis. Counter maps are considered for the different places of Manipur region by considering the variation of peak ground acceleration for return periods. These results may be of use to planners and engineers for selection of site, earthquake resistant structures designing and, may help the state administration in seismic hazard mitigation.

Ellingwood (2001) estimated the earthquake risk assessment of the building by applying the probabilistic risk analysis tools for two decades. He focused on the3 probability based codified designed and reliability based condition asse3ssment of existing structures. The steel frames weld connected are designed. A nonlinear dynamic analysis is done to study the behaviour in the importance of inherent randomness and modelling uncertainties in the performance of the buildings through fragility analysis. The seismic hazard analysis is done by considering the ground motion from California strong ground motion network.

Dymiotis et al (2012) studied on the probabilistic assessment of reinforced concrete frames in filled with clay brick walls and subjected to earthquake loading. The adopted methodology extends that previously developed by the writers for bare RC frames designed with EC8 by introducing additional random variables to account for the uncertainty in the masonry properties. Masonry infill walls are modelled as a four-nodded isoperimetric shear panel elements of complex hysteretic behaviour. Dynamic inelastic time-history analyses of 2D frame models are carried out using DRAIN-2D/90. The program utilizes the lumped mass approach and point hinge idealizations for line members.

III BUILDING DESIGN:

Open Ground Storey building frames with different Multiplication Factors:

The buildings frames considered for numerical analysis in the present study are located in Indian seismic zone V with medium soil conditions. These frames are designed as an Ordinary moment resisting frames, seismic loads are estimated as per IS 1893 (2002) and the design of the RC elements are carried out as per IS 456 (2000) standards. The characteristic strength of concrete and steel were taken as 25MPa and 415MPa. The buildings are assumed to be symmetric in plan. Typical bay width and column height in this study are selected as 3m and 3.2m respectively for all the frames. The different building configurations are chosen from 6 storeys to 10 storeys by keeping the number of bays as six for all the frames. The building configurations for the OGS building with different MF of different frames are shown in Figure 3.2. The sectional details of the ground storey columns obtained for various MFs are provided in Table 3.1.

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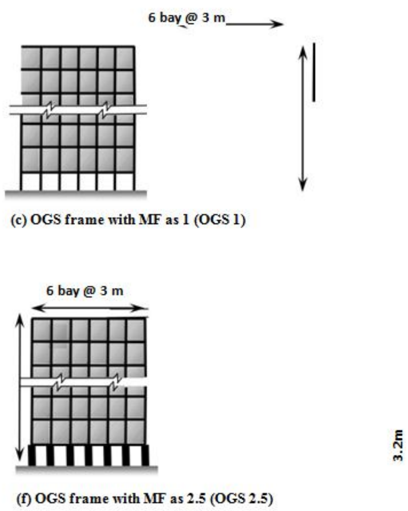


Figure 3.2 Elevation of building frames considered

The different building configurations are chosen from 6 storeys to 10 storeys by keeping the number of bays as six for all the frames. The building configurations of different frames are shown in Figure 3.2. The sectional details of the ground storey columns obtained for various MFs are provided in Table 3.1. Explain the stepped configurations nicely.

Table 3.1 Details of Open Ground Storey frames

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

Building frame with stepped irregularities:

The buildings frames with vertically irregular frames are considered for performance assessment using fragility curves. The buildings frames are assumed to be located in Indian seismic zone V with medium soil conditions. These frames are designed as an Ordinary moment resisting frames, seismic loads are estimated as per IS 1893 (2002) and the design of the RC elements are carried out as per IS 456 (2000) standards. The characteristic strength of concrete and steel were taken as 25MPa and 415MPa. The buildings are assumed to be symmetric in plan. Typical bay width and column height in this study are selected as 3m and 3.2m respectively for all the frames. Table 3.2 presents the description and designation of the vertically irregular frames considered. The elevations of all the vertically irregular frames are displayed in Figures 3.3a to 3.3d. ST1 stands for vertically irregular frame with single storey steps without any infill walls. STFF1 represents vertical irregular buildings with single storey steps with infill walls uniformly throughout.

Table3.2 Details of stepped irregular frames

Sl No.	Frame Description	Designation
1	6 to 10 storey and 6 bay, BARE framed with single storey stepped type	ST1
2	6 to 10 storey and 6 bay, BARE framed with double storey stepped type	ST2
3	6 to 10 storey and 6 bay, FF framed with single storey stepped with infill type	STFF1
4	6 to 10 storey and 6 bay, FF framed with double storey stepped with infill type	STFF2

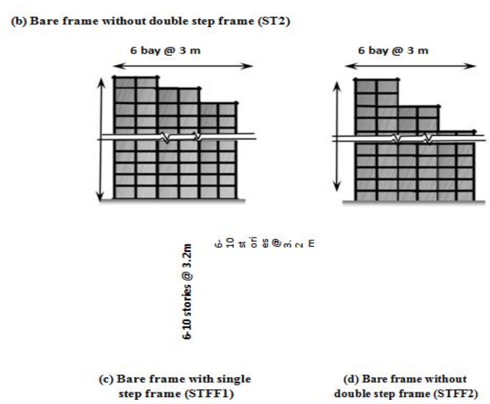


Figure 3.3 Elevation of stepped building considered

SAMPLING

Material properties of concrete, steel and masonry used in the construction are random in nature. To incorporate the uncertainties in concrete, steel and masonry strength, a Latin Hypercube sampling scheme is adopted using MATLAB (2009) program. Table 3.3 shows the mean and covariance of each random variable considered. The values for concrete and steel are taken from Ranganathan (1999) and that for masonry is taken from Kaushik et.al. (2007).

Table 3.3 Details of random variables used in LHS scheme

Material	Variable	Mean	COV(%)	Distribution	Remarks
Concrete	f_{ck} (MPa)	30.28	21	Normal	Uncorrelated
Steel	f_y (MPa)	468.90	10	Normal	Uncorrelated
Masonry	f_m (Mpa)	6.60	20	Normal	Uncorrelated

IV MODELLING AND ANALYSIS:

30 models are considered for each case, which is modelled in Seismostruct (2009) for nonlinear analysis. Concrete is modelled as per Mander et al. (1988) and reinforcements using a bilinear steel model with kinematic Strain hardening. Infilled masonry walls are modelled according to Crisafulli (1997) which takes into account of the stiffness and strength degradations in each cycle, which is implemented in SeismoStruct. Hilber-Hughes Taylor series scheme is adopted for the time step analysis and skyline technique is used for matrix storage.

PERFORMANCE LEVELS:

Performance levels are the levels to indicate the damage states of the building under seismic loading. Performance levels for a typical building pushed laterally to failure is shown in the Figure 3.4& table 3.4 .A typical Three performance levels, Immediate Occupancy (IO), Life safety (LS) and collapse Prevention (CP),are considered in the present study. The inter-storey drift (S_c) corresponding to these performance levels has been taken as 1%, 2% and 4% respectively as per FEMA356.

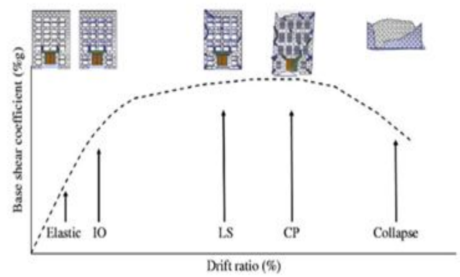


Figure 3.4 Damage states of a typical building pushed to failure (Courtesy, FEMA356)

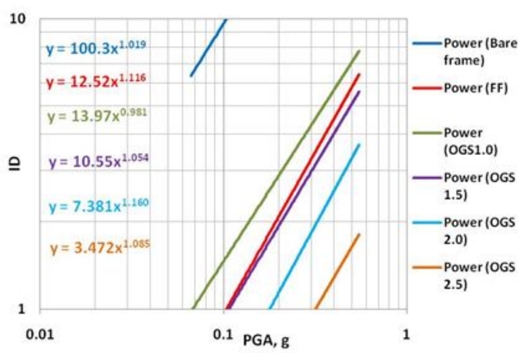
Table 3.4 Damage limits with various structural performance levels (FEMA356) for RC frames

Limit states designation	Performance level	Inter-storey Drifts Sc for MRF, (%)
IO	Light repairable damage	1
LS	Moderate repairable damage	2
CP	Near collapse	4

PERFORMANCE OF 10 STOREY 6 BAY OGS BUILDING FRAMES:

Table 3.5 Parameters of Probabilistic Seismic Demand Models for OGS buildings for 10, 8 and 6 storeyed frames for various infill walls configurations

Building types	10 Storey 6 Bay		8 Storey 6 Bay		6 Storey 6 Bay	
	A	b	a	b	a	b
BF	100.3	1.019	104.63	1.1085	156.62	1.2108
FF	12.522	1.1166	11.925	1.0964	11.932	1.098
OGS 1	13.975	0.9815	14.065	0.9748	16.921	1.0053
OGS 1.5	10.558	1.0549	11.606	1.0802	13.14	1.0976
OGS 2	7.3815	1.1606	7.7746	1.0908	9.6038	1.2256
OGS 2.5	3.472	1.0853	4.6186	1.1267	6.2698	1.2852



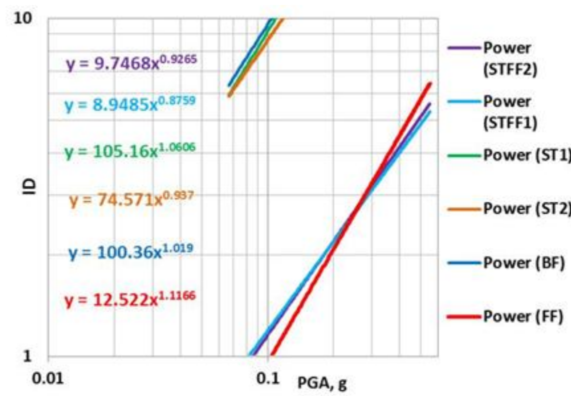
Comparison of PSDM models for various OGS frames, Bare and Full In filled Frame

PERFORMANCE OF FRAMES WITH STEPPED IRREGULARITIES:

A comparison of PSDM models for 10 storeyed building case study for all the infill wall configurations are drawn in a log-log graph as shown in the Figure 3.20

Table 3.7 Parameters of Probabilistic Seismic Demand Models for 10, 8 and 6 storeyed for various infill walls configurations for stepped type buildings

Building types	10 Storey 6 Bay		8 Storey 6 Bay		6 Storey 6 Bay	
	a	b	a	b	a	b
Bare frame with single step without infill (ST1)	105.16	1.06	68.07	0.86	125.90	1.18
Bare frame with double step without infill (ST2)	74.57	0.92	84.41	1.16	93.20	1.13
Bare frame with single step with fully infill (STFF1)	8.95	0.88	10.89	1.02	14.11	1.16
Bare frame with double step with fully infill (STFF2)	9.75	0.93	12.23	1.11	11.11	1.79



Comparison of PSDM models for various frames with stepped geometry

V CONCLUSIONS

The conclusion of the study is categorised into two parts. In the first part the behaviour of OGS Buildings are explained. And the stepped type buildings performances are mentioned in the second part.

OGS buildings:

The probability of exceedance and fragility curves and drawn for all the frames at is calculated for 6, 8 and 10 storeyed OGS frames with different MFs at different performance levels as IO. LS and .CP.

Probabilistic seismic demand models (PSDM) are developed for all the OGS frames considered for the analysis using log-log graph. A comparison of PSDM. models for all the building case studies with various infill wall configurations are plotted. The fragility curves are developed considering EDP as inter-storey drift at ground storey. From the PSDM model as per the methodology explained in the previous sections, for three performance levels such as IO, LS and CP.

Stepped building:

The same procedure was adopted for the generating the fragility curves for stepped type building. From the PSDM models the vertically irregular building it can be concluded that the inter storey drifts for frames without infill walls (BF, ST1 and ST2) are significantly higher than frames with infill walls (FF, STFF1 and STFF2). The inter-storey drifts of vertically irregular buildings designed with various stepped configurations without infill walls (ST1, ST2) are only marginally different. From the fragility curves of the vertically irregular buildings it is observed that the stepped frames are found to be marginally safer than corresponding regular frames. The same behavior is observed in the case vertically irregular buildings with infill walls (STFF1, STFF2).

The vertically irregular building with single and double stepped type with infill wall is safer than that of FF and all other type of building considered for all the cases. As some of the frames are not present in the stepped buildings at top, compared to a FF frame, the mass and hence the inertia forces acting at top storeys would be less. This may be the reason for the marginally good behaviour observed in the case of vertically irregular buildings.

Reliability analysis:

The present study is also focused on the seismic reliability assessment of typical vertically irregular building with various configurations. For the analysis Manipur region is chosen the hazard curve developed by pallav et.al. (2012) is considered which has plotted by considering different regions. From the entire region Ukhraul is selected for the analysis which is the worst case among all. The hazard curve is combined with the fragility curve to find the joint probability of failure and corresponding reliability.

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