Indian J.Sci.Res. 17(2): 514 - 521, 2018

ISSN: 0976-2876 (Print)
ISSN: 2250-0138(Online)

SEISMIC RISK ASSESSMENT OF REINFORCED CONCRETE BUILDING

[1]Uday sai, [2]M Satyanarayana Reddy, [3]G Srikanth
[1]Site Engineer, Cherryhill Interiors, Begumpet, India
[2] Department of Civil Engineering, Aurora's Engineering College, Bhongir
[3] Department of Civil Engineering, College- University college of Engineering, OU, Hyderabad-500007

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 earthquakes.

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

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.

II. Objective of the Study

Based on the previous discussions, the objective of the present study has been identified as follows

- To study the seismic performance of buildings with extreme vertical irregularity

[1]Corresponding Author

- Using fragility analysis.
- To develop the Probabilistic seismic demand model for the considered buildings.
- To study the relative performance of the building with the regular frames in Probabilistic frame works.
- To study the relative performance of OGS buildings designed for various MFs.
- To study the seismic hazard analysis of the buildings
- To conduct a reliability analysis and to identify the reliability indices values for all the building frames.

Scope and Limitations of the Study

The RC framed Buildings are considered for the analysis by assuming regular in plan. The buildings considered (6-10 storey buildings) without basement, shear wall and plinth beams. The contribution of Infill walls are considered as non-integral with RC frames. The Out of plane action of masonry walls are neglected in the analysis. The asymmetric arrangement of infill walls are ignored of the buildings. The Soil structure interaction effects are not considered in the analysis. The Flexibility of floor diaphragms are neglected and considered as rigid diaphragm. The base of the column is assumed to be fixed in the analysis

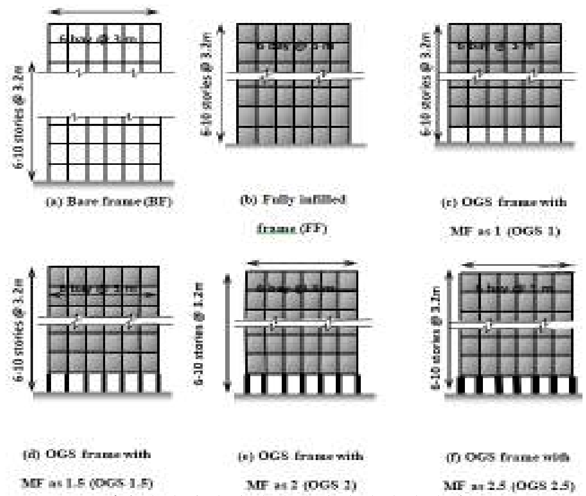
II. Literature Reviews

Tantala and Deodatis (2002) considered a 25 story of reinforced concrete moment resisting frame Building having three-bays. They have generated fragility curves for awide 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-Δ 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. Performance limit state: inelastic displacement demand and corresponding deformations for immediate occupancy and collapse prevention are evaluated. From the fragility curves finally they have concluded that for the collapse prevention performance level, a good correlation between spectral displacement limit and the number of stories was observed but the same observation was not valid for the immediate occupancy level deduced that all the parameters affect the fragility curves, except the stiffness ratio α which influences only the fragility curve which corresponds to the heavy damage state

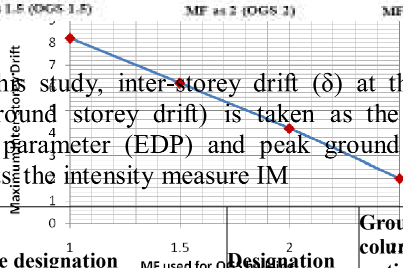
Pallav et al (2012) estimated the spectral acceleration of the Manipur region through the probabilistic seismic hazard analysis (PSHA). The area considered for the analysis is divided into different zones. By consideration of past earthquake data the earthquake recurrence relations are evaluated for 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. 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.

In this study, inter-storey drift (δ) at the first floor level (ground storey drift) is taken as the engineering damage parameter (EDP) and peak ground acceleration (PGA) as the intensity measure IM



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

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 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).

Details of random variables used in LHS scheme

Modelling and Analysis

15 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. 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 (Sc) corresponding to these performance levels has been taken as 1%, 2% and 4% respectively as per FEMA356.

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

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

Variation of Maximum inter-storey drift with MF used for OGS building

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

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

Performance of 10 Storey 6 Bay OGS Building Frames

PSDM models for Open Ground Storey building frames with different Multiplication Factors

For developing a fragility curve, Nonlinear dynamic analyses of 30 building models are conducted and the maximum inter storey drift (ID) at any storey is recorded. The parameters of the power law model are found out by regression analysis for each frame to develop PSDM model.

The parameters, „a‟ and „b‟ of the PSDM models obtained for all the frames are summarised in the Table 3.5. 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 3.5. It can be seen that the inter storey drifts for bare frame is significantly higher than all the remaining cases. This is due to the less lateral stiffness of the bare frame by neglecting infill walls. The inter-storey drift of OGS building designed for MF 1.0 is more than that of regular building (FF), in which brick masonry infill walls are provided in all the storeys uniformly. The maximum inter-storey drift of OGS frame designed with MF of 1.5 is less by about 16 % (maximum) than that for regular frame (FF) for all PGA.

It can be seen that as the MF increases the inter-storey drift decreases. The inter-storey drift of OGS building designed with MF of 2.5 is about 50% less than that in an OGS frame designed using a MF of 2.0. Similarly, the maximum inter-storey drift reduction in an OGS building designed with MF of 2.0 compared to that of MF of 1.5 is about 33%.

The variation of maximum inter-storey drift with the MF used for the design of OGS buildings is plotted in Figure 3.6.

Parameters of Probabilistic Seismic Demand Models for OGS buildings for 10,8 and 6 storeyed **frames** for various infill walls configuration

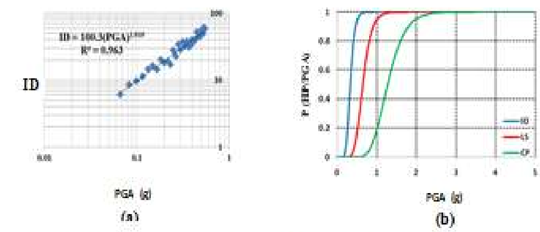


Figure 3.7(a) Probabilistic Seismic Demand Models (b) Fragility Curves of 10 Storey 6 Bay Bare Frame

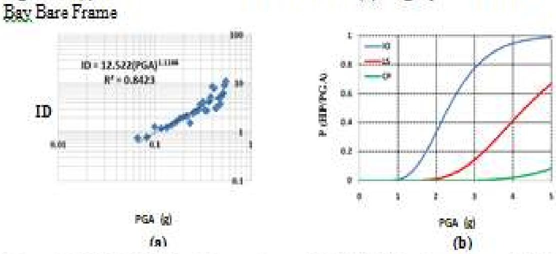


Figure 3.8 (a) Probabilistic Seismic Demand Models (b) Fragility Curves of10 Storey 6 Bay Fully Infill Frame

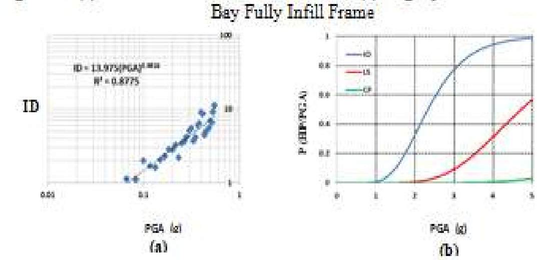


Figure 3.9 (a) Probabilistic Seismic Demand Models (b) Fragility Curves of 10 Storey 6 Bay OGS 1.0 Frame

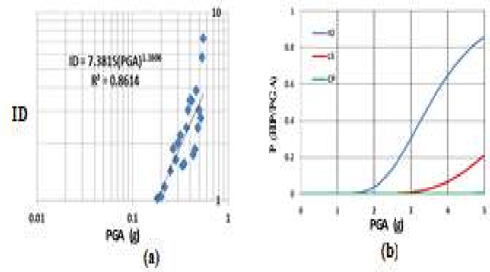


Figure 3.11 (a) Probabilistic Seismic Demand Models (b) Fragility Curves of 10 Storey 6 Bay OGS 2.0 Frame

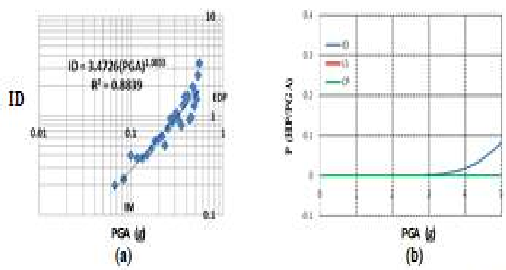


Figure 3.12 (a) Probabilistic Seismic Demand Model (b) Fragility Curves, of 10 Storey 6 Bay OGS 2.5Frame

Fragility curves for Open Ground Storey building frames (considering EDP as inter-storey drift at various storeys)

The application of MF in the ground storey may reduce the inter-storey drift at ground but may increase for adjacent storeys. In order to study this effect, fragility curves are developed for OGS buildings considering EDP as maximum inter-storey drift at different storeys. Figure 3.13 presents the fragility curves of the building frames for different storeys for a 10 storey 6 bay bare frame building. It is observed that the second storey and first storey is fragile compared to ground storey. The same pattern is followed in all the performance levels except that the difference between the fragilities is increasing in the order for IO, LS and CP.

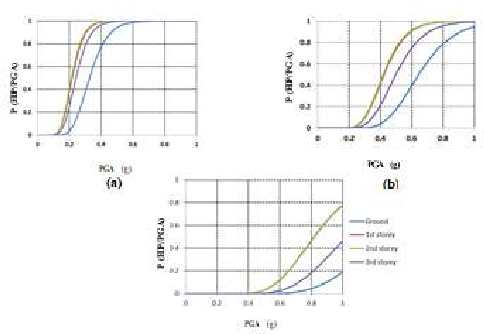
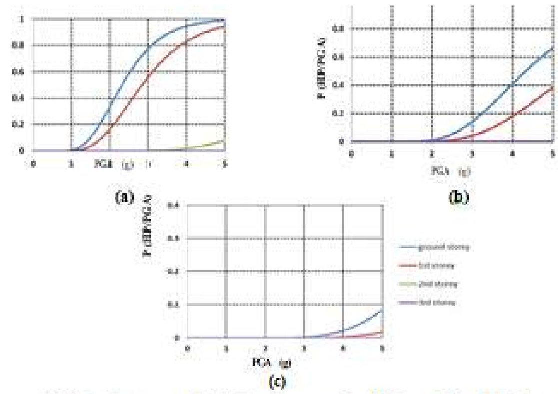
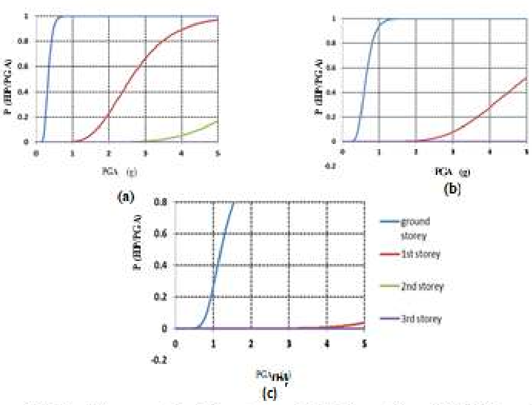


Figure 3.13 Fragility curves for different storeys for 10 Storey 6 bay Bare frame for performance levels (a) IO (b) LS (c) CP

Fig 3.14presents the fragility curves of the 10 storey 6 bays FF frame building for different storeys. It can be seen that the ground storeyis more fragil compared to all the other storeys. The order of fragilities decreases in the order ground, first, second and third storeys. The same pattern is followed in all the performance levels, IO, LS and CP



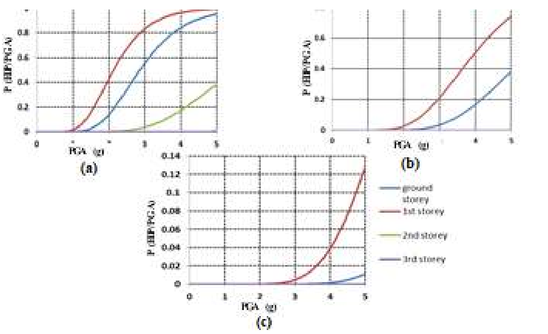
ure 3.14 Fragility curves for different storeys for 10 Storey 6 bay FF frame for performance levels (a) IO (b) LS (c) CP



'igure 3.15 Fragility curves for different storeys for 10 Storey 6 bay OGS1.0 frame for performance levels (a) IO (b) LS (c) CP

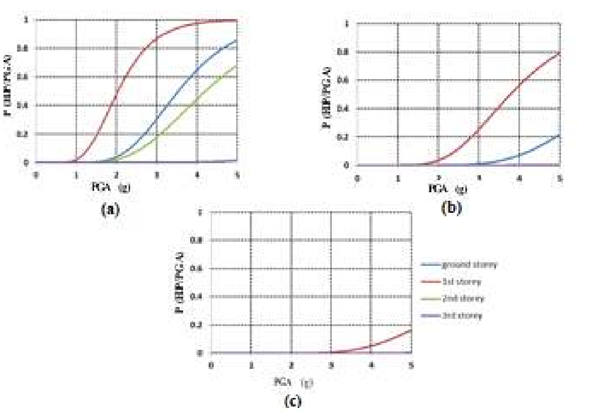
Figure 3.15 presents the fragility curves of the 10 storey 6 bayOGS1.0 frame building for different storeys. It can be seen that the ground storeyis more fragile compared to all the other storeys. The difference between fragility of ground storey compared to other storeys is much wider than observed in FF frame. This building represents the case of a large number of existing OGS buildings designed ignoring the MF. This case is an extremely vulnerable situation of an OGS frame that should be avoided. The same trend is followed in all the performance levels, IO, LS and CP.

Fragility curves for different storeys for 10 Storey 6 bay OGS1.0 frame for performance levels (a) IO (b) LS (c) CP



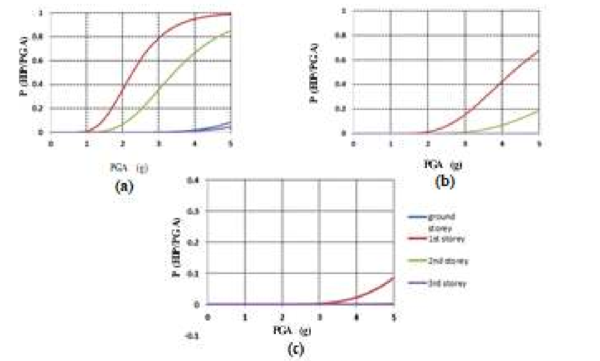
ure 3.16 Fragility curves for different storeys for 10 Storey 6 bay OGS1.5 frame for performance levels (a) IO (b) LS (c) CP

Figure 3.16 presents the fragility curves of the 10 storey 6 bayOGS1.5 frame building for different storeys. It can be seen that the first storey is more fragile compared to all the other storeys. The ground storey became safer compared to first storey when MF increased from 1.0 to 1.5. The exceedance probability of inter-storey drift at ground storey is reduced by 25% at a PGA of 3g. This is perhaps due to the reduction of inter-storey drift at ground storey. The same trend is followed in all the performance levels, IO, LS and CP.



gure3.17 Fragility curves for different storeys for 10 Storey 6 bay OGS2.0 frame for performance levels (a) IO (b) LS (c) CP

Figure 3.17 shows the fragility curves of the 10 storey 6 bay OGS2.5 frame building for different storeys. It can be seen that as the MF increased from 2.0 to 2.5, the ground storey is found to be safer than both first and second storey. The exceedance probability of inter-storey drift at ground storey is reduced by about 100% at a PGA of 3g. It may be due to the reduction of inter-storey drift at ground storey. The same trend is followed in all the performance levels, IO, LS and CP.



igure 3.18 Fragility curves for different storeys for 10 Storey 6 bay OGS2.5 frame for performance levels (a) IO (b) LS (c) CP

Fig 3.18OGS2.5 frame building for different storeys. It can be seen that as the MF increased from 2.0 to 2.5, the ground storey is found to be safer than both first and second storey. The exceedance probability of inter-storey drift at ground storey is reduced by about 100% at a PGA of 3g. It may be due to the reduction of inter-storey drift at ground storey. The same trend is followed in all the performance levels, IO, LS and CP

Table 3.6 Most fragile storeys from Fragility Analysis

Frame	**Most fragile storey**	**GRound storey compared**
Bare Frame	Second	55% less
Full Infilled	Ground Storey	0%
OGS 1.0	Ground Storey	0%
OGS 1.5	First Storey	25% less
OGS 2.0	First Storey	70% less
OGS 2.5	First Storey	100% less

Fragility curves for BF, FF, OGS-1, OGS1.5, OGS2 and OGS-2.5 buildings for three performance levels namely, IO, LS and CP are generated. The variation of exceedance probability of the inter-storey drift with the PGA is shown in Figure 3.19. The bare frame (BF) is found to be more vulnerable than the FF and OGS frame for all three performance levels considered. The OGS buildings designed by magnification factors 1.5, 2 and 2.5 are safer than that of FF in all the cases. The magnification factor 2.5 is likely to increase the performance than actually needed by decreasing the inter-storey drift. The same behaviour is observed in the case of eight and six storied frame

Figure 3.19 Fragility curves for 10 Storey 6 bay building frame for various cases at (a) IO (b) LS (c) CP, levels

Numerical integration of a (a) fragility curve & (b) hazard curve for probability of failure. The parameters at the fragility-hazard interface must be dimensionally consistent for the probability estimate to be meaningful. The reliability index for corresponding probability of failure can be found by the following standard Equation.

$$\beta = -\phi^{-1}(pf)$$

Φ^{-1} is the inverse standard normal distribution.

Assessment Using the Reliability indices

The reliability index is estimated from the fragility curves as per the procedure explained previous section. The reliability index is calculated for each PGA, which will yield reliability indices corresponding to each PGA. In order to check the target reliability to be achieved by the building frames for various PGAs and performance levels, target reliabilities using some acceptable standards are to be selected. In the present study, Target Reliability Indices in accordance with ISO 2394 (1998) is used and is shown in Table 4.1. This table shows the target reliability requirement for each performance level (consequences of failure). The assessment of performance of each building is carried out by comparing the reliability indices obtained for each building with corresponding target reliability indices corresponding to moderate level of consequences of failure. In order to assess the performance of the buildings at collapse prevention, the target reliability indices is taken as 3.8.

Target reliability Index in accordance with IS 2394

Relative Cost of Measures	Consequences of Failure		
	Some **IO**	Moderate **LS**	Great **CP**
High	**1.5**	**2.3**	**3.1**
Moderate	**2.5**	**3.1**	**3.8**
Low	**3.1**	**3.8**	**4.3**

Among all frames, bare frames are found to be more vulnerable due to higher values of failure probability. The stiffness and strength of infill walls are neglected in the bare frame analysis and the force demands in the bare frame is high and hence they are more vulnerable. In reality the infill walls will contribute stiffness and strength to the building, which increases the performance of the building.

From , it can be seen that Bare frames (BF) are not able to meet the target reliability suggested by ISO 2394 1998 in all the performances levels where as the full infilled frames (FF) meets the target reliability in all performances levels.

The infill walls are ignored at analysis and design stage, in the current design methodology. In reality, the infill walls which is ignored and provided at the time of construction, contribute to some stiffness and strength to the global performance of the buildings (e.g. fully infilled frames).

However, for an Open ground storey building the same design methodology may not guaranty the required performance. However in the present study OGS1 marginally reaches the Target Reliability in all the performance levels, which may not be always true. This implies that more research is required in this direction. For OGS 2.5 Reliability Indices are found to be twice that of target reliability, which indicate that the factor MF may be more conservative. For optimum design of an OGS building, particularly for the design magnification factor, the target reliability can be a considered as a basis.

III. 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.

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 From the fragility curves it is observed that the bare frame is the most fragile out of all the frames considered. The PGA increases the conditional probability o fexceedance of the inter-storey drift increases. For OGS buildings the maximum inter-storey drift are found to be decrease as the increase of MF.

Among the all buildings the Inter-storey drift of bare frame (BF) is found to significantly higher that FF and OGS frames. The maximum inter-storey drift of ground storey of OGS frame decreases by 16% compared to FF when it is designed for a MF of 1.5. For a MF of 2.5, the inter-storey of ground storey is reduced by 50% compared to that of OGS buildings designed with MF of 2.0. Similarly, the maximum inter-storey drift reduction in an OGS building designed with MF of 2.0 compared to that of MF of 1.5 is found to be about 33%. Also the fragility curves are developed for ground, first, second and third storey to observe the most vulnerable storey for all the considered building. It is found that in case of bare frame, the second storey is the fragile and it is 55% more fragile than ground storey. In the case of fully infilled frame and OGS1.0, the ground storey is found to be more vulnerable that other storeys. As the MF increases from 1.0 to 1.5 or more than 1.5 (2.0 and 2.5), the ground storey becomes safer. In all three cases for MF = 1.5, 2.0 and 2.5, the first storey is more fragile compared to ground storey by 25%, 70% and 100% respectively

References

- Afarani, M., and Nicknam, A. (2012)**.** **"**Assessment of Collapse Safety of Stiffness Irregular SMRF Structures According toIDAApproach." J**.** Basic and Applied Scientific Research**,** 2 (7), 65666573.
- Arlekar, J.N., Jain, S. K., and Murty, C.V.R. (1997). "Seismic response of RC frame buildings with soft first storeys." *Proceedings of CBRI golden jubilee conference on natural hazards in urban habitat*, New Delhi.
- ASCE 7 (2005). "Minimum Design Loads for Buildings and Other Structures.American Society of Civil Engineers", USA. 2005.
- Asokan, A. (2006). "Modelling of Masonry Infill Walls for Nonlinear StaticAnalysis of Buildings under Seismic Loads." M.Tech Thesis, Institute of Technology Madras at Chennai.
- ATC 58 50% Draft (2009) "Guidelines for Seismic Performance Assessmentof Buildings." Applied Technology council, Redwood City, CA.