Open Ground Storey Buildings designed as per various International Codes – A Seismic Performance Comparison Study

[1] Robin Davis P., [2]Haran Pragalath D.C., [3]Pradip Sarkar

Abstract- **Open Ground Story (OGS) framed structures where the ground story is kept open without any masonry wall, mainly for parking purposes, are increasingly found in urban regions. Weakness of this kind of structures perhaps was exposed in the past earthquakes. OGS buildings are conventionally designed considering a bare frame analysis ignoring the stiffness of the infill walls present in the upper storeys. This analysis ignoring the stiffness of infill walls under-estimates the inter-storey drift and thereby the force demand in the ground storey columns. A Multiplication Factor (MF) is suggested by different universal codes to compute the design forces in the ground story columns. Present study focus on the assessment of seismic performance of a typical four storeyed OGS building designed with MFs recommended by major codes. The probabilistic seismic demand models, fragility curves and the reliability indices for all models are developed including bare frame and fully infilled frame.**

Keywords: Infilled Frames, Equivalent Strut Model, Concrete01, Hysteretic, Pinching.

I. INTRODUCTION

Due to limited space and increase in population in cities for the past few decades, vehicle parking space for residential apartments is a matter of major concern. Hence the trend has been to utilize the ground storey of the building itself for parking. These types of buildings having no infill masonry walls in ground storey, but infilled in all upper storeys, are called Open Ground Storey (OGS) buildings. They are also known as 'pilotis', or 'stilted buildings'. There is significant advantage of these type of buildings functionally but from a seismic performance point of view such buildings are considered to have increased vulnerability.

The stiffness and strength of the ground storey is significantly low compared to adjacent storeys. Collapse of this type of buildings was predominantly due to the formation of soft-storey mechanism in the ground storey columns and hence termed as extreme soft-storey buildings. Past earthquakes demonstrated the vulnerability of OGS buildings.

different from that of the bare frame. In conventional design practice, the stiffness contribution of infill walls present in upper storeys of OGS framed buildings are ignored in the Conventionally, this type of buildings are designed considering a bare frame analysis ignoring the stiffness of the infill walls present in the upper storeys (Bare frame). Bare frame analysis ignoring the stiffness of infill walls under-estimates the inter-storey drift and thereby the force demand in the ground storey columns. A Multiplication Factor (MF) is introduced by different universal codes to compute the design forces in the ground story columns. It can be seen that the multiplication factors recommended by existing literatures (Kaushik *et. al.* 2006; Fardis and Panagiotakos, 1997; Fardis *et. al.* 1999; EC 8, 2004; Scarlet, 1997 ; Hashmi and Madan, 2008; Arlekar *et*. *al*., 1997; Davis *et. al.* 2010a) do not consider the uncertainties associated with earthquake loading and structural properties. The present study evaluates the performance of various schemes of multiplication factors suggested by different international codes in a probabilistic framework for different performance objectives.

II. METHODOLOGY

The methodology adopted in the present study is to evaluate the seismic risk of the OGS buildings in terms of fragility curves and reliability indices. An accepted simplified method reported by Ellingwood (2001) for the seismic risk is adopted in the present study.

Limit states define the capacity of the structure to withstand different levels of damage. The median inter-storey drift limit states for both RC moment resisting frames defining the capacity of the structure at various performance levels (SC) are suggested by Ghobarah (2000) and ASCE/SEI 41-06 (2007). Drift limits for RC frames as per ASCE/SEI 41-06 (2007) are considered in the present study as 1% and 4% for light repairable damage (IO) and near collapse (CP) performance level respectively.

III. FRAMES CONSIDERED

The building frame considered for numerical analysis in the present study is designed for the highest seismic zone (zone V with PGA of 0.36g) as per Indian standard IS 1893 (2002) considering medium soil conditions (N-value 10 to 30). The characteristic strength of concrete and steel are taken as 25MPa and 415MPa respectively. The buildings are assumed to be symmetric in plan, and hence a single plane frame is considered to be representative of the building along one direction. Typical bay width and column height in this study are selected as 5m and 3.2m respectively, as observed from the study of typical existing residential buildings. A

1. Assistant Professor, Department of Civil Engg., NIT Rourkela, Odisha.
2. Research Scholar, Department of Civil Engg., NIT Rourkela, Odisha.
3. Associate Professor, Department of Civil Engg., NIT Rourkela, Odisha.

configuration of four storeys and two bays is considered. The dead load of the slab (5 m × 5 m panel) including floor finishes is taken as 3.75 kN/m^2 and live load as 3 kN/m^2. The design base shear (V_B) is calculated as per equivalent static method (IS 1893, 2002). The structural analysis for all the vertical and lateral loads is carried out by ignoring the infill wall strength and stiffness (conventional). The design of the RC elements are carried out as per IS 456 (2000) and detailed as per IS 13920 (1993). In order to study the effect of MF values on the probability of failure of OGS building, different MF values suggested by various international codes are considered to design the ground storey columns and/or first storey columns. Fully infilled frame (FF) and bare frame (BF) are also considered in the study for comparison which are designed without applying any MF (MF = 1.0). Different international codes considered in this study are Indian code (IS 1893, 2002), Bulgarian code (Bulgarian seismic code, 1987), Israel code (SII, 1995) and Euro code (EC 8, 2003). Fig. 1 shows the configurations of bare frame (BF), fully infilled frame (FF), Open ground storey frame with MF equal to unity ($OGS_{1.0}$) and various OGS frames designed with MF suggested by different codes.

IV. MODELING FOR NONLINEAR ANALYSIS

As per the methodology adopted, it is required to conduct a series of nonlinear dynamic time history analyses of all the selected frames. Opensees Laboratory tool developed by Frank *et. al*. (2014) is used for nonlinear time history analyses. Force-based nonlinear beam-column element that considers the spread of plasticity along the element is used for modelling the beams and columns. The concrete is modelled by considering the effect of confinement due to the special confining detailing in the beams and columns using the Kent and Park (1971) model. Steel reinforcing bars are modelled using uniaxial Giuffre-Menegotto-Pinto steel material model with isotropic strain hardening. Infill wall model proposed by Celarec *et. al*. (2012) is considered in the present study.

A Selection of Earthquake Ground Motion

Selection of earthquake ground motions for dynamic analysis is more challenging task as each earthquake has its unique property involving so many uncertainties. Haselton *et. al*. (2012) has worked on selection of earthquakes for time history analysis and shared time history data for far field and near field ground motions based on FEMA P695 (2012). All far field earthquake data from this set of earthquake ground motions is used in the present study.

B…. Material uncertainty

Material properties of concrete, steel and infill walls used in the construction are random in nature. It is important to incorporate the uncertainties in all possible material and modelling parameters in the computational model to have a more realistic representation of the responses in a probabilistic assessment. The mean (COV) of concrete, steel, shear strength of masonry and damping ratio are considered in the present study as 30.28 MPa (21.0), 468.9MPa (10.0), 0.20MPa (12.0) and 5% (40.0) respectively.

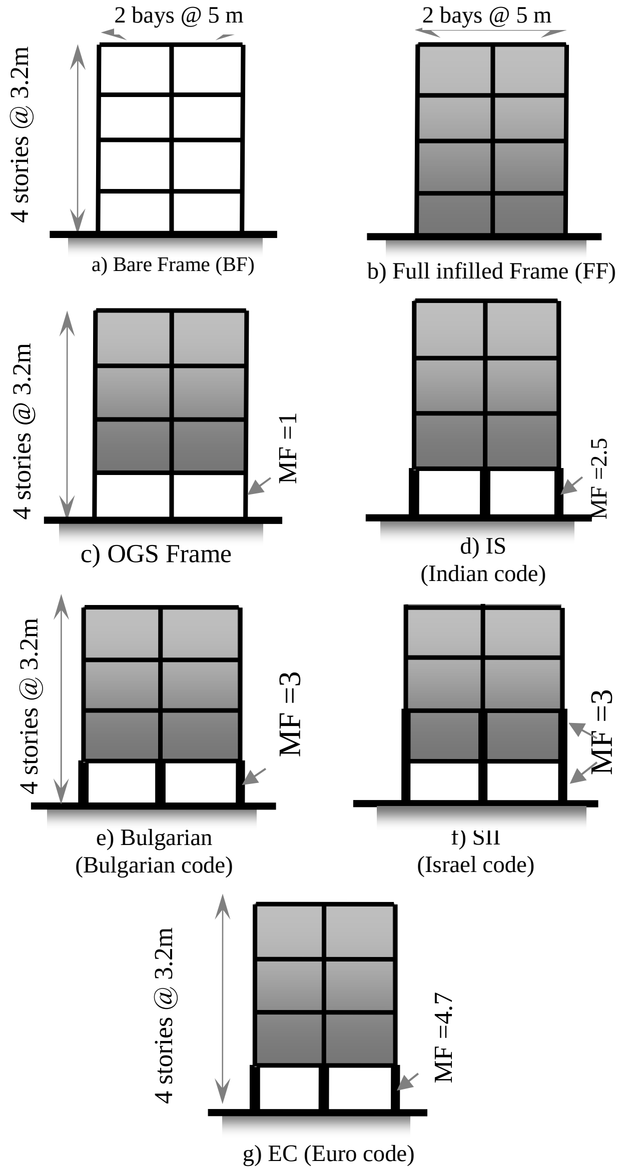


Fig.1: Four storey RC frames considered in the study

V. PROBABILISTIC SEISMIC DEMAND MODEL (PSDM)

The 44 ground motions are scaled linearly from 0.1g to 1g and each computational model is analysed for a particular earthquake (randomly selected) with a particular PGA. A total of 44 nonlinear dynamic times history analyses are performed and the maximum inter-storey displacement (EDP) for each storey are monitored. The inter-storey drifts (maximum of all storeys) along with the corresponding PGAs (IM) are plotted in a logarithmic graph. Each point in the plot shown in Fig. 2

represents the PGA values and the corresponding percentage of maximum inter-storey drift in each of the 44 time history analysis for all the frames. A power law relationship for each frames is fitted using regression analysis, which represents PSDM model for the corresponding frames. The regression coefficients *a* and *b*, are found for each frame and reported in Fig. 2. The PSDM model provides the most likely value of inter-storey drift (in mm) in the event of an earthquake of certain PGA (up to 1g) in each frame. Depending on the values of parameters '*a* & *b*', the vulnerability of the particular frame can be identified. It can be seen from Fig. 2 that OGS1.0 frame is more vulnerable.

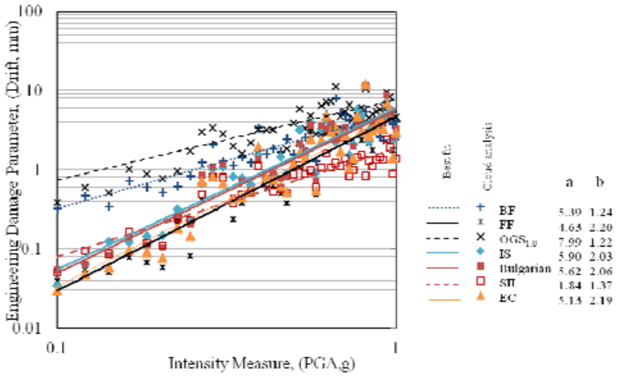


Fig.2. PSDM Models for all frames considered

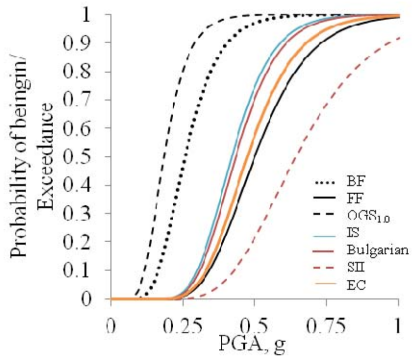
VI. FRAGILITY CURVES

Having computed the PSDM models (a & b), the dispersions of inter-storey drifts $\beta_{D/IM}$ from the best fitted PSDM and dispersion component β_{comp} are calculated. In order to study the performance of OGS buildings designed with MFs suggested by different codes, the fragility curves are developed for all the frames for each performance limit states.

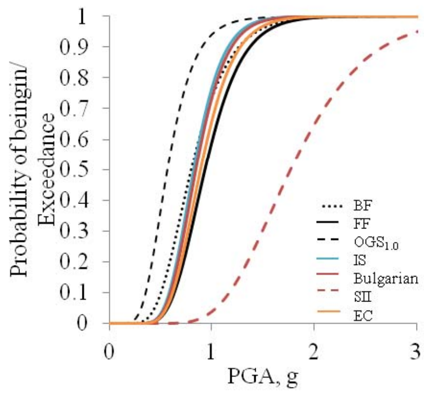
The OGS frames are designed considering different MF values suggested by various codes. In order to study the effect of MF values on the performance, the fragility curves of all frames are developed for the IO and CP performance levels as shown in Fig. 3a and 3b respectively. As the MF value (applied in ground storey alone) increases the performance of the frames (IS, Bulgarian and EC) also increases. The failure of this group of frames is found to be due to the failure of the first storey. If the MF is applied to both ground and first storeys, the performance of the frames is significantly increases. This can be seen from the lower values of exceedance probabilities of fragility curve at each PGA's for the frame SII (designed using Israel code) which performs better than other frames.

VI. RELIABILITY INDICES

In order to understand the relative performance of each frame quantitatively, the corresponding reliability indices are calculated for each frame. The reliability indices are estimated by combining the fragility curve for a particular limit states with hazard curves. In present study, hazard curve of North East India is chosen for reliability index estimation. Reliability index is calculated for two performance objectives such as namely Immediate Occupancy (IO) at DBE level (0.83g) and Collapse Prevention (CP) at MCE level (1.08g). From the fragility curves, the corresponding reliability indices are computed for each frame and listed in the Table 1 for IO and CP performance levels. It can be seen that the reliability index (1.36 and 2.25) for frame $OGS_{1.0}$ at both IO and CP performance levels are found to be the lowest indicating its vulnerability.



a) Fragility Curve for IO performance



b) Fragility Curve for CP performance

Fig.3. Fragility curve for the frames

Table 1: Reliability Index (β_{pf}) for all frames

Frame Configuration	Performance objective	
	IO at DBE	CP at MCE
BF	1.54	2.60
FF	2.16	2.85
$OGS_{1.0}$	1.36	2.25
IS	2.02	2.72
Bulgarian	2.05	2.75
SII	**2.39**	**3.20**
EC	2.12	2.81

The reliability indices for the FF frame is found to be 2.16 (IO) and 2.85 (CP) which are more than the corresponding indices for frames, IS, Bulgarian and EC. This means that the scheme of application of MF only in ground storey may not provide sufficient reliability as that of FF frame. It can be observed from Table 1 that the reliability of SII frame is much higher than FF. The application MF in both ground and first storeys is a better scheme than only in ground storey for typical four storeyed frames.

VII. CONCLUSIONS

There is disparity in the values of MFs and the scheme of application proposed by various International codes. Many literatures have reported that the basis of MF proposed by different codes lacks rational basis. Present study is an attempt to study the performance in a probabilistic framework, of a typical four storeyed OGS building designed with MF suggested by various international codes. In order to achieve the above objective, the OGS frames are designed considering MF values suggested by IS 1893 (2002), Bulgarian seismic design code (1987), SII (1995) and EC 8 (1996). The probabilistic seismic demand models, fragility curves and the reliability indices (for a selected seismic hazard) for all cases are developed including bare frame (BF) and fully infilled frame (FF). The following major conclusions are drawn on the basis of fragility curves and the corresponding reliability indices.

- The open ground storey building designed with no multiplication factor ($OGS_{1.0}$) is found to be more vulnerable than Bare Frame (BF) and Fully Infilled Frame (FF). Performance of Fully Infilled frame is found to be superior due to the presence of infill walls in all the storeys including ground storey.
- Application of MF only in ground storey proposed by Indian, Bulgarian and Euro codes is found to be not an appropriate solution to achieve the satisfactory performance of OGS building. These frames could not match the reliability of a fully infilled frame.
- The scheme of application of MF in both open ground storey and adjacent first storey suggested by SII (1995) is found to be a better solution compared to the scheme of MF application only in the ground storey. The frame designed with this scheme could yield reliability indices more than that for fully infilled frame.

REFERENCES

[1] Arlekar, J. N., S. K. Jain and C. V. R. Murty. “Seismic response of RC frame buildings with soft first storeys,” *Proceedings of the CBRI golden jubilee conference on natural hazards in urban habitat. New Delhi,* 1997.

[2] ASCE/SEI 41-06. “Seismic Rehabilitation of Existing Buildings,” *American Society of Civil Engineers. USA,* 2007.

[3] ATC 58 100% Draft. .”Guidelines for Seismic Performance Assessment of Buildings” *Applied Technology Council, Redwood City, CA,* 2012

[4] Bulgarian Seismic Code, (1987). “Code for Design of Buildings and Structures in Seismic Regions,” *Bulgarian Academy of Science Committee of Territorial and Town System at theCouncil of Ministers, Sofia, Bulgaria,* 1987

[5] Celarec D., Ricci P. And Dolsek M.“The sensitivity of seismic response parameters to the uncertain modelling variables of masonry-infilled reinforced concrete frames,” *Engineering Structures*. vol. 35, pp 165–177, 2012

[6] Cornell, C. A., F. Jalayer, R.O. Hamburger and D.A. Foutch. “The Probabilistic Basis for the 2000 SAC/FEMA Steel Moment Frame,” *Guidelines. Journal of Structural Engineering*; vol 128(4), pp 526-533, 2002.

[7] Davis, P. R., Menon D. and Prasad, A. M. “Earthquake-Resistant Design of Open Ground Storey RC Framed Buildings”, *Journal of Structural Engineering*, vol 37(2), pp 117-124, 2010a.

[8] Davis P. R., Padhy K. T, Menon D. and Prasad. A. M.” Seismic fragility of Open Ground Storey buildings in India,” *9th US National and 10th Canadian Conference on Earthquake Engineering, Toronto*, Paper # 926, 2010b.

[9] Ellingwood. B. R. “Earthquake risk assement of building structures,” *Reliability engineering and system safety*. vol. 74, pp 251-262, 2001

[10] Eurocode 8. “Design Provisions for Earthquake Resistance of Structures Part 1–3” *General Rules-Specific Rules for Various Materials and Elements, DD ENV 1998–1-3: European Committee of Standardization, Brussels, Belgium*, 1996.

[11] Fardis, M. N. and Panagiotakos, T. B. “Seismic design and response of bare and masonry-infilled reinforced concrete buildings, Part II: Infilled structures,” *Journal of Earthquake Eng*. vol.1 (3),pp 475–503. 1997

[12] Fardis, M.N., Negro, P., Bousias, S.N. and Colombo, A. “Seismic design of open-storey infilled RC buildings,” Journal of Earthquake Engineering. vol.3(2), pp 173-197, 1999/

[13] FEMA P695. Quantification of Building Seismic Performance Factors, prepared by the Applied Technology Council, Redwood City: California for the Federal Emergency Management Agency, Washington, D.C., 2012.

[14] Frank McKenna; Christopher McGann; Pedro Arduino; Joseph Allen Harmon.”OpenSeesLaboratory,” https://nees.org/resources/openseeslab. 2014

[15] Ghobarah A. “Performance-based Design in Earthquake Engineering: State of Development,” *Engineering Structures*. vol 23, pp 878-884, 2000.

[16] Haselton., C., B., Whittaker A. S., Hortacsu A., Baker J. W., Bray J. And Grant D.N. “Selecting and Scaling Earthquake Ground Motions for Performing Response-History Analyses,” *Proceedings of the 15th World Conference on Earthquake Engineering, Lisboa, Portugal*, 2012.

[17] Hashmi, A. K. and Madan A. “Damage forecast for masonry infilled reinforced concrete framed buildings subjected to earthquakes in India,”*Current Science*. Vol.94, pp61-73, 2008.

[18] IS 13920. “Ductile detailing of Reinforced concrete structures subjected to seismic forces - code of practice,” *Bureau of Indian Standards, New Delhi*, 1993.

[19] IS 1893 Part I. “Indian Standard Criteria for Earthquake Resistant Design of Structures,” *Bureau of Indian Standards. New Delhi*, 2002.

[20] IS 456. “Indian Standard for Plain and Reinforced Concrete Code of Practice,” *Bureau of Indian Standards, New Delhi,* 2000.

[21] Kaushik, H.B., Rai, D.C., and Jain, S.K.. “Code approaches to seismic design of masonry infilled reinforced concrete frames: A state-of-the-art review,” *Earthquake Spectra*. vol.22(4), pp 961-983, 2006.

[22] Kent D, park R. “Flexural mechanics with confined concrete,” *Journal of Struct Div, ASCE.* vol.97(ST7), pp 1969-90, 1971.

[23] Nielson, B.G. “Analytical Fragility Curves for Highway Bridges in Moderate Seismic zones,” *Ph.D. Thesis, Georgia Institute of Technology*, 2005.

[24] Pallav K, Raghukanth S. T. G. and Konjengbam Darunkumar Singh., “Probabilistic seismic hazard estimation of Manipur*,” India, Journal of geophysics and engineering*. 9:516–533, 2012.

[25] Rajeev P. and Tesfamariam S. “Seismic fragilities for reinforced concrete buildings with consideration of irregularities,” *Structural Safety* vol. 39, pp 1-3, 2012.

[26] Scarlet, A. “”Design of soft stories-A simplified energy approach,” *Earthquake Spectra*. 13:305-315. 1997.

[27] Song, J. and Ellingwood, B. R. “Seismic reliability of special moment steel frames with welded connections: II”. *Journal of Structural Engineering*. 125(4):372, 1999.

[28] Standards Institution of Israel (SII). “Design provisions for earthquake resistance of structures,” *SI 413, Tel-Aviv, Israel*, 1995.