Seismic Performance of Open Ground Storey RC Buildings for Major International Codes

D. J. Chaudhari[1], Prajakta T. Raipure[2]

[1]*Professor, Applied Mechanics Department, overnment College of Engineering, Amravati, Maharashtra, India*
dilipbhanu.chaudhari@gmail.com
[2]*Post Graduate Student, Applied Mechanics Department, Government College of Engineering, Amravati, Maharashtra, India*
praju.raipure@gmail.com

Abstract: **Vulnerability studies are carried out before an earthquake occurrence for assessing the need to strength essential facilities and structures against future earthquakes. For providing sufficient parking spaces, now a day's ground storey of the building is utilized. The buildings having no infilled walls in ground storey, but which are in-filled in all upper storey, are called Open Ground Storey (OGS) buildings. Open ground storey framed buildings are generally analyzed as linear bare frame analysis. Design codes give multiplication factors on the design forces in the columns of ground storey. The present study attempts to estimate and compare performance of open ground storey building designed with multiplication factors given by major international codes. A typical (G+9) OGS framed building is considered and the design forces for the ground storey columns are evaluated based on various codes and ground storey columns are designed. The performance of each building is studied using the Fragility Analysis method introduced by Cornell (2002). Models of buildings designed with different multiplication factors are developed in ETABS Software for nonlinear dynamics analysis on which a set of twenty natural time histories is applied. In the present study, Fragility Curves are generated for each building, by developing a Probabilistic Seismic Demand Model (PSDM). The relative performances of different storeys of each building are compared using fragility curves for different performance levels. Results show that performance of upper storeys while applying multiplication factor only to the ground storey needs to be checked. Performances of OGS frames, (ground storey drift) increases in the increasing order of multiplication factors.**

Keywords: **Open ground storey, multiplication factors, fragility, performance levels, PSDM Model**

1. INTRODUCTION

The vulnerability of an element is defined as the probability that the said element will sustain a specified degree of structural damage given a certain level of ground motion severity [1]. A large number of existing buildings in India need seismic evaluation due to various reasons such as, nonconformity with the codal requirements, revision of codes and design practice and change in the use of building. Hence fragility estimation of the existing RC buildings in India is a growing concern. Building fragility curves are lognormal functions that describe the probability of reaching, or exceeding, structural and nonstructural damage states when it is subjected to certain ground motion intensity [2]. These curves take into account the variability and uncertainty associated with capacity curve properties, damage states and ground shaking [3].

1.1 Open Ground Storey

Open ground storey (OGS) buildings are commonly constructed in India and all over world since they provide much needed parking space in an urban environment. Collapses of buildings in Bhuj earthquake are mostly due to the formation of soft-storey mechanism in the ground storey columns. Figure 1 represents an example of typical open ground storey provided for parking spaces.
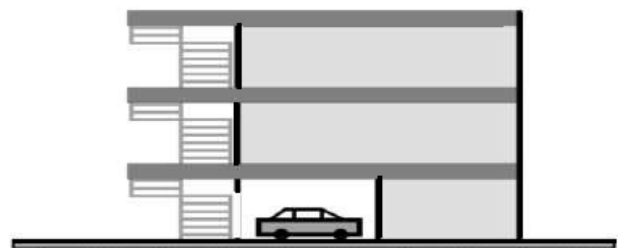

Fig.1.: Soft storey for parking space

The sudden reduction in lateral stiffness and mass in the ground storey tends to increase stresses in the ground storey columns under seismic loading. Design based on bare frame analysis results in underestimation of the bending moments and shear forces in the ground storey columns, which is responsible for the damages observed. Therefore it is necessary that the ground storey columns must have sufficient strength, stiffness and adequate ductility.

TABLE 1: Multiplication Factor (MF) As Per Various Codes

Code	Criteria	Expression for MF	MF used
Indian	$\dfrac{K_i}{K_{i+1}} < 0.7$	2.5	2.5
Euro	Drastic reduction of infill in any storey	$\left[1 + \dfrac{\Delta V_{RW}}{\sum V_{ED}}\right]$ 1.5 - 4.68	4.68
Bulgarian	$\dfrac{K_i}{K_{i+1}} < 0.5$	3	3
Israel	$\dfrac{K_i}{K_{i+1}} < 0.7$	0.6R R=3.5 for low ductility R=5 for medium ductility (2.1 – 3.0)	2.1 applied to both ground and 1st storey

In the aftermath of the Bhuj earthquake, the IS 1893 code was revised in 2002, giving new design recommendations to address soft story buildings. Clause 7.10.3(a) of IS 1893:2002 states: The columns and beams of the soft storey are to be designed for 2.5 times the storey shears and moments calculated under seismic loads of bare frames. The factor 2.5 can be said as a multiplication factor (MF) or Magnification factor. This multiplication factor (MF) is supposed to be the compensation for the stiffness discontinuity. Other international codes also recommend different multiplication factors for this type of buildings which are given in Table 1. The main objective of this work is to study and compare the seismic performance of typical OGS buildings designed as per applicable provisions in international codes in a Probabilistic framework and to make use of Probabilistic Seismic Demand Model to generate fragility curves.

2. DEVELOPMENT OF FRAGILITY CURVES

The fragility can be expressed in closed form using following equation,

$$P(C - D \leq 0/IM) = \emptyset\left(\frac{\ln \dfrac{S_d}{S_c}}{\sqrt{\beta_{d/IM}^2 + \beta_c^2}}\right)$$

Where, C is the drift capacity, D is the drift demand, S_d is the median of the demand and S_c is the median of the chosen damage state (DS). $\beta_{d/IM}$ and β_c are dispersion in the intensity measure and capacities respectively. Above Eq. can be rewritten as Eq. for component fragilities (Nielson, 2005) as

$$P(DS/IM) = \emptyset\left(\frac{\ln IM - \ln IM_m}{\beta_{comp}}\right)$$

Where $IM_M = exp\left(\dfrac{\ln S_c - \ln a}{b}\right)$,

a and b are the regression coefficients of the probabilistic Seismic Demand Model (PSDM) and the dispersion component,
$\beta_{D/IM}$ is given as

$$\beta_{D/IM} = \sqrt{\frac{\sum(\ln(d_i) - \ln(a\,IM^b))^2}{N - 2}}$$

β_{comp} is given as,

$$\beta_{comp} = \sqrt{\frac{\beta_{d/IM}^2 + \ln IM_m}{b}}$$

The dispersion in capacity, βc is dependent on the building type and quality of construction. For βc, ATC 58 50% draft suggests 0.10, 0.25 and 0.40 depending on the quality of construction. In this study, dispersion in capacity has been assumed as 0.25.

The flowchart in figure 2 represents how the fragility curves are drawn using method suggested by Cornell *et. al* (2002) [3].
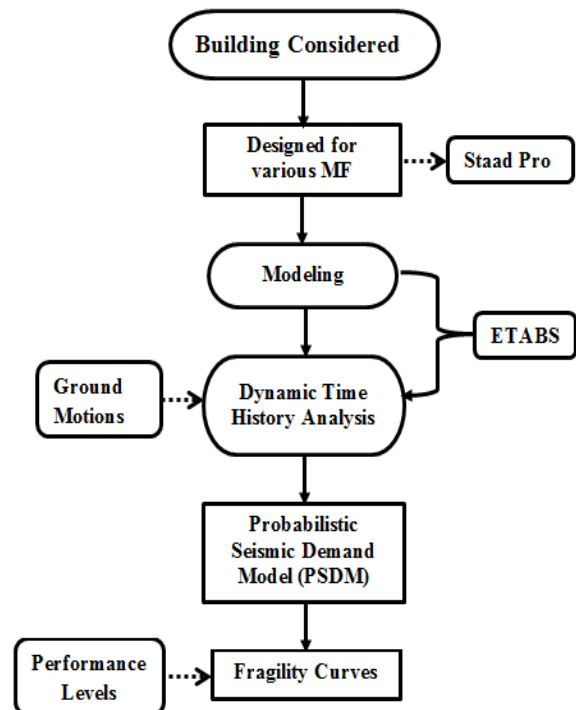
Fig.4. Flowchart for Development of Fragility Curves

3. MODELLING

Analysis and design by using IS 1893:2002 Part 1, and 456:2000 is carried out in the software STAAD PRO.

3.1 Details of Buildings Considered

A ten-storey six-bay OGS RC frame that represents a symmetric building in plan is considered. Concrete and steel grades are taken as M25 and Fe415 respectively. Bay width and column height are taken as 3m and 3.2m respectively. Slab thickness is of 150 mm. A live load of 3 KN/m^2 is considered at all floor levels except top floor, where it is considered as 1.5KN/m^2. The building considered is located in seismic zone V having Z = 0.36 with medium soil and R value considered as 3 for ordinary RC moment resisting frame (OMRF). Parapet wall of 0.6 m is considered. The columns and beams considered are of sizes 450mm x 450mm and 230mm x 350mm respectively.
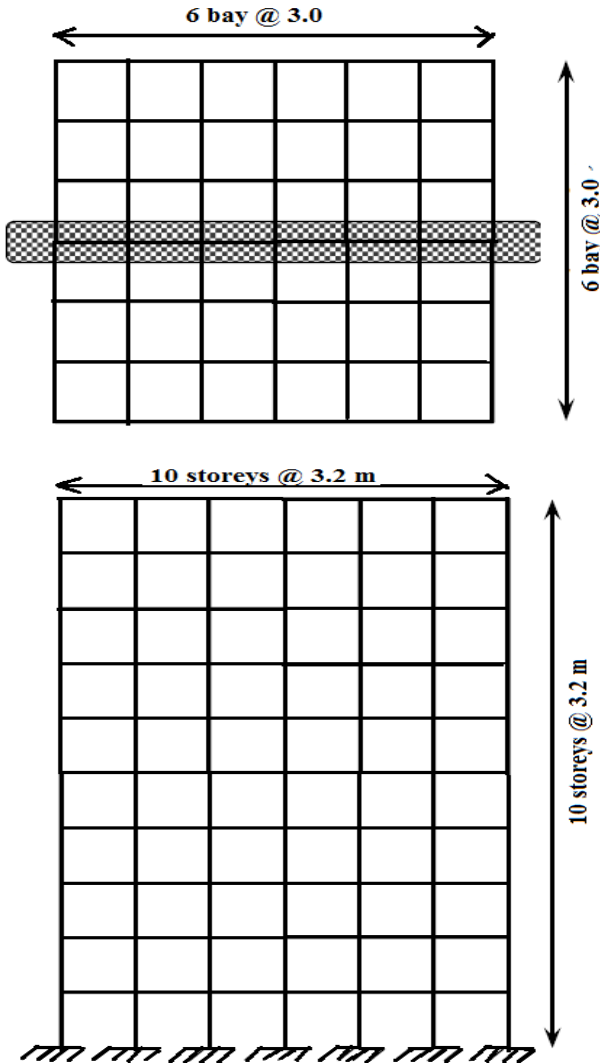

Fig. 3. Plan and Elevation Of Building Considered

As the building is an OGS frame, the ground storey columns are to be designed taking into account the MFs for all major international codes as considered.

TABLE 2: Design Details of The Buildings Considered

Frame designation (10 Storey 6 Bay)	Ground storey column section	% Reinf. Provided
Indian (MF = 1)	450 X 450	3.93
Indian (MF = 2.5)	750 X 750	3.57
Bulgaria (MF = 3)	800 X 800	3.93
Euro (MF = 4.68)	1250 X1250	3.86
Israel (MF = 2.1)	650 X 650	3.8

3.2 Nonlinear Dynamic Analysis

Twenty different time histories including some of the Indian time histories collected from strong ground motion database are used to carry out nonlinear dynamic analysis to capture the maximum inter-storey drift at ground, 1st and 2nd storey. Each Building frames are modeled in the ETABS Software (Version 9.7.3).

4. RESULTS AND DISCUSSIONS

4.1 Probabilistic Seismic Demand Model (PSDM)

It has been suggested by Cornell (2002) that the median engineering demand parameter (*EDP*) can be estimated by using Power Log model which is given by equation,
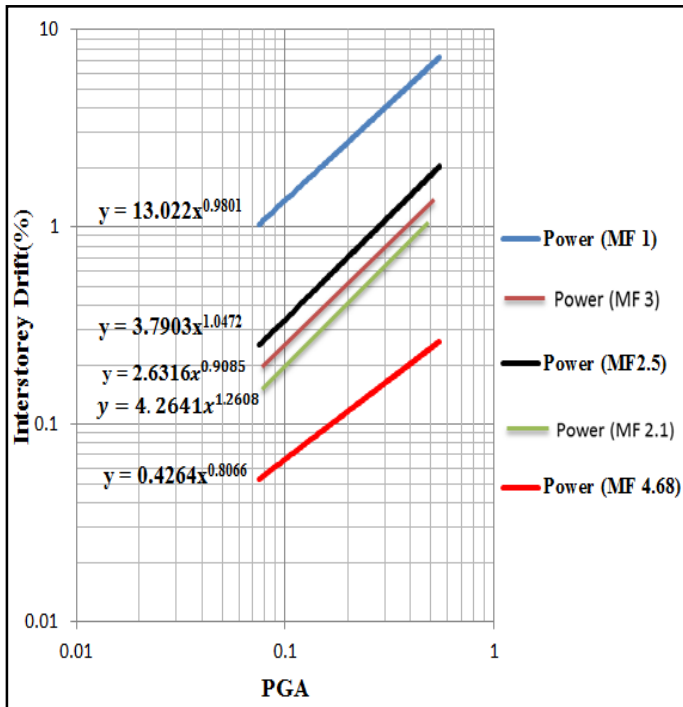
$$EDP = a\ IM^b$$

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

The nonlinear dynamic analyses are used to build the PSDM. Nonlinear time history analyses of twenty models have been performed in ETABS to obtain a set of twenty inter-storey drifts for the corresponding PGAs for ground, 1st and 2nd storey. The parameters '*a*' and '*b*' of the equation are determined for buildings considered by performing a regression analysis using power-law. The demand models for buildings considered are obtained using linear regression analysis. The inter-storey drift at the ground storey is more for the OGS 1.0 and the inter-storey drift also reduces as the MF increases.

TABLE 3: Parameters of Probabilistic Seismic Demand Model (PSDM)

Name of building	a	b
MF 1	13.022	0.9801
Indian 2.5	2.7903	1.0472
Bulgaria 3	2.6316	0.9085
Euro 4.68	0.4264	0.8066
Israel 2.1	4.2641	1.2608

$$y = 13.022x^{0.9801}$$
$$y = 3.7903x^{1.0472}$$
$$y = 2.6316x^{0.9085}$$
$$y = 4.2641x^{1.2608}$$
$$y = 0.4264x^{0.8066}$$

Power (MF 1)
Power (MF 3)
Power (MF2.5)
Power (MF 2.1)
Power (MF 4.68)

Fig. 4. PSDM models of all the OGS buildings

4.2 Building Performance Levels

Three performance levels as given in table 4 are considered which will be directly related to the extent of damage sustained by the building during a damaging earthquake.

TABLE 4. Damage Limits With Various Structural Performance Levels for RC Frames

Limit state designation	Performance level	Inter storey Drifts, S_c (%)
Immediate occupancy(IO)	Light repairable damage	1
Life safety(LS)	Moderate repairable damage	2
Collapse prevention(CP)	Near collapse	4

4.3 Comparison of Fragility Curves

The application of multiplication factors increases the strength and stiffness of the ground storey columns. It is observed from Figure 5 that the damage exccedance probability of the OGS frame designed with MF = 1.0 is about 80% for IO performance level, about 15-20 % for LS level and close to 0 % for CP level. As the ground storey columns have increased their column sections, it can be seen from Figure 6, that the performance of the building (probability of exceedance of inter-storey drift decreased) is increased when compared to the building designed with MF = 1. The probability of exceedance is almost zero for all the three performance levels IO, LS and CP. The same behaviour is observed for remaining cases such as Bulgarian (Figure 7), Euro (Figure 8), Israel (Figure 9).
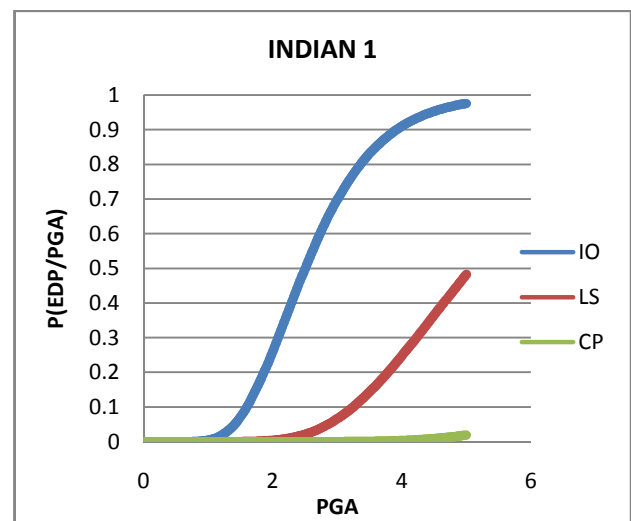
Fig. 5. Fragility Curves for OGS (India 1)
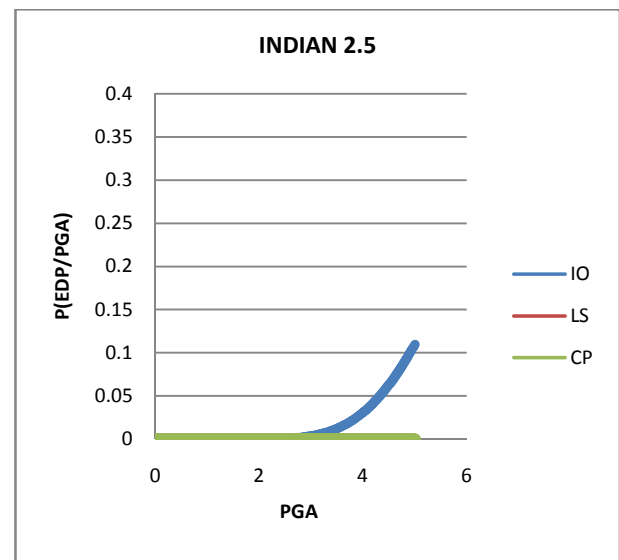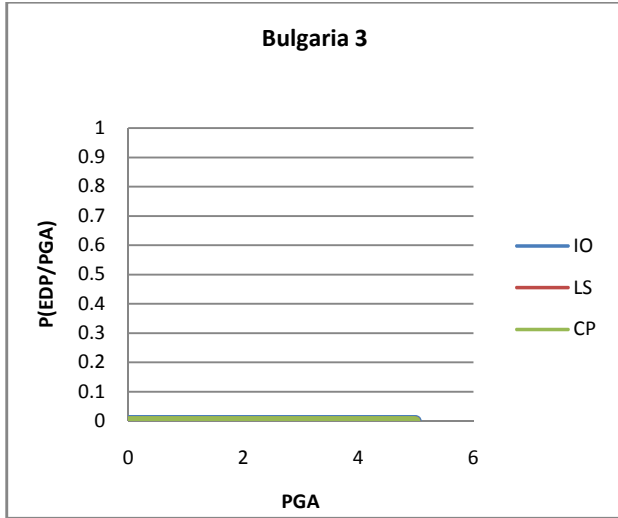

Fig. 6. Fragility Curves for OGS (India 2.5)

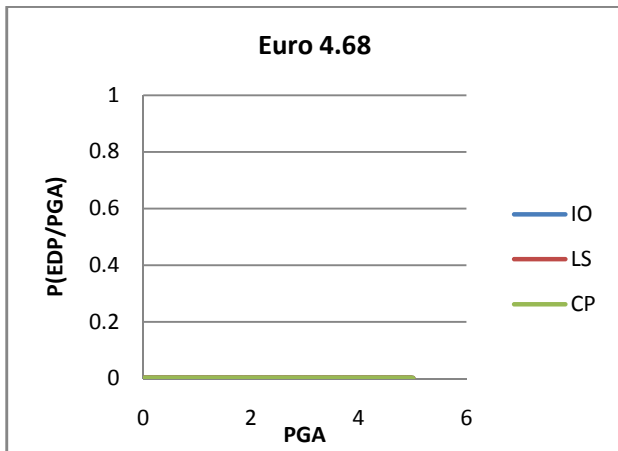**Fig. 7. Fragility Curves for OGS (Bulgaria 3)**

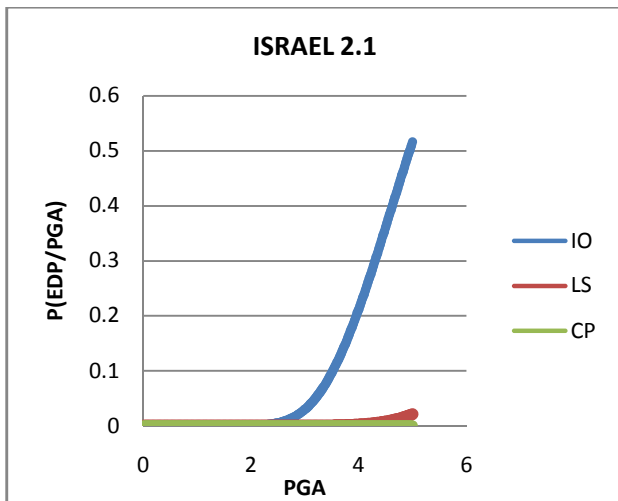**Fig. 8. Fragility Curves for OGS (Euro 4.68)**

Fig. 9. Fragility Curves for OGS (Israel 2.1)

4.3 Comparison of Fragility Curves at Various Storeys for IO level

The fragility curves for ground, 1st, 2nd storeys for IO performance levels is developed and are shown in the Fig. 10 to 14. Fig. 10 shows fragility curves for the OGS frame designed for MF = 1.0 for different storeys. It is observed that the first storey is more vulnerable than the upper storeys. Fig. 11 shows the storey wise exceedance probability of the building designed using MF, 2.5 which shows that the first storey is more vulnerable than the second and ground storeys. This implies that performance of the above storeys also needs to be checked while using multiplication factors only to ground storey. The same behavior is observed (Fig. s 12, 13) for all other codes except for the Israel code (Fig. 14) which applies a factor of 2.1 for both ground and first storey which reduces the exceedance probability considerably and uniformly in all storeys, compared other codes.
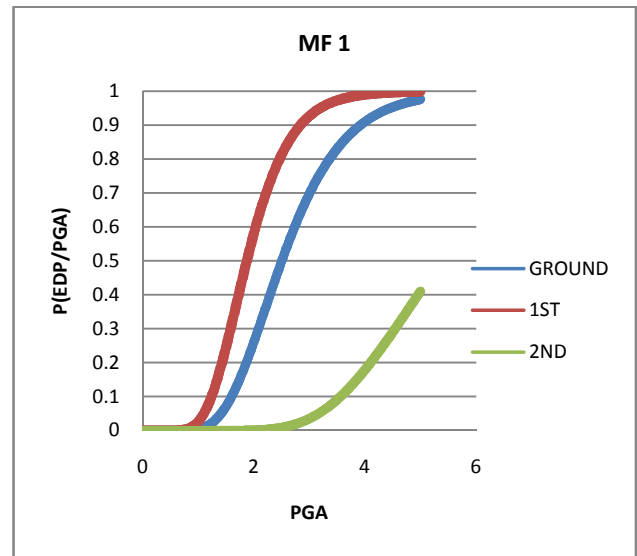

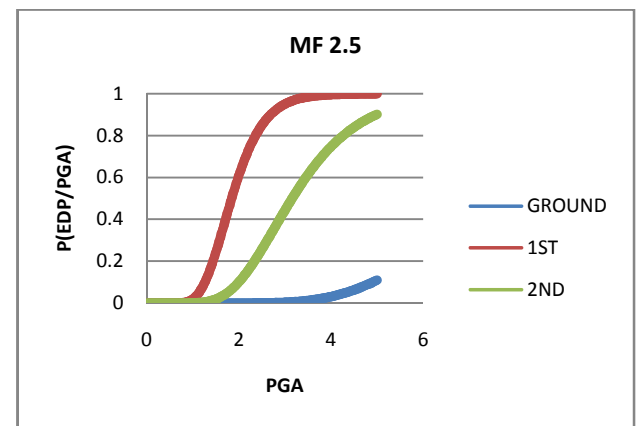**Fig. 10. Fragility Curves for various storeys (MF 1)**

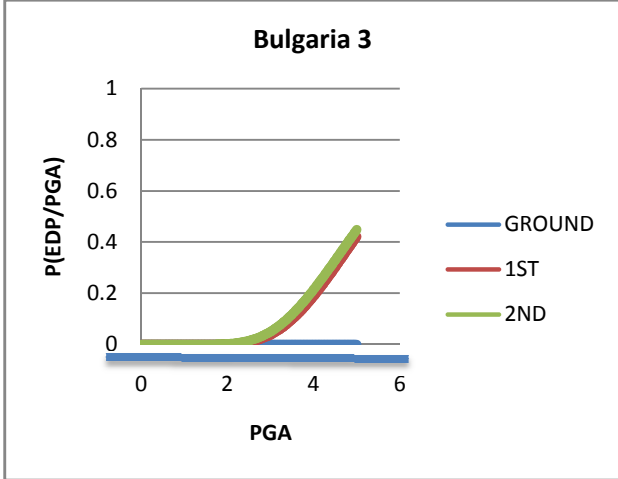**Fig. 11. Fragility Curves for various storeys (MF 2.5)**

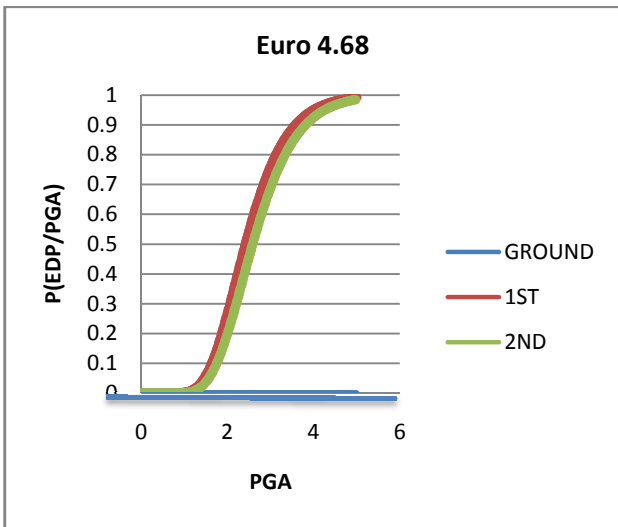**Fig. 12. Fragility Curves for various storeys (MF 3)**

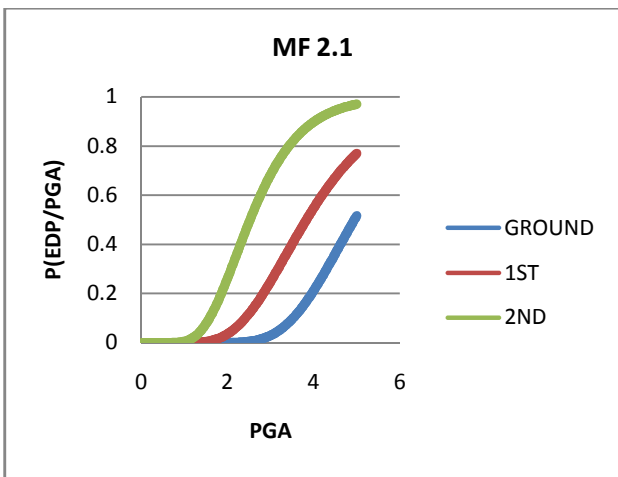**Fig. 13. Fragility Curves for various storeys (MF 4.68)**

Fig. 14. Fragility Curves for various storeys (MF 2.1)

4.5 Comparison of Fragility Curve For Each Storeys For IO Level

Fragility curves for each storey for different codes are compared to understand the behaviour of stories other than ground storey. Fig. 15 represents the fragility curve of ground storey for various codes. As the Israel code uses the MF factor to both ground and 1st storey the resulting fragility is more at ground storey compared to that of other codes. Fig. 16 represents the fragility curve of first storey showing that the probability of exceedance of inter-storey drift is same for all the codes except for Israel code which considers MF for first storey i.e. the first storey of all the frames designed by codes other than Israel code remains same to yield same exceedance probability. Fig. 17 represents the fragility curves for second storey. It can be seen that the fragility of the second storey is marginally same for all the codes.
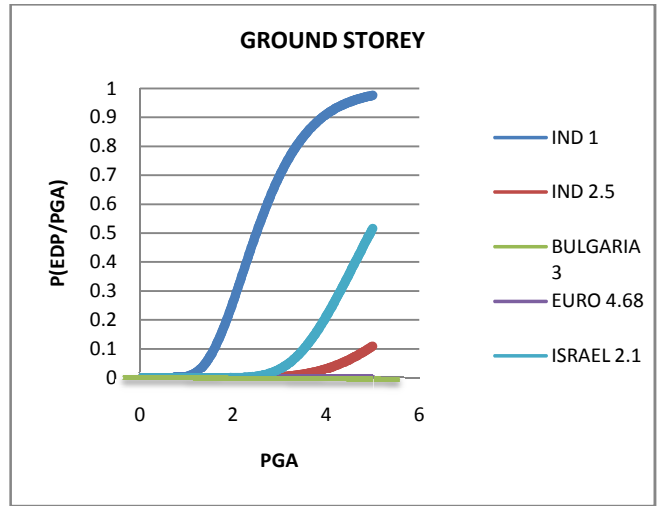

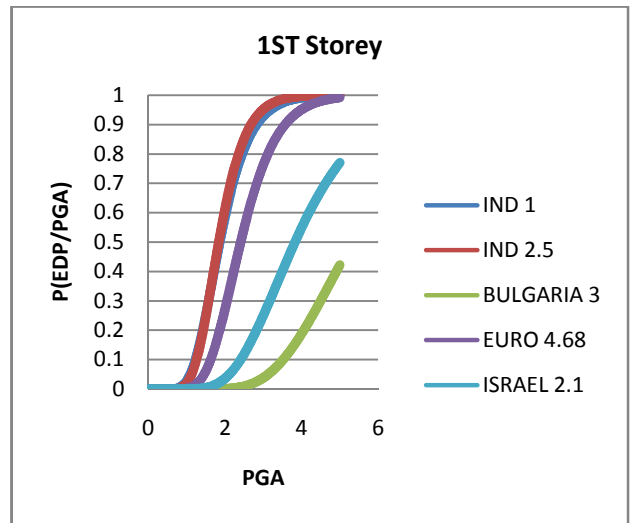**Fig. 15. Fragility Curves For GROUND Storey**

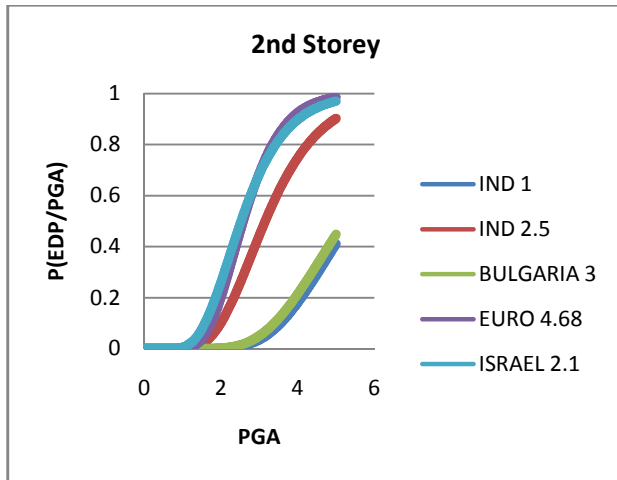**Fig. 16. Fragility Curves For First Storey**

Fig. 17. Fragility Curves For Second Storey

5. CONCLUSIONS

Based on the above research works following conclusions are obtained:

1. Performances of the OGS frames, in terms of ground storey drift is increasing in the increasing order of MFs used by all codes for all the performance levels.

2. In case of Indian code first storey is more vulnerable than ground storey whereas for Israel code it is not so. Relative vulnerability of first storey increases due to strengthening of the ground storey.

3. Application of magnification factor only in the ground storey may not provide the required performance in all the other stories. It is seen that the OGS buildings designed using Israel code, which considered the MF in

the adjacent storey, performed better compared to Indian which indicates that the application of multiplication factor in the adjacent storeys may be required to improve the performance of OGS buildings.

REFERENCES

[1] Robin Davis, Devdas Menon And Meher Prasad, "Earthquake-Resistant Design Of Open Ground Storey RC Framed Buildings", *Journal Of Structural Engineering, Vol. 37, No. 2, 117-124, June-July 2010.*

[2] Masanobu Shinozuka, Maria Q. Feng, Ho-Kyung Kim, and Sang-Hoon Kim (2000) *"*Nonlinear Static Procedure For Fragility Curve Development" *Journal Of Engineering Mechanics,* Vol. 126, No.12, 1287-1295

[3] Cornell, C. Allin, Fatemeh Jalayer, Ronald O. Hamburger And Douglas A Foutch, (2002) "The Probabilistic Basis For The 2000 SAC/FEMA Steel Moment Frame Guidelines", *Journal Of Structural Engineering* 128(4), 526-533.

[4] Monalisa Priyadarshani , Robin Davis P. (2012) Seismic Risk Assessment Of RC Framed Vertically Irregular Buildings. Mtech. Thesis, National Institute Of Technology, Rourkela

[5] Bhagavathula Lohitha, S.V. Narsi Reddy "Earthquake Resistant Design Of Low-Rise Open Ground Storey Framed Building" *International Jornal Of Modern Engineering Research (IJMER), Vol. 4, Iss.6, June. 2014.*

[6] Saurabh Singh Saleem Akhtara And Geeta Bathama "Evaluation Of Seismic Behavior For Multistoried RC Moment Resisting Frame With Open First Storey" *International Journal Of Current Engineering And Technology Vol.4, No.1, 01 February 2014.*

[7] Akkar, S., H. Sucuoglu and A. Yakut (2005) "Displacement-based fragility functions for low- and mid-rise ordinary concrete buildings," *Earthquake Spectra*, 21(4), 901-927.

[8] Monalisa Priyadarshini, Robin Davis P, Haran Pragalath D C and Pradip Sarkar. "Seismic Reliability Assessment Of Typical Soft-Storey RC Building In Manipur Region" *International Conference on Innovations in Civil Engineering. 9th and 10th May 2013.*