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Multiplication Factors for Design of Open Ground Story RC Building – A Probabilistic Approach

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Abstract - Open ground story buildings are considered as soft story framed buildings and causes potential thread in the event of earthquakes. This type of buildings cannot be ignored in construction as it has many functional advantages where land cost is high. International codes addresses this issue and suggest to use Multiplication Factor for design values. And there is huge disparity about the codes and their performance is not clearly studied. In the present study typical four story frame is chosen and reliability index are developed using probabilistic approach. In the present study, formula for MF is pro-posed based on the safety level named as Reliability Index.

***Keywords*:** Multiplication Factor, Open Ground Story, Fragility Curves, Reliability Index

1. Introduction

Open Ground Story (OGS) are the buildings where, ground story will not have any infill walls and the upper story will have infill walls. This type of buildings is becoming more popular in city and densely populated areas due to its functional advantage, but they also considered as dangerous type of irregular buildings, as it comes under soft story building category. This type of buildings undergoes large displacement in ground story building under seismic loading due to sudden reduction in lateral strength and stiffness. Large lateral displacements are developed at the first floor level under seismic loading, which increases the forces and curvatures of the columns in ground story. The development of soft-story mechanism is formed in ground story column and leads to collapse. Contribution of infill walls stiffness on upper story are neglected in conventional design practice, and hence structurally modelled without infill wall stiffness. This type of analysis results under estimation of axial forces (P-delta Effects), shear forces and bending moments and these effect is responsible for the failures. Different inter-national codes and other published literature also addressed this problem with similar concept. Studied the quantification of seismic forces in OGS buildings and proposed a different multiplication factor based energy principles ranging from 1.86 to 3.28 as the number of story increases from six to twenty[1]. [2] conducted a push-over analyses and non-linear time history for OGS buildings, similarly many authors and international codes suggest to use MF for OGS buildings. Present study addresses these issues by considering the variation in MF in a probabilistic frame works.

2. Methodology

The method used in this study is to determine the seismic safety level of OGS building in terms of safety/reliability index. Developed seismic fragility curves and seismic hazard are used to develop reliability index. The methodology re-ported by [3] is used in the present. The limit state probability can be found using the following equation,

$$P[LS_i] = \int F_R(x) \frac{dG_A}{dx} dx \qquad (1)$$

Where FR(x) is the fragility curve and GA is the Hazard curve in continuous form.
The reliability index can be found using below equation.

$$\beta_{Pf} = -\phi^{-1}(P[LS_i]) \qquad (2)$$

Where ϕ( ) - standard normal distribution. Developed a Seismic Hazard curve for north east regions in India is choosen in the the present study as it has the highest seismic zone and one of the seismic active region in India. [4] Seismic Fragility curve expressions in closed form as follows:

$$P(D \geq C \mid IM) = \phi\left(\frac{\ln \frac{S_D}{S_C}}{\sqrt{\beta_{D|IM}^2 + \beta_c^2}}\right) \tag{3}$$

Where, D – demand, C - capacity at chosen limit state, drift is chosen as a damage parameter. SD and SC are the median of the demand and the chosen limit state (LS) respectively. Where $\beta_{d/IM}$ is a dispersion in intensity measure and β_c is dispersions in capacities. A fragility curve can be calculated for each limit state. The detailed methodology can be found in [5]. RC frames drift limits as per [6] is considered in present study. For light repairable damage (IO), moderate repairable damage (LS) and near collapse (CP) are 1%, 2% and 4% respectively.

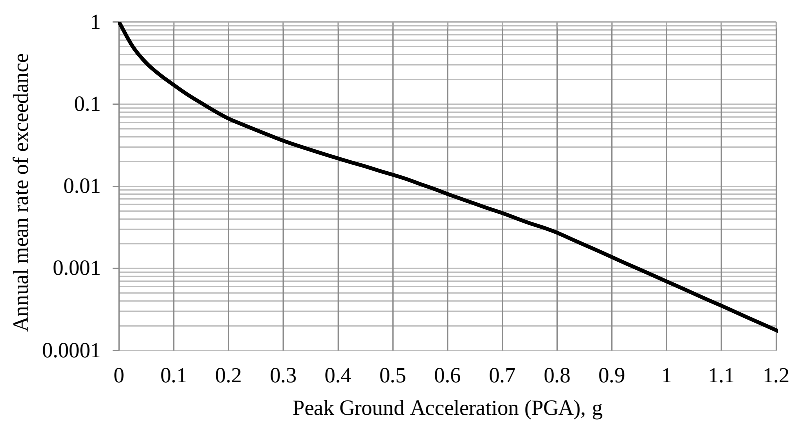


Fig. 1: Seismic hazard curves of North East region, India (Pallav *et. al*, 2012)

3. Fragility Curves Of Selected Frames

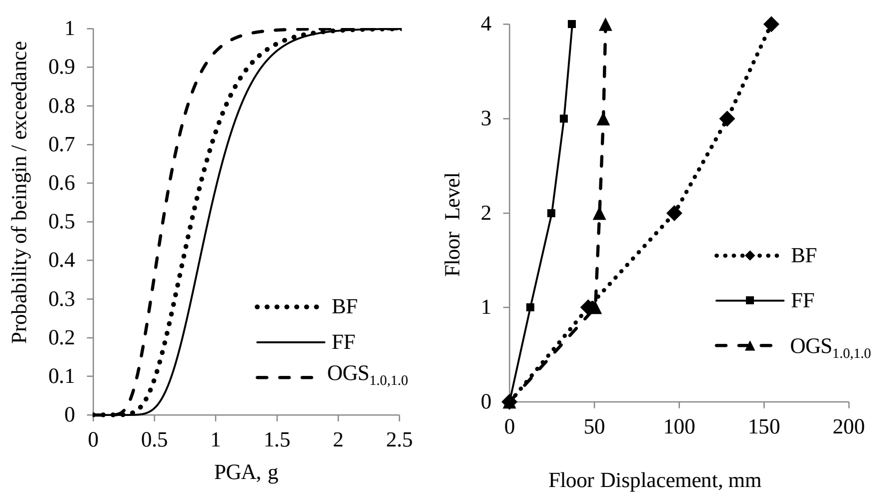
Building selected in the present study is symmetrical in plan and hence single frame is considered along one direction. Floor height and Bay width is considered as 3.2m and 5m respectively. Dead load, live load and seismic loads are considered during the design stage and load combinations are considered as per the standards. During design stage stiffness and strength of infill walls are ignored as a standard practice due to uncertainties in infill walls. Strength of steel is considered as 415 N/mm2 and for concrete as 25 N/mm2. To find the behaviour and the effect of Multiplication Factor (MF) for OGS buildings in terms of exceedance probability, different MF values are chosen, such as 1.5, 2.0, 2.5 and 3.0. To understand the behaviour of OGS building in the present study a comparative study is performed along with fully infilled frame (FF) and bare frame (BF). Where BF is denoted with MF as 1.0.

As MF values are used in the ground and first stories, different subscripts are used to represent the different frames varies with MF values in the ground and first stories respectively to differentiate among OGS frame. For example, $OGS_{x,y}$ represents, an OGS with MF selected in the ground story as 'x' and that selected in the first story as 'y'. Numerical model presented in this study can be found in [5],[7]. 44 numbers of far field earthquake are taken form [8] and converted to match Indian design spectrum, similar earthquakes are also used in [9]. These converted earthquake records are considered for non-linear dynamic analysis (NLDA) in this study. Latin Hypercube sampling scheme is considered to incorporate the uncertainty in the materials strength and stiffness. Infill walls are modelled using equivalent strut, detailed modelling techniques can be found in [5] &[10].

The simplified procedure, developed by [3] is used to develop fragility cures and the seismic risk of OGS buildings and other buildings in terms of reliability index. This methodology involves following parts. The calculation of the seismic hazard for particular location, P [A = a], described by the annual probabilities of specific levels of earthquake motion. Then the calculation of global response of the structural system in terms of maximum inter-story drifts by conducting a series of Nonlinear Time history analyses. Third part is the calculation of probability of exceedance for particular limit states. And the final part is to find Reliability Index.

4. Fragility Curves Of Selected Frames

For all the frames, Probabilistic seismic demand model (Power law) are calculated and its coefficients a and b are found. Using PSDM model and dispersions for the frames, fragility curves are developed. This is developed to understand the behaviour of different frames have different MFs (in ground and/or first story) by understanding the probability of being in or exceedance of each damage limit state (*Sc*). Fragility curves for fully infilled frame (FF), bare frame (BF), and Open Ground story building with MF of 1.0 (OGS1.0,1.0) are shown in Fig 2a. It can be observed that exceedance probability for OGS1.0,1.0 is higher than that of Bare frame and Fully infilled frame. Due to the presence of infill wall strength and stiffness present in the ground story, FF frame shows the better performance as compared with BF and OGS frames. Fig 2. Shows the maximum displacement profile in story level for the typical chosen earthquake. Ground story roof dis-placement is higher for OGS1.0,1.0 frame when compared with other story roof displacements and this behaviours looks like an inverted pendulum. Fully in-filled frame have less story displacements as compared to all, this proves that infill wall can enhance the building performance in many folds as it has good strength and stiffness under lateral loads. For eg: from Fig. 2a it can be seen that Fully infilled frame(infill walls in the ground storey) reduces the probability of exceedance in story drift by about 50% at a PGA of 0.4g as compared with Bare Frame.

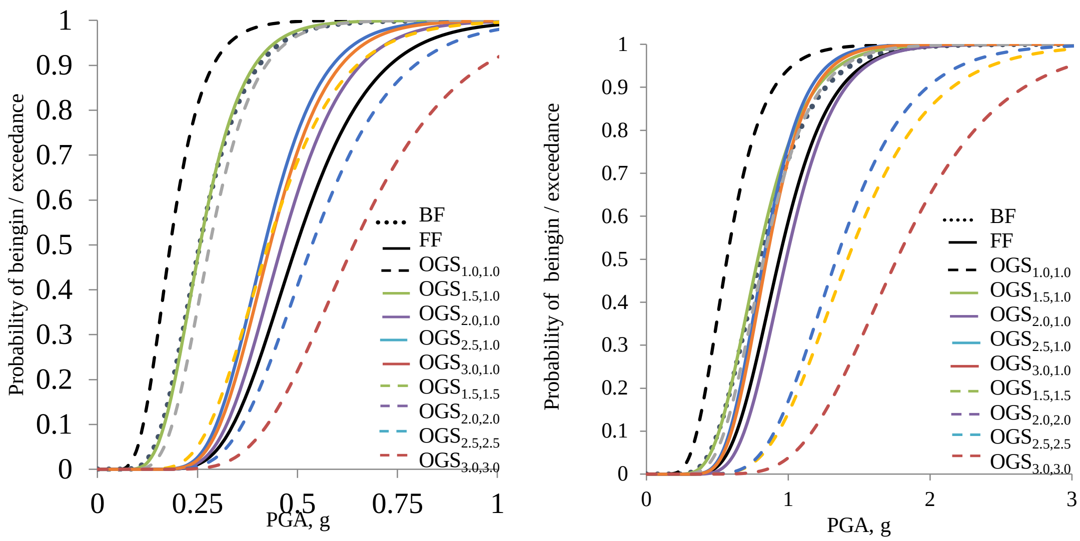


a) IO level Fragility curve b) Story wise displacement profiles

Fig. 2: Fragility curves and typical maximum displacement profiles for four story frames

4.1. Significance of MF in both Ground and Adjacent Stories

It can be see that the application of MF only in the ground story leads to the story stronger, but this makes to adjacent story weaker, which does not improve the performance of the building. This behaviour is observed when MF of 2.0, 2.5 and 3.0 are used in the ground story alone. Story wise fragility curves are considered to illustrate this behaviour. Fig. 3a shows the story wise fragility curves for the frames OGS3.0,1.0 considering inter-story drift at each story as the engineering damage parameter. From the fragility curve, it can be seen that, for the first story is more fragile than the ground story for any intensity measure (PGA). Hence it can be inferred that the MF, applied to a single story and not to the adjacent story may lead to failure of adjacent story. In order to avoid such unfavourable situations, MFs of 2.0, 2.5 and 3.0 are applied to both the stories. Fig. 3b shows the story wise fragility curves for the frames OGS3.0,3.0 considering inter-story drift at each story as the engineering damage parameter. It can be observed that use of MF in both stories (ground and first) make the building to perform significantly better than that of MF applied only in the ground story. The performance of four story OGS frame considered in the present study shows good performance when MF applied in both stories. However, for OGS buildings with a number of stories, more than four may require the application of MF in more than two stories. For a generalized conclusion, a detailed study is required by considering frames having a number of stories more than four.



a) Fragility Curve for IO performance b) Fragility Curve for CP performance

Fig. 3: Fragility Curves for the selected frames

5. Comparison of Reliability Indices

For two performance levels, reliability Index are calculated, namely immediate occupancy and collapse prevention. From the story wise 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 lowest reliability index (β_{pf} =1.54) for the frame BF at the IO performance level is governed by the failure of the first story. The minimum value of reliability index of the FF frame is found to be 2.16 (IO) for the failure of ground story which represents the failure of the entire frame. The least value of the reliability indices for the failure of each story is marked for all the frames.

Reliability index obtained for OGS1.0, 1.0 is about 1.36, this vale is very low and this is due to the failure of ground story. The reliability indices for the first, second and third stories are found to be more than 5.0. This shows the soft-story formation at the ground story with intact upper stories.

As MF applied to the ground story increases, (represented by frames OGS1.5, 1.0, OGS2.0, 1.0) the reliability values in all the stories reduce. As the MF increased to above 2.0 (represented by frames OGS2.5, 1.0, OGS3.0, 1.0), the reliability index is governed by failure of the first story. The reliability indices values for OGS frames with MF applied to both stories (OGS1.5, 1.5, OGS2.0, 2.0 OGS2.5, 2.5 and OGS3.0, 3.0) are more than that of corresponding frames designed with MF applied in only ground story (OGS1.5, 1.0, OGS2.0, 1.0 , OGS2.5, 1.0 and OGS3.0, 1.0) and hence the scheme of MF applied to both stories perform better.

OGS3.0, 3.0 perform better than all other frames, and it is incidentally one of the schemes recommended by the Israel code (SII, 1995) for the Open Ground Story type of buildings. However, the authors feel that as the number of stories increases (more than four), by applying the MF even in two stories (ground and first stories) may make above adjacent story (second story) vulnerable. Further study on this behaviour requires consideration of OGS buildings with a number of stories more than four. Fig. 19 and 20 shows the variation of reliability index with PGA values for all the frames considered for the IO and CP performance levels. For taking a decision on the choice of MF for a particular OGS building in performance based framework, this plot can be used along with target reliability limits as per the requirements of stakeholder.

Table 1: Reliability Index (β_{pf}) for frames (EDP -inter-story drift of each story)

Frame	Story level					
	IO			CP		
	G	1st	2nd	G	1st	2nd
BF	1.62	**1.54**	1.77	**2.60**	2.67	3.56
FF	**2.16**	2.46	2.89	**2.85**	3.54	4.46
$OGS_{1.0,1.0}$	**1.36**	5.91	6.63	**2.25**	9.41	10.2
$OGS_{1.5,1.0}$	**1.63**	2.87	4.06	**2.60**	4.57	6.50
$OGS_{2.0,1.0}$	**2.00**	2.10	2.95	3.55	**2.96**	4.80
$OGS_{2.5,1.0}$	2.31	**2.02**	2.89	4.52	**2.72**	4.51
$OGS_{3.0,1.0}$	2.83	**2.05**	2.92	5.40	**2.75**	4.57
$OGS_{1.5,1.5}$	**1.70**	3.14	4.51	**2.67**	5.48	7.49
$OGS_{2.0,2.0}$	**2.02**	2.26	2.63	**3.43**	3.57	3.86
$OGS_{2.5,2.5}$	**2.16**	2.23	2.43	3.67	**3.39**	3.42
$OGS_{3.0,3.0}$	2.57	**2.39**	2.35	4.44	3.84	**3.20**

6. Expression For MF In Terms Of Target Reliability Index

In order to propose an equation relating the reliability index and a MF for various four story OGS frames, the variation of β_{pf} is plotted as shown in Fig. 21 along with MFs (applied in both ground and first stories) for different PGA levels, such as 2% in 50 years (MCE) and 10% in 50 years (DBE). Linear relationships are fitted for both DBE and MCE levels using regression analysis and the equations are displayed in Fig. 4 along with R^2 values. These relationships can be used as a helpful guideline to choose the MF values (to be applied in both ground and first stories) for a required target reliability while designing a four storied OGS frames in a performance based framework.

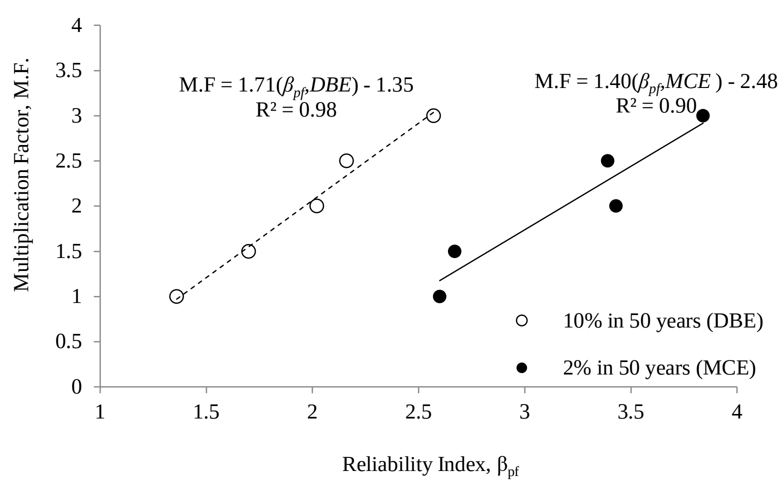


Fig. 4: Reliability Index vs. Multiplication Factor (applied in both ground and first story) for a DBE & MCE

7. Conclusions

Technical International codes and literatures suggested to use MF and there is a lot of dis-parity among them. The basis of MF proposed by different codes lacks a rational basis as reported in literatures. Present study is an effort to provide a theoretical basis to propose MF for a typical four story OGS building. In order to achieve the above objective in terms of selection of MF, different schemes of OGS frames are designed by choosing different MF values of 1.0, 1.5, 2.0, 2.5 and 3.0. The PSDM, fragility curves and the reliability indices are found for various scheme of OGS buildings including BF and FF. The conclusions are derived based on the developed fragility curves and reliability index.

Compare to Bare frame and fully infilled frame, open ground story framed building with no MF is found to be more vulnerable. Due to the presence of infill wall strength and stiffness, Fully infilled frame found to be performed well. It is found that MF applied only to a ground story and not to the adjacent story (first story) may lead to failure of adjacent story and according the entire building. Therefore, application of MF only in the ground story suggested by few national codes may not be treated as an appropriate scheme. The scheme of application of MF in both open ground story and adjacent first story is found to be efficient and is recommended for design standard. Expressions for MF to be applied in the two stories in terms of reliability index for a desired performance objective is proposed for four story OGS frame. The method presented here can be a helpful guideline to decide the multiplication factor and its scheme of application for any other Open Ground Story buildings.

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