PERFORMANCE BASED SEISMIC EVALUATION OF G+9 RC BUILDINGS WITH OPENINGS IN INFILL WALLS

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ABSTRACT

The unreinforced masonry infill walls are commonly used in multistorey framed buildings across the world in recent past. Window and door openings are inevitable part of the infill walls. The presence of openings significantly reduces the lateral strength and stiffness of the infilled frames. In the present paper it is envisaged to study the seismic vulnerability of two-dimensional RC multistorey building models, with the varying percentage of central openings in unreinforced masonry infill walls ranging from 10 to 35% located in zone III. The unreinforced masonry infill walls are modeled as pin-jointed single equivalent diagonal struts. Equivalent static, response spectrum, and nonlinear static pushover analysis were carried out as per the IS 1893 (Part 1): 2002 and FEMA 440 guidelines using SAP 2000 V14.2 software. User defined hinges are assigned at the rigid ends of beams, columns, and struts. The results are compared with the natural period, base shear, lateral displacement, storey drift, hinge status at performance point, ductility ratio, safety ratio, and global stiffness amongst the models. Authors conclude that increase in openings in infill walls increases the vulnerability of building models.

Keywords: Oopenings, User Defined Hinge, Non-Linear Static Analysis, Performance Point, Ductility Ratio, Safety Ratio, Global Stiffness

I. INTRODUCTION

RC frame structures are built with brick masonry and/or concrete block as infill walls in most of the countries. These infill walls significantly increases the stiffness and strength of the infilled frame. Generally infill walls are considered as non-structural elements during deign. The RC frame action behaviour with masonry infill walls illustrates the truss action, where the infill wall behaves as the diagonal strut and absorbs the lateral load under compression. Several buildings constructed in urban India and across the world have the ground storey frames without infill walls leading to soft open ground storey. Thus, upper storeys move almost together as a single block and most of the lateral displacement of the building occurs in the open ground storey due to earthquake excitation.

Door and window openings are inevitable parts of any structure. However, the presence of openings in infill walls affects the lateral stiffness of the frames considerably and hence needs investigation. Reduction of the lateral strength of the structure due to the presence of the openings in the infill walls depends upon the various factors such as percentage of opening, aspect ratio, and the location of the opening in the masonry wall. In the Indian seismic code [1] there is no provision regarding the stiffness and openings in the masonry infill wall. Whereas clause 7.10.2.2 and 7.10.2.3 of the "Proposed draft provision and commentary on Indian seismic code IS 1893(Part 1): 2002", [S K Jain and Murty][2] defines the provision for calculation of stiffness of the masonry infill and a reduction factor for the opening in infill walls.

II. ANALYTICAL MODELLING

In the present paper 2D RC frame G+9 multi-storeyed buildings are considered. The plan and elevation of the building are shown in Fig 1 and 2. The bottom storey height is 4.8 m and upper storeys height is 3.6 m [3]. The building is assumed to be located in zone III, M-25 grade of concrete and Fe-415 grade of steel are considered. The stress-strain relationship is used as per IS: 456-2000 [4]. The unreinforced brick masonry infill walls are modeled as pin-jointed equivalent diagonal struts. M3 (Moment), V3 (Shear), PM3 (axial force with moment), and P (Axial force) user defined hinge properties are assigned at rigid ends of beam, column, and strut elements. The 10% to 35% [3] percentage of central openings are considered and seven analytical models are developed as mentioned below,

Model 1 - Building has no walls and the building is modeled as bare frame, however masses of the walls are considered.

Building has no walls in the first storey and unreinforced masonry infill walls in the upper storeys, with varying central opening, however stiffness and masses of the walls are considered.

Model 2 -10% of the total area of infill.

Model 3 - 15% of the total area of infill.

Model 4 - 20% of the total area of infill.

Model 5 -25% of the total area of infill.

Model 6 - 30% of the total area of infill.

Model 7 - 35% of the total area of infill.

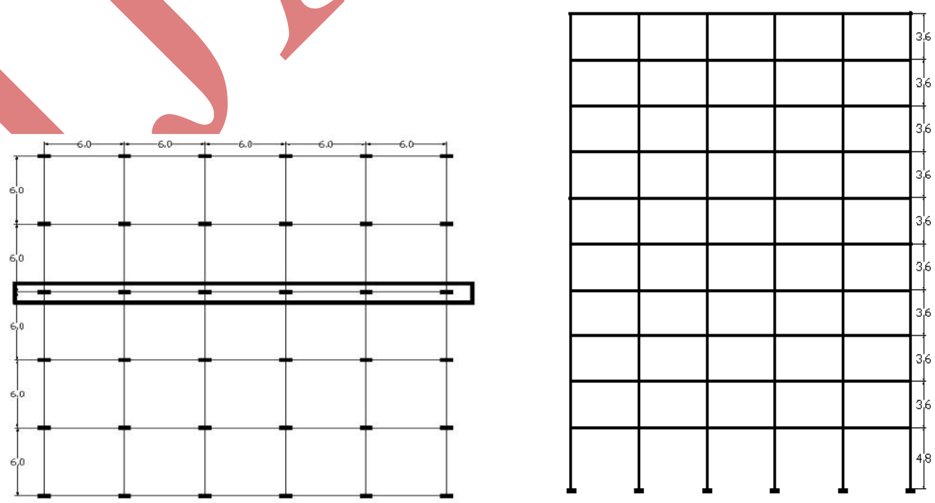

Fig 1. Plan of the building and elevation of ten storeyed bare frame building

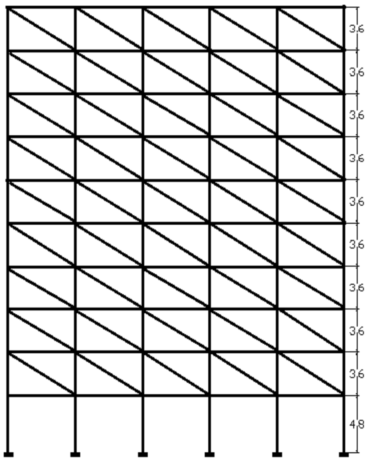

Fig 2. Elevation of ten storeyed infill frame building models with openings (10% to 35%)

III. METHODOLOGY OF THE STUDY

In this present study, equivalent static and response spectrum method as per the seismic code IS 1893 (Part 1): 2002 for the bare frame and concrete block infill walls with varying percentage of openings (10% to 35%) are carried out and an effort is made to study the effect of seismic loads. Their performance point and location of hinges are evaluated using nonlinear static pushover analysis.

3.1 User defined hinges

The definition of user-defined hinge properties requires moment–curvature analysis of each element. For the problem defined, building deformation is assumed to take place only due to moment under the action of laterally applied earthquake loads. Thus, user-defined M3 and V3 hinge was assigned for beam, PM3 hinge was assigned for column and axial load P was assigned for strut. The calculated moment-curvature values for beam (M3 and V3), column (PM3), and wall (P) are given as input in SAP2000.

3.2 Pushover analysis

Pushover analysis is a static non-linear procedure in which the magnitude of the lateral load is incrementally increased maintaining a predefined distribution pattern along the height of the building. With the increase in the magnitude of loads, weak links and failure modes of the building can be found. Pushover analysis can determine the behavior of a building, including the ultimate load and the maximum inelastic deflection. At each step, the base shear and the roof displacement can be plotted to generate the pushover curve for that structure. Pushover analysis as per FEMA 440 [5] guide lines is adopted. The models are pushed in a monotonically increasing order in a particular direction till the collapse of the structure. The models are pushed in a monotonically increasing order in a particular direction till the collapse of the structure. 4% of height of building [6] as maximum displacement is taken at roof level and the same is defined in to several steps The global response of structure at each displacement level is obtained in terms of the base shear, which is presented by pushover curve. Pushover curve is a base shear versus roof displacement curve. The peak of this curve represents the maximum base shear, i.e.

maximum load carrying capacity of the structure; the initial stiffness of the structure is obtained from the tangent at pushover curve at the load level of 10% [7] that of the ultimate load and the maximum roof displacement of the structure is taken that deflection beyond which the collapse of structure takes place.

IV. RESULTS AND DISCUSSION

4.1 Fundamental Natural Period

It is the first (longest) modal time period of vibration [1]. The codal IS: 1893(Part1)-2002 and analytical (SAP 2000) natural periods of the building models are presented in Table 1.

Table 1. Codal and analytical natural periods

Model No.	Analytical (sec)	Code (sec)
1	2.462	1.129
2	1.2917	0.611
3	1.2962	0.611
4	1.3049	0.611
5	1.3126	0.611
6	1.3208	0.611
7	1.3295	0.611

Stiffness of the building is directly proportional to its natural frequency and hence inversely proportional to the natural period. That is, if the stiffness of the building decreases, the natural periods are longer. From the above results we conclude that, the natural periods of model 2 is shorter when compared with the model 1 by 47.53%. As the percentage of openings increases (10% to 35%), the fundamental natural periods longer from model 2 to model 7 by 2.84%.

4.2 Base Shear

It is the total design of lateral force at the base of the structure [1]. The base shear for equivalent static method ($\bar{V}_B$) and response spectrum method (V_B) as per IS 1893 (Part 1): 2002 by applying the scale factor (SF), for the various building models are listed in the below Table 2.

Table 2. Base shear and scaling factor for building models

Model No.	$\bar{V}_B$ in kN	V_B in kN	Scale Factor
1	534.57	228.88	2.34
2	1063.08	476.28	2.23
3	1029.45	463.6	2.22
4	995.74	450.47	2.21
5	962.11	437.02	2.2
6	925.8	422.43	2.19
7	894.77	408.78	2.18

The base shear is function of mass, stiffness, height and natural period of the building structure. In the equivalent static method design horizontal acceleration value obtained by codal natural period is adopted and basic assumption in the equivalent static method is that only first mode of vibration of building governs the dynamics and the effect of higher mode is not important, therefore in this method higher modes are not considered. So that's why base shear obtained from equivalent static method are larger than the dynamic response spectrum method, where in the dynamic response spectrum all the modes are considered. From the above results it is observed that, the percentage of central openings increases the base shear decreases from model 2 to model 7 by 15.83% and 14.17% for equivalent static method and response spectrum method.

4.3 Lateral Displacement

The profiles of lateral displacements for the building models obtained by equivalent static (ESM) and response spectrum method (RSM) are shown in Fig 3.

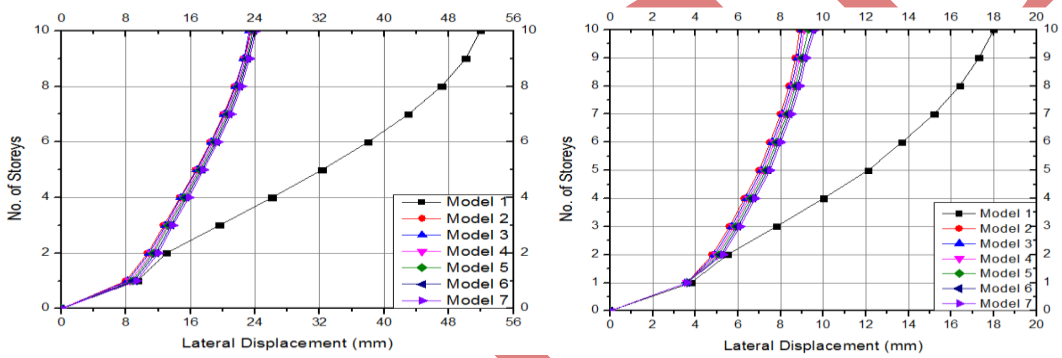

Fig 3. Lateral displacements for infill as a concrete block by ESM and RSM for building models

The lateral displacement of a building is a function of the stiffness, the lateral displacement of the building decreases with the increase in the lateral stiffness; from the above Fig 3 shows that, displacement of the model 2 to model 7 is less than model 1. From the above results it is observed that, there is decrement in the lateral displacement of model 2 when compared with the model 1 by 54.72 % and 50.55% for equivalent static method and response spectrum method. As the percentage of openings increases, the displacement increases from model 2 to model 7 by 2.49% and 7.3% for equivalent static method and response spectrum method.

4.4 Storey Drift

The storey drift is calculated for all the buildings along longitudinal direction for the equivalent static method and response spectrum method. The profiles of storey drift are shown in Fig 4.

As per the clause 7.11.1 of IS: 1893(Part 1)-2002 the storey drift should be within the 0.004times the story height [1] i.e. 19.2 mm for the bottom storey and 14.4mm for the upper storeys respectively. The storey drift for all models are within the limit for all the frames. From the above results it can be conclude that, there is decrement in the storey drift of model 2 compared to the model 1 by 64.70% and 60% for equivalent static method and response spectrum method. Finally from these results it can be conclude that the storey drift was found within the 0.004 times the storey height for all the models. The storey drift at the first storey is found more as compared to the upper storeys this is due to the soft storey.

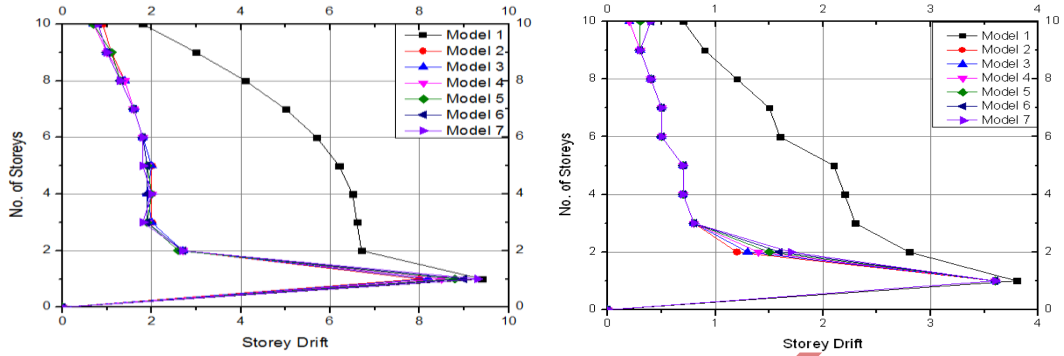

Fig 4. Storey drift for infill as a concrete block by ESM and RSM for building models

4.5 Performance Evaluation of Building Models

Performance based seismic evaluation of all the models is carried out by non linear static pushover analysis (i.e. Equivalent static pushover analysis and Response spectrum pushover analysis). User defined hinges are assigned for the seismic designed building models along the longitudinal direction.

4.5.1 Performance point and location of hinges

The base force, displacement and the location of the hinges at the performance point, for various performance levels along longitudinal direction for all building models are presented in the Table 3 and Table 4.

Table 3. Performance point and location of hinges for infill as a concrete block for building models by equivalent static pushover analysis

Model No.	Performance point			Location of hinges								
	Displacement mm		Base force kN	A-B	B-IO	IO – LS	LS-CP	CP-C	CD	DE	>E	Total
1	Yield	78.56	689.23	261	55	4	0	0	0	0	0	320
	Ultimate	287.32	861.54	230	30	18	17	6	9	10	0	320
2	Yield	41.66	1690.4	386	18	4	0	2	0	0	0	410
	Ultimate	116.84	2099.68	362	20	12	6	6	2	2	0	410
3	Yield	42.1	1676.25	384	18	5	1	0	2	0	0	410
	Ultimate	120.04	2090.74	360	18	12	7	10	1	2	0	410
4	Yield	42.54	1658.37	382	18	7	0	2	1	0	0	410
	Ultimate	123.24	2078.89	360	18	12	4	6	2	8	0	410
5	Yield	42.98	1642.97	386	18	6	0	0	0	0	0	410
	Ultimate	126.44	2063.26	364	18	7	2	8	3	8	0	410
6	Yield	43.42	1627.04	384	22	4	0	0	0	0	0	410
	Ultimate	129.64	2053.1	358	14	14	3	6	4	11	0	410
7	Yield	43.86	1610.31	386	15	6	2	0	1	0	0	410
	Ultimate	132.84	2042.79	362	16	9	0	8	5	10	0	410

Table 4. Performance point and location of hinges for infill as a concrete block for building models by response spectrum pushover analysis

Model No.	Performance point		Location of hinges									
	Displacement mm		Base force kN	A-B	B-IO	IO - LS	LS-CP	CP-C	CD	DE	>E	Total
1	Yield	80.24	692.35	280	21	4	0	2	8	5	0	320
	Ultimate	289.36	882.26	230	44	18	0	6	9	14	0	321
2	Yield	39.87	1727.45	380	16	5	4	4	0	1	0	410
	Ultimate	110.26	2123.68	360	22	15	4	0	3	6	0	410
3	Yield	40.42	1717.45	378	16	2	2	0	6	6	0	410
	Ultimate	114.46	2113.48	361	16	12	10	1	2	8	0	410
4	Yield	40.97	1703.45	382	15	7	4	0	2	0	0	410
	Ultimate	118.66	2103.28	358	16	12	8	5	6	5	0	410
5	Yield	41.53	1691.45	380	20	6	2	0	2	0	0	410
	Ultimate	122.86	2093.08	356	20	12	3	5	4	10	0	410
6	Yield	42.14	1677.45	384	12	6	5	0	2	1	0	410
	Ultimate	127.06	2082.88	358	18	8	6	4	8	8	0	410
7	Yield	42.72	1669.45	380	15	10	5	0	0	0	0	410
	Ultimate	131.26	2073.98	354	14	7	10	5	8	12	0	410

The base force of the building depends on its lateral strength, as the stiffness of wall is considered in the soft storey buildings; the base force is more than that of the bare frame building. As the percentage of central openings increases, the stiffness of the building decreases.

From the above results, there is decrement in the base force at the ultimate state from model 2 to model 7 is 2.22% and 2.37% by equivalent static and response spectrum method. In most of the buildings, flexural plastic hinges are formed in the first storey because of open ground storey. The plastic hinges are formed in the beams and columns. From the above Table 3 and table 4 we can observed that, the hinges are formed within the life safety range at the ultimate state is 92.18%, 97.56%, 96.83%, 96.09%, 95.36%, 94.88%, and 94.39% for equivalent static pushover analysis method. Similarly 91.25%, 97.80%, 97.32%, 96.09%, 95.36%, 95.12%, and 94.14% for response spectrum pushover analysis method. We can also observed that, the hinges are formed beyond the CP range at the ultimate state is 7.81%, 2.43% 3.17%, 3.90%, 4.63%, 5.12%, and 5.60% for equivalent static pushover analysis method. Similarly 9.03%, 2.19%, 2.68%, 3.90%, 4.63%, 4.88%, and 6.09% for response spectrum pushover analysis method. From the above results it can be concluded that, as the percentage of central openings increases, stiffness decreases. The base force decreases with increase in the percentage of central openings. Flexure hinges are found within the life safety range at the ultimate state for both equivalent and response spectrum pushover method. Few collapse hinges are formed in bottom storey columns of soft storey models and the may be same are retrofitted to enhance the performance of buildings.

4.6 Ductility Ratio

Ductility ratio means it is the ratio of collapsed yield (CY) to the initial yield (IY) [8]. Ductility ratio (DR) for building models are tabulated in the below Table 5.

Table 5. Ductility ratio for building models by equivalent static and response spectrum pushover analysis

Model No.	Equivalents Static Method			Response Spectrum Method		
	IY	CY	DR	IY	CY	DR
1	78.56	287.32	3.66	80.24	289.36	3.61
2	41.66	116.84	2.8	39.87	110.26	2.77
3	42.1	120.04	2.85	40.42	114.46	2.83
4	42.54	123.24	2.9	40.97	118.66	2.9
5	42.98	126.44	2.94	41.53	122.86	2.96
6	43.42	129.64	2.99	42.14	127.06	3.02
7	43.86	132.84	3.03	42.72	131.26	3.07

From above result it is clear that the ductility ratio of the bare frame is larger than that of the soft storey models, hence ductility ratio increases in the column stiffness and decreases with increase in the wall stiffness. For equivalent static method, model 1 and model 7 have crossed the targeted value. For response spectrum method model 1, model 6, and model 7 have crossed the targeted value.

4.7 Safety Ratio

The ratio of base force at performance point to the base shear by equivalent static method is known as safety ratio. If the safety ratio is equal to one then the structure is called safe, if it is less than one than the structure is unsafe and if ratio is more than one then the structure is safer [9].

Table 6. Safety ratio for building models by equivalent static and response spectrum pushover analysis

Model No.	Equivalent Static Method			Response Spectrum Method		
	Base force at performance point	Base Shear at ESM	SR	Base force at performance point	Base Shear at ESM	SR
1	861.54	534.57	1.61	882.26	534.6	1.65
2	2099.68	1063.08	1.98	2123.68	1063	2.00
3	2090.74	1029.45	2.03	2113.48	1029	2.05
4	2078.89	995.74	2.09	2103.28	995.7	2.11
5	2063.26	962.11	2.14	2093.08	962.1	2.18
6	2053.10	925.80	2.22	2082.88	925.8	2.25
7	2042.79	894.77	2.28	2073.98	894.8	2.32

For equivalent static method, model 2 to model 7 is found to be 1.23 to 1.42 times safer and for response spectrum method, 1.21 to 1.40 times safer compared to the model 1. From the above results it can be conclude that soft storey building models are safer compared to the bare frame building model.

4.8 Global Stiffness

The ratio of performance force shear to the performance displacement is called as global stiffness [9]. Global stiffness (GS) for ten storeyed building models are tabulated in the below Table 7.

Table 7. Global stiffness for ten storeyed building models by equivalent static and response and spectrum pushover analysis

Model No.	Equivalent Static Method			Response Spectrum Method		
	Base force at Performance point (PB)	Displacement at Performance point (PD)	Global stiffness (GS)	Base force at Performance point (PB)	Displacement at Performance point (PD)	Global stiffness (GS)
1	861.54	287.32	3	882.26	289.36	3.05
2	2099.68	116.84	17.97	2123.68	110.26	19.36
3	2090.74	120.04	17.42	2113.48	114.46	18.46
4	2078.89	123.24	16.87	2103.28	118.66	17.73
5	2063.26	126.44	16.32	2093.08	122.86	17.34
6	2053.1	129.64	15.84	2082.88	127.06	16.39
7	2042.79	132.84	15.38	2073.98	131.26	15.8

From the above results it is very clear that, as percentage of openings increases, the stiffness decreases. There is decrement in the global stiffness from model 2 to model 7 by 14.41% and 18.39% for equivalent static method and response spectrum method. The global stiffness of model 2 increases compared to the model 1 by 83.30% and 84.24% for equivalent static method and response spectrum method. From the above results it can be conclude that, the global stiffness is found more in the soft storey building models compared to the bare frame building model.

V. CONCLUSION

Based on the results obtained from different analysis for the various building models, the following conclusion is drawn.

1. As the percentage of openings increases from 10% to 35%, the fundamental natural period increases.
2. The codal and analytical time period do not tally each other because codal calculation is depends on empirical formula.
3. As the stiffness of the building decreases with the increase in the percentage of central opening varies from 10% to 35% from model 2 to model 7, the base shear decreases.
4. As the percentage of central opening increases, the lateral displacement increases.
5. For the equivalent and response spectrum method, the storey drift is found to be within the limit for all building models.
6. The base force at performance point decreases with increases in the percentage of central openings from 10% to 35%.
7. Flexural hinges are found within the life safety range at the ultimate state for both equivalent static method and response spectrum method.
8. Soft storey building models are safer compared to the bare frame building.
9. Global stiffness is more in the soft storey building models compared to the bare frame building. As the percentage of openings increases, the global stiffness decreases.

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