SEISMIC EVALUATION OF MULTISTOREY RC BUILDINGS WITH OPENINGS IN MASONRY INFILL WALLS

Geeta P Shetteppanavar[1], Dr. S. S.Dyavanal[2]

[1]PG student @Civil Engg. Dept. KLE Technological University , Hubballi , India
[2] Professor @Civil Engg. Dept. KLE Technological University , Hubballi , India

---

Abstract – *The openings present in infill walls like windows doors, and ventilators are unavoidable. Openings reduce stiffness and lateral strength of Reinforced Concrete framed structures. In the present study, three storey and six storey two dimensional building with no infill walls in ground storey with user defined hinges models are considered . Properties of user defined hinges are obtained using moment curvature equations. Bare frame and infill frame buildings are modeled considering special moment resisting frame (SMRF) for medium soil profile and zone III. Brick infill walls are modeled as pin jointed single equivalent diagonal strut. Pushover analysis is carried out for user defined hinge properties as per FEMA 440 guidelines using SAP2000 software. Change in natural period , base shear, and lateral displacements are studied .*

***Key Words*: Equivalent static method , pushover analysis , global stiffness , ductility ratio , safety ratio, hinge location .**

1.INTRODUCTION

The increase in urban population and scarcity of space have considerable influence on the development of vertical growth consisting of low rise, medium rise and high rise buildings. Earthquake causes the random motions in all directions, radiating from the epicenter[1]. In India, most of the existing RC buildings in this earthquake region do not meet the present seismic requirements because these are mainly designed for gravity loads only. A large number of buildings in India are constructed with masonry infills for functional and architectural reasons[9]. Masonry infills are normally considered as non-structural elements and their stiffness contributions are generally ignored. However , infill wall tends to interact with the frame when the structure is subjected to lateral loads, and also show energy-dissipation characteristics under seismic loading. Masonry walls contribute to the stiffness of the infill under the action of lateral load. For the structure to perform better during the earthquakes, it should be analyzed and designed as per the IS 1893 (Part 1) : 2002.

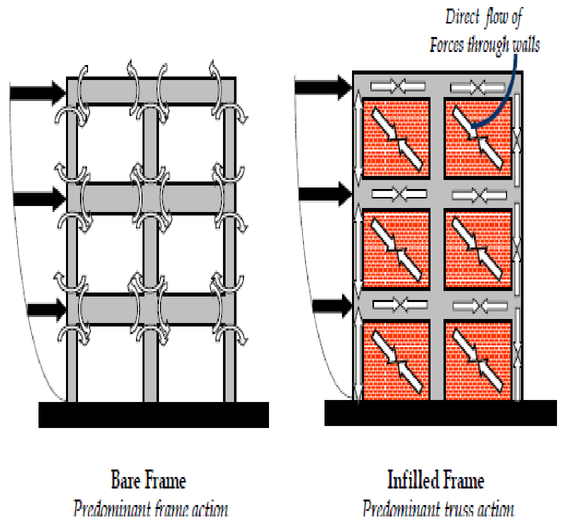

Fig.1: Change in lateral load transfer mechanism owing to inclusion of masonry infill walls [9]

2.1 Description of structure

In the present study 2D frames with G+2 and G+5 storeys are considered. These consist of typical beam–column RC frame buildings with no shear walls, located in seismic zone 3 and intended for office use. The bottom storey height is 4.8 m and typical storey height is taken as 3.6m for all buildings. The buildings are kept symmetric to avoid torsional response under pure lateral forces.

In the seismic weight calculations, only 25% of the live load is considered. The buildings are modeled to represent all existing components that influence the mass, strength, stiffness and deformability of the structure. Slab loads are applied on the beam. Brick infill walls are modeled by considering pin jointed single equivalent diagonal strut. The material properties and thickness of struts are same as that of masonry wall; the effective width of strut is calculated by formula as proposed by Stafford Smith and Hendry, M (moment hinge), PM (axial force and moment hinge), V (Shear hinge) and P (axial force hinge) hinge properties as per FEMA 440 guidelines are assigned at both ends of beam, column and strut elements respectively.

The following models are considered for the study as follows,

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

Model 2 - Building has no walls in the first storey and one full unreinforced masonry infill wall in the upper storeys, with central opening of 15% of the total area of infill. Stiffness and masses of the walls are considered.

Model 3 - Building has no walls in the first storey and one full unreinforced masonry infill wall in the upper storeys, with central opening of 25% of the total area of infill. Stiffness and masses of the walls are considered.

The material properties considered in the present work are as shown in Table 1.

The plan of the building is shown in the Fig. 2 and elevation of the building models are shown in Fig. 3 to Fig. 6.

Table 1: Material properties of the building model

Material Properties	Values
Characteristic strength of concrete, F_{ck}	25 Mpa
Yield stress for steel, F_y	415 Mpa
Modulus of Elasticity of steel, E_s	20,0000 Mpa
Modulus of Elasticity of concrete, E_c	25000 Mpa
Modulus of Elasticity of brick wall	3285.9 Mpa

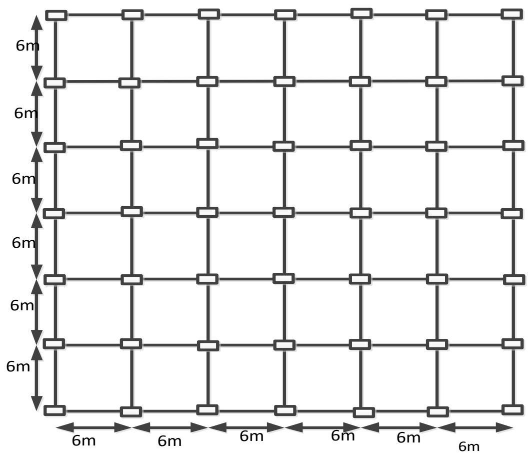

Fig.2 : Plan of building model

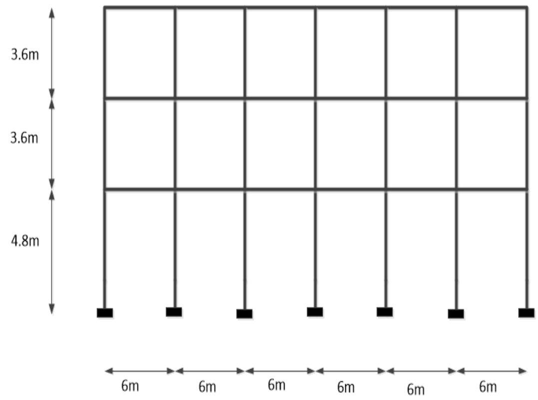

Fig.3 : Elevation of the three storey bare frame building model

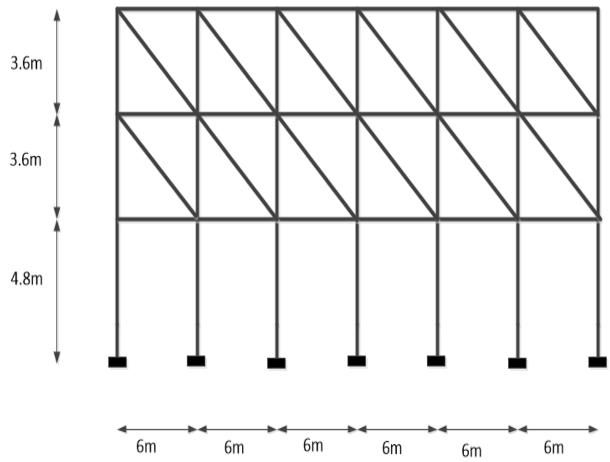

Fig.4 : Elevation of the three storey building models with SEDS with openings (15% and 25%)

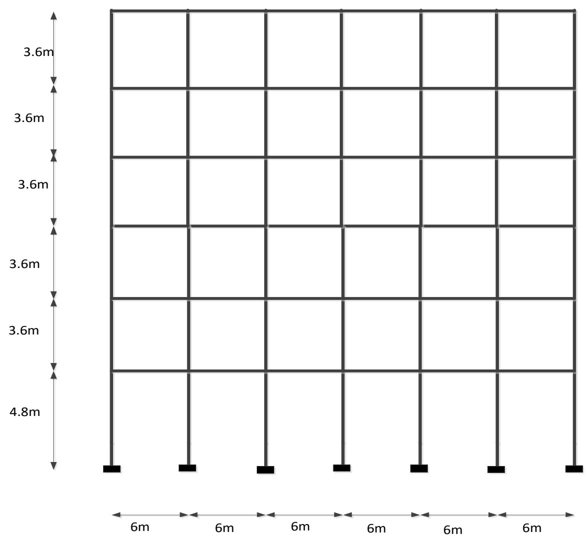

Fig. 5: Elevation of the six storey bare frame building model

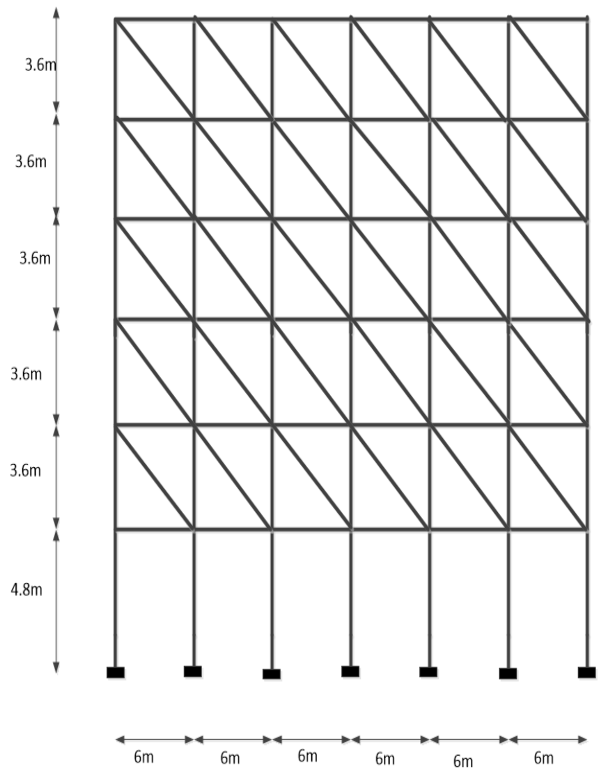

Fig. 6: Elevation of the six storey building models with SEDS with openings (15% and 25%)

2.2 User Defined Hinges

The definition of user-defined hinge properties requires analysis of moment – curvature equation of each element. For the problem defined, deformation of building is assumed to take place only due to moment under the action of laterally applied earthquake loads. Thus user-defined M3 hinge and V3 hinges for beams, PM3 hinges for columns and P hinges for struts are assigned. The calculated moment-curvature values for beam (M3 and V3), column (PM3), and load deformation curve values for strut (P) are substituted instead of default hinge values in SAP2000.

3. RESULTS AND DISCUSSIONS

The results are presented for each of the building models considered, for the linear and nonlinear analyses carried out by using SAP2000 . An effort is made to study the effect of openings in the infill walls on the lateral resistance of the building and nonlinear behavior of the building by seismic analysis. The results of natural periods, base shear, lateral displacements, and storey drift for different building models are presented and compared by equivalent and response spectrum analyses. Building models are evaluated by nonlinear static pushover analysis, in which the ductility ratio, safety ratio and global stiffness of the buildings are studied.

3.1 Natural Periods

It is the first (longest) modal time period of vibration [6]. The analytical (SAP2000) and codal IS 1893 (Part1) : 2002 [6] natural periods of the various building models are tabulated in the Table 2.

Table 2 Analytical and codal natural periods for brick masonry infill.

	Analytical (sec)		Code (sec)	
Model No.	3 Storey	6 Storey	3 Storey	6 Storey
1	1.42	1.765	0.483	0.782
2	0.98	1.076	0.197	0.374
3	1.01	1.103	0.197	0.374

From the above table, it is very clear that, 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.

For variation of the natural period from model 1 to model 3 as shown in the table, illustrates that the presence of openings in the brick masonry reduces the stiffness of the buildings, thereby increasing the natural period and the amount of reduction in the stiffness depends on the percentage of openings.

From the above results we conclude that, as the percentage of central openings increases from 15% to 25%, the fundamental natural periods are longer because there is a reduction in stiffness of the building. In the presence of infill stiffness the natural periods are shorter as compared to bare frame natural period. The natural period directly affects the spectral acceleration S_a/g, it can be observed in Fig.2 of IS 1893 (Part1) : 2002 , where the spectral acceleration coefficient increases as the time periods are shorter. The codal time period and analytical time period do not tally each other because codal calculation is depends on empirical formula.

3.2 Base Shear

It is the total design lateral force at the base of the structure. The base shear for ESM and RSM methods as per IS 1893 (Part 1): 2002 and the scale factor (SF) for the building models are listed in the Table 3 and 4.

Table 3: Base shear for three storey building models

Model No.	Infill wall as brick		
	$\bar{V}_B$ in Kn	V_B in Kn	SF

1	260.596	121.005	2.153
2	312.294	215.705	1.447
3	297.817	209.731	1.42

Table 4: Base shear for six storey building models

Model No.	Infill wall as brick		
	$\bar{V}_B$ in kN	V_B in kN	SF
1	334.543	163.089	2.05
2	650.89	375.081	1.73
3	618.547	361.548	1.71

The base shear is function of mass, stiffness, height and natural period of the building structure.. As storey increases for tall buildings the flexibility increases and higher modes come in to picture. For three storey building models, the base shear is found more in soft storey building (model 2) compare to bare frame building (mode l) by 19.8% for brick masonry infill by ESM. Similarly 43.72% for brick masonry infill by RSM. For six storey building models, the base shear is found more in soft storey building (model 2) compare to bare frame building (mode l) by 48.58% for brick masonry infill by ESM. Similarly 56.52% for brick masonry infill by RSM.

Hence it can be concluded that, the design of base shear increases with increases in mass and stiffness of masonry infill wall. As the percentage of openings increases from 15% to 25% for brick masonry infill , the scaling factor decreases. As the number of storey increases with increase in size of openings scaling factor increases.

3.3 Lateral Displacement

Lateral displacement profiles for the three and six storey building models obtained by equivalent static (ESM) and response spectrum method (RSM) are shown in chart 1 to chart 4 and results are given in Table 5 to Table 8.

Table 5: Lateral displacements for brick infill by ESM for three storey building models in mm

Storey No.	Model No.		
	1	2	3
3	29.5	11.6	12.0
2	21.4	11.1	11.8
1	11.8	10.1	10.1

Table 6: Lateral displacements for brick infill by RSM for three storey building models in mm

Storey	Model No.		
No.	1	2	3
3	8.7	5.9	6.0
2	6.8	5.8	5.9
1	4.9	4.7	4.7

Table 7: Lateral displacements for brick infill by ESM for six storey building models in mm

Storey	Model No.		
No.	1	2	3
6	50.4	12.6	13.2
5	44.8	11.9	12.4
4	37.1	11.1	11.3
3	27.6	9.8	10.1
2	15.9	8.7	9.1
1	7.6	7.1	7.2

Table 8: Lateral displacements for brick infill by RSM for six storey building models in mm

Storey	Model No.		
No.	1	2	3
6	13.2	6.3	6.4
5	12.5	5.9	6.0
4	10.9	5.5	5.6
3	9.8	5.0	5.1
2	7.9	4.5	4.7
1	4.1	3.4	3.5

The lateral displacement of a building is a function of the stiffness, the lateral displacement of the building increases with the decreases in the lateral stiffness; lateral displacement along y axis and number of storey along x axis are plotted. From the Fig to Fig shows that, displacement of the model 2 and model 3 are less than model 1.

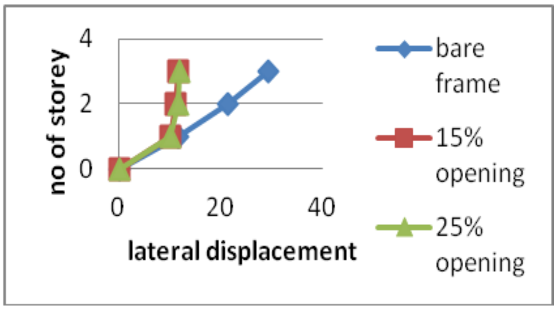

Chart-1 Lateral displacements for masonry infill by ESM for three storey building models

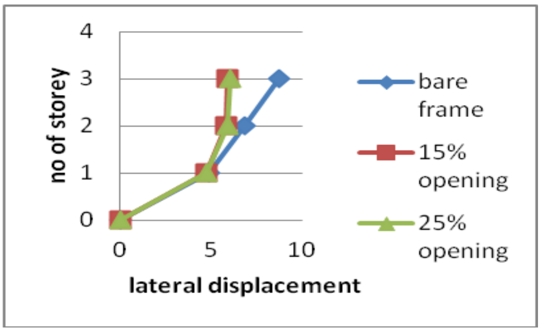

Chart-2 Lateral displacements for masonry infill by RSM for three storey building models

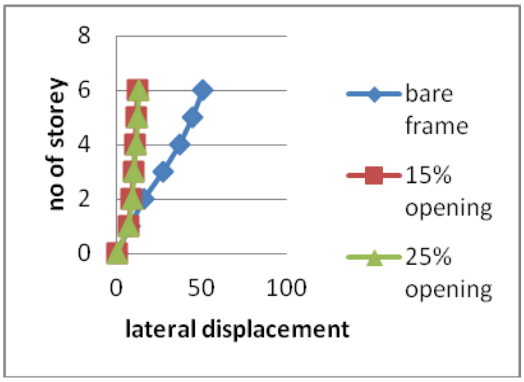

Chart-3 Lateral displacements for masonry infill by ESM for six storey building models

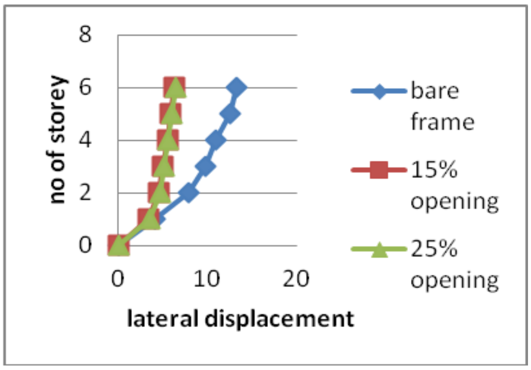

Chart-4 Lateral displacements for masonry infill by RSM for six storey building model

For three storey building models, there is decrement in the lateral displacement of soft story building (model 2) when compared with the bare frame building (model 1) by 60.67% for brick masonry infill by ESM. Similarly 32.18% for brick masonry infill by RSM. For six storey building models, there is decrement in the lateral displacement of soft story building (model 2) when compared with the bare frame building (model 1) by 75.00% for brick masonry infill by ESM. Similarly 52.27% for brick masonry infill by RSM.

From the above results it can be concluded that, as the percentage of central openings increases from 15% to 25% the lateral displacement increases and it leads to be higher flexibility in the buildings.

Performance Evaluation of Building Models

Performance based seismic evaluation of all the models is carried out by Equivalent static pushover analysis . User defined hinges are assigned for the seismic designed building models along the longitudinal direction.

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 8 and Table 9.

Table 8 : Performance point and location of hinges for brick masonry infill for three storey building models by equivalent static pushover analysis with user defined hinges

Model No.	Performance Point			Location of Hinges					
	Displacement mm		Base Force kN	A-B	B-IO	IO - LS	LS-CP	CP to E	Total
1	Yield	62.1	430.24	92	4	4	0	8	108
	Ultimate	260.44	670.54	77	6	16	1	8	108
2	Yield	24.64	786.49	115	12	4	3	4	138
	Ultimate	89.35	916.74	110	14	2	4	8	138
3	Yield	25.44	782.24	116	11	7	1	3	138
	Ultimate	97.55	904.48	112	9	12	4	1	138

Table 9 : Performance point and location of hinges for brick masonry infill for six storey building models by equivalent static pushover analysis with user defined hinges.

Model No.	Performance Point			Location of Hinges					
	Displacement mm		Base Force kN	A-B	B-IO	IO - LS	LS-CP	CP to E	Total
1	Yield	68.56	530.25	180	16	8	0	0	204
	Ultimate	288.32	720.2	120	46	17	0	21	204
2	Yield	26.03	1263.6	244	6	8	3	3	264
	Ultimate	92.64	1643.2	228	10	15	2	9	264
3	Yield	26.83	1257.8	248	12	4	0	0	264
	Ultimate	100.84	1633.1	231	10	6	4	13	264

From the above results it can be concluded that, as the stiffness of infill wall is considered in the soft storey buildings, base force is more than that of the bare frame building. The stiffness of the building decreases with the increase in percentage of central openings from 15% to 25%. The performance of all the building models is within the life safety range at the ultimate state for equivalent static method. These results reveal that, seismically designed multi-storey RC buildings are safe to earthquakes.

Ductility Ratio (DR) : Ductility ratio means it is the ratio of collapsed yield (CY) to the initial yield (IY) .

Safety Ratio (SR): The ratio of base force at the performance point to base shear by ESM is defined as safety ratio (SR).

Global Stiffness (GS): The ratio of base force and displacement at the performance point is known as global stiffness of the structure.

Table 10:

	DR		SR		GS	
Model	3 storey	6 storey	3 storey	6 storey	3 storey	6 storey
1	4.62	4.15	2.51	2.06	2.58	2.57
2	3.78	3.57	2.89	2.49	10.21	17.63
3	3.82	3.59	3	2.59	9.56	16.68

The ductility ratios of the bare frame is larger than the soft storey building models specifying stiffness of infill walls not considered during analysis. The ductility ratio is more in bare frame compare to the soft storey building models. And also from the above results reveal that, increase in openings increases the DR nearer or slightly more than the target value.

From the above results it can be concluded that, the safety ratio values are more than 1, the building models are safer. The soft storey buildings are safer than the bare frame building models.

From the above results it can be concluded that, as the percentage of central openings increases from 15% to 25% the global stiffness decreases. And also from the above results reveal that, RC multi-storeyed buildings designed considering earthquake load combinations prescribed in earthquake codes are stiffer to sustain earthquakes.

3. Conclusions

Based on the results obtained from different analysis for the various building models, the following conclusions are,

1. As the percentage of openings increases from 15% to 25%, the fundamental natural periods are longer.

   The codal and analytical time period do not tally each other because codal calculation is depends on empirical formula. And also lateral displacement increases.

2. As the stiffness of the building decreases with the increase in the percentage of central opening varies from 15% to 25% from model 2 to model 3, the base shear decreases.

3. For the ESM and RSM , the storey drift is found to be within the limit for all building models.

4. Flexural hinges are found within the life safety range at the ultimate state for equivalent static method .

5. Ductility ratio are found more in the bare frame compare to the soft storey building models for both equivalent. Soft storey building models are safer and stiffer compared to the bare frame building models.

Design Data for the Buildings

Design Data for the models are as shown in table 11.

Table 11: Input data for the building models

Structure	SMRF
No. of storey	G+2 and G+5
Type of building use	Official
Seismic zone	III
Material Properties:	
Young's modulus of M_{25} concrete, E_C	25 x 10^6 kN/m^2
Grade of concrete	M25

Grade of steel	Fe 415
Density of reinforced concrete	25 kN/m^3
Member Properties:	
Thickness of slab	0.120 m
Beam size	0.3x0.45 m
Column size(3 and 6 storeyed)	0.3x0.5 m
Thickness of wall	0.30 m
DL Roof finishes	1.5 kN/m^2
DL Floor finishes	1.0 kN/m^2
LL Roof	1.0 kN/m^2
LL Floor	3.0 kN/m^2

REFERENCES

1. Agarwal, P. and Shrikhande, M. (2006), "Earthquake Design of Structures" Prentice Hall of India Private Limited New Delhi India.

2. Applied Technology Council (1996), "Seismic Evaluation and Retrofit of Concrete Buildings", Vol.1& 2, California.

3. Das, D. and Murty, C.V.R. (2004), "Brick Masonry Infills in Seismic Design of RC Framed Buildings (Part 2)", The Indian Concrete Journal ,pp 31-37

4. Federal Emergency Management Agency, FEMA-440 (2005), "Improvement of Nonlinear Seismic Analysis Procedures". California.

5. IS 456:2000, "Code of Practice for Plain and Reinforced Concrete", Bureau of Indian Standards, New Delhi, India.

6. IS 1893 (Part 1): 2002, "Criteria for Earthquake Resistant Design of Structures", Bureau of Indian Standards, New Delhi 110002.

7. Jain, S.K. and Murty, C.V.R.(2002), "Proposed Draft Provision and Commentary on Indian Seismic Code IS 1893 (Part 1)", Department of Civil Engineering, Indian Institute of Technology Kanpur.

8. Mondal, G., and Jain, S.K.(2008), "Lateral Stiffness of Masonry Infilled Reinforced Concrete (RC) Frames with Central Opening", Earthquake Spectra, Vol 24, No 3, pp 701-723, Indian Institute of Technology, India, 2008.

9. Murthy, C.V.R. (2005), "How Earthquake do Affects Reinforced Concrete Buildings", Earthquake Tip 17, IITK-BMTPC, Indian Concrete Journal, January-2005.

10. P Rathod and Dr.S.S Dyavanal(2014), "Pushover Analysis of Seven Storeyed RC buildings with Openings in Infill walls", IJETT, Vol.14, Number 3, pp 71-76.

11. Shekhappa H and Dr.S.S.Dyavanal(2015), "Nonlinear static analysis of g+6 rc building with infill walls and user defined hinges",IRJET,Vol.2,pp 2060-2065.