

Effect of Masonry Infills on Seismic Performance of RC Frame Buildings

Dev Raj Paudel¹, Santosh Kumar Adhikari²

P.G. Student, Department of Civil Engineering, Andhra University, Visakhapatnam, Andhra Pradesh, India¹

P.G. Student, Department of Civil Engineering, Andhra University, Visakhapatnam, Andhra Pradesh, India²

ABSTRACT: Reinforced concrete frames with masonry infill walls are widely used systems as an internal partition and external walls in many part of the world. The infill walls are used for mainly partition and insulation purposes rather than structural purposes and usually not considered as structural elements in structural design. However, during earthquakes, these infills contribute to the response of the structure and the behaviour of infilled frame buildings is different from that predicted for bare frame structures. For this purpose, models of (G+5) and (G+9) RC framed building assumed to be located in Seismic zone-V have been considered. Masonry walls stiffness is included in the models by converting them into equivalent diagonal strut according to FEMA-356. Linear Dynamic analysis (Response Spectrum Analysis) has been performed as per IS: 1893:2002. Non –Linear static Pushover analysis has been used to study the effect of infills on dynamic characteristics, yield patterns and seismic performance. The results are compared with parameters like natural period, storey shear, storey drift, displacement and hinge status at performance points among the models considered.

KEYWORDS: Seismic performance, Reinforced concrete, Masonry infills, Diagonal strut, Pushover analysis

I. INTRODUCTION

In many countries, construction of RC framed buildings with masonry infill is a common practice. And it is the one of the oldest construction material still in use because of its functionality and availability. In general practice of building analysis, the strength and stiffness of masonry walls are not taken into account. However, during earthquakes, these infill walls contribute to the response of the structure and the behaviour of infilled framed buildings is different from that predicted for bare frame structures i.e. lateral load transfer mechanism changes from frame action into truss action as masonry infills act as diagonal strut. It results in considerable increase in stiffness and strength, reducing displacements. However, these effects may or may not be advantageous depending on the case. Infill walls are stiff but brittle elements. If the surrounding frame is not strong enough, infill walls can cause unforeseen damages such as premature failures in columns such as shear, compression or tension failures. Another negative effect may be the development of soft-storey mechanism in the structure. The change in storey stiffness along the height of building is if lesser than 80 percent of the average lateral stiffness of the three storeys above, then it is said to be having soft storey. This mechanism is more likely to occur in the structures without infill walls at bottom storey which is usually done in order to provide parking facilities at ground storey.

Another issue in the building is openings for windows and door. Due to openings the stiffness of the structure reduces depending upon the size of the opening. When the size of the opening is small then only strut action is possible. If the opening size increases the stiffness of the structure decreases. The failure of infill with openings under the action of lateral load is mainly due to the concentration of stresses near the openings.

The different techniques used for the numerical simulations of infilled frames can be divided into two type's namely micro models and macro models. For present study macro modelling of masonry infill using equivalent diagonal strut has been done as per FEMA-356, which was also suggested by Mainstone in 1971 (strut width). These diagonal struts carry only compression. The major objective of present study is to model the infill as an equivalent diagonal strut, and to find the effect of infills on the frame when infills are considered as structural components.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

II. MODELLING OF INFILL PANEL

The masonry infill walls are replaced with diagonal compression member (or) strut with appropriate mechanical properties. The thickness of the strut is equal to the thickness of the wall. The strut is assigned with hinges at both ends in order to take care of moment at strut frame intersection. As per FEMA-356 the equivalent width of diagonal strut is given by expressions:

$$a = 0.175 \times r_{inf} \times (\lambda_1 \times h_{col})^{-0.4}$$

where,

$$\lambda_1 = ((E_i \times t \times \sin 2\theta) / (4 \times E_f \times I_c \times h_{inf}))^{1/4}$$

$$\theta = \tan^{-1}(h_{inf} / l)$$

- h_{col} - Column height between center lines of beam (m)
- E_i - Modulus of elasticity of infill material (kN/m²)
- E_f - Modulus of elasticity of frame material (kN/m²)
- T - Thickness of wall (m)
- h_{inf} - Height of the infill (m)
- l - Length of the infill (m)
- I_c - Moment of inertia of column (m⁴)
- θ - Slope of infill diagonal to the horizontal
- r_{inf} - Diagonal length of infill panel

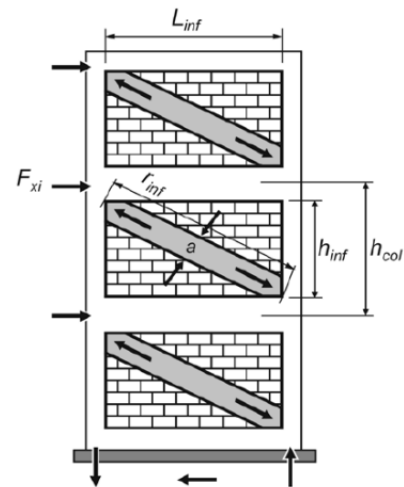


Fig1: Compression strut analogy-Concentric struts [4]

III. BUILDING MODELLING AND ANALYSIS

For the study, six and ten storeys building both having plan area 20 m*16 m (20 m along x-direction and 16 m along y-direction) were considered to be located in Zone V. The total height of building was 18.2 m for 6 storey and 30.2 m for 10 storey building with ground floor height of 3.2 m and inter storey height of 3m in both buildings. M25 grade concrete and Fe415 steel is used. The modulus of elasticity of concrete is taken as $5000\sqrt{f_{ck}}$, As per IS: 456:2000 and E_i as $550f_m$, where f_m is characteristics strength of brick infill considered as 5.0 N/mm². The live load on floors is taken as 3kN/m². The thickness of external and internal infill wall were taken as 230mm and 115mm respectively. For both 6 storey and ten storey building 4 models for each case is considered.

Case I: Six storey building

Model 1: Six storey bare frame model, however mass of infill walls were included in the model.

Model 2: Six storey full infill masonry model, Building has full brick infill masonry wall in all storey.

Model 3: Six storey with soft ground storey, Building has full brick infill masonry wall in all storey except first storey (ground floor).

Model 4: Six storey with 35% opening in infill masonry model, Building has infill masonry with 35% opening in wall in all storey.

Case II: Ten storey building

Model 5: Ten storey bare frame model, however mass of infill walls were included in the model.

Model 6: Ten storey full infill masonry model, Building has full brick infill masonry wall in all storey.

Model 7: Ten storey with soft ground storey, Building has full brick infill masonry wall in all storey except first storey (ground floor).

Model 8: Ten storey with 35% opening in infill masonry model, Building has infill masonry with 35% opening in wall in all storey.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

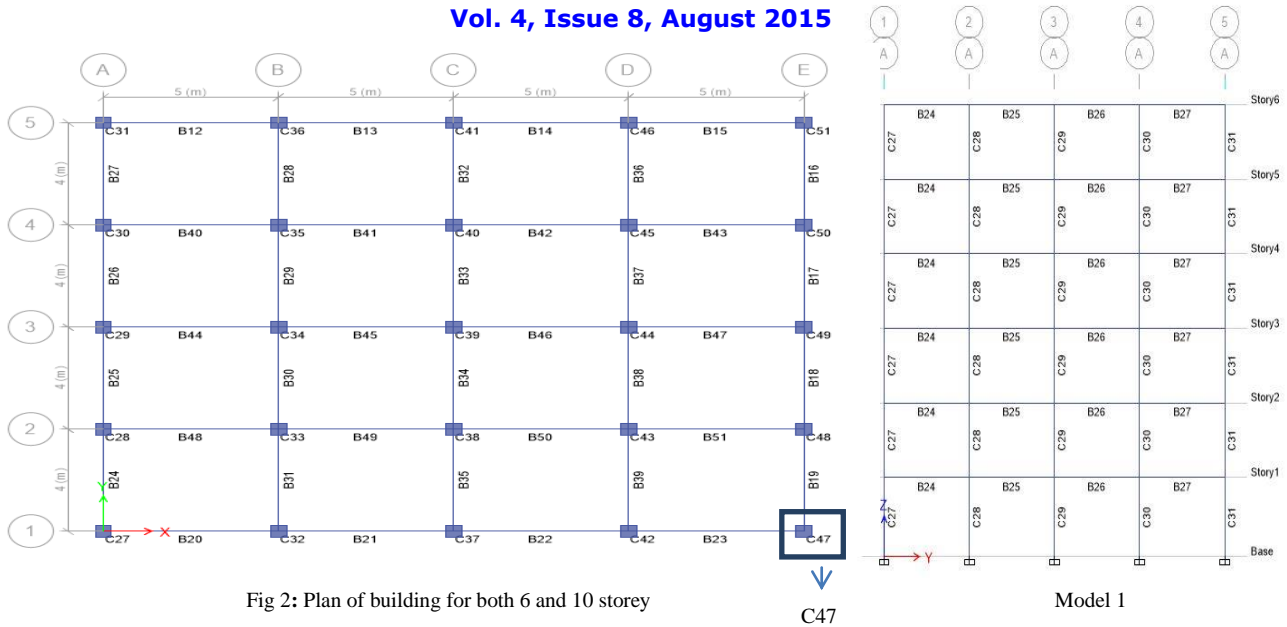


Fig 2: Plan of building for both 6 and 10 storey

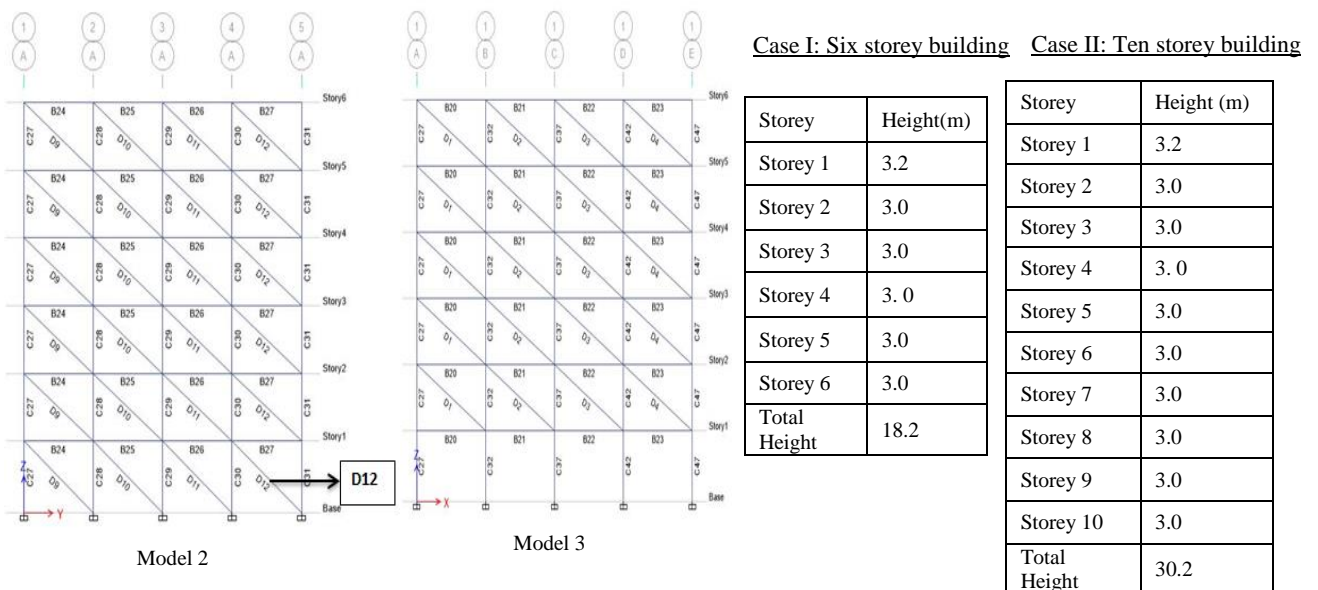


Fig 3: Elevation of building showing three different cases

Response spectrum analysis has been performed as per IS: 1893-2002 for each building. Parameters like storey drift, storey shear, time period of buildings, forces in column were studied. Nonlinear Static Analysis (pushover analysis) has been performed in SAP2000.

IV. RESULTS AND DISCUSSIONS

4.1 Fundamental time period of buildings: The fundamental time period of fully infill frame in both longitudinal and transverse direction are less than those in bare frame as well as infill frame with 35% opening and infill frame with soft ground storey. Time period obtained from IS code are (0.366, 0.409) i.e. T_x and T_y respectively for six storey building and (0.607, 0.679) for ten storey building which seems to be much lesser than those obtained from analytical models.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

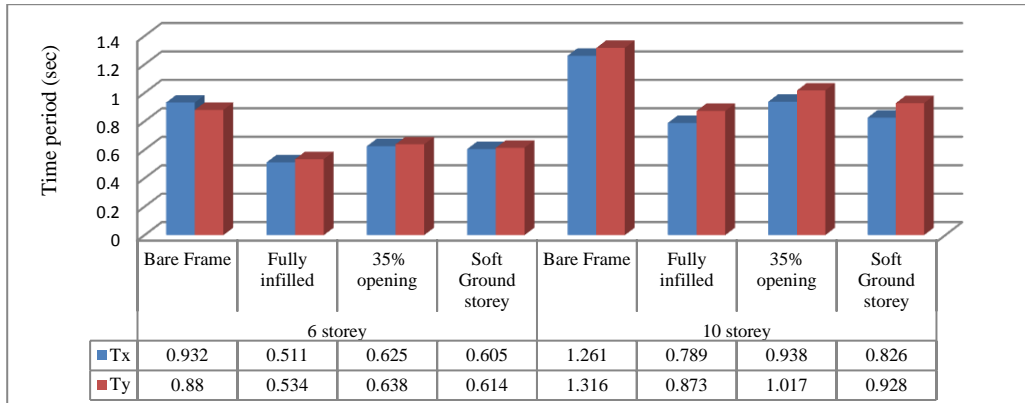


Fig 4: Fundamental time period in sec

4.2 Lateral Displacement & Storey Drift:

The table given below shows the lateral displacement of various storey of both buildings in both longitudinal and transverse direction. Inclusion of infills in model increases the stiffness of building and reduces displacement.

Table 1: Lateral displacement of six storey building

Storey	Displacement (mm)							
	Bare Frame		Fully Infill Frame		35% Opening in Infill		Soft Ground Storey	
	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy
6	29.60	26.30	9.00	9.80	13.40	13.90	11.10	11.70
5	27.90	24.80	8.50	9.30	12.70	13.20	10.70	11.20
4	24.40	21.70	7.60	8.20	11.20	11.60	9.80	10.20
3	19.20	17.20	6.10	6.60	9.00	9.30	8.50	8.70
2	12.70	11.40	4.20	4.50	6.10	6.30	6.70	6.70
1	5.50	5.00	2.00	2.20	2.80	3.00	4.30	4.20

TABLE 2: LATERAL DISPLACEMENT OF TENS STOREY BUILDING

Storey	Displacement (mm)							
	Bare Frame		Fully Infill Frame		35% opening in infill		Soft Ground Storey	
	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy
10	49.90	47.60	20.50	22.10	28.30	29.40	21.40	23.60
9	48.40	46.30	19.80	21.40	27.50	28.60	20.80	22.90
8	45.90	44.00	18.80	20.30	26.10	27.10	19.80	21.80
7	42.30	40.70	17.40	18.70	24.10	25.00	18.40	20.30
6	37.70	36.40	15.50	16.70	21.50	22.40	16.60	18.40
5	32.20	31.40	13.30	14.40	18.50	19.30	14.50	16.20
4	25.90	25.60	10.80	11.70	15.00	15.80	12.10	13.60
3	18.90	19.20	8.10	8.90	11.10	11.90	9.40	10.90
2	11.50	12.30	5.20	5.80	7.00	7.80	6.60	7.90
1	4.40	5.30	2.20	2.70	2.90	3.50	3.20	4.50

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

Figure below shows the storey drift of buildings in transverse direction. Similarly, storey drifts are reduced after inclusion of infill walls in frame system. For bare frame system drifts are maximum for both buildings (6 and 10 storey). In case of open ground storey, lack of infill in storey 1 has resulted in higher drift values.

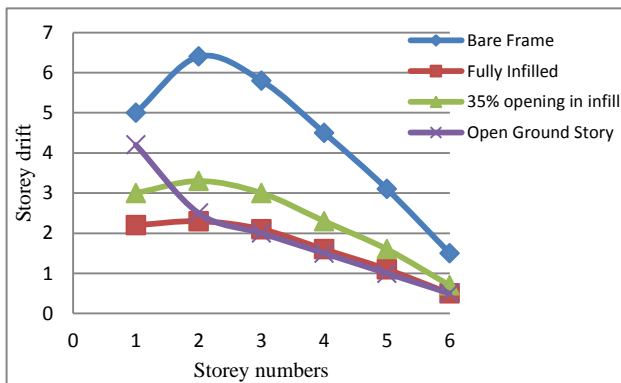


Fig 5: Storey drift in Y-direction for 6 storey building

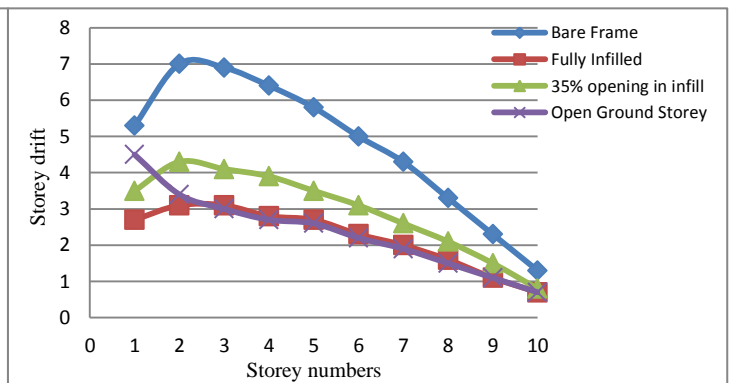


Fig 6: Storey drift in Y-direction for ten storey building

4.3 Axial Force and Bending Moment

Forces on column C-47 have been studied. The table below shows the variation of axial force on column. Since the load transfer mechanism of building after inclusion of infills shifts from predominant frame action to truss, axial forces on column increases and bending moment gets reduced.

Table 3: Axial force in column C-47 (kN) of Six storey building

Storey No.	Bare Frame	Fully infilled	35% opening in infill	Soft Ground Storey
1	1338.24	1539.38	1483.79	1484.58
2	1072.61	1243.70	1197.85	1253.87
3	806.44	939.59	903.51	938.94
4	548.83	643.76	617.35	643.34
5	310.09	365.46	349.56	365.08
6	100.98	119.35	113.96	119.01

Table 4: Axial force in column C-47 (kN) of ten storey building

Storey No.	Bare Frame	Fully infilled	35% opening in infill	Soft Ground Storey
1	2894.10	3237.84	3140.66	3175.61
2	2561.34	2873.77	2786.87	2886.12
3	2220.41	2491.46	2415.94	2491.24
4	1879.41	2112.21	2046.43	2111.93
5	1543.27	1737.93	1681.97	1737.71
6	1216.51	1372.71	1326.83	1372.52
7	904.36	1021.91	986.47	1021.74
8	613.86	692.33	667.60	692.16
9	357.54	392.31	378.34	392.13
10	127.51	131.69	127.40	131.50

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

From the chart below for Case I, it can be observed that the infill action of infill has reduced the bending moment in column by huge amount. Moreover, Incase of soft ground storey there is considerable increase in bending moment at storey 1 as that of fully infill frame. Similar pattern of results can be obtained for ten storey building.

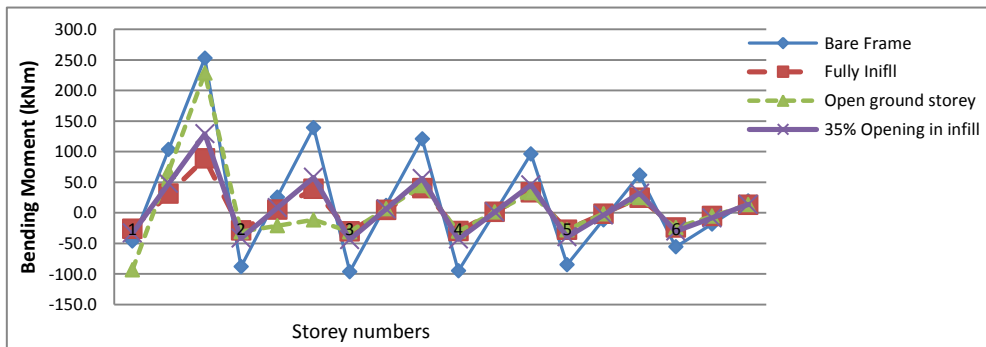


Fig 7: Variation of bending moment in column C-47 of six storey building

4.4 Axial force in strut

In order to study axial force on strut which represents the masonry infill, strut D-12 is chosen. For this same dimension of infill panel for both buildings at particular level were considered. From fig it can be observed that stress on strut of ten storey building is much higher in comparison to six storey building. Similarly strut at lower floor have more axial force than that of upper floor although having same section of strut.

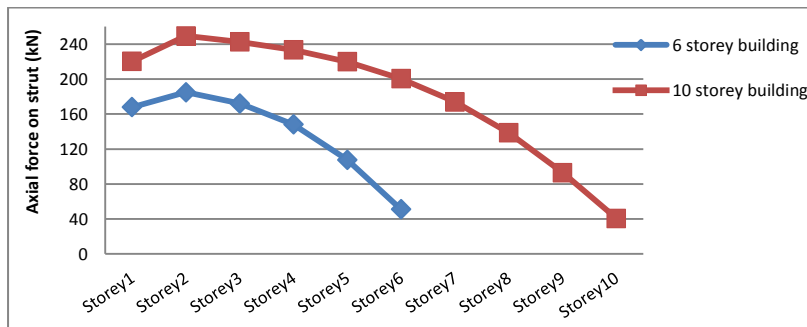


Fig 8: Variation of axial force in strut D-12

4.7 Pushover curves

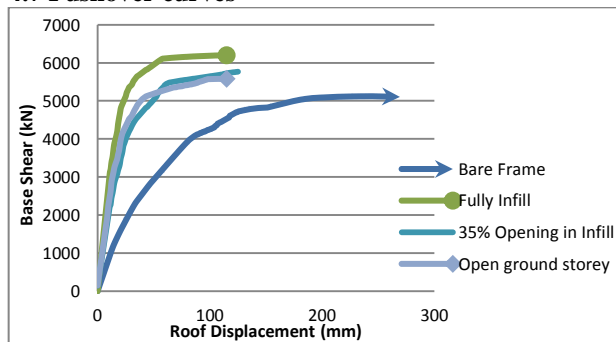


Fig 9: Base Shear Versus Roof Displacement curve for six storey building along Xdirection

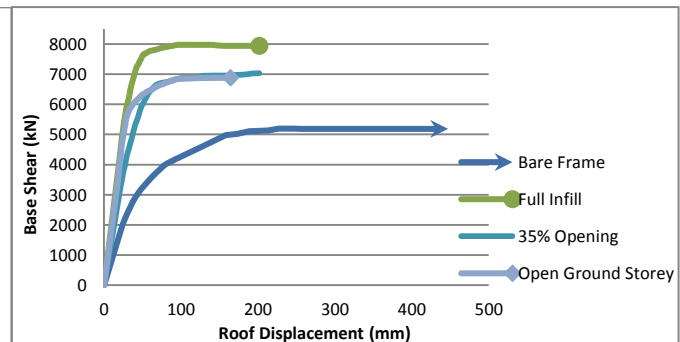


Fig 10: Base Shear Versus Roof Displacement curve for ten storey building along Xdirection

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

From Pushover curve it can be observed that consideration of infill stiffness gives more base shear capacity along X for both buildings and similar results can be seen along Y direction also. However the ductility in both cases reduces significantly. Consideration of opening in infill and soft ground storey reduces the stiffness of building. So Base Shear capacity for both cases in X direction is decreased.

4.6 Performance point and location of hinges by Pushover analysis

The base shear capacity and displacement at performance point as well as location of the hinges at different performance levels were listed in table below:

Table 5: Performance Point and location of hinges for Case I- Six Storey Building

Load Case: Push X	Performance Point		Location of Hinges								
	Displacement (mm)	Base Shear (kN)	A to B	B to IO	IO to LS	LS to CP	CP to C	C to D	D to E	Beyond E	Total
Bare Frame	106.13	4412.78	575	203	2	0	0	0	0	0	780
Fully Infill Frame	56.30	6113.53	817	118	10	8	0	0	0	67	1020
35% Opening in Infill	67.69	5486.38	768	165	2	6	0	0	0	79	1020
Soft Ground Storey	65.61	5323.37	790	125	18	2	0	0	0	45	980

Table 6: Performance Point and location of hinges for Case II- Ten Storey Building

Load Case: Push X	Performance Point		Location of Hinges								
	Displacement (mm)	Base Shear (kN)	A to B	B to IO	IO to LS	LS to CP	CP to C	C to D	D to E	Beyond E	Total
Bare Frame	141.33	4776.78	1013	287	0	0	0	0	0	0	1300
Fully Infill Frame	77.82	7755.46	1372	199	25	12	0	0	0	92	1700
35% Opening in Infill	92.15	6863.68	1349	220	21	16	0	0	0	94	1700
Soft Ground Storey	89.62	6821.87	1395	142	49	8	0	0	0	66	1660

The performance point of building its corresponding displacement as well as location of hinges are tabulated in above tables. It is observed that the base shear at performance point of bare frame is minimum while in case of fully infill frames it is maximum for both six and ten storey building, whereas values of base shear of infill with 35% opening and soft ground storey are in between above two. In almost all of the models more number of flexural plastic hinges is formed at first storey. Performance of bare frame building lies in IO range. It has been observed that in case of uniformly infilled frame buildings, plastic hinges formation starts with infill, modelled as strut in case of RC frame with infill and then beam ends and base columns of lower stories, and then propagates to upper stories which is shown in figure below:

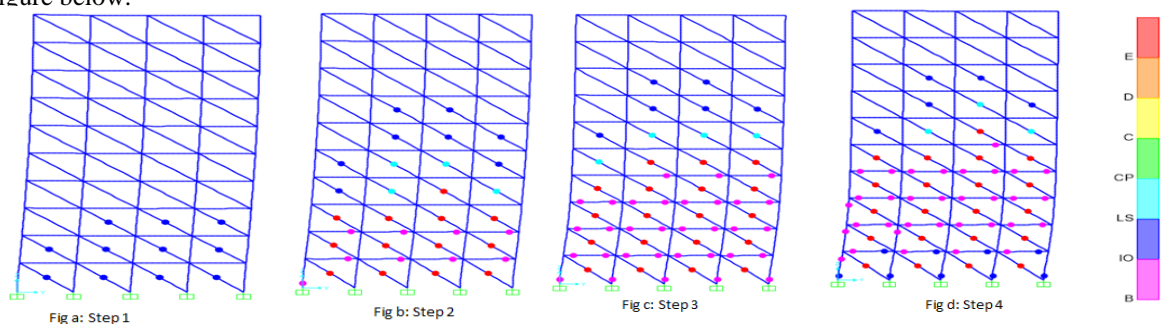


Fig 11: Step by Step Deformation by Pushover Analysis of 10 storey building along Y-direction

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

V. CONCLUSIONS

The study considers the seismic performance of RC framed buildings with infill, including set of six and ten storey building with different infill configuration. From the study it has been observed that masonry infill have significant effect of dynamic characteristics, strength, stiffness and seismic performance of buildings. Fundamental period of vibration was lower for fully infill model and higher for bare frame model. The time period given by IS 1893:2002 vary largely to those obtain from modal analysis. Axial forces on columns have increased and bending moment has decreased due to inclusion of infill in the frames. With increase in height of building the stress in infills are increased for same dimensions of infill panel.

Results of Pushover analysis shows that Inclusion of infill beef up the overall stiffness, strength and energy dissipation, reducing displacement, inter storey drift demand of the structure The better collapse performance of fully-infilled frames is associated with the larger strength and energy dissipation of the system, associated with the added walls. Similar trends are seen in both cases; 6 and 10-storey RC frame buildings.

REFERENCES

- [1] Agarwal. P & Shrikhande M, Earthquake Resistant Design of Structures, Prentice Hall of India Pvt. Ltd., India, (2006).
- [2] Diptesh Das and C.V.R.Murty (2004) "Brick masonry infills in seismic design of RC framed buildings" Part 1- Cost implications, The Indian Concrete Journal (2004).
- [3] FEMA (2000). Prestandard and Commentary for the Seismic Rehabilitation of Buildings (FEMA 356). Prepared by ASCE for Federal Emergency Management Agency, Washington, D.C., USA.
- [4] Ghassan Al-Chaar "Evaluation strength & stiffness of Unreinforced Masonry Infill Structures", US army Corps of Engineers, (January 2002)
- [5] Haroon Rasheed Tamboli and Umesh.N.Karadi "Seismic Analysis of RC Frame Structure with and without Masonry Infill", Indian Journal of Natural Sciences, Vol.3 / Issue 14/ October 2012.
- [6] Mainstone, R. J., 1971. On the stiffness and strength of infilled frames, Proceedings of the Institution of Civil Engineers, supplement IV, 57–90 (paper 7360S).
- [7] Paulay, T., and Priestley, M. J. N. (1992). Seismic Design of Reinforced Concrete and Masonry Buildings. Wiley-Interscience, New York.
- [8] Praveen Rathod, Dr. S.S Dyavanal. "Seismic evaluation of multistorey RC buildings with openings in unreinforced masonry infill walls with user defined hinges" International Journal of Mechanical and Production Engineering (ISSN 2320-2092), Vol.2, Issue 10-October 2014.
- [9] Prof.P.BKulkarni, Pooja Raut, Nikhil Agrawal "Linear Static Analysis of Masonry Infilled R.C. Frame With & Without Opening Including Open Ground Storey" International Journal Of Innovative Research In Science, Engineering And Technology.
- [10] Stafford-Smith, B., and Carter, C. (1969). A Method of Analysis of Infilled Frames. Proceedings of the Institution of Civil Engineers 44, 31-48.
- [11] Yogendra Singh and Dipankar Das " Effect of URM infills on seismic performance of RC frame buildings" 4th International conference on Earthquake Engineering, Taipei Taiwan, Paper No. 064, October 2-13, 2006