Pushover Analysis of High Rise Reinforced Concrete Building with and without Infill walls

Phadnis P.P.[1], Prof. (Dr.) Kulkarni D. K.[2]

[1]Research Scholar, Department of Technology, Shivaji University, Kolhapur, 416004, Maharashtra, India
e-mail: punashri.phd@gmail.com
[2]Professor, Department of Civil Engineering, S. D. M. College of Engineering and Technology, Dharwad, 580002, Karnataka, India

---***---

Abstract - *Masonry walls are built in between reinforced concrete frame and generally considered as non-structural element. In design of building self weight of wall is considered as uniformly distributed load on beam without considering the stiffness and strength contribution of wall. In this study the effect of masonry walls on high rise building is studied. Nonlinear static analysis on high rise building with different configuration is carried out. For the analysis G+10 reinforced concrete framed building is modeled. The width of strut is calculated by using equivalent strut method. Seismic performance of various configurations of infill in reinforced concrete frames is obtained by performing nonlinear static analysis in SAP2000. The results of infill frames are compared with bare frame model.*

Key Words**: Infill wall, equivalent strut, high-rise building, nonlinear static analysis, stiffness**

1. INTRODUCTION

Unreinforced brick masonry walls used as infill in reinforced cement concrete moment resisting frames are very common in India and in other developing countries. Masonry is a commonly used construction material in the world. The primary function of masonry is either to protect inside of the structure from the environment or to divide inside spaces for functional utility. When masonry infill is considered to interact with their surrounding frames, the lateral stiffness of the structure largely increases. In many countries situated in seismic regions, reinforced concrete frames are used as infill fully or partially by brick masonry panels with or without openings. Although the infill panels significantly enhance both the stiffness and strength of the frame, their contribution is often not taken into account because of the lack of knowledge of the composite behavior of the frame and the infill.

The effect of masonry infill panel on the response of reinforced concrete frames subjected to seismic action is widely recognized and has been subject of numerous experimental investigations, while several attempts to model it analytically have been reported. Infill wall can be modeled in several forms such as, equivalent diagonal strut, equivalent frame model, continuum model i.e. shell or membrane element, pier and spandrel model, finite element model, etc. In present study, infill walls are modeled as equivalent strut approach and seismic performance of various configurations of infill in reinforced concrete frames are compared with bare frame model. The main objective of this was to investigate the effect of masonry infill walls on the seismic behavior of reinforced concrete High-Rise building G + 10 stories with nonlinear static analysis method.

2. DESCRIPTION OF STRUCTURAL MODEL

The available modeling approaches for masonry infill can be grouped into micro and macro models. Micro models (continuum or finite element model) capture the behavior and its interaction with frames in much in detail, but these models are computationally expensive. While, macro models (equivalent strut and equivalent frame) try to capture overall behavior of the infill are approximate but computationally efficient. The diagonal strut model can be single diagonal strut, two diagonal strut or three-strut model. The single strut model is efficiently used in capturing behavior of infill in seismic analysis [1; 2; 3]. Three-strut model can estimate force resultants in RC members with sufficient accuracy, in addition to modeling the local failures in infill and in beams and columns due to interaction between masonry infill and RC frame. It was also observed that the single-strut model can be effectively used in cases soft or open storey buildings [4; 5]. Infill behaves like compression strut between column and beam and compression forces are transferred from one node to another. Masonry infill panels have been modeled by two strut elements along the two diagonals. Nonlinear gap elements have also been used, which are active in compression only [6]. There are various formulae derived by research scholars and scientist for width of strut. In this study, stiffness of wall is considered in plane of loading. For infill wall located in a lateral load resisting frame the stiffness and strength contribution of the infill are considered by modeling the infill as an equivalent strut approach given by FEMA- 356 [7] as below

$$a = 0.175(\lambda_1 h_{col})^{-0.4} r_{inf} \quad (1)$$

$$\lambda_1 = \left[\frac{E_m t \sin(2\theta)}{4E_{fe} I_{col} h_{inf}}\right]^{1/4} \quad (2)$$

where,
h_{col} = Column height between centre lines of beams
h_{inf} = Height of infill panel
E_{fe} = Expected modulus of elasticity of frame material
E_m = Expected modulus of elasticity of infill material
= $550 \times f_m$
I_{col} = Moment of inertia of column
r_{inf} = Diagonal length of infill panel
t = Thickness of infill panel and equivalent strut
θ = Diagonal angle
f_m = Compressive strength of masonry

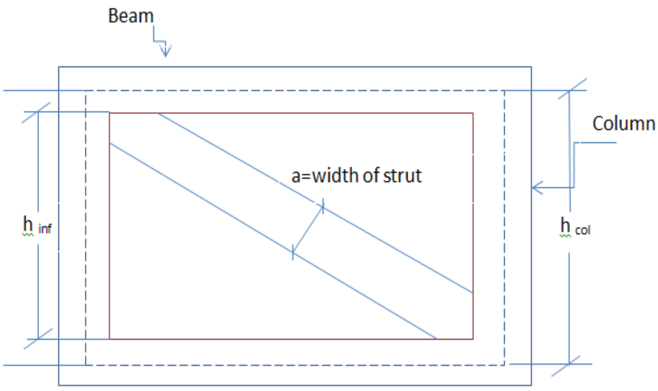


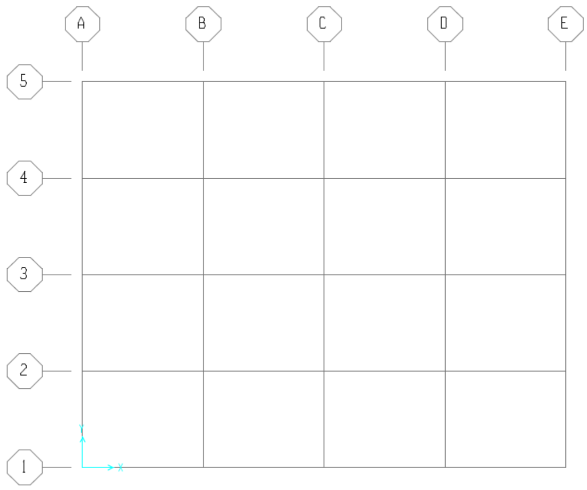
Fig -1: Equivalent width of strut

In this study, four different models of eleven storey building symmetrical in plan are considered. Buildings are modeled using 40% masonry infill, but arranging them in different configuration as shown in fig. 2. The building has four bays in x-direction and y-direction with plan dimensions 20m×16m and storey height of 3.0m for each floor. Size of beam is 450mm×600mm and size of column is 750mm×750mm for bottom four stories and 450mm×600mm for upper stories. The columns are assumed to be fixed at the ground level. Depth of slab is considered as 120mm. Weight of floor finishes is 1.5kN/m². Imposed load is considered as 2kN/m² on roof and 4kN/m² on floor. Slab loads have been distributed to frame elements according to yield line pattern.

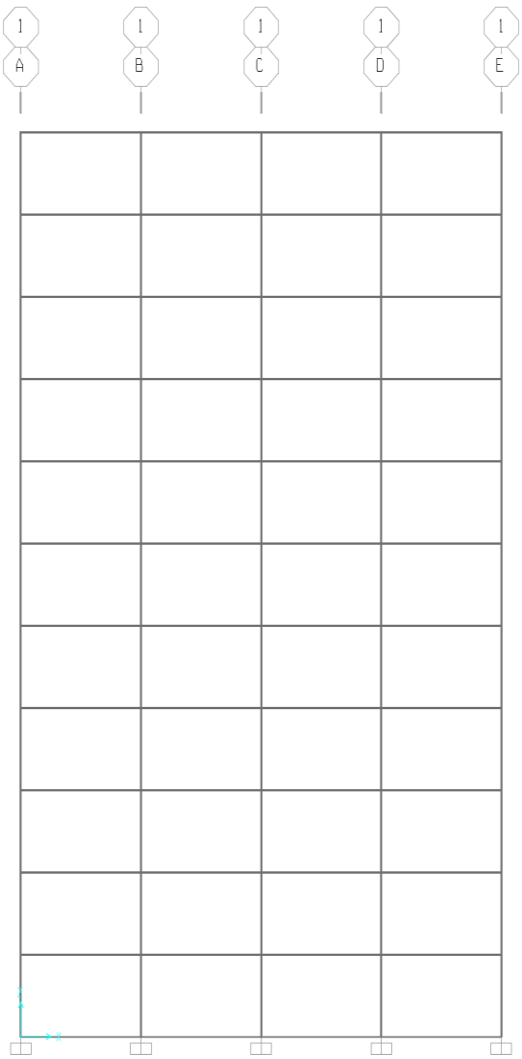
M20 grade of concrete is used with modulus of elasticity 22360MPa, Fe415 grade of steel is used with yield strength of 415MPa with elastic modulus 2×10^5MPa and unit weight of brick masonry is 20kN/m² with modulus of elasticity 2035MPa. Seismic zone V is considered for analysis.

To observe effect of infill on the behavior of frame buildings, following four different models are considered in the study.

Model I: Bare frame
Model II: Masonry infill are arranged in outer periphery
Model III: Masonry infill are arranged in outer periphery with soft storey
Model IV: Masonry infill are arranged as lift core

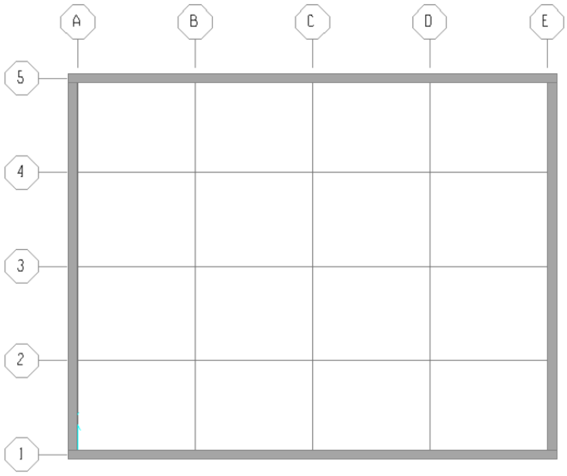


Plan

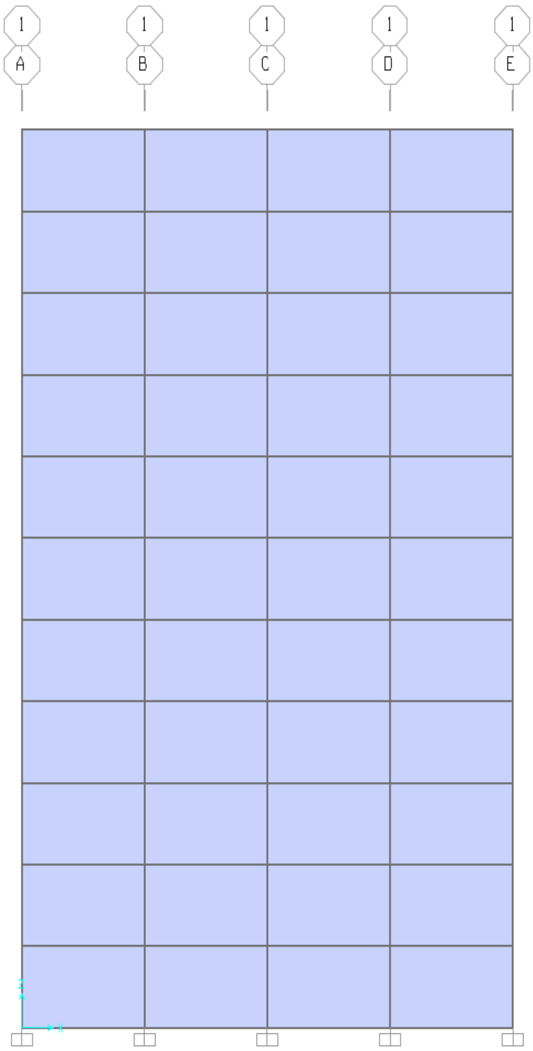


Sectional elevation

Model I

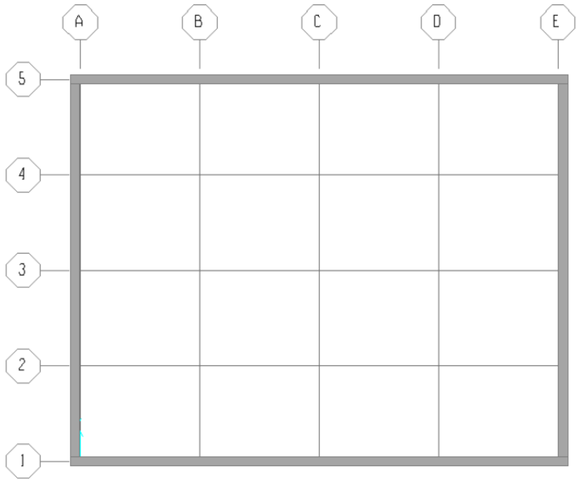


Plan

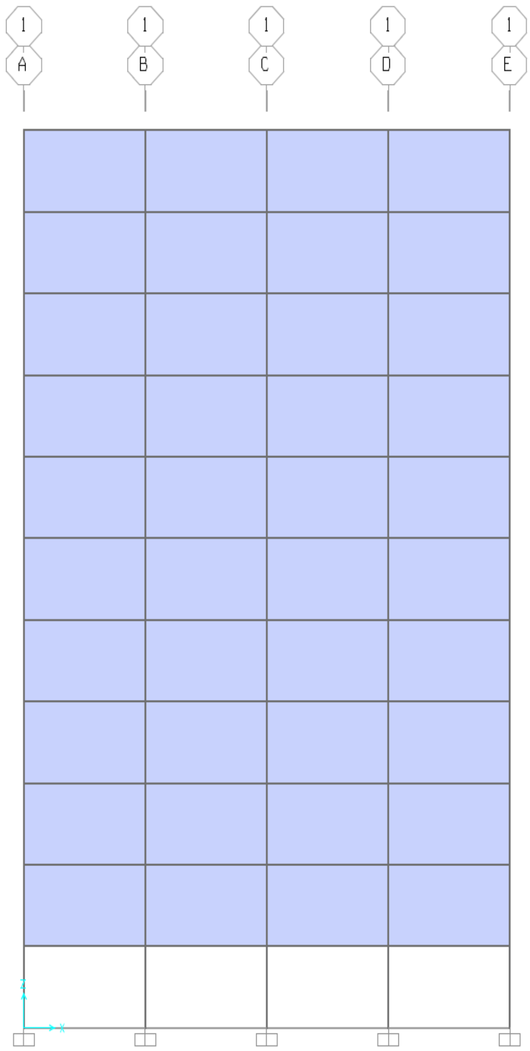


Sectional elevation

Model II

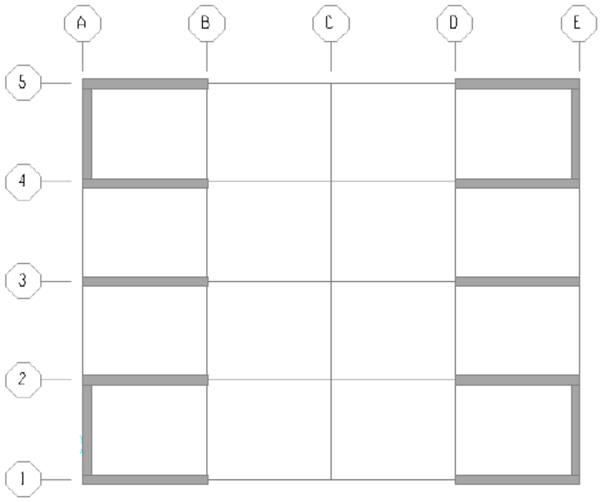


Plan

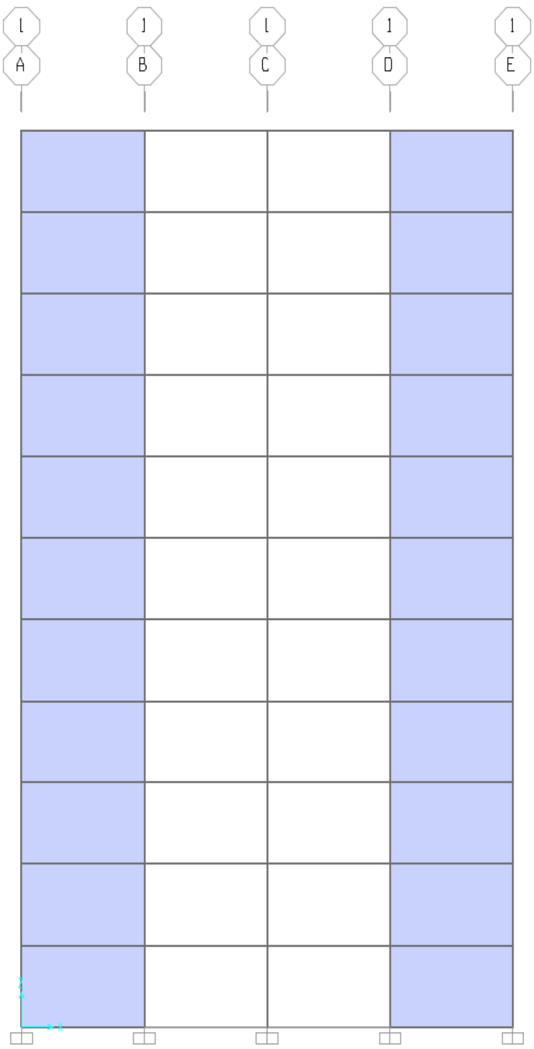


Sectional elevation

Model III



Plan



Sectional elevation

Model IV

Fig -1: Plan and Elevation of Eleven Storeys Reinforced Concrete Buildings

3. NONLINEAR ANALYSIS

In present study, nonlinear pushover analysis is used to determine the seismic response of structural system. Nonlinear analysis procedures help to demonstrate how building really works by identifying modes of failure and the total potential for progressive collapse. Under the Nonlinear Static Procedure, a model is subjected to gravity analysis (DL+0.5LL) and simultaneously displaced using preselected lateral load pattern until roof displacement reaches to a target displacement, and resulting internal deformations and forces are determined. Three different lateral load pattern used are -

1. Uniform load distribution in which forces are proportional to product acceleration and storey masses,
2. Modal which is proportional to product of the amplitude of first elastic mode and mass (m) of each storey
   $$F_i = \frac{m_i \phi_i}{\sum m_i \phi_i} \quad (3)$$
   where,
   ϕ_i = Amplitude of the elastic first mode of the storey
3. Codal in which lateral load distributed across the height of the buildings based on equation as per IS: 1893-2002 are used for the analysis.
   $$V_B = A_h W \quad (4)$$
   $$Q_i = V_B \frac{W_i h_i^2}{\sum_{i=1}^{n} W_i h_i^2} \quad (5)$$
   where,
   V_B = Design base shear as per IS: 1893 (Part-I): 2002
   Q_i = Lateral force at floor i
   W_i = Seismic weight at floor i
   H_i = Height of floor I measured from base
   n = No. of storey of building

Columns and beams are modeled as frame elements. Default M3 hinges are assigned to beams and interacting PMM hinges are assigned to columns as per FEMA356. Masonry infill panels are modeled as single strut element with both ends pinned and active in compression only. Pushover analysis is carried out by displacement control method with the target displacement 4% of total height of building as per ATC40, 1996 [8]. Depending upon the properties of elements, acceptance criteria are defined according to FEMA356 and ATC40, as Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP) as shown in fig. 2. Here, these three points are defined as 10%, 60% and 90% of plastic hinge deformation capacity.

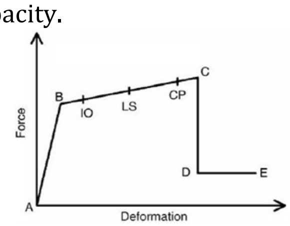


Fig -2: Force Vs Deformation Curve

The resulting base shear and top displacements are considered to plot pushover curve.
Performance evaluation using uniform lateral load pattern resulted in higher base shear and then in decreasing order for first modal and codal load pattern.
Model II, III and IV (with infill) has increased base shear and decreased displacement with application of three different load patterns than Model I (bare frame). This shows that lateral strength and stiffness in increased due to presence infill panels.

4. RESULTS AND DISCUSSIONS

Fundamental natural period as per IS: 1893-2002 [9] and as per analysis using SAP2000 [10] software of various models are tabulated in table 1.

Table1: Fundamental Natural Time period (sec) of various models

Model No.	Model I	Model II	Model III	Model IV
IS: 1893-2002	1.0326	0.6641	0.6641	0.6641
SAP2000	0.6883	0.6417	0.6447	0.6725

The analytical Fundamental Natural Time Period does not match with the Time Period from empirical expression of the IS: 1893-2002. Introduction of infill panel in the reinforced concrete frame reduces time period of bare frames.
Base shear and top displacement at performance levels are tabulated in table 2 for uniform, first modal and codal load pattern respectively.

Table2: Base shear (P) and top displacement (Δ) at performance levels for different configuration subjected to lateral load patterns

Model No.	Performance Level →	IO		LS		CP	
	Lateral Load Pattern ↓	P (kN)	Δ (mm)	P (kN)	Δ (mm)	P (kN)	Δ (mm)
Model I	Uniform	7161.49	59.19	9628.94	152.40	11069.46	257.26
	First modal	5525.93	65.73	6329.14	105.06	8386.71	349.17
	Codal	4123.40	50.41	6665.20	219.89	7307.59	352.70
Model II	Uniform	6244.89	30.94	18831.74	163.18	27050.44	297.48
	First modal	5223.16	36.78	13939.73	169.70	20103.19	304.38
	Codal	4972.67	41.13	12408.73	175.48	17604.44	307.64
Model III	Uniform	5759.69	29.27	13612.41	101.26	21556.20	241.41
	First modal	5117.69	36.45	11986.58	136.70	17567.65	270.34
	Codal	4917.78	41.21	12125.26	176.16	16797.65	309.27
Model IV	Uniform	6791.25	34.21	19611.21	167.90	26936.98	301.50
	First modal	5340.97	37.73	14325.56	173.18	19820.65	305.52
	Codal	4436.09	37.43	12200.94	172.30	19889.14	407.16

Chart 1 represents resulting pushover curve for different models subjected to uniform, first modal, codal load pattern respectively.

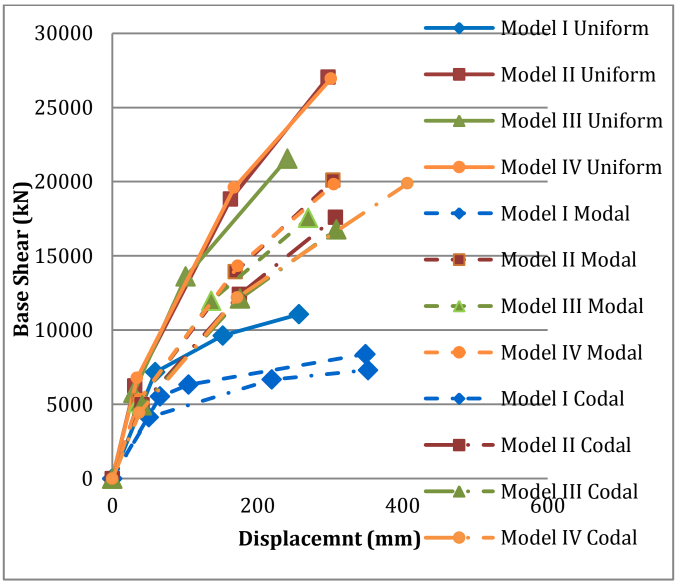


Chart -1: Force-displacement relationship

Performance evaluation using uniform lateral load pattern resulted in higher base shear and then in decreasing order for first modal and codal load pattern.
Model II, III and IV (with infill) has increased base shear and decreased displacement with application of three different load patterns than Model I (bare frame). This shows that lateral strength and stiffness is increased due to presence infill panels.

5. CONCLUSIONS

The seismic behaviors of different configurations of infill wall panels are considered. Bare frame acts primarily as a moment resisting frame with the formation of plastic hinges at the joints under lateral loads. In contrast, the infill frame behaves like a braced frame resisted by a truss mechanism formed by the compression in the masonry infill panel. The results of the analyses indicate that the infill can completely change the distribution of damage throughout the structure. The based on above result and discussion, the following conclusion can be drawn.

1. Due to infill walls in the High Rise Building top story displacement is reduces.
2. Time period of Building is reduced and Base shear is increased.
3. The presence of non-structural masonry infill walls can modify the seismic behavior of R.C.C. Framed High Rise building to large extent.
4. Arrangements of infill walls also alter the displacement and base shear in case of soft story.

REFERENCES

[1] D. Das and C.V.R. Murthy, "Brick Masonry infills in seismic of RC framed buildings: Part 1- Cost Implications", The Indian Concrete Journal, July 2004. Vol. 78, No. 7, pp. 39-43.

[2] R. Davis, P. Krishnan, D. Menon, A. M. prasad, "Effect of Infill Stiffness on Seismic Performance of Multi-Storey RC Framed Buildings in India", 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada, August 1-6, 2004, Paper No. 1198.

[3] G. Amato, L. Cavaleri, M. Fossetti and M. Papia, "Infilled Frames: Influence of vertical load on the Equivalent Diagonal Strut Model", The 14th World Conference on Earthquake Engineering, October 12-17, 2008, Beijing, China.

[4] H.B. Kaushik, D. C. Rai, and S. K. Jain, "Rational Approach to Analytical Modeling of Masonry Infill in Reinforced Concrete Framed Buildings", The 14th World Conference on Earthquake Engineering, October 12-17, 2008, Beijing, China.

[5] Diana M. Samoilă, "Analytical Modelling of Masonry Infills", Acta Technica Napocensis: Civil Engineering and Architecture, Vol. 55, No. 2, 2012, pp. 127-136.

[6] Y. Singh and D. Das, "Effect of URM Infills on Seismic Performance of RC Frame Buildings", 4th International Conference on Earthquake Engineering Taipei, Taiwan, October 12-13, 2006, paper no. 64.

[7] ATC 40, Volume 1 (1996) "Seismic evaluation and retrofit of concrete buildings", Applied Technology Council, Seismic Safety Commission, State of California.

[8] FEMA 356-2000, , "Prestandard and Commentry for the Seismic Rehabilitation of Buildings, Federal Emergency Management Agency", Washington D.C.

[9] IS: 1893(Part I) - 2002, "Criteria for Earthquake Resistant Design of Structure, General Provisions and Buildings", Bureau of Indian Standard, New Dehli.

[10] SAP2000 V-14, CSI. Integrated finite element analysis and design of structures basic analysis reference manual; Berkeley (CA, USA); Computers and Structures Inc.