

Simulation of Brick Infill and Effect of Openings on RC Frames using ANSYS

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Abstract

An infill frame is defined as a dual system, which consists of bricks or concrete blocks filling the inter-planar voids between lower and upper beam and space between side columns of reinforced or steel frame. Despite the fact that infill enhances both strength and stiffness of the moment resisting frames; their role is ignored in the design due to insufficient knowledge of the composite behaviour of infill and frames. It is credible, that a major portion of the lateral load is shared by the infill. This paper deals with translating existing experimental data into analytical methods. To understand the behaviour of brick masonry, a G+1 structure was modelled in ANSYS and results were obtained. The present study is also aimed at finding the effect of openings in brick walls and captive column effect. When infill walls are omitted in the bottom storey, a soft storey is formed compared to stiffer stories at top. By response spectrum analysis it has been proved that the structural time period for frame with infill decreases by 2 to 3 times compared to frames without infill. The results showed that the soft storey building frame attracts 40% more shear force than frame excluding soft storey effect. The variation in time period at different mode shapes, with and without infill is presented in the paper. The phenomenon of captive column was replicated and formation of short column is shown in the pilot study.

Keywords: Captive Column, Response Spectrum Analysis, Shear Rigidity, Soft Storey Effect, Structural Time Period

1. Introduction

Brick infill is extensively used in building construction as interior and exterior partition wall reason being aesthetics and functional needs. Infill frame is a structural composite system which consists of a steel or reinforced concrete frame with masonry or concrete panels filling the planar rectangular voids between lower and upper beams and side columns. In-filled frame is a complex statically indeterminate problem. As a composite system, its structural behaviour depends on individual elements. The frame is strengthened by the infill's to form a shear resisting element and in turn, the infill panel is

strengthened by the beneficial containment effects of the frame. After initial cracking of the infill, the frame prevents it from disintegration by its confining action while the infill maintains its stiffening effect of the frame. The combined effect results in a system which has a high level of stiffness and strength of the infill with the ductility of the surrounding frame. There has been significant research work being done in the field of behaviour of masonry infill frame structures in order to develop a rational approach to design such frames. Stafford smith and polykov¹ were the 1st to consider brick infill in the design.

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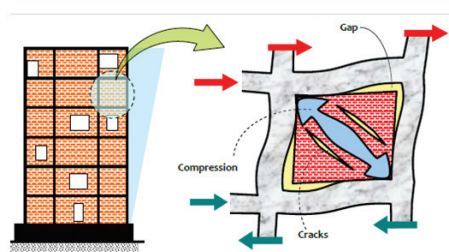


Figure 1. Equivalent Diagonal Strut.

(Ref Earthquake behavior of building, Gujarat state disaster management authority)

Just after construction the infill frame composite act as cantilever wall. Slight stress concentrations occur at the four corners, while the middle of the panel develops an approximately pure state of shear. As the in-plane loading on infill continues, there is a separation initiated at the interface of masonry and the frame members (beam and column) at the off-diagonal corners. Once a gap is formed, the stresses at the tensile corners are relieved while those near the compressive corners are increased (Figure 1). As the load continues to increase, further separation occurs between the masonry panel and the frame, resulting in contact only at the frame sections near the loaded corners. Due to this behaviour of infill frame it resembles a braced frame with one diagonal member. This has led to the concept of replacing the masonry infill with an equivalent diagonal strut when modelling the behaviour of the system. Mallick and Garg² found that there is formation of shear slot between frame and infill due to which the rotational degree of freedom of beam gets restrained. That means according to him, there is no deformation in beam due to shear forces and axial forces when infill panel is considered in design. According to Koset et al³ the infill walls cracks even at very small lateral loads. Thus it is necessary to consider the opening and closing of cracks in infill during analysis. Many buildings are irregular in plan due to unsymmetrical arrangement of partition walls. Because of architectural and structural consideration sometimes there is eccentricity between centre of mass and centre of rigidity, shown in figure 2.

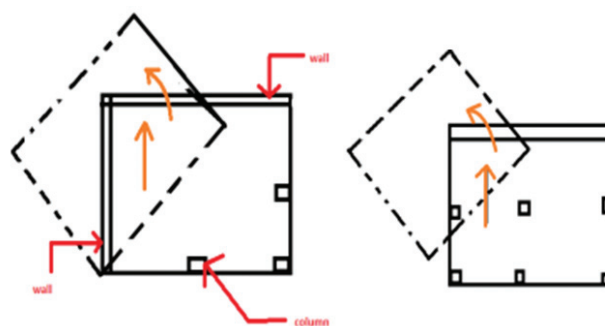


Figure 2. Twisting due to walls on 2 or 1 side (in plan).

This causes an unbalanced distribution of mass and stiffness in the building. Due to the eccentricity developed, torsion occurs in the structure, which will consequently result in additional forces and stresses in members. This torsion is however ignored in conventional designs due to the absence of infill walls in design. When infill frame composite is subjected to lateral load, the deformation is in double curvature. The lateral movement of the upper part of column causes the column to lean against the infill as well as to compress the infill along the leading diagonal.

Three potential modes of failure due to the interaction between wall and frame are illustrated⁴ in figure 3.

1.1 Shear Cracking

This steps down through the joints of brick masonry concentrating horizontal shear stresses in the bed joints.

1.2 Diagonal Cracking

These cracks penetrate in parallel direction along the main diagonal. These are generated by the tensile stresses occurring due to the convergence of the stress trajectories on opposite side of main diagonal converging at mid portion of infill. These stresses are more at the centre where tensile stresses are less and tend to become zero near corners where tensile stress is further suppressed.

1.3 Corner Crushing

As there is significant compressive stress at corner, the infill crushes over a portion near corner. In this, a corner

of the infill at one of the ends of the diagonal strut may be crushed against the frame due to the high compressive stresses in the corner. Since the infill bears on the frame not as a concentrated force exactly at the corners, but over short lengths of the beam and column adjacent to each compression corner, thus this crushing failure is spread over a portion.

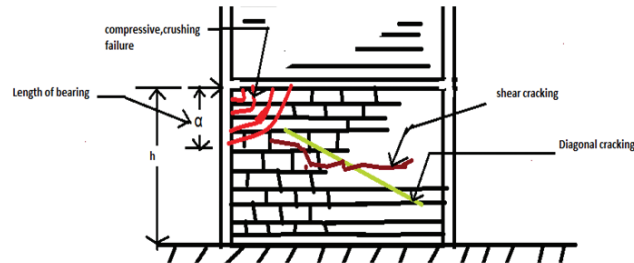


Figure 3. Pattern of failure for masonry panel.

2. Purpose of Study

The major areas on which this paper is focused upon are,

- To estimate the difference in stiffness between ordinary moments resisting frame and frame with brick confinement.
- To find the impact on strength characteristics of moment resisting frames when infill are considered.
- To study the change in dynamic behaviour of frame due to brick infill.
- To study the effect of different size and position of openings on the infill frame composite.
- To recapitulate and understand the concept of captive column effect on reinforced concrete frames.

3. Research Methodology

Finite element modelling is considered to be a very powerful and versatile tool in engineering for analysis of problems of structural and continuum mechanics. In our pilot study a linear static analysis using ANSYS Civil FEM has been performed to estimate the behaviour of infill-frame composite. The modelling details and procedure to connect individual elements are discussed as following:

3.1 Beam and Column Modelling

The beam and column elements are modelled using 2 node 188 elements in ANSYS.

3.2 Brick Modelling

There are 2 ways to model brick masonry,

3.2.1 Micro Modeling

It is done by finite element technique considering mortar specification, brick specifications, the interaction between brick and mortar, the interaction between infill wall and frame.

3.2.2 Macro Modeling

In this it is assumed that the brick wall is homogeneous and isotropic material with equivalent mechanical properties which makes the work very simple. Although the accuracy is more in micro modelling, macro modelling yields a simple and easy calculation.

To model our brick infill, quad 4 noded element was taken in ANSYS with plane stress with thickness condition.

With the above presented data and a G+1 single bay frame was modelled in ANSYS as shown.

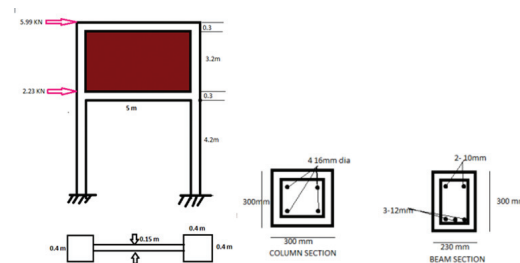


Figure 4. Model and reinforcement details.

Using 'equivalent static method of dynamic analysis as per IS 1893:2002⁵ the loads on the G+1 story building were calculated. The reinforcement adopted for analysis are shown in figure 4.

3. Experimental Investigations

3.1 Stiffness

To estimate the stiffness of bare frame and in-filled frame, standard procedure of 'equivalent strut' was adopted and is represented in this paper.

Stafford Smith 1966, carried out a wide range of tests on 150mm square micro-concrete model infill's bounded by steel frames subjected to diagonal load. According to his observation, he adopted the equivalent diagonal strut method.

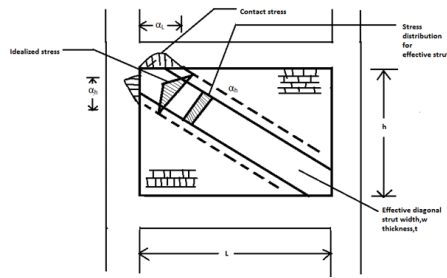


Figure 5. Equivalent strut model of infill frame.

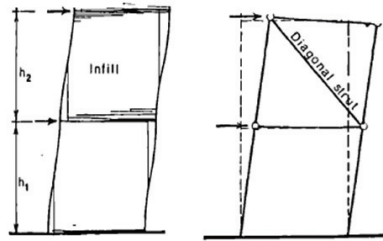


Figure 6. Replacement Of infill with Diagonal Strut.

$$W = 1/2 \sqrt{\alpha_h^2 + \alpha_L^2} \quad (1)$$

$$\theta = \tan^{-1} (h/L) \quad (2)$$

$$\alpha_h = \pi/2 \left(E_f I_c h / 2 E_m t \sin 2\theta \right)^{1/4} \quad (3)$$

$$\alpha_L = \pi \left(E_f I_b L / 2 E_m t \sin 2\theta \right)^{1/4} \quad (4)$$

α_L = Length of contact between wall and beams

α_h = Length of contact between wall and columns

w = width of the diagonal strut

I_C, I_B = Moment of inertia of the column and the beam of the frame

L = Length of the infill wall

H = height of the infill wall

E_m = Elastic modulus of masonry wall = 13,800 MPa

$\theta = \tan^{-1} (h/l) = \tan^{-1} (3.2/5) = 32.619^\circ$

$E_f = 5000 \sqrt{20} = 22,360.6 \text{ N/mm}^2$

T = 0.15 m

T = thickness of the infill wall

$$\alpha_h = \frac{\pi}{2} \frac{22.36 \times 10^6 \times 6.75 \times 10^{-4} \times (2.9)^{1/4}}{(2 \times 1.38 \times 10^7 \times .15 \times 0.90)} = 0.5171 \text{ m}$$

$$\alpha_L = \frac{\pi}{2} \frac{22.36 \times 10^6 \times 5.175 \times 10^{-4} \times (5.03)^{1/4}}{(2 \times 1.38 \times 10^7 \times .15 \times 0.90)} = 1.089 \text{ m}$$

Equivalent width of strut:

$$W = 1/2 \sqrt{(0.5171^2 + 1.089^2)} = 0.609 \text{ m}$$

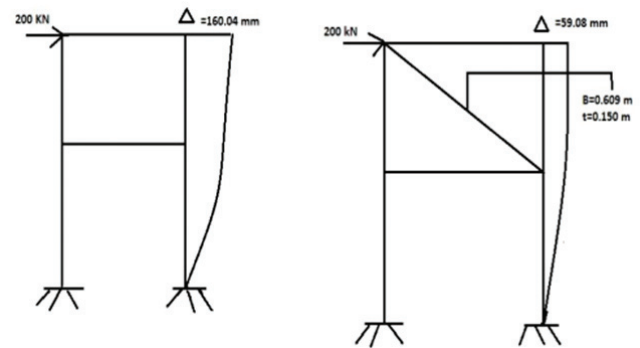


Figure 7. Deflection values for frames.

$$K_{\text{without infill}} = 200/0.150 = 1333.33 \text{ kn/m}$$

$$K_{\text{with infill}} = 200/0.059 = 3389.8 \text{ kn/m}$$

$$K_{\text{with infill}} / K_{\text{without infill}} = 2.54$$

3.2 Strength

The infill panel adds to the lateral load capacity of the bare frame and thus results in increase in strength.

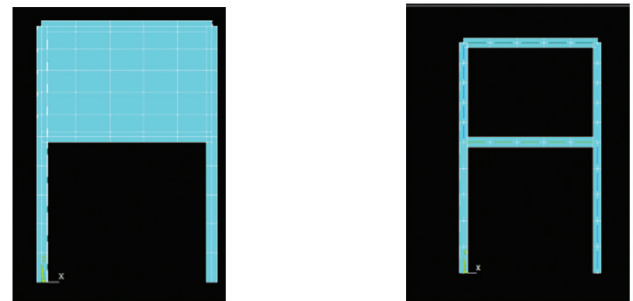


Figure 8. ANSYS model for bare frame and frame with infill.

The lower storey of the building is often not provided with infill walls for parking purposes. In that the columns

are unable to provide adequate shear resistance during the earthquake. To visualize this analysis was done for 2 models as shown.

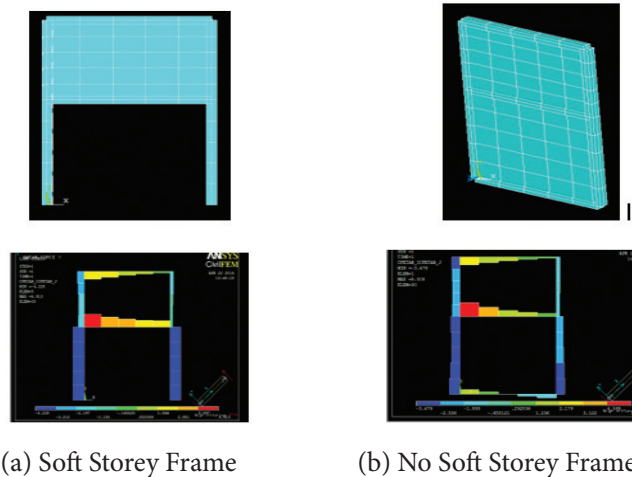
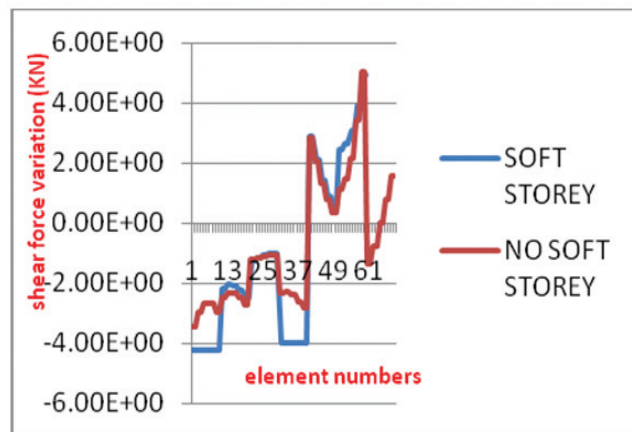


Figure 9. ANSYS Models and Shear Force Diagram.



The results obtained are tabulated here,

Element	Shear FY (kN)	Shear FY (kN)
1	-4.23E+00	-3.48E+00
1	-4.23E+00	-3.48E+00
2	-4.23E+00	-3.01E+00
2	-4.23E+00	-3.01E+00
3	-4.23E+00	-2.71E+00
3	-4.23E+00	-2.71E+00
4	-4.23E+00	-2.72E+00
4	-4.23E+00	-2.72E+00
5	-4.23E+00	-2.99E+00
5	-4.23E+00	-2.99E+00
6	-2.19E+00	-2.52E+00
6	-2.19E+00	-2.52E+00

7	-2.06E+00	-2.37E+00
7	-2.06E+00	-2.37E+00
8	-2.07E+00	-2.36E+00
8	-2.07E+00	-2.36E+00
9	-2.24E+00	-2.50E+00
9	-2.24E+00	-2.50E+00
10	-2.49E+00	-2.72E+00
10	-2.49E+00	-2.72E+00
11	-1.26E+00	-1.25E+00
11	-1.26E+00	-1.25E+00

Figure 10. Variation of shear force.

3.5 Effect of Opening

Infill wall invariably consist of openings of different sizes and at different locations which results in reduction of stiffness and load carrying capacity of infill. The various size and location of openings taken for the pilot study are shown in the Table 1.

Table 1. Position and size of opening

Opening percentage area	Left of the diagonal;	Top of the diagonal	On the diagonal	Down of the diagonal	Right side of the diagonal
2.25%					
4.0%					
6.25%					
9.0%					

The max value of axial forces and bending moments for different size of openings are shown in the figures below.

The results obtained by varying the position of 9% opening is as shown below

3.6 Captive Column Failure

Kwon chu⁶ in his case study on an RC building in ICA,

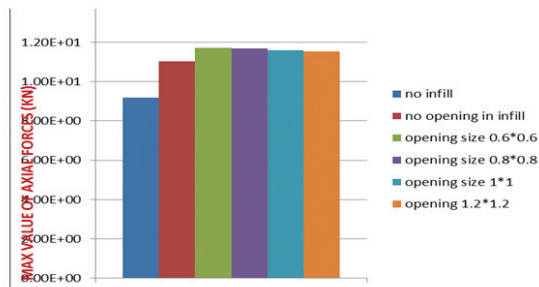


Figure 11. Maximum value of axial force for different opening size.

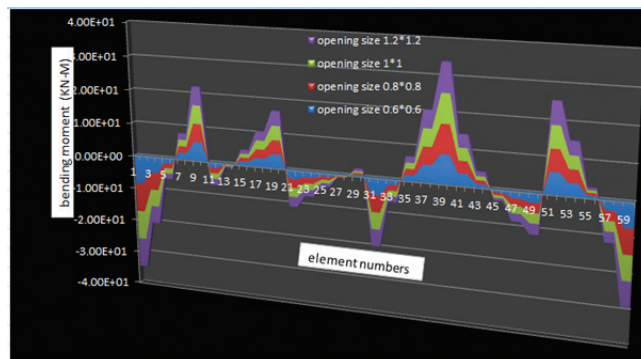


Figure 12. BM variation for different opening size.

PERu which was severely damaged during the pisco chinch earthquake, showed that shear force attracted by columns with infill was significantly higher than those

without infill's. He found that severe damage to the structure occurred by failure of captive column at base level as a result of the discontinuity of the foundation walls in height.

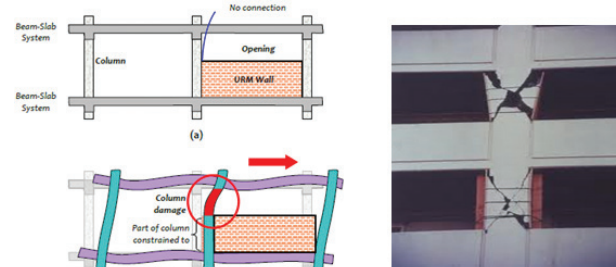


Figure 13. Capital column failures.

(Ref Earthquake behavior of building, Gujarat state disaster management)

The effective length of the column portion next to opening decreases and behaves as short column which attracts more shear force as compared to long column which is away from opening.

This phenomenon results in captive column effect and formation of X shaped cracks which is a significant feature of shear failure

Figure 14 shows modelling of frame for the analysis of captive column effect and the variation of shear force at different elements.

Table 2. Variation in BM by varying position of opening

	right side	left side	at bottom	at top	at centre
Element	Bending MZ(kN*m)	Bending MZ(kN*m)	Bending MZ(kN*m)	Bending MZ(kN*m)	Bending MZ(kN*m)
1	-8.66E+00	-8.71E+00	-8.70E+00	8.71E+00	-8.72E+00
2	-8.66E+00	-8.71E+00	-8.69E+00	-8.68E+00	-8.72E+00
3	-5.13E+00	-5.15E+00	-5.16E+00	-5.15E+00	-5.18E+00
4	-5.13E+00	-5.15E+00	-5.16E+00	-5.17E+00	-5.18E+00
5	-1.59E+00	-1.59E+00	-1.60E+00	-1.62E+00	-1.64E+00
6	-1.59E+00	-1.59E+00	-1.60E+00	-1.62E+00	-1.64E+00
7	1.94E+00	1.97E+00	1.87E+00	1.94E+00	1.91E+00
8	1.94E+00	1.97E+00	1.87E+00	1.94E+00	1.91E+00
9	5.47E+00	5.53E+00	5.40E+00	5.49E+00	5.45E+00
10	5.47E+00	5.53E+00	5.40E+00	5.49E+00	5.45E+00

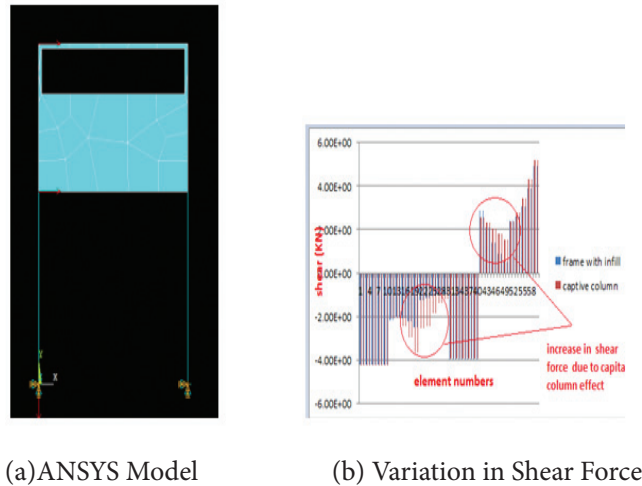


Figure 14. ANSYS Model and variation of shear force.

4. Result and Discussion

During stiffness analysis it was observed that that infill panels increase the stiffness of bare frame by 2.54 times. The increase in initial stiffness, obtained for small strains, can reach 7 times that of bare frame. The result obtained from the strength analysis showed that the provision of infill frames cause rise in the axial forces whereas there is reduction in bending moment.

Thus we can say that the existence of masonry wall can change the structural behaviour from flexural action into axial action. The effects of conversion of flexural action into axial action are as follows:

- Reduction in lateral deformation.
- Increase in axial load in column and foundation.
- Creation of concentrated shears at top and bottom of the column.
- Creation of concentrated shears at beginning and end of beam.
- Creation of shears at foundation.

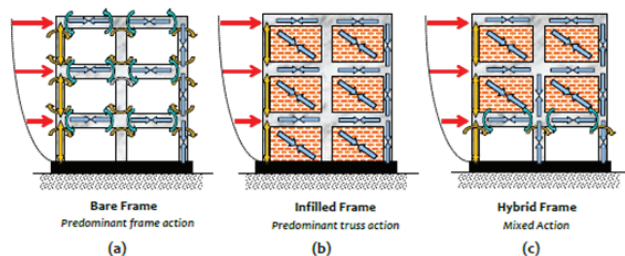


Figure 15. Conversion of flexural behavior to axial behavior.

Spectral behaviour of frame infill composite showed that when the stiffness provided by the infill panel was included in the analysis the structural time period decreased shortly. By stiffening the frame with infill masonry the natural time period of vibration is decreased due to increase in weight. It is visualized that the time period for framed building is 2 to 3 times higher than infill frame composite building. The opening results in an enormous rise in axial force and bending moment in the frame infill composite. With different opening percentage it was realized that as the opening size increases there is fall in axial force and increase in bending moment. By varying 9% opening position in infill it was observed that if the opening is located outside the main diagonal its effect in reduction of strength and stiffness is less as compared to the effect caused by opening along main diagonal. If openings are large and centrally located it may interfere with diagonal bracing action, thereby causing premature shear failure of the sections on either side of diagonal. Thus it is always advisable to provide opening of small sizes located away from the main diagonal. In the Captive Column Analysis it was observed, that part of the column which is just next to an opening behave as a short column, whereas the part of the column which was confined by brick walls did not showed significant movement. The analysis for capital column showed that there is increased shear demand at element 18-25 and 40-45 which are near the opening.

5. References

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