Seismic Performance Evaluation of RC Frame Building With Infill Walls

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Abstract- *Masonry infill walls, which generally have high stiffness and strength, significantly affect the seismic response of reinforced concrete frame buildings. Before the introduction of IS 1893 (Part I)-2016 practice of structural design in India was to consider masonry infill panels as non-structural elements and their strength and stiffness was neglected. As per IS 1893(Part I):2016 for RC frame buildings with unreinforced masonry infill walls, it is mandatory to consider the effect of infill walls in calculating storey stiffness and strength of buildings. The state-of-the-art research work considers infill walls as either finite element models (shell elements) or equivalent single strut models. But both these methods do not represent the actual behaviour of infill walls during an earthquake. The partial contact of infill with the reinforced concrete frame can be represented by an equivalent 3- strut model. For the sake of comparison an eight storied reinforced concrete frame building is analyzed and designed as bare frame model and infill frame; walls modeled as equivalent 3-struts. Linear dynamic analysis is performed using ETABS 2015. The effects of modeling brick masonry infill walls on time period of structure, base shear, bending moments in beams and columns, axial forces in columns and storey displacements are determined in the present study for various seismic zones. Results illustrate that the structural response reduces considerably when the effect of infill walls is considered, because most of the lateral forces are then transferred to the infill walls as axial forces.*

Keywords- Bare frame, Infill frame, Masonry infill walls, 3-strut model, Seismic Zone, Response spectrum

I. INTRODUCTION

Reinforced concrete (RC) frame buildings with masonry infill walls are widely constructed for commercial, industrial and multi storey residential uses in various seismic regions of India. In such buildings the primary function of external walls is to protect the occupants from environmental hazards and internal walls are used to create partitions. Masonry infill typically consists of bricks or concrete blocks constructed between beams and columns of a reinforced concrete frame. The masonry infill panels are generally not considered in the design process and are treated as architectural (non-structural) components. But in reality, the presence of masonry infill walls has a significant impact on the seismic response of a reinforced concrete frame building, increasing structural strength and stiffness (relative to a bare frame). It changes the lateral load transfer mechanism from predominant frame action to truss action [1] as shown in Figure 1.1.

Properly designed infills can increase the overall strength, lateral resistance and energy dissipation of the structure. An infill wall reduces the lateral deflections and bending moments in the frame, thereby decreasing the probability of collapse.

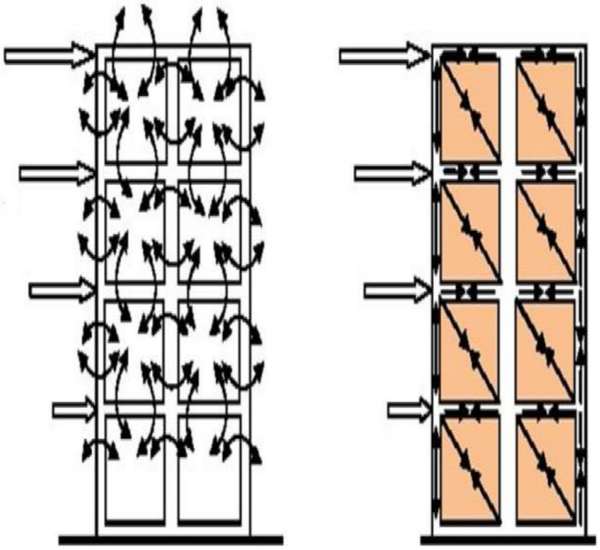


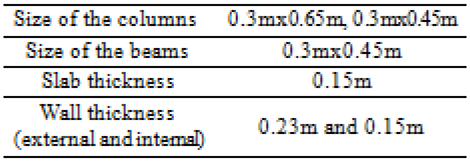
Figure 1.1: Change in lateral-load transfer mechanism due to masonry infill

The suitability of a model for masonry infills in RC frames is judged depending upon several factors, namely, time required and effort involved in modelling, ability to model lateral stiffness and strength of infill frame, and ability to model failure modes in not only infills but also in RC members of the frame [1]. The 3-strut model is a better choice than the other models because of its simplicity over the finite element models, and its effectiveness in predicting the realistic force resultants and modes of failure in RC frame elements as compared to the 1-strut model. Under lateral forces when strut action develops, a finite area of infill is physically connected to the beams and columns of the frame. This finite area can be effectively modelled using a 3-strut model [2]. In case of frames with full height masonry infills, FEMA 356 also recommends evaluating the effect of strut compression forces applied to the columns and the beams, eccentric from the beam column joint. Modulus of elasticity of brick masonry plays an important role for modelling of brick infill walls. The elastic modulus of masonry 'E_m', is taken from an experimental study as E_m=550f'_m MPa, where f'_m is the masonry prism strength in MPa [3]. Transfer of bending moments from RC frame to masonry is prevented by specifying moment releases at both ends of the struts [4]. The present study investigates the variation in percentage of reinforcement of RC frame building with brick masonry infill walls (Infill Frame) for different earthquake zones. The variation in percentage of reinforcement without brick masonry infills (Bare Frame) is also obtained for different earthquake zones for comparative study. The effects of modelling brick masonry infill walls on time period of structure, base shear, bending moments in beams and columns, axial forces in columns and storey displacements are determined in the present study for various seismic zones.

II. MODELLING OF BUILDING IN ETABS 2015

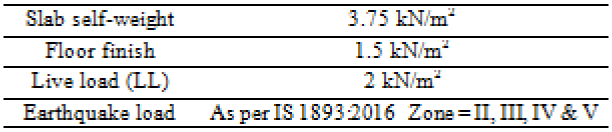
Each span in the plan is of 4 metres which consequently results in each floor area of 256 square metres and the number of storeys is eight (G+7), with the first storey designated as ground storey. The height of ground storey is 3.5 metres whereas that of other storeys is 3 metres, since it is a common practice to use the ground storey for commercial purpose. Grade of concrete and reinforcement is M30 and HYSD500 respectively. Modulus of elasticity for masonry is 4200Mpa. Schedule of structural members and loading data are shown in Tables 2.1 and 2.2 respectively. For dynamic analysis importance factor and response reduction factor are taken as 1 and 5 respectively. Elevation of the building and nomenclature used for beams and columns in analysis and design are shown in Figures 3.1 and 3.2 respectively. For the purpose of comparison, at each location, the cross sectional dimension of beams and columns are kept same in all the zones. The gravity loading (DL and LL) data also remains unchanged. So the only varying factor is earthquake load. The three dimensional (3D) view of the bare frame and infill frame model is shown in Figures 2.3 and 2.4 respectively.

Table 2.1: Schedule of Structural members



Size of the columns	0.3mx0.65m, 0.3mx0.45m
Size of the beams	0.3mx0.45m
Slab thickness	0.15m
Wall thickness (external and internal)	0.23m and 0.15m

Table 2.2: Loading Data



Slab self-weight	3.75 kN/m^2
Floor finish	1.5 kN/m^2
Live load (LL)	2 kN/m^2
Earthquake load	As per IS 1893:2016 Zone = II, III, IV & V

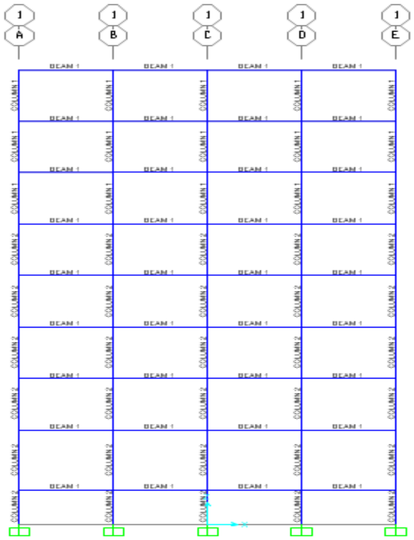


Figure 2.1: Elevation of the building

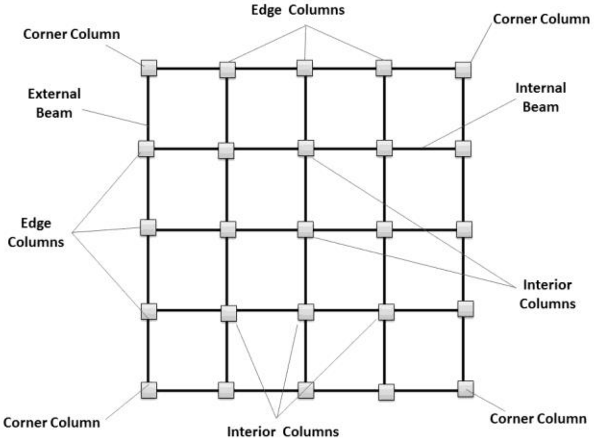


Figure 2.2: Nomenclature used for beams and columns

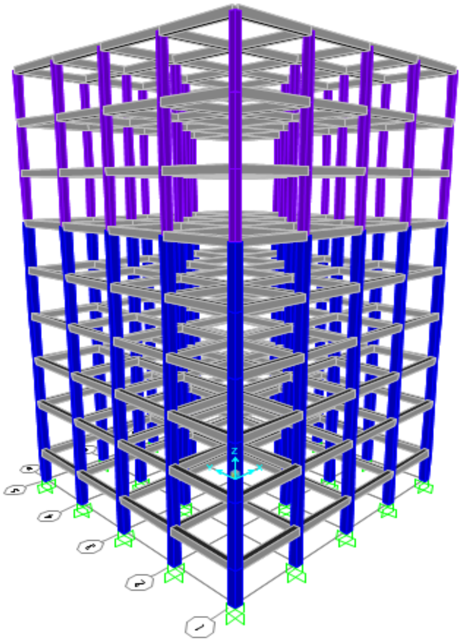


Figure 2.3: 3D view of Bare frame model

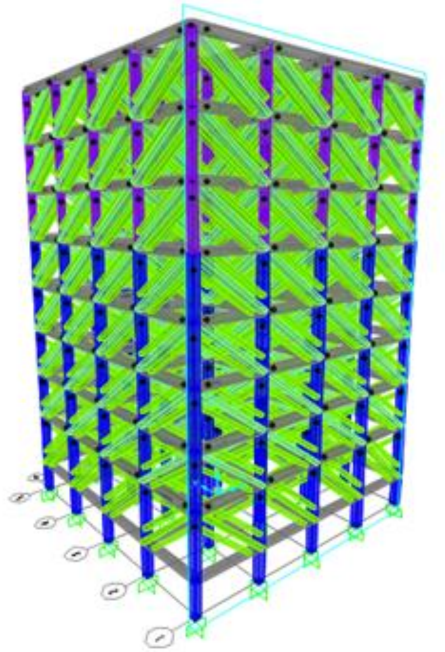


Figure 2.4: 3D view of Infill frame model

2.1 Load Combinations

The load combinations shown in Table 2.3 are used in the seismic analysis, as per *IS 1893-2016, Clause 6.3.1.2*. Earthquake load is considered in +X and +Y directions.

Table 2.3: Load Combinations

1.5 (DL+LL)	1.2(DL+LL-EQY)	1.5(DL-EQY)	0.9DL-1.5EQY
1.2(DL+LL+EQX)	1.5(DL+EQX)	0.9DL+1.5EQX	
1.2(DL+LL-EQX)	1.5(DL-EQX)	0.9DL-1.5EQX	
1.2(DL+LL+EQY)	1.5(DL+EQY)	0.9DL+1.5EQY	

2.2 Modeling of Brick Masonry Infill Walls

For equivalent 3-strut model, width of central diagonal strut is one-eighth of the diagonal length of wall, and width of off-diagonal struts is half the width of the diagonal strut. In this way, total width of all equivalent struts considered is one-fourth of the diagonal length of wall [2].

In the 3-strut model, location of equivalent struts is an important parameter. Out of the three struts, the off-diagonal struts are connected to the columns at the center of the distance α_m known as the vertical length of contact between infill and column as shown in Figure 2.5, suggested in the literature as:

$$\alpha_m = \frac{\pi}{2} \sqrt[4]{\frac{4E_c I_c h_m}{E_m t \sin(2\theta)}} \qquad \text{(i)}$$

where E_c and E_m are modulus of elasticity of concrete and masonry material in MPa, respectively, I_c is moment of inertia of column section in mm^4, h_m and *t* are height and thickness of masonry infill wall in mm, respectively, and θ is angle in degrees of inclination of the equivalent diagonal strut with the horizontal.

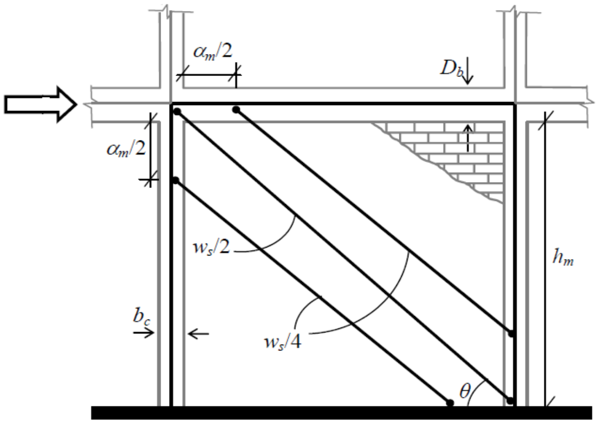


Figure 2.5: Details of 3-strut model for masonry infills

III. RESULTS AND DISCUSSIONS

Natural periods of the Bare Frame (BF) and Brick Masonry Infill Frame (IF), calculated from modal analysis are shown in Figure 3.1 for the nine modes considered. The final Base shears for the two frames are shown in Figure 3.2 for various seismic zones. For IF natural time period is smaller and it attracts higher base shear as compared to BF. Time period decreases with increase in mode number and base shear increases with higher seismic zone.

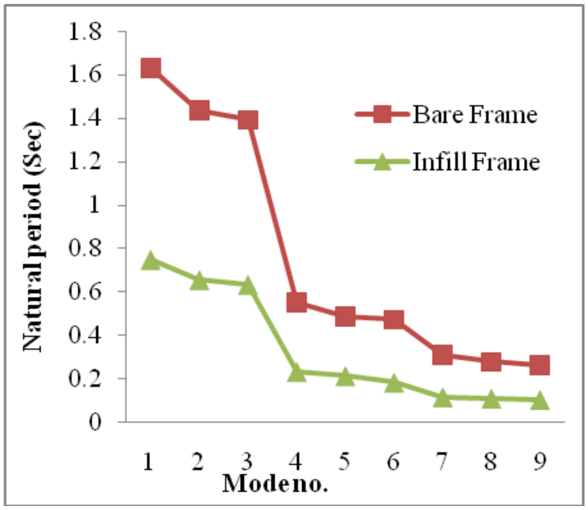


Figure 3.1: Variation of Natural period for different seismic zones

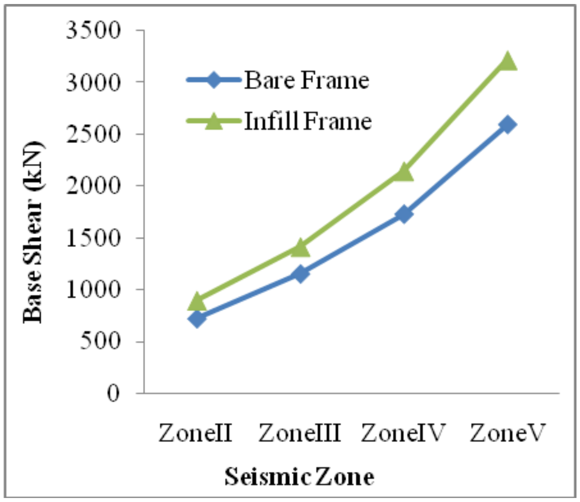


Figure 3.2: Variation of Base Shear for different modes

Comparisons of bending moments in beams and columns for both the frames for different types of loading are shown in Figures 3.3 and 3.4 respectively. The bending moments in the beams at mid-span location are higher for BF as compared to IF. The increment in mid-span bending moment of an IF beam is very negligible as the zone changes. Similar behaviour as mid-span is also observed in case of support bending moments, i.e. they are higher in case of BF as compared to IF. The bending moments at supports in beams of BF are almost 2.5 times of IF. Bending moments in columns of IF are higher as compared to BF at all the locations of columns, due to the shear from strut action of infill. The difference is maximum for corner columns and minimum for interior columns.

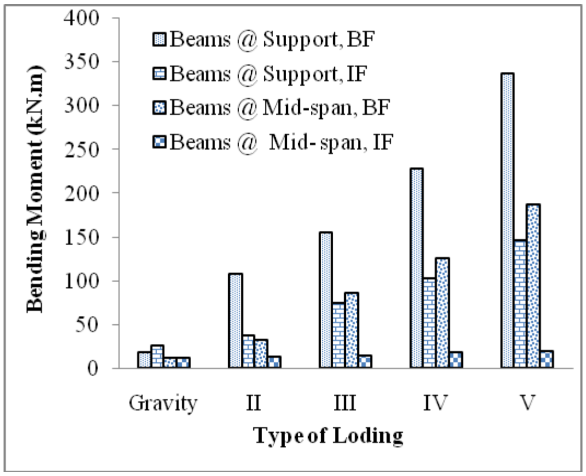


Figure 3.3: Comparison of Bending moments in Beams for different types of loading

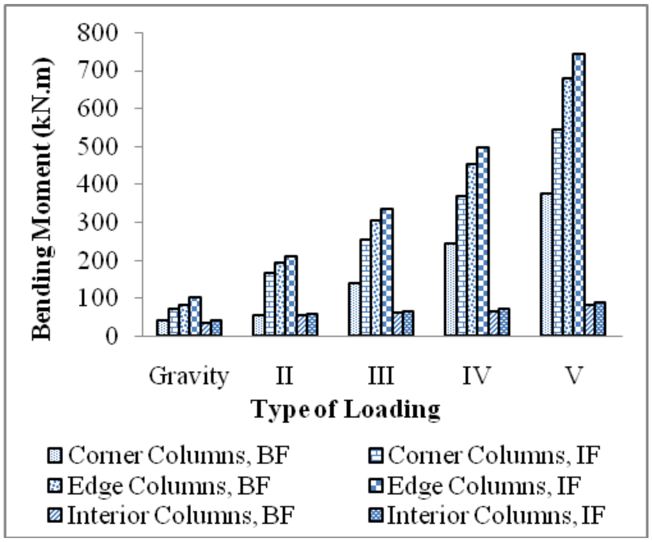


Figure 3.4: Comparison of Bending moments in Columns for different types of loading

Comparison of axial forces in columns for the BF and IF are shown in Figure 3.5 for different types of loading. For lateral loads due to earthquake, the axial forces are higher in columns of IF as compared to BF due to strut action. This is true for all the locations of column. The difference between axial forces of BF and IF is maximum at corner column location and minimum at interior location. Variations in storey displacements for BF and IF are shown in Figure 3.6.

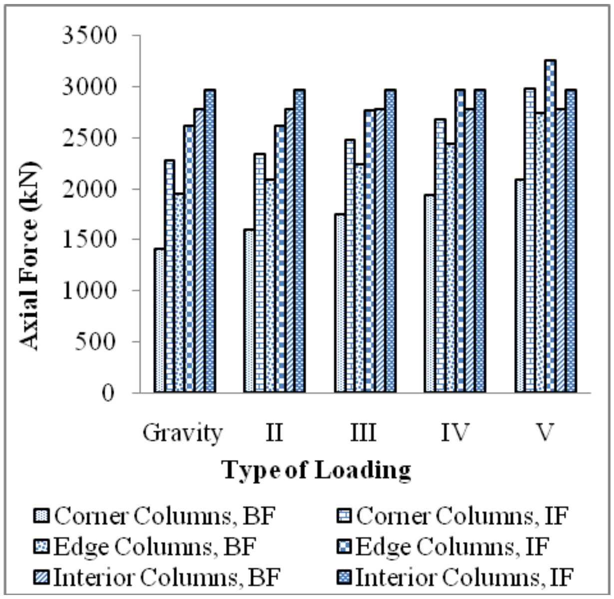


Figure 3.5: Comparison of Axial forces in Columns for different types of loading

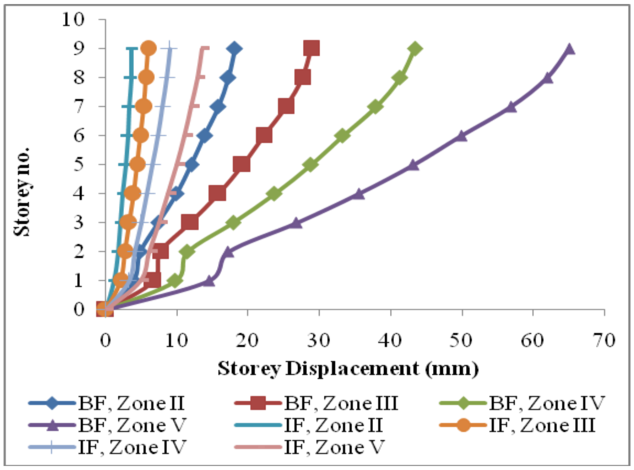


Figure 3.6: Variation of storey displacements for different seismic zones

The variation in percentage of reinforcement for beams and columns are shown in Figures 3.7 and 3.8 respectively for different types of loading. At support and mid-span location of beams of the BF, the percentage of reinforcement is high as compared to IF for all the seismic zones. At support location of beams the variation in percentage of reinforcement is 0.17% to 1.64% for BF and 0.17% to 0.81% in case of IF for seismic zones II to V. The variation in percentage of reinforcement for columns is 1.04% to 5.4% for BF and 1.37% to 6.2% for IF for seismic zones II to V. The percentage of reinforcement in columns of Zone V is above the allowable limit (4%), as the same size is used in all the zones for the sake of comparison.

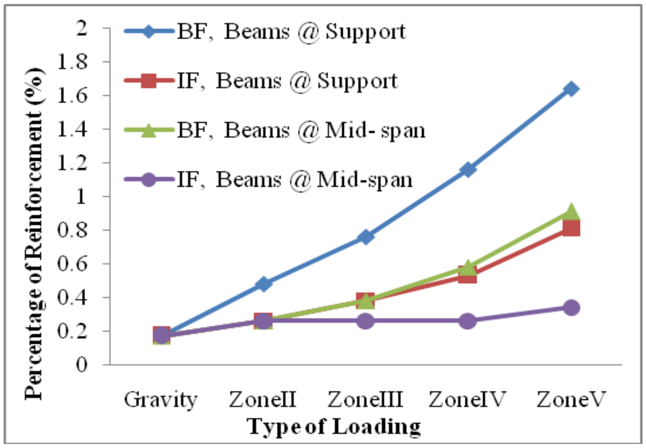


Figure 3.7: Variation in Percentage Reinforcement for Beams in different seismic zones

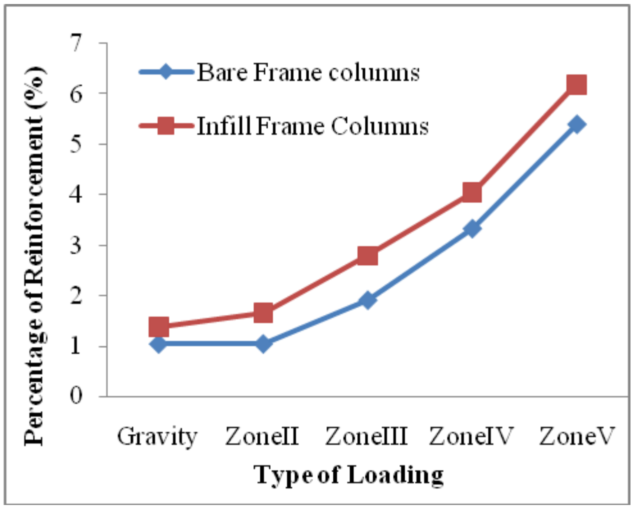


Figure 3.8: Variation in Percentage Reinforcement for Columns in different seismic zones

IV. CONCLUSIONS

The following conclusions have been made based on the present study:

- The time period of the first mode of vibration for the frame with infills is 0.748sec, whereas, for the bare frame it is 1.633sec. This reduction in time period is due to the increased stiffness of the frame with infill. Similar behaviour is observed for higher modes.
- The fundamental period calculated from empirical formula of IS 1893:2016 for frame with infills is 0.62 sec. The modal period of bare frame is 1.63 sec and that of infill frame is 0.75 sec. Hence it can be concluded that the effect of stiffness of infill walls is considered in the IS code empirical formula, but only for calculating the base shear.
- The base shear increases by around 23.79% for the frame with infills as compared to the bare frame. This

is due to higher stiffness of infill frame as compared to bare frame.

- The top storey displacements, in all the seismic zones, are reduced by around 79.26% in frame with infills when compared to that of bare frame.
- Percentages of reinforcement in Beams of IF are very less as compared to BF. Percentages of reinforcement are slightly higher in Columns of IF as compared to BF.
- Shape of the columns should preferably be square, so that they can economically resist the bending moment and shear due to strut action of infills in both the directions.
- Hence, accounting for infills in the analysis and design leads to slender frame members, thereby reducing the overall cost of the structural system.

V. ACKNOWLEDGEMENT

The authors acknowledge Department of Civil Engineering, Dr. Vithalrao Vikhe Patil College of Engineering, Ahmednagar for providing various facilities during the completion of this work.

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