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Performance of Reinforced Concrete Frame with Masonry Infill under Dynamic Loads

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Abstract: Infill panels are widely used as interior partitions and external walls in buildings, but they are usually treated as non-structural elements and in a lot of cases their stiffness is not included in the reinforced concrete design. While performing the evaluation of existing reinforced concrete buildings, to know the actual behavior of structure, effect of infill need to be incorporated in seismic evaluation. The masonry infill has been modeled as an equivalent diagonal structural element using Main-stone theory. Pushover analysis has been carried out on bare frame and frame with infill. The result shows that infill, if present in all storeys, gives a significant contribution to the energy dissipation capacity. Seismic performance assessments indicate that, the infill frame has the lowest collapse risk and the bare frame is found to be the most vulnerable to earthquake-induced collapse. The diagonal strut has been modeled using E-tabs software and pushover analysis is performed. The example building is analyzed; the effect of masonry infill in seismic evaluation of bare frame and frame with masonry infill is studied. The results obtained from the analysis are compared in terms of strength and stiffness with bare frame.

***Keywords:** Seismic performance, dynamic loads, masonry infill, Pushover analysis, Main-stone theory*

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1. Introduction

Reinforced concrete (RC) frame buildings with masonry infill walls have been widely constructed for commercial, industrial and multi-family residential uses in seismic-prone regions worldwide. Masonry infill typically consists of brick masonry or concrete block walls, constructed between columns and beams of a RC frame. These panels are generally not considered in the design process and treated as non-structural components. In country like India, Brick masonry in-fill panels have been widely used as interior and exterior partition walls for aesthetic reasons and functional needs. Though the brick masonry infill is considered to be a nonstructural element, but it has its own strength and stiffness. Hence, if the effect of brick masonry is considered in analysis and design, considerable increase in strength and stiffness of overall structure may be observed. Present code, IS 1893(Part-I): 2000 of practice does not include provision of taking into consideration the effect of infill. It can be understood that, if the effect of in-fill is taken into account in the analysis and design of frame, the resulting structure may be significantly different. Significant experimental and analytical research is reported in various literatures, which attempts to explain the behavior of in filled frames [1].

Moreover, in-fill, if present in all storeys gives a significant contribution to the energy dissipation capacity, decreasing significantly the maximum displacements [9]. Therefore the contribution of masonry is of great importance, even though strongly depending on the characteristics of the ground motion, especially for frames which has been designed without considering the seismic forces. When sudden change in stiffness takes place along the building height, the storey at which this drastic change of stiffness occurs is called a soft storey. According to IS 1893(Part-I): 2000 [10], a soft storey is the one in which the lateral stiffness is less than 50% of the storey above or below.

Another important issue is related to the numerical simulation of in-filled frames. The different techniques for idealizing this structural model can be divided into two, local or micro-models and simplified macro models [9] [15]. The first group involves the models, in which the structure is divided into numerous elements to take into account of the local effect in detail, whereas the second group includes simplified models based on a physical understanding of the behavior of the in-fill panel. In this paper the strength and stiffness of the brick masonry in-fill is considered and the brick masonry in-fill is modeled using diagonal strut. The diagonal strut is designed in such a way that it carries only compression. The diagonal strut has been modeled using in E-Tabs software and pushover analysis is performed. The major objective of the paper is to model the brick in-fill panel as equivalent struts using E-Tabs software. The analysis is performed using “Non-linear static analysis” for understanding the improvement in stiffness parameters. The results obtained from the analysis are compared in terms of strength and stiffness with bare frame results.

1.1 Modeling of Infill Panel

A method based on equivalent diagonal strut approach for analysis and design of in-filled frames subjected to in-plane forces was proposed in various literatures [2, 3, 8, 12, 13]. The state-of-art indicates that the constrictive relation of the strut element has been developed only for the single strut model. Fig.1 shows the details of equivalent strut model.

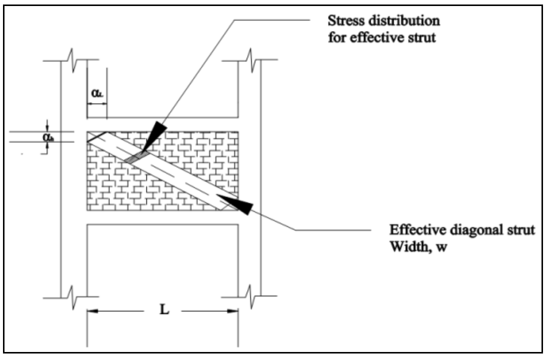

***Fig 1** Equivalent diagonal strut*

Currently, only single strut model suggested by Mainstone [7, 1, 8] is used in non-linear static analysis of RC frames with in-fill walls. The formulation for calculating the equivalent width of diagonal strut is given by expression,

$$w = 1.414\alpha_h$$

$$\alpha_h = \frac{\pi}{2\lambda_h} \qquad \lambda_h = \sqrt[4]{\frac{E_m t \sin 2\theta}{4E_c I_c h}}$$

Where,

W = Equivalent Diagonal width
E_m = Young's modulus of Masonry
θ = Angle whose tangent is the In-fill Height to length aspect ratio
t = Thickness of Masonry Infill
h= Height of masonry Infill
E_c = Young's modulus of concrete
I_c= Moment of Inertia of concrete

1.2 Design and Analysis of Infill

A typical ten storey multi-family residential building, with five bays in longitudinal as well as in transverse direction is considered as shown in Fig. 2. The grade of concrete used isM20 and that for steel is Fe415. As per IS: 456: 2000, the modulus of elasticity is taken as5000(*fck*)0.5. The unit weight of concrete and Poisson's ratio are taken as 25kN/m^3 and 0.2 respectively. For masonry *Emf, is taken as* 550*fm,* where *fm*is characteristics strength of brick in-fill taken as 4.0 N/mm^2. Floor and roof slab is taken as 150mm thick. The external and internal wall thickness is taken to be 230mm and115mm thick respectively. The live load on roof and floors are taken to be 1.5kN/m^2 and 3.5 kN/m^2 respectively. Sizes of beam are 400x500mm and that of columns are 400x400mm. The building is located in zone V.

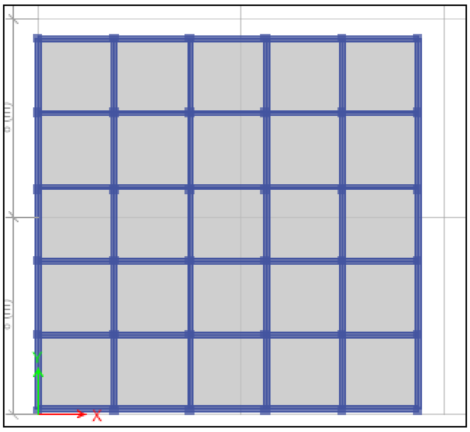

***Fig 2 (a)** Plan of frame*

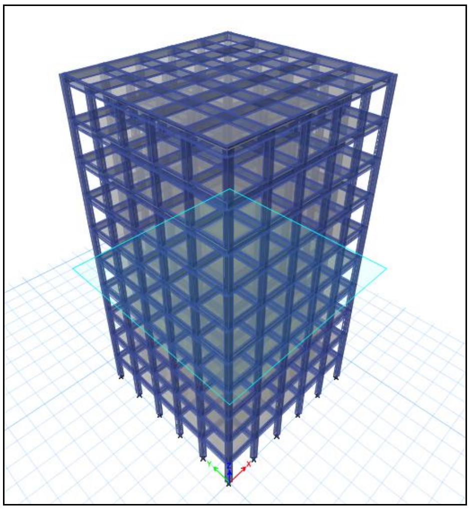

***Fig 2 (b)** Elevation of frames*

2. Methodology of the Present Work

Non-linear static analysis is the method used for determining the earthquake response of the structural systems. This method varies in methodology as nonlinear static pushover analysis and nonlinear dynamic time history analysis. In this study, nonlinear static pushover analysis is used to determine earthquake response of the structure using E-Tabs software. Pushover analysis can be performed using Forced controlled and Displacement control. In forced controlled method of analysis, a pre-defined load patterns are applied on the structure and results are obtained. But due to this "pre-defined" load pattern actual behavior cannot be determined.

In displacement controlled method the target displacement as specified by FEMA, is applied at the top nodal point and the results are obtained. From the literature [6], displacement controlled results are found more convenient, hence in this paper displacement controlled method of analysis is being used. Displacement-controlled pushover analysis is performed on three-dimensional building. The rigid floor diaphragm two-way action of slab is considered. The proportion of floor loads is taken to be the first lateral mode shape, which is obtained for free vibration analysis of building model as specified byIS1893(Part-I): 2002. This is valid for the buildings with fundamental period of vibration up to about1.0 sec

While performing a pushover analysis, a target displacement of 0.04H is specified as the limit for the roof displacement. (Here, H is the height of the building). The capacity spectrum ordinates, namely spectral acceleration S_a, and spectral displacement S_d can also be obtained from the capacity curve. For pushover analysis, beams and columns were modeled with concentrated plastic hinges for flexure and shear at the column and beam faces, respectively. Beams have both moment and shear hinges, whereas columns have axial load and biaxial moment hinges and shear hinges in two directions. The normalized moment-rotation relation for the hinges were obtained from IS 456:2000 [16]. In this paper a default hinge properties is being considered. It is being observed from literature review that there are about 5% variations in results obtained from default and user defined hinge properties [13].

3. Results and Discussions

The example building is analyzed; the effect of masonry infill in seismic evaluation of bare frame and frame with infill is studied. In this section the results obtained from the analysis performed on the eight storey bare frame and frame with infill are discussed.

3.1 Fundamental Time Period of Buildings

Fundamental natural time period of frames, as per IS 1893(Part-I): 2002 and as per analysis using E-tabs software are shown in Table 1. It is seen that, the time period of frame with infill has been decreased by 30% as compare to bare frame. Thus, the effect of earthquake on structure is considerably reduced. The comparison of time periods indicated that, the empirical formula gives lower time period thus imposes large base shear on building.

***Table1:** Fundamental Time Period in Sec*

Standard	In-Filled Frame		Bare Frame	
	In-Plane	Out-of-Plane	In-Plane	Out-of-Plane
Indian Code	1.035	1.173	1.434	1.434
Using Software	1.548	1.434	2.123	2.123

3.2 Effect of Variation of Infill Amount on Storey Displacements

The displacement of buildings at various storey levels is shown in Table 2. These displacements are also plotted for both buildings. The infill act as equivalent diagonal strut which is responsible to increases the storey stiffness. From Fig3, it is clear that the inclusion of effect of infill drastically decreases the storey displacements. The whole building sways like an inverted pendulum with maximum sway concentrated in the ground storey in case of bare frame. The ground story columns act as the pendulum rod while the rest of the building acts as a rigid pendulum mass. As a consequence, large movements occur locally in the ground storey alone, thereby inducing large damage in the columns during an earthquake.

3.3 Comparison of base shear

Base shear is a very important parameter for seismic evaluation of buildings. In the present study, shear developed at the base of the building due to response spectrum load for no in-fill condition and in-fill condition has been evaluated and compared. The results are shown in Fig.4. Although the result indicates that the presence of in-fill, there is a significant increase in total base shear carrying capacity of in-fill frame as compare to bare frame. For ten storied building base shear increases by about 30 percent.

4. Conclusions

Effect of unreinforced masonry in-fill on seismic behavior of RC frame buildings has been studied by performing Push-Over analysis. It is observed that masonry infill have significant effect on dynamic characteristics, stiffness, strength and seismic performance of buildings. IS: 1893-2002 gives highly conservative time period formula for in filled frame buildings.

***Table2:** Displacement at Various Storey Level*

Storey	*Frame Without In-Fill Displacement (mm)*	*Frame With In-Fill Displacement (mm)*
0	0	0
1	83.41	49.96
2	103.51	62.42
3	123.42	76.41
4	150.65	90.64
5	170.71	109.46
6	184.64	121.41
7	202.68	134.34
8	224.42	147.32
9	228.31	151.63
10	231.68	156.34

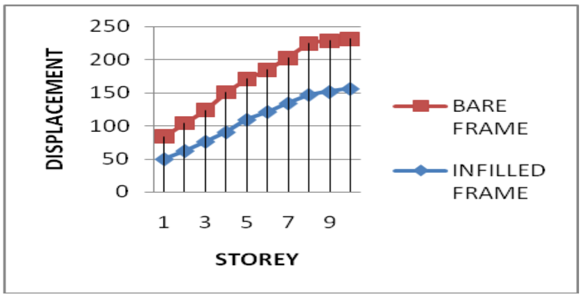

***Fig3:** Displacement for Bare Frame and Frame with Infill*

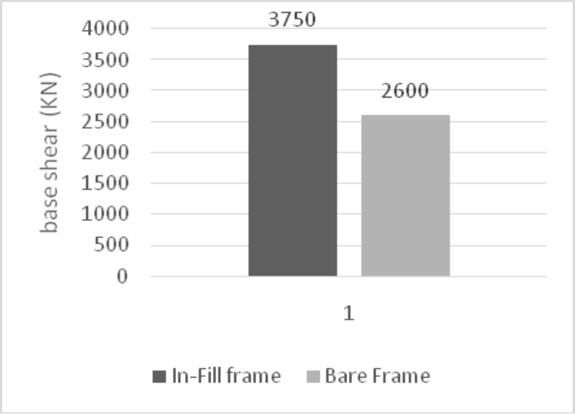

Fig4: *Comparison for Ultimate Base shear*

It was observed from the study that the without in-fill, structure showed early formation of plastic hinges and structures failed at an early load stage itself. Whereas the masonry in-filled 3D structure showed a delayed formation of plastic hinge and improving the lateral capacity of the structure.

The locations of plastic hinges are changed and generally the damage contributions in different storey are also changed, thus the in-fill walls prevents the damages concentrated in top storey and has a positive effect on damage contributions in all directions. As expected, the presence of in-fill can guarantee higher overall stiffness and strength, reducing the inter-storey drift demand of the structure.

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