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Pushover analysis of Multi-storied RC Buildings with and without Openings in Infill Walls

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Abstract—*Masonry infill which is considered as a non-structural element increases initial stiffness and strength of reinforced concrete (RC) frame buildings. Many urban multi-storey building in India today have open first storey as an unavoidable feature. This is primarily being adopted to accommodate parking or reception lobbies in the first storey. This open first storey is also termed as "Soft Storey". These provisions reduce the stiffness of the lateral load resisting system. The masonry infill walls will have openings such as doors and windows which are inevitable parts of any structure. In the present study, it is attempt to access the performance of masonry infilled reinforced concrete (RC) frames with open first storey of with and without opening. In this paper, symmetrical (G+3) RC frame building located in seismic zone-V is considered by modelling of initial frame. With reference to FEMA-273, & ATC-40 which contain the provisions of calculation of stiffness of infilled frames by modelling infill as a "Equivalent diagonal strut method". The pushover analysis is to be carried out on the models such as bare frame, and strut frame with openings, which is performed by using computer software SAP2000 from which different parameters are computed. Pushover analysis is carried out for either user-defined nonlinear hinge properties or default-hinge properties, available in some programs based on the FEMA-356 and ATC-40 guidelines. The pushover analysis shows the pushover curves. This non-linear static analysis gives better understanding and more accurate seismic performance of buildings of the damage or failure element. The study has found that infill panels increase the stiffness of the structure. While the increase in the opening percentage leads to a decrease on the lateral stiffness of infilled frame and the fundamental natural periods are longer and earthquake force carrying capacity reduces marginally.*

Keywords*: Multi-storey buildings; soft storey; infill walls as a diagonal strut; Pushover analysis; SAP2000*

1. INTRODUCTION

There are a large number of buildings in India which are constructed with reinforced concrete (RC) frames and with un–reinforced masonry infill panels for architectural design and other functional requirements. The infill panels are classified as non-structural elements and these structures are designed by considering them as dead load and neglecting any kind of stiffness and strength of infill panels because the bond between masonry infill and reinforced concrete frames is negligible [1]. However, the presence of infill walls has a significant structural contribution by improving the stiffness, strength against any kind of lateral loads [2]. Mulgund and Kulkarni (2011) showed the comparison in performance of a RC bare frames and frames with various infill combinations by considering a G+6 building modelled using ETABS 9.5 software. They concluded that using RC frames without any regard to infill leads to underestimation of base shear [3]. The infill panels of multi-storeyed buildings with soft ground storey were modelled as single strut method for obtaining the structural behaviour [4]. Strength and drift demand of columns of RC-framed buildings with soft-ground storey were investigated by Haque and Amanat (2008). 6, 9 and 12 storeyed buildings models were analysed by providing 0%, 10%, 30%,

50%, and 70% infills. Infills on upper floor were modelled as diagonal struts keeping the ground floor free of infills. They found that total base shear and design column shear and moments on open ground floor are significantly magnified. [5]

The presence of openings for the purpose of doors and windows in the infill for major and functional requirements of the buildings. With the increasing of the percentage of openings in infill walls increase the flexibility of the building [6].

This paper analyzes the effect masonry infill on seismic performance of RC buildings combine with different percentages of openings.

2. MODEL DESCRIPTION

A three-dimensional four-storeyed reinforced concrete frame buildings with plan and elevation as shown in *Fig. 1* and *Fig. 2* is considered. The building is assumed to be located in earthquake zone V with highest seismicity as per Indian code [7]. The stress-strain relationship is used as per IS 456: 2000. [8]. The brick masonry infill walls are modelled as pin-jointed equivalent diagonal struts. M3 (Moment) foe beam, PM3 (axial force with moment) for the column as default hinge properties, and P (Axial force) for strut as user defined hinge properties assigned at rigid ends of the beam, column, and strut elements. The density of concrete and brick masonry is 25 and 20 kN/m^3 respectively. Young's modulus of concrete and brick masonry is taken to be 22360 MPa and 5625 MPa. Poison's ratio of concrete is 0.2. Different percentages of openings (10% to 40% of central openings) are considered for the performance analysis by SAP 2000 [9].

- Model 1 - Modelled as bare frame,
- Model 2 –In filled wall considered without opening and soft storey assumed.
- Model 3 - 10% opening considered.
- Model 4 - 20% opening considered.
- Model 5 - 30% opening considered.
- Model 6 - 40% opening considered.

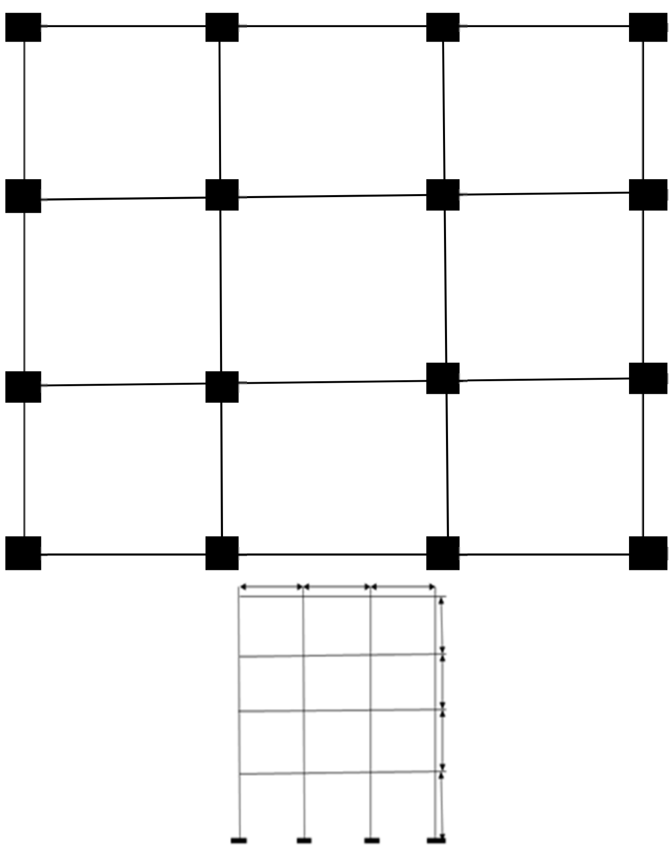

Fig. 1: Plan and elevation of the Bare frame.

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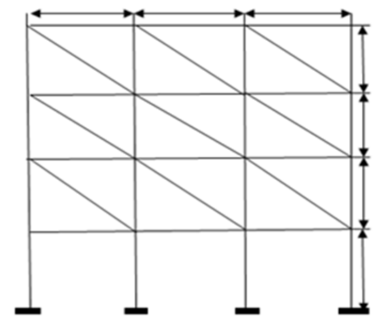

Fig. 2: Elevation of models with infill wall and soft storey considered.

TABLE I.

Properties of the Reference RC Frame Model	
Parameters	**Values**
Dimension of beam	*300 X 400 mm*
Length of the bay	*5 m*
Dimension of column	*450 X 450 mm*
Floor to floor height	*3.5 m*
Ground storey height	*4.5 m*
Seismic Zone	*V*
Grade of Concrete	*M20 and Fe415*
Unit weight of RCC	*25kN/m^2*
Unit weight of Masonry	*20 kN/m^2*
Imposed Load	*2 kN/m^2 roof and 4 kN/m^2*
Terrace water proofing	*2 kN/m^2*
Floor Finish	*1 kN/m^2*
Depth of slab	*125 mm*
Height of parapet wall	*1 m*
Clear cover of beam and column	*20 mm and 60 mm*
Brick wall thickness	*250 mm*

MATHEMATICAL MODELLING

Dead Load Calculation of Slab

- Terrace Level---

Total Load per metre length = 30.625 KN/m

- Floor Level ---

Total Load per metre length = 20.625 KN/m

Live Load Calculation of Slab

- Terrace Level---

Total load per metre length = 10KN/m

- Floor Level ---

Total Load per metre length = 20 KN/m

Dead Load Calculation of Wall

Total load per metre length = 22.5 KN/m

A. Equivalent Diagonal Strut Modeling Of Infill Walls without Opening

One of the most common methods of infilled walls is on the basis of pin jointed equivalent diagonal strut i.e. the system is modelled as like a braced frame and infill walls as web element. The main thing in this approach is to find the effective width for the pin jointed diagonal strut. Here I used the following formula proposed by mainstone. [10]

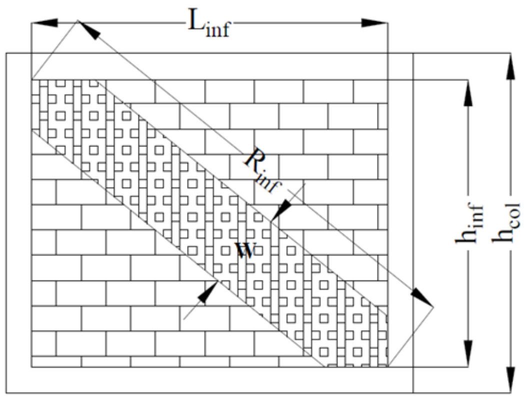

Fig. 3: Strut model analogy of in-filled frame

w = 0.175 $(\lambda H)^{-0.4}$ D Where, $\lambda = \sqrt[4]{\frac{E_i t \sin 2\theta}{4E_f h I_c}}$

λ = Stiffness reduction factor= 0.98612

E_i = Modulus elasticity of masonry infill

= 5625000 kN/m^2

E_f= Modulus elasticity of frame

= 22360000 KN/m^2

I_c = Moment of inertia of columns = 0.003417 m^4

$\theta = \frac{h_{inf}}{l_{inf}}$

D = diagonal length of infill

Width of diagonal strut, W = 0.577

B. Equivalent Diagonal Strut Modeling of Infill Walls with Opening.

The findings of the present study using the finite-element method, conduct to the following relationship for the infill wall stiffness reduction factorλ.

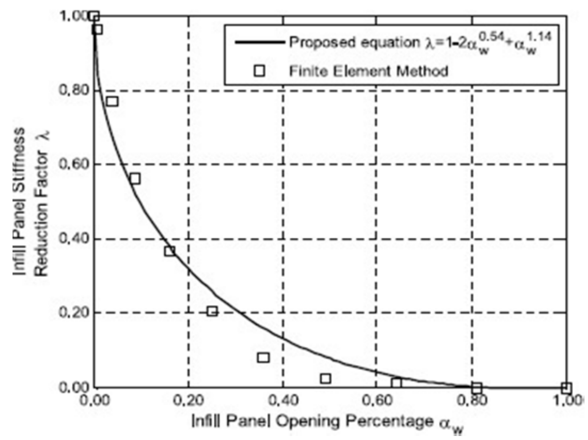

Fig. 4: Stiffness reduction factor λ vs. infill panel opening percentage α_w

$$\lambda = 1 + \alpha^{1.14} - 2\alpha^{0.54}$$

In which α^w is the infill wall opening percentage (area of opening to the area of infill wall).

C. Pushover Analysis

Pushover analysis is one of the important methods available to understand the behaviour and vulnerability of structures subjected to earthquake loads. The non-linear static analysis is an improvement with the compare of the linear static or dynamic analysis in the sense that it allows the inelastic behaviour of the structure [11]. The methods assume a set of static incremental lateral load over the height of the structure. The method is relatively simple to be implemented and provides information on the strength, deformation and ductility of the structure and the distribution of demands. The loads are monotonically increased until the peak response of the structure is obtained on a base shear vs. roof displacement plot which is called pushover curve. Researchers have developed several pushes over analysis methods. This paper considers the procedures prescribed by FEMA 306[12]. Maximum displacement equal to 4% of the height of the building at roof level and a number of steps in which this displacement must be applied are defined. Pushover curve is a base shear versus roof displacement curve, which enlightens about the shear force developed at the base of the structure at any stage of push.

D. Element Description of SAP 2000

Frame element in SAP2000 is modelled as a line element having linearly elastic properties and nonlinear force-displacement characteristics, individual frame elements are modelled as hinges represented by a series of straight line segments.

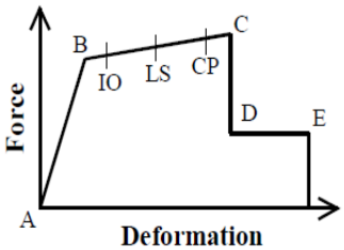

Fig. 5: Force-Deformation for Pushover Hinge

Point A represents the unloaded condition and point B corresponds to yielding of the element. The ordinate at C represents the nominal strength and abscissa at C represents the deformation at which significant strength degradation begins. The drop from C to D represents the initial failure of the element and resistance to earthquake loads beyond point C is unreliable. The residual resistance from D to E allows the frame elements to sustain gravity loads. Beyond point E, the maximum deformation capacity, gravity load can no longer be sustained there are three types of hinge properties given in SAP2000. They are default hinge properties, user-defined hinge properties and generated hinge properties.

3. RESULTS AND DISCUSSIONS

Fig. 6 shows lateral displacements of model with different percentages of openings. It is predicted that lateral displacement at roof level of the building increases with the increase in the openings percentages. These results refer to higher flexibility in the buildings with an increase in percentage of openings.

The ratio of base force and displacement at the performance point is known as the global stiffness of the structure. Fig. 7 shows the stiffness variation with different percentage of openings. It is estimated that the base shear increase with the consideration of infill Again it decreases with decrease in opening percentages.

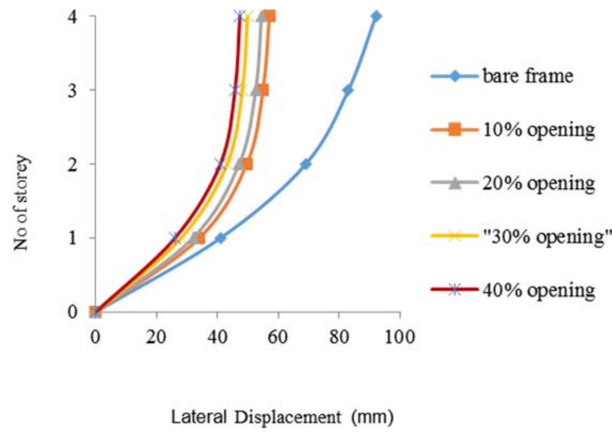

Fig. 6: No of Storey vs. Lateral Displacement

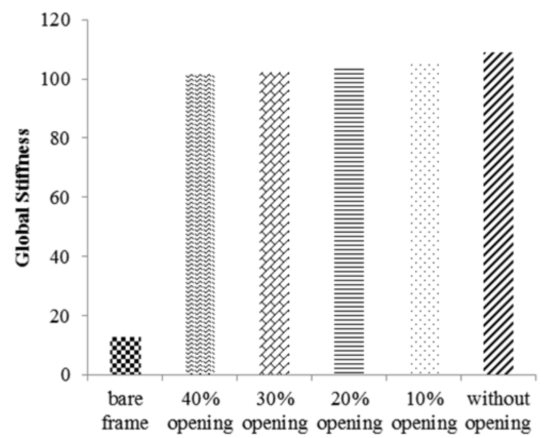

Fig. 7: Variation of global stiffness with different percentages of openings

Fig. 8 shows variation of global stiffness with different percentage of openings. As the percentage of openings increases the fundamental time periods are also longer indicating that stiffness has decreased (Fig 9).

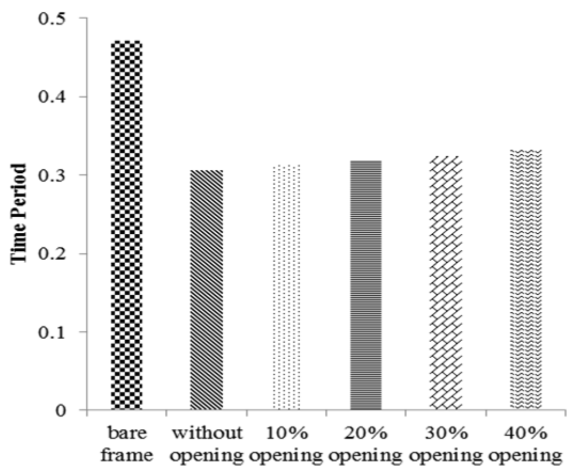

Fig. 8: Variation of time period with different percentages of opening

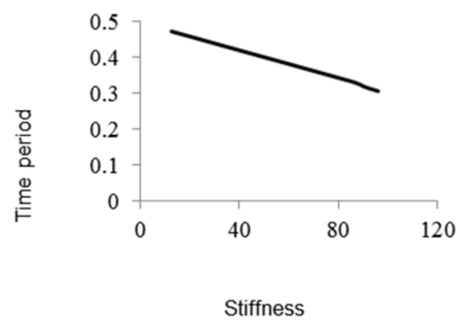

Fig. 9: Time period vs. global stiffness

Fig. 10 shows the base shear vs. lateral displacement. The base shear of the bare frame is low at the same lateral displacement when compared with the infilled frame.

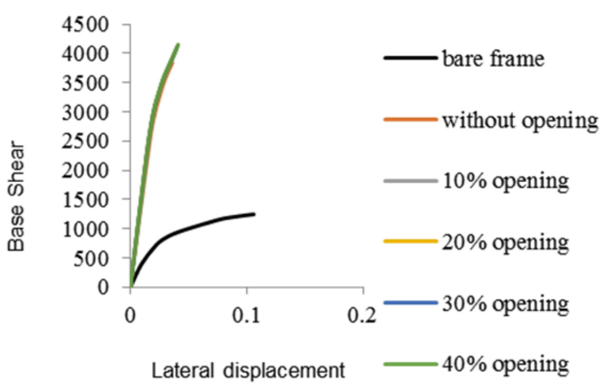

Fig. 10: Comparison of pushover graph

4. CONCLUSION

The performance of RC buildings with infill and openings is investigated by using pushover analysis. Following conclusions are estimated.

i) Lateral displacement at roof level of the building increases with the increase in the openings percentages.

ii) The base shear increase with the consideration of infill. Again it decreases with decrease in opening percentages.

ii) As the percentage of openings increases the fundamental time periods increases which shows increase in openings increase the flexibility.

iii) The base shear of the bare frame is low at the same lateral displacement when compared with the infilled frame

Hence consideration of infills and openings are quite essential for seismic design by passing which may under estimate the seismic forces.

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