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Effects of Openings in Shear Wall on Seismic Response of Structure

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ABSTRACT
The paper investigates the effects of openings in shear wall on seismic response of structures. For parametric study 6 and 12 storied 7x3 bays apartment buildings with typical floor plan of 35mx15m and floor height of 3m with different openings size and location in shear walls were modeled in STAAD pro. An equivalent static analysis for three dimensional models of the buildings was performed as per IS 1893 (part 1): 2002. Seismic responses of the analyzed structures were compared. The results reveal that for opening area < 20%, the stiffness of the system is more affected by the size of openings than its arrangement. However, for opening area >20%, the stiffness of the system is significantly affected by openings configuration in shear walls.

***Keywords* -** Openings in shear wall, Stiffness of shear wall, Seismic response.

I. INTRODUCTION

Shear walls are introduced in modern tall buildings to make the structural system more efficient in resisting the horizontal loads that arises from wind and earthquake. The introduction of shear wall represents structurally efficient solution to stiffen a building structural system. The main function of shear wall is to increase the rigidity of lateral load resistance.

II. OBJECTIVE OF THE STUDY

Shear walls in apartment buildings may have rows of openings that are required for windows in external walls or for doors ways or corridors in internal walls. The size and location of openings may vary from architectural and functional point of view. It may have adverse effect on stiffness of shear wall as well as on the seismic response of frame-shear-wall structures. Relative stiffness of shear walls is important since lateral forces are distributed to individual shear wall according to their relative stiffness. Thus, the main objective of this study is to study the effects of openings & its configurations in shear wall on seismic response of the buildings.

III. STIFFNESS/RIGIDITY OF SHEAR WALL

The stiffness/rigidity of a shear wall in a given direction (R_x or R_y) is defined as a force required per unit displacement in the given direction. Varyani (2002) states that the deflection (Δ_x) of a wall element regarded as a deep cantilever beam fixed at base due to a shear V_x applied in x direction at a height h′ from top is composed of deflection due to bending and shear (Figure 1). The deflection (Δ_x) is given

$$\Delta_x = \frac{V_x h^3}{3EI_y} + \frac{V_x h' h^2}{2EI_y} + \frac{1.2\,V_x h}{A_y G} \qquad (1)$$

Where,

E = modulus of elasticity of material of shear wall
$G = \frac{E}{2(1+\nu)}$ = shear modulus of material of shear wall
I = moment of inertia of shear wall about the axis of bending
A = area of web about the axis of bending
Δ = deflection due to applied shear in a given direction
h = height of shear wall element
h′ = height of applied shear above the top of wall element

Assuming Poisson’s ratio ‘ν’ = 0.17 and V acts at the top of shear wall making h′ = 0, the rigidity of the wall element in x direction is given by:

$$R_x = \frac{V_x}{\Delta_x} = \frac{1}{\dfrac{h^3}{3EI_y} + \dfrac{2.81h}{A_y E}} \qquad (2)$$

Similarly, the rigidity of the wall element in y direction is given by:

$$R_y = \frac{V_y}{\Delta_y} = \frac{1}{\frac{h^3}{3EI_x} + \frac{2.81h}{A_xE}} \quad (3)$$

3.1. Solid rectangular shear wall

For solid rectangular shear wall with t << L

$$I_y = \frac{L^3t}{12} \quad (4)$$

$$I_x = \frac{Lt^3}{12} \approx 0 \quad (5)$$

Substituting the above values in Eq. (2), the rigidity of shear wall in the direction of its length R_x (say R)

$$R_x = \frac{Et}{\frac{4h^3}{L^3} + \frac{2.81h}{L}} \quad (6)$$

From definition, $R = \frac{1}{\Delta}$

$$\Delta_{\text{solid wall}} = \frac{\frac{4h^3}{L^3} + \frac{2.81h}{L}}{Et} \quad (7)$$

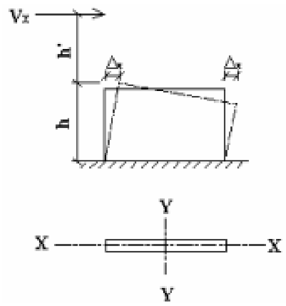


Fig.1:- Deflection of cantilever shear wall

3.2. Shear wall with opening

Piers in a wall formed by openings may be regarded as fixed at both ends as shown in Figure 2. The bending deflection term h3/3EI will be reduced to h3/12EI, as presented in Eqs. (2) and (3) (Varyani, 2002). The rigidity of a pier in the direction of its length is given by:

$$R = \frac{Et}{\frac{h_o^3}{l^3} + \frac{2.81h_o}{l}} \quad (8)$$

Displacement of pier is thus given by :

$$\Delta_{\text{pier}} = \frac{\frac{h_o^3}{l^3} + \frac{2.81h_o}{l}}{Et} \quad (9)$$

Where,
h_o = height of opening
l = length of pier

The rigidity of wall with openings may be calculated neglecting the effects of the axial shortening of piers by judicious use of the principles of series and parallel. End condition of solid strip is not clearly mentioned.

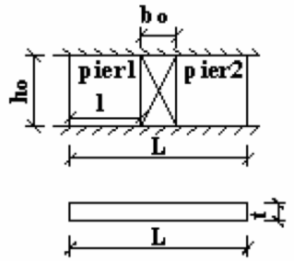


Fig.2:- Wall element fixed at both ends

Neuenhofer (2006) developed finite element algorithm to calculate the stiffness of shear walls with opening. It was implemented in computing package MATLAB to investigate the accuracy of simplified method. The results from finite element analysis were compared with that calculated using the simplified method in which fixed-fixed action was assumed for solid strip. Error in the simplified method for the stiffness of wall with small aspect ratio was found remarkably higher that that obtained from wall with higher aspect ratio.

The end condition of solid strip for the present study was assumed as fixed-fixed same as pier. Thus, the displacement of solid strip was calculated using the relation:

$$\Delta_{\text{solid strip}} = \frac{\frac{h_o^3}{L^3} + \frac{2.81h_o}{L}}{Et} \quad (10)$$

Likewise, displacements of pier 1 and pier 2, as shown in Figure 2 were calculated using the Eq. (9), and the combined displacement of piers was obtained using the relation:

$$\Delta_{\text{piers}} = \frac{1}{\frac{1}{\Delta_{\text{pier1}}} + \frac{1}{\Delta_{\text{pier2}}}} \quad (11)$$

Hence $\Delta_{\text{wall}} = \Delta_{\text{solid wall}} - \Delta_{\text{solid strip}} + \Delta_{\text{piers}}$ (12)

The rigidity of wall with opening is given by:

$$R_x = \frac{1}{\Delta_{\text{wall}}} \quad (13)$$

IV. RESPONSE OF SHEAR-WALL STRUCTURE WITH OPENINGS IN SHEAR WALL

To study the effects of size and location of openings in shear walls on seismic response of buildings, three dimensional FEM models of 6 and 12 storied 7x3 bays frame-shear-wall buildings with typical floor plan of 35mx15m (Figure 3) and floor height of 3m were developed in the structural analysis program STAAD pro. Beams and columns were modeled using beam elements. Shear walls and floor slabs were modeled as plate elements and rigid diaphragms respectively.

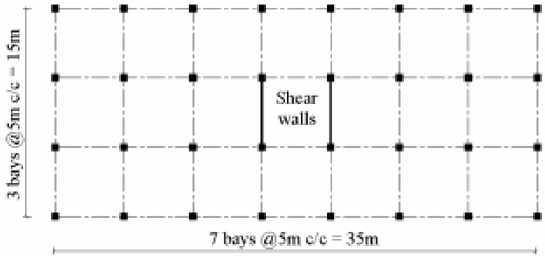


Fig.3:- Typical floor plan for 6 and 12 storied buildings

The buildings were assumed as apartment buildings with dual system (shear wall and special moment resisting frame), situated in seismic zone V. Preliminary design of the structural elements modeled in the buildings, was performed based on gravity loads and imposed loads according to IS 875 (Part 2): 1987. Lateral loads due to earthquake were calculated using seismic coefficient method given in IS 1893 (Part1): 2002, in which Importance factor (I) = 1, Zone factor (Z) = 0.36 and Response reduction factor (R) = 5 were used. After several analyses in STAAD Pro., using an equivalent static lateral force analysis for various load combinations as per IS 1893 (Part 1): 2002, final dimensions of the member elements for further analysis were obtained. The maximum percentage of reinforcement was limited to 4% of concrete gross area as per IS 456: 2000, assuming concrete grade of M25 for all structural elements. Maximum story drift was limited to 0.004 times the story height.

Horizontally centered door openings of 2.1-m height, were increased from 14% to 35% varying the door width ‘b_o’. Similarly, window openings of 2 m width, located at 0.6m from floor level, were increased from 16% to 28% varying the opening height ‘h_o ’, to study the effects of openings configurations in shear wall on seismic responses of the frame-shear-wall structures. Door openings of 1m x 2.1m were located at different horizontal distance ‘e_h’ from the edge of shear wall. Similarly, window openings of 2m x 1.2m were located at different vertical distance ‘e_v’ from floor level, to see the effects of openings location. For the structural analysis, lateral load due to earthquake was applied in the direction parallel shear walls.

Rates of increase in top displacements and decrease in base shears in shear walls were found relatively the same for both 6 and 12 storied buildings. Thus, only the results of 6-story buildings are presented in this paper as presented in Figures 4 to 9.

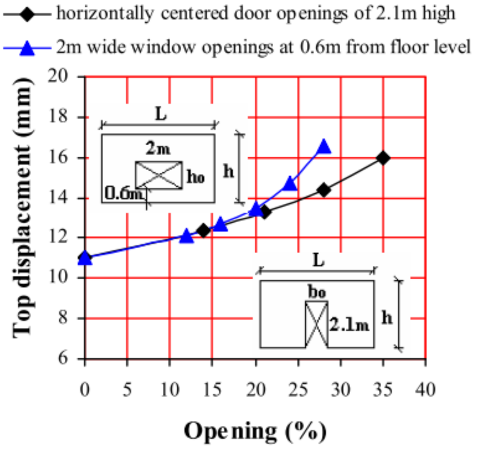


Fig.4:- Top displacement of 6-story building

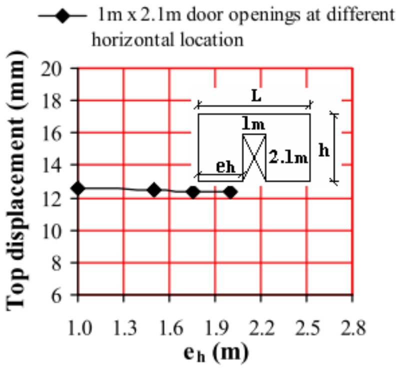


Fig.5:- Top displacement of 6-story building

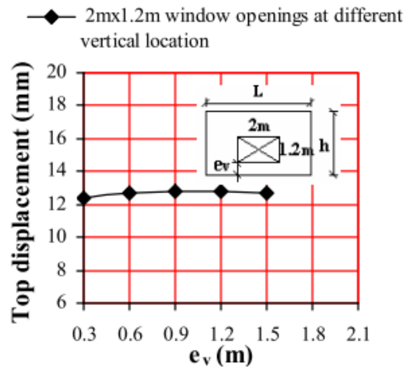


Fig.6:- Top displacement of 6-story building

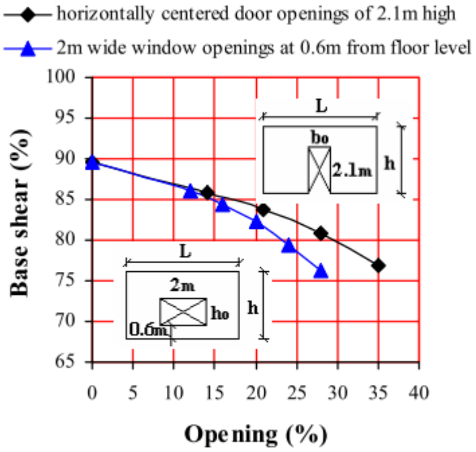


Fig.7:- Base shear in shear walls of 6-story building

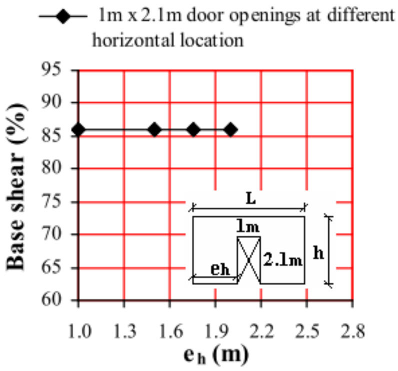


Fig.8:- Base shear in shear walls of 6-story building

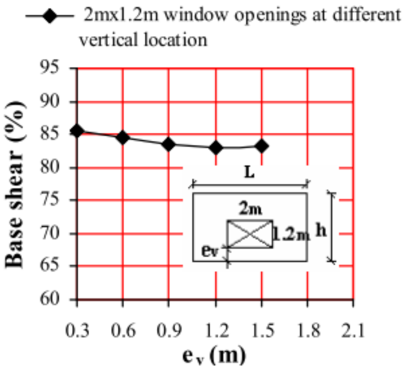
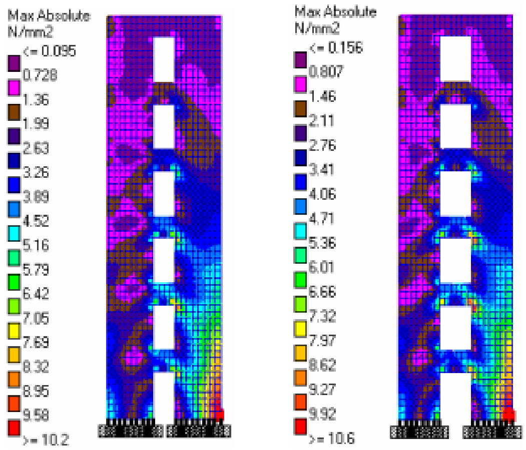


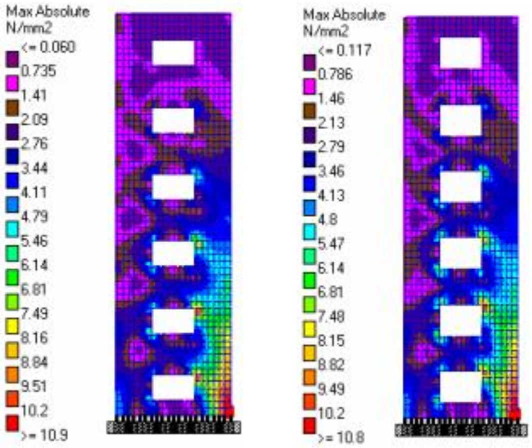
Fig.9:- Base shear in shear walls of 6-story building

The results indicate that the stiffness of the system decreases with increase in openings sizes in the shear walls. The stiffness of the frame-shear-wall structures is not only affected by the width of openings in the shear walls, but also affected by the height of openings in shear walls. For the shear wall with opening area less than 20% of the wall area, the percentage increase in top displacement of the system is almost same for different opening arrangements in the walls. Shear walls with horizontally centered doors give almost same stiffness as windows of equal area horizontally centered at 0.6m from floor level, for openings area less than 20%. However, opening configurations in shear walls has significant effects on the stiffness of the system when the opening area in the shear walls is larger than 20%. Figure 4 shows that the top displacement of the 6-story building with door openings of 28% in each story level is about 14.5mm where as it is 16.5mm with same opening area of windows at 0.6m from floor level. Thus, the difference between top displacements of the buildings with two different configurations is 14% for same opening area. The vertical location of window openings has been found to be more sensitive than the horizontal location of door openings, in reducing the stiffness the system.

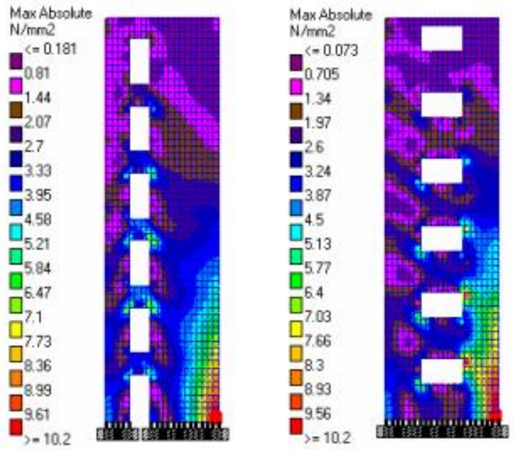
The absolute maximum principle stress diagrams as presented in Figure 10 show that arrangement of the opening area < 20% has negligible effect on maximum absolute stress and its location in shear wall. However, the maximum absolute stress at opening corners increases significantly as the opening size increases.



(a) Horizontally centered door openings of different size



(b) Window openings of different size at 0.6m from floor level



(c) Door openings at 1m from edge of wall and window openings at 1.5m from floor level

Fig.10:- Maximum absolute principle stress distribution in shear wall with different size and location of doors and windows in shear walls

V. CONCLUSION

From the results it is concluded that for opening area < 20% of shear wall area, the stiffness of shear-wall structure is more affected by the size of openings than their arrangement in the shear walls. However, for opening area>20% of shear wall area, the stiffness of the system is significantly affected by the openings arrangement in shear walls. Effects of horizontal location of door openings of size 1m x 2.1m can be neglected on the stiffness of the system. However, vertical location of window opening significantly affects the stiffness of the system.

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