Seismic Analysis of RC Shear Wall Frame Buildings with and Without Openings in Shear Wall

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Abstract - *The paper investigates the effects of openings in shear wall on seismic response of structures. For parametric study 15 storied 4mx5m bays apartment buildings with typical floor plan of 25mx12m and floor height of 3m with different openings size and location in shear walls were modeled in ETABS-2015. An equivalent dynamic 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 < 15%, the stiffness of the system is more affected by the size of openings than its arrangement. However, for opening area >15%, the stiffness of the system is significantly affected by openings configuration in shear walls.*

Key Words: Openings, Shear wall, Stiffness, Seismic response, Rigidity, Modifier

1. 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.

2. 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.

3. 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;

$$\Delta_x = \frac{V_x h^3}{3EI_y} + \frac{V_x h' h^2}{2EI_y} + \frac{1.2V_x h}{A_y G} \qquad (01)$$

Where,
E = modulus of elasticity of material of shear wall
G = E/2(1+ν) = 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:

$$R_x = \frac{V_x}{\Delta_x} = \frac{1}{\frac{h^3}{3EI_y} + \frac{2.81h}{A_y E}} \qquad (02)$$

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

$$R_y = \frac{V_y}{\Delta_y} = \frac{1}{\frac{h^3}{3EI_x} + \frac{2.81h}{A_x E}} \qquad (03)$$

3.1. Solid rectangular shear wall

For solid rectangular shear wall with t << L

$$I_y = \frac{L^3 t}{12} \qquad (04)$$

$$I_x = \frac{L t^3}{12} \approx 0 \qquad (05)$$

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

$$R_x = \frac{Et}{\frac{4h^3}{L^3}+\frac{2.81h}{L}} \qquad (06)$$

From definition, R = 1/Δ

$$\Delta_{soild\ wall} = \frac{\frac{4h^3}{L^3}+\frac{2.81h}{L}}{Et} \qquad (07)$$

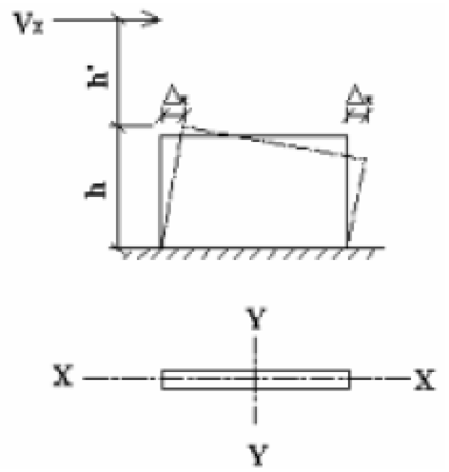

Fig -1: Deflection of cantilever shear wall

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 $h^3/3EI$ will be reduced to $h^3/12EI$, as presented in Eqs. (2) and (3) (Varyani, 2002). The rigidity of a pier in the direction of its length is given by:

$$R = \frac{Et}{\frac{{h_o}^3}{l^3}+\frac{2.81h_o}{l}} \qquad (08)$$

Displacement of pier is thus given by :

$$\Delta_{pier} = \frac{\frac{{h_o}^3}{l^3}+\frac{2.81h_o}{l}}{Et} \qquad (09)$$

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.

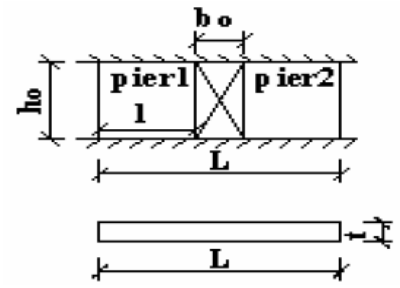

Fig -2: Wall element fixed at both ends

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:

$$\Delta_{soild\ strip} = \frac{\frac{{h_o}^3}{L^3}+\frac{2.81h_o}{L}}{Et} \qquad (10)$$

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:

$$\Delta_{pier} = \frac{1}{\frac{1}{\Delta_{pier1}}+\frac{1}{\Delta_{pier2}}} \qquad (11)$$

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

The Rigidity of wall with opening is given by;

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

4. 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, Seventeen building models with 15 storeys having same floor plan area of 25m X 12m dimensions are considered for this study. The floor plan is divided into 5 bays in X-direction and 3 bays in Y-direction. Centre to centre distance between two grids are 5m in X-direction and 4m in Y-direction. The storey height for the building is taken as 3m for all the floors.

In common practice, floor plan will be same for all floors in apartment buildings. So the building models considered here are having same floor plan in all floors and shear walls at same location for both direction. Shear walls of same section are used for same height of buildings throughout the height. Only the sizes of the openings in shear walls are changed and the locations of opening are changed for a particular size. Table1 & 2 show the sizes and locations of openings used in the shear walls of the proposed typical frame-shear wall structures.

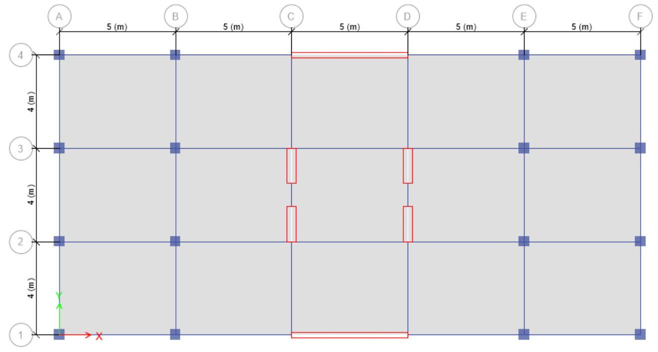

Fig -3: Plan of Building

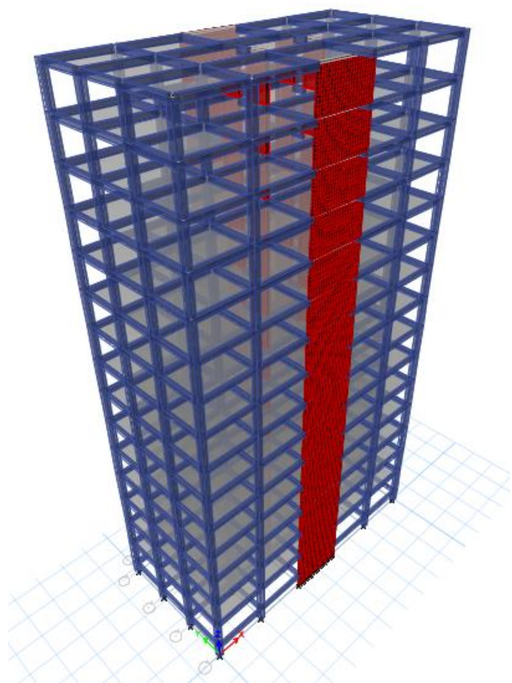

Fig -4: 3D View of Building

The Research work is divided into two parts for the convenience of understanding the effect of opening sizes and locations discretely. In the first part of work the sizes of openings increases and the effects are compared with the shear wall having no openings in the building model. Horizontally centred opening of variable sizes are provided in the wall above the floor level. In the second part of work size of opening is kept constant to a typical door size of 1.2m x 2.25m (i.e. 18% of opening area) but location of opening is changed in horizontal direction with different eccentricities and the results are compared. The eccentricity (e_h) for the opening is taken from centre of wall to centre of opening which increase from 0.25m to 1.25m.

Table -1: Building Models with different opening sizes in shear walls.

MODEL TYPE	OPENING SIZE		OPENING INTENSITY	ECCENTRICITY
	X	Y		
	mm	mm	%	mm
MODEL1	0.0	0.0	0.00	0
Model-2	0.5	0.5	1.67	0
Model-3	1.0	0.5	3.33	0
Model-4	1.5	0.5	5.00	0
Model-5	1.0	1.0	6.67	0
Model-6	1.5	1.0	10.00	0
Model-7	2.0	1.0	13.33	0
Model-8	1.5	1.5	15.00	0
Model-9	2.0	1.5	20.00	0
Model-10	2.0	2.0	26.67	0
Model-11	2.5	2.5	41.67	0

Table -2: Building Models with shear wall having opening size of a standard Door (1.2m x2.25m) at different horizontal positions

MODEL TYPE	OPENING SIZE		OPENING INTENSITY	ECCENTRICITY
	X	Y		
	mm	mm	%	mm
Model-12	1.2	2.25	18.00	0.00
Model-13	1.2	2.25	18.00	0.25
Model-14	1.2	2.25	18.00	0.50
Model-15	1.2	2.25	18.00	0.75
Model-16	1.2	2.25	18.00	1.00
Model-16	1.2	2.25	18.00	1.25

To study the effects of opening all the seventeen building models mentioned above are analysed using standard package ETABS 2015

Primarily the building models were analysed for linear static case i.e. Response spectrum analysis for zone IV and design is checked. Different parameters such as time period, base shear and maximum displacements are compared for these models for linear static case. The response spectrum function considered in the response spectrum analyses. A damping ratio of 5 % is taken in the analyses and the SRSS (Square root of sum of squares) method is used in combining individual modal contributions.

5. RESULTS

It has been observed that by increasing the size of opening has much dominant effect only when the percentage of opening has increase above 15%.

It has been observed that by increasing the size of opening has much dominant effect than by changing the position of opening. The shear wall loses much of its strength when the size is increased above 15% of the opening area. Moreover if the position of opening is in the side of the wall for a larger opening area, it also affects the strength of wall in greater proportion.

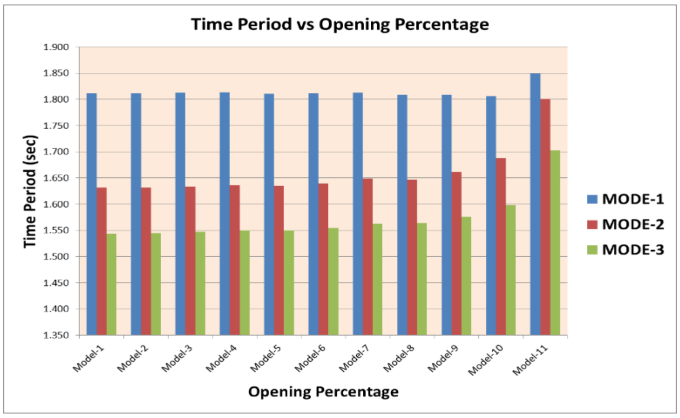

Chart -1: Comparison of different Time Periods vs different opening sizes in shear wall

As we can see in above chart, time period is increasing abruptly just from the Model-8, which has 15% opening size. This increase in time period will lead to get higher value of Sa/g and the same will increase the base shear. This will results higher seismic forces in the structural elements like wall, column and beams. However this effect can be beneficial as well in some case, when the time seismic acceleration curves goes down to reduce Sa/g value.

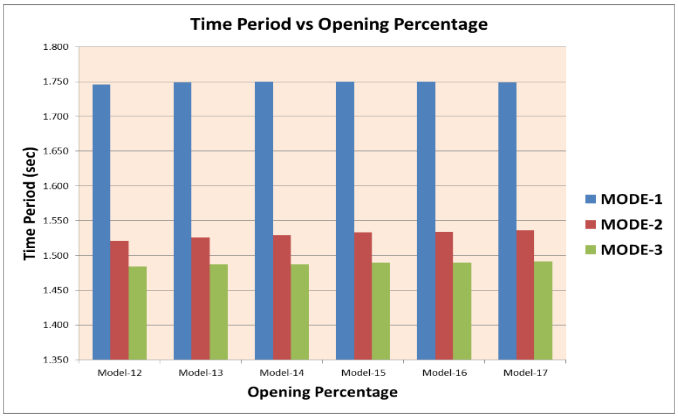

Chart -2: Comparison of different Time Periods vs opening location in shear wall

In the second case (opening with different eccentricity) the time period is not changing much, so the opening location is not so much effective.

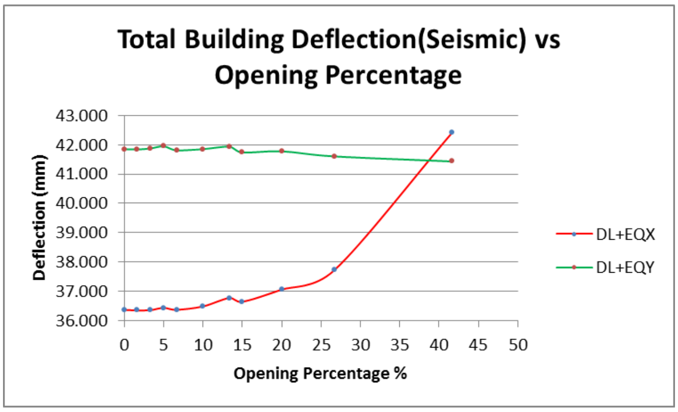

Chart -3: Comparison of total building deflection due to seismic loads vs opening sizes in shear wall

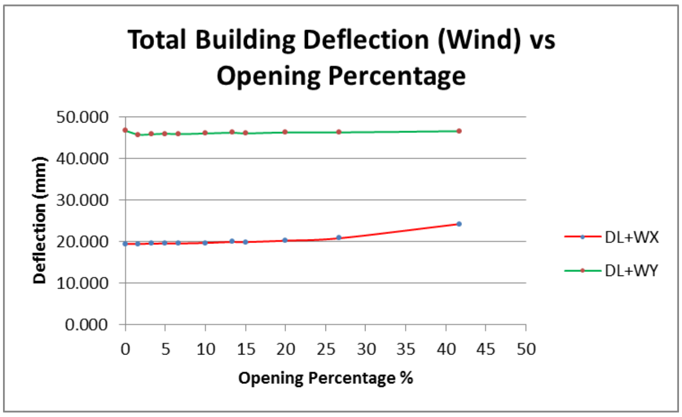

Chart -4: Comparison of total building deflection due to wind loads vs opening sizes in shear wall

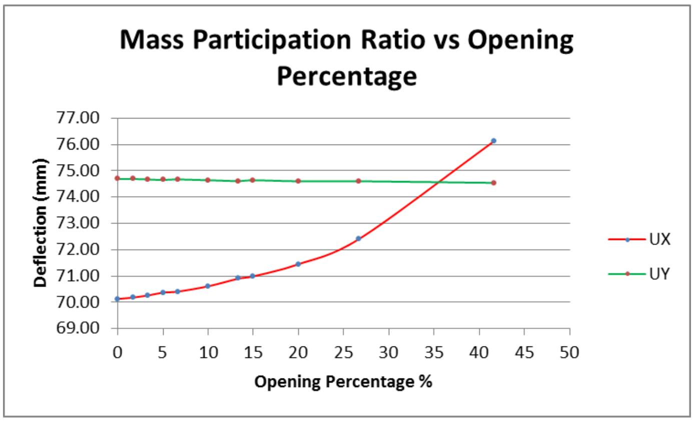

Chart -4: Comparison between building mass participation ratio vs opening sizes in shear wall

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 15% 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 centred doors give almost same stiffness as door of equal area for openings area less than 15%.

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 15%.

Top displacement of the building with door openings of 18% in each story level is about 30.7mm where as it is 32.3mm with same opening area placed with eccentricity of 1.25m. Thus, the difference between top displacements of the buildings with two different configurations is 5.06% for same opening area.

6. CONCLUSION

The response and stiffness of frame shear wall structure is more affected by the size of opening than their locations in shear wall. However the response of the building is better when the openings are provided in the centre of the wall as compared to their eccentric positions. The response and behaviour of frame shear wall structure remains almost similar for an opening up to 15% of shear wall area as that of shear wall with no openings. The values of seismic responses namely time period and maximum displacement are found in increasing order

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