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Research Paper

Effects of opening in shear walls of 30- storey building

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Tall towers and multi-storey buildings have fascinated mankind from the beginning of civilization, their construction being initially for defense and subsequently for ecclesiastical purposes. These tall buildings because of its height, is affected by lateral forces due to wind or earthquake actions tends to snap the building in shear and push it over in bending. In general, the rigidity (i.e. Resistance to lateral deflection) and stability (i.e. Resistance to overturning moments) requirement become more important. Shear walls (Structural walls) contribute significant lateral stiffness, strength, and overall ductility and energy dissipation capacity. In many structural walls a regular pattern of openings has to be provided due to various functional requirements such as to accommodate doors, windows and service ducts. Such type of openings reduces the stiffness of the shear wall to some extent depending on the shape and size of the opening. In the present parametric study, efforts are made to investigate and critically assess the effects of various size of openings in shear walls on the responses and behaviors of multi-storey buildings. The 30 storey Prototype buildings with different types of openings in shear wall with and without incorporating the volume of shear wall reduced in the boundary elements are analyzed using software E-TABS using Response spectrum method (1893(Part-1)-2002) and Time history method.

1 Introduction

Tall towers and multi-storey buildings have fascinated mankind from the beginning of civilization, their construction being initially for defence and subsequently for ecclesiastical purposes. The growth in modern tall building construction, which began in the 1880s, has been largely for commercial and residential purposes due to the rapid growth of the urban population and the consequent pressure on limited space. The high cost of land, the desire to avoid a continuous urban sprawl, and the need to preserve important agricultural production have all contributed to drive residential or commercial buildings upward.

A tall building may be defined as one that, because of its height, is affected by lateral forces due to wind or earthquake actions to an extent that they play an important role in the structural design. High rise building is a structure vertically

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cantilevered from the ground level subjected to axial loading and lateral forces. Lateral forces generated either due to wind blowing against the building or due to the inertia forces induced by ground shaking which tend to snap the building in shear and push it over in bending.

In general, the rigidity (i.e. Resistance to lateral deflection) and stability (i.e. Resistance to overturning moments) requirement become more important. Basically there are two ways to satisfy these requirements in a structure. The first is to increase the size of members beyond and above the strength requirements. The second and more elegant approach is to change the form of structure into something more rigid and stable to confine the deformation and increase stability. But for building taller than 10-stories, frame action obtained by the interaction of slabs and columns is not adequate to give the required lateral stiffness [1]. It also has become an uneconomical solution for tall buildings. However it can be improved by strategically placing shear walls (structural walls) as it very effective in maintaining the lateral stability of tall buildings under severe wind or earthquake loading.

Shear walls contribute to significant lateral stiffness, strength, and overall ductility and energy dissipation capacity. Shear wall is widely adopted because of its strength, stability and stiffness to resist lateral loads. They have considerable stiffness in their own plane but usually very little stiffness in the perpendicular direction and their satisfactory performance depends on the stiffening effect of floor diaphragms, which prevent buckling of walls. In many shear walls a regular pattern of openings has to be provided due to various functional requirements such as to accommodate doors, windows and service ducts. Such type of openings reduces the stiffness of the shear wall to some extent depending on the shape and size of the opening. It is seen that small opening in shear walls do not have much effect on the lateral deflections, whereas larger openings produce larger effects. Shape of openings also plays a significant role [3].

Kobayashi et al. [2] tested 26 wall specimens to examine the effect of small openings on the strength and stiffness of shear walls in rector buildings. The parameter tested were the shape, number of local arrangement of the openings and reinforcing method around the openings. Kim and Lee [3]) had developed out an efficient analysis method that can be used regardless of the number, size and location of openings in shear wall using super elements is derived by introducing fictive beams. Balkaya and Kalkan [4] investigated the load capacity and stress distribution around the openings by conducting three-dimensional nonlinear pushover analyses on typical shear wall dominant building structures. The results of this study indicated that the stress flow and crack patterns around the openings of the 3D cases were drastically different than those computed for the 2D cases. Rai, et al. [5] had studied the importance of shear wall in Tall buildings and investigated the control of damage to buildings by way of increasing the stiffness by providing shear walls and thereby restricting the lateral deflections under the lateral loads. Singh, et al. [6] had carried out a study on a hypothetical 13 storey RC framed building with infill brick panels to investigate the effect of openings in shear walls. Khatami et al. [7] carried out the time history study for 10 storey tall concrete buildings, addressing the effects of openings in concrete shear walls under near fault earthquake ground motions. A building was modelled with three different types of lateral resisting systems: complete shear walls, shear walls with square opening in the centre and shear wall with opening at right end side.

In the present parametric study, efforts are made to investigate and critically assess the effects of various size of openings in shear walls on the responses and behaviours of multi-storey buildings. The lateral displacements and inter-storey drift of the buildings with periphery shear wall and shear wall having different size of openings are evaluated, for two cases (i) without incorporating the reduced volume/area of shear wall opening (ii) the volume of shear wall reduced due to opening is incorporated in the adjacent boundary elements by increasing the dimension of boundary elements. The results thus obtained are compared with bare frame to evaluate the effects of openings on the overall responses of buildings. In the present study, the analyses of buildings is carried out in E-TABS using the methods mentioned below:

1. Response spectrum method (IS:1893-2000) [9]and
2. Time history method

2 Prototype Building and Study Parameters of Structure

The parametric study has been carried out on 30 storey building. The plan dimensions of the considered buildings are 25 m x 25 m and having 5 bays of 5 m lengths in each direction. The floor plan of the building is shown in figure 1. The dimensions of structural members of a typical 30-story symmetric RC frame building were designed for the most critical load combination using the relevant Indian Standards IS 456 [10] and IS 1893[9]. The building consists of an assembly of cast in place reinforced concrete beams of 300mm x 500mm, columns of size 900mm x 900mm for 1-15 storey and 600mm x 600mm for 16-30 storey, Slab Thickness– 150 mm, height of each storey– 3.5m, Shear wall thickness– 250 mm. Concrete Grade- M30, Steel Grade- fy 415 MPa.

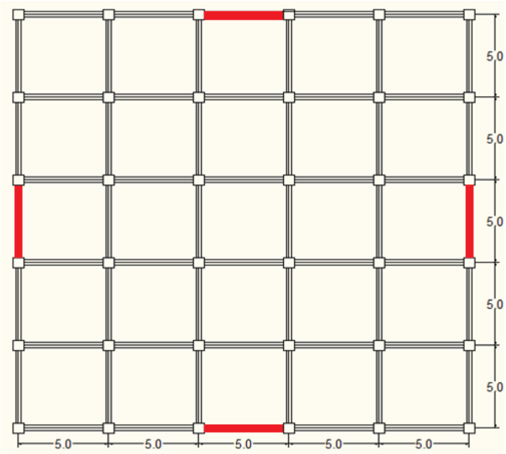


Figure 1: Building Plan

In first case comparison is done between the buildings with shear wall having different size of openings. And in second case volume of shear wall reduced due to openings is incorporated in the adjacent boundary elements by increasing the dimensions of boundary elements. The buildings described in table 1 are considered.

Table 1 - Building Description

Sr. No.	Building Type
1	Bare Frame
2	Shear Wall is provided in the middle bay on building periphery
3	Opening of 2m x 2.1m is provided centrally in shear wall
4	Opening of 2m x 2.8m is provided centrally in shear wall
5	Opening of 3m x 2.1m is provided centrally in shear wall
6	Opening of 3m x 2.8m is provided centrally in shear wall

3 Response Evaluation of Building Having Shear Wall With Openings Without Incorporating Reduced Area

The 30 storey Prototype buildings with different types of openings in shear wall without incorporating the area/volume of shear wall reduced by the opening are analyzed using Response spectrum method as per IS:1893-2000 [9] and Time history method.

3.1 Response evaluation using response spectrum method

The word spectrum in seismic engineering conveys the idea that the response of buildings having a broad range of periods is summarized in a single graph. For a given earthquake motion and a percentage of critical damping, a typical response spectrum gives a plot of earthquake related response such as acceleration, velocity, and deflection for a complete range of a building periods.

Considered prototype building is analyzed using the response spectrum method of IS 1893 (Part-1):2002 assuming building lies in zone V and medium soil below it. The importance factor and response reduction factor is taken as 1 and 5 respectively.

The displacement and drift values obtained from response spectrum analysis are multiplied with a correction factor and which is equal to ratio of base shear of static coefficient method to response spectrum method. Thus, for the considered building the static and the dynamic base shears are as follows. The correction factor for 30 storey building is discussed below in table 2 for Illustrations.

Table 2: Correction Factor.

Sr. No.	Building Type	$V_{B\ Static}$	$V_{B\ Dynamic}$	Correction Factor
1.	Bare Frame	2371.64	2077.2	1.14
2.	Shear Wall is provided in the middle bay on building periphery.	2740.66	2728.81	1.00
3.	Opening of 2m x 2.1m is provided centrally in shear wall	2668.64	2651.36	1.01
4.	Opening of 2m x 2.8m is provided centrally in shear wall	2597.85	2520.12	1.03
5.	Opening of 3m x 2.1m is provided centrally in shear wall	2622.19	2563.7	1.02
6.	Opening of 3m x 2.8m is provided centrally in shear wall	2503.2	2374.72	1.05

3.1.1 Displacements along the lateral direction

Fig. 2 shows the comparison of lateral displacement of 30 storey buildings with shear wall having different size of opening analyzed using response spectrum method.

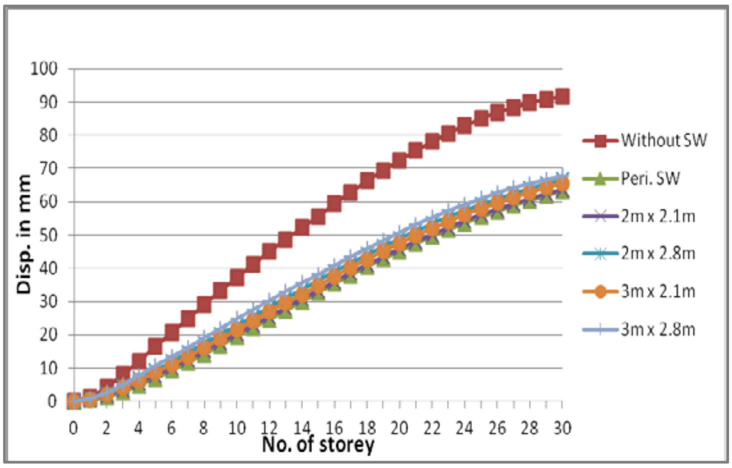


Figure 2: Displacement Comparison between different sizes of openings

As seen from the figure 2 the maximum displacement is 91.61mm for building without shear wall, which reduces to 63.37mm after the provision of shear wall. The displacement increases to 63.74mm for 2m x 2.1m opening, further after the provision of 2m x 2.8m opening the displacement increases to 66.65mm. For 3m x 2.1m opening the displacement becomes 65.48mm and for maximum opening of 3m x 2.8m opening the displacement is 67.79mm.

3.1.2 Inter-storey Drift

Fig. 3 shows the inter storey drift of 30 storey buildings with shear wall having different size of opening.

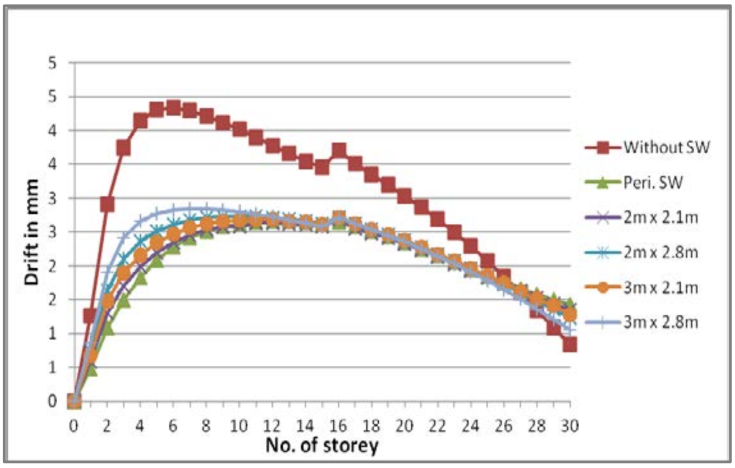


Figure 3: Inter-storey Drift Comparison between different size of openings

From figure 3 it can be seen that interstorey drift of 4.33 mm is maximum for building without shear wall, it is reduced to 2.664mm for building with peripheral shear wall. It is increased to 2.692mm for opening of 2m x 2.1m. For the opening of 2m x 2.8m opening the interstorey drift is increased to 2.734mm compared to building with peripheral shear wall. Further the interstorey drift becomes 2.721mm for and 3m x 2.1m opening and 2.902mm for 3m x 2.8m opening.

3.2 Response Evaluation of Prototype Building Using Time History Method

In this method of analysis, a selected earthquake motion is applies directly to the base of the structure. For the full duration of the earthquake, Instantaneous stresses throughout the structure are evaluated at small time interval. Considered prototype building is analyzed using 1987 Superstition hills recorded at Westmorland fire station. The main steps of time history analysis are as follows.

1) Selection of the earthquake record.
2) Digitization of the record as a series of small time intervals.
3) Setting up of the mathematical model of the structure.
4) Application of the digitized record to the model.
5) Determination of the maximum member stresses by using the output records.

3.2.1 Displacements along the lateral direction

Fig. 4 shows the lateral displacement of 30 storey buildings with shear wall having different size of opening analyzed using time history method.

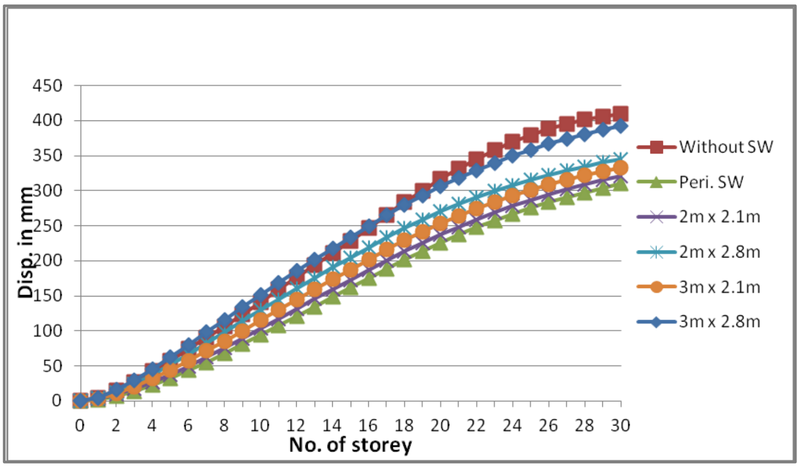


Figure 4: Displacement Comparison for superstition hills time history

The maximum displacement for building without shear wall is 410.0mm. But in case of building with peripheral shear wall the maximum displacement is 310.05mm. The displacement increases as the size of opening increases, for 2m x 2.1m, opening maximum displacement is 321.48mm and for 2m x 2.8m it increases to 345.09mm, moreover for 3m x 2.1m opening it increases to 333.30mm compared to 310.05mm of peripheral shear wall. Top displacement of 392.21mm is for opening of 3m x 2.8m.

3.2.2 Inter-storey Drift

Fig. 5 shows the inter-storey drift of considered 30 storey buildings with shear wall having different size of opening analyzed using time history method.

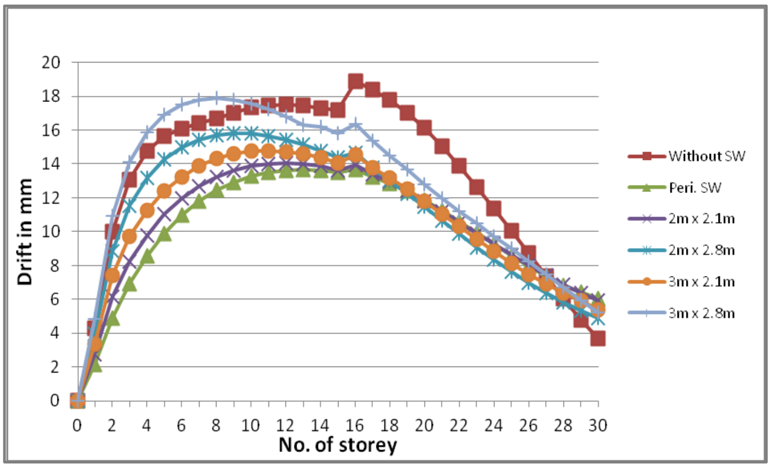


Figure 5: Inter-storey drift comparison for superstition hills time history

From figure 5, the maximum interstorey drift is 18.898mm for building without shear wall, which reduces to 13.662mm after the provision of shear wall. The interstorey drift increases to 14.046mm for 2m x 2.1m opening, further after the provision of 2m x 2.8m opening the interstorey drift increases to 15.824mm. For 3m x 2.1m opening the drift becomes 14.788mm and for maximum opening of 3m x 2.8m opening the interstorey drift is 17.889mm.

3.2.3 Stress concentration pattern on shear wall

Fig. 6 shows the stress concentration patterns in the shear walls having different size of opening. The stress concentration is maximum for load combination of 1.5(DL + FF ± $EQ_{X/Y}$) Maximum direct stress in 20 storey building having different size of openings are shown in table 3,

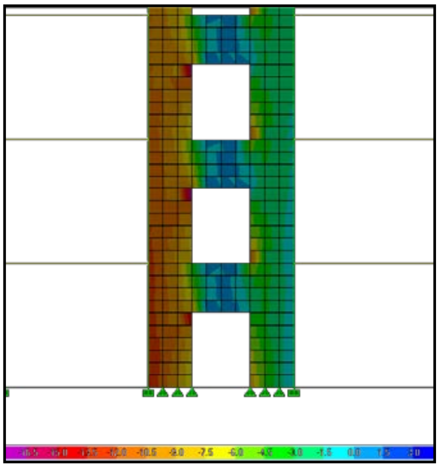
Table 3: Stresses in Shear Wall

Size of opening	Direct Stress (N/mm^2)
2m x 2.1m	17.810
2m x 2.8m	17.908
3m x 2.1m	20.132
3m x 2.8m	18.136

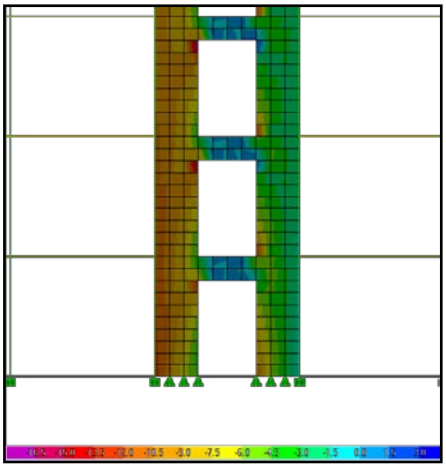
The time period of first five modes of considered 30 storey buildings is shown in Table 4.

Table 4: Time period comparison of 30 storey buildings.

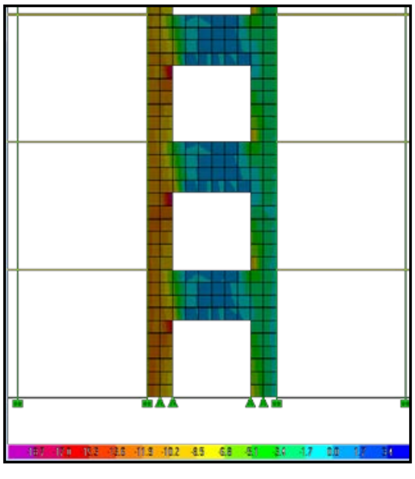
Sr. No.	Building Type	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
1	Bare frame	4.399	4.399	3.668	1.535	1.535
2	Peripheral shear wall	3.614	3.614	2.659	1.109	1.109
3	2m x 2.1m opening	3.642	3.642	2.679	1.144	1.144
4	2m x 2.8m opening	3.723	3.723	2.759	1.207	1.207
5	3m x 2.1m opening	3.680	3.680	2.712	1.176	1.176
6	3m x 3.8m opening	3.826	3.826	2.869	1.279	1.279



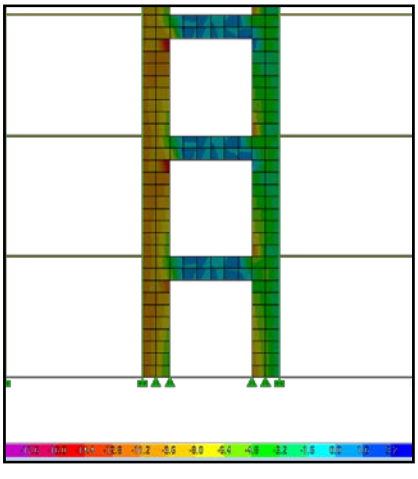
6 (a): 2m x 2.1m Opening



6(b): 2m x 2.8m Opening



6 (c): 3m x 2.1m Opening



6 (d): 3m x 2.8m Opening

Figure 6 Stress concentration patterns in the shear walls

4 Response Evaluation of Building Having Shear Wall with Openings with Incorporating Reduced Area/Volume

In this case the volume of concrete removed due to the provision of opening in the shear walls is included in the existing boundary elements by increasing the size of boundary elements as shown in figure 7. In the present study building is analyzed, using response spectrum and time history methods, by considering the same parameters as described earlier.

Example: for shear wall with 2m x 2.1m opening the volume of concrete removed due to the provision of opening = 2 m x 2.1 m x 0.25 m = 1.05 m^3.This much volume is to be accommodated in the two adjacent boundary elements, thus the size of existing boundary element is increased to 1070 mm x 900 mm from 1-15 storey and 850 mm x 600 mm from 16 – 30 storey. Similarly it is calculated for all size of openings. The table 5 shows the revised size of boundary elements for the considered building.

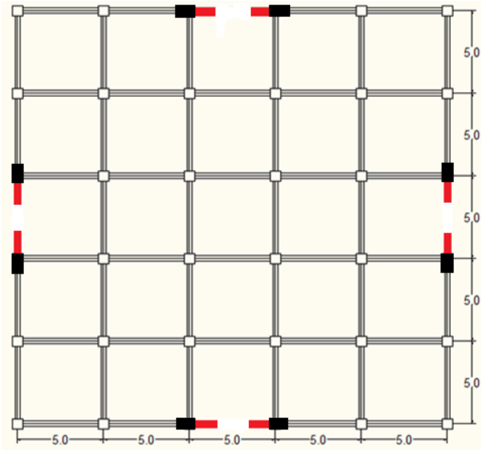


Figure 7: Building Plan with opening and revised boundary elements

Table 5: Description of openings in 30 story buildings

Sr. No.	Building Type	Size of new boundary element	
		Storey 1-15	Storey 16-30
1.	Shear Wall with 2m x 2.1 opening	1070 mm x 900 mm	850 mm x 600 mm
2.	Shear Wall with 2m x 2.8 opening	1122 mm x 900 mm	933 mm x 600 mm
3.	Shear Wall with 3m x 2.1 opening	1150 mm x 900 mm	975 mm x 600 mm
4.	Shear Wall with 3m x 2.8 opening	1233 mm x 900 mm	1100 mm x 600 mm

4.1 Response evaluation of prototype building using response spectrum method

4.1.1 Displacements along the lateral directions

Fig. 8 shows the lateral displacement of 30 storey buildings with shear wall having different size of opening analyzed using response spectrum method.

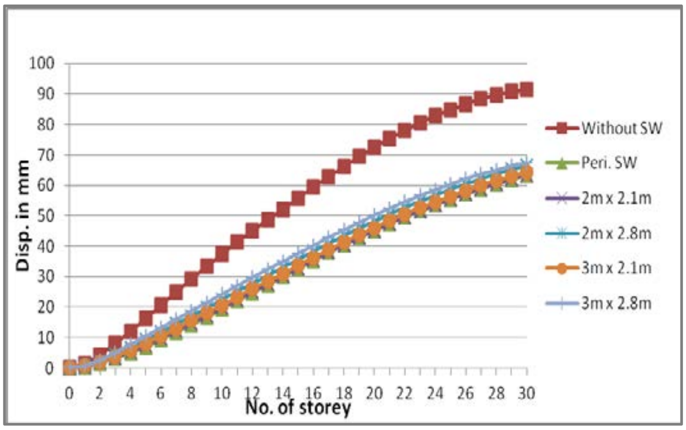


Figure 8: Displacement Comparison between different sizes of openings.

As seen from the figure 8, the maximum displacement is 91.61mm for building without shear wall, which reduces to 63.37mm after the provision of shear wall. The displacement increases to 63.45mm for 2m x 2.1m opening, further after the provision of 2m x 2.8m opening the displacement increases to 66.41mm. For 3m x 2.1m opening the displacement becomes 64.43mm and for maximum opening of 3m x 2.8m opening the displacement is 67.51mm.

4.1.2 Inter-storey Drift

Fig. 9 shows the inter-storey drift of 30 storey buildings with shear wall having different size of opening analyzed using response spectrum method.

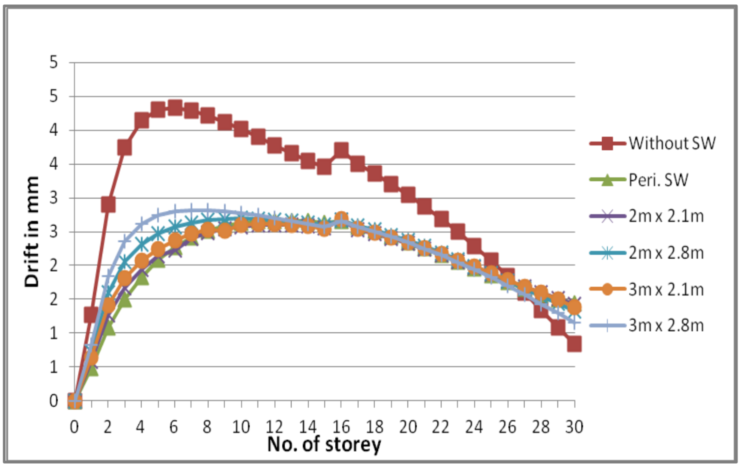


Figure 9: Inter-story Drift Comparison between different size of openings

From figure 9, the maximum interstorey drift is 4.333mm for building without shear wall, which reduces to 2.664mm after the provision of shear wall. The interstorey drift increases to 2.673mm for 2m x 2.1m opening, further after the provision of 2m x 2.8m opening the interstorey drift increases to 2.694mm. For 3m x 2.1m opening the drift becomes 2.690mm and for maximum opening of 3m x 2.8m opening the interstorey drift is 2.813mm.

4.2 Response evaluation of prototype building using time history method

4.2.1 Displacements along the lateral directions

Fig. 10 shows the lateral displacement of considered 30 storey buildings with shear wall having different size of opening analyzed using time history method.

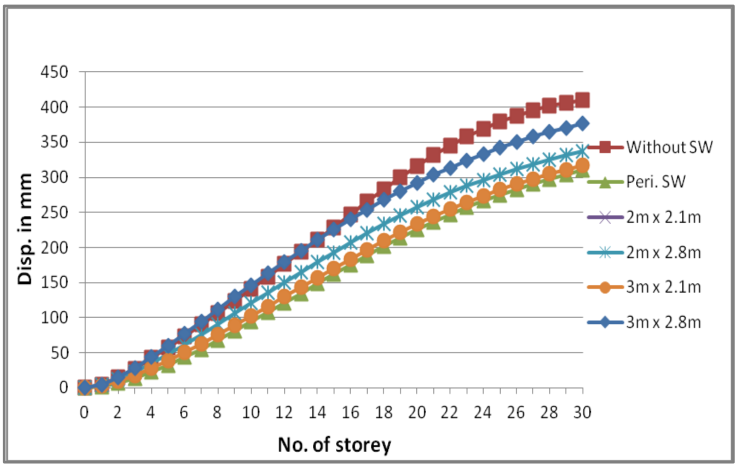


Figure 10: Displacement Comparison for Superstition hills time history

The maximum displacement for building without shear wall is 410.0mm. But in case of building with peripheral shear wall the maximum displacement is 310.05mm. The displacement increases as the size of opening increases, for 2m x 2.1m, opening maximum displacement is 314.20mm and for 2m x 2.8m it increases to 336.93mm, moreover for 3m x 2.1m opening it increases to 317.30mm compared to 310.05mm of peripheral shear wall. Top displacement of 376.51mm is for opening of 3m x 2.8m.

4.2.2 Inter-storey Drift

Fig. 11 shows the inter-storey drift of considered 30 storey buildings with shear wall having different size of opening analyzed using time history method.

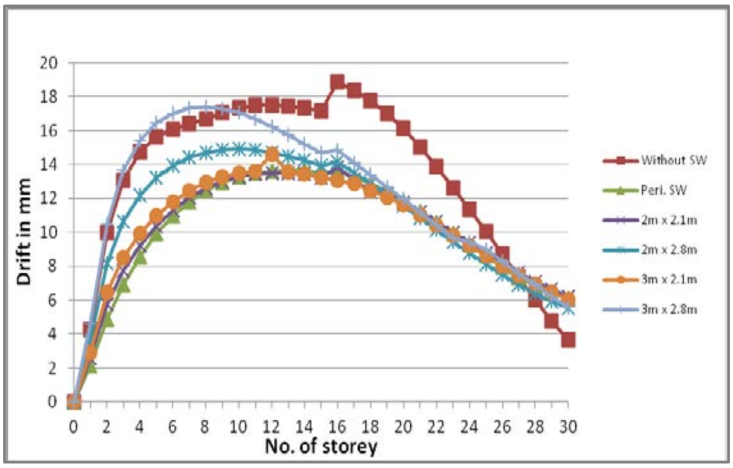


Figure 11: Inter-storey Drift Comparison for Superstition hills time history

From figure 11 it can be seen that inter-storey drift of 18.898mm is maximum for building without shear wall, it is reduced to 13.662mm for building with peripheral shear wall. It is increased to 13.829mm for opening of 2m x 2.1m. For the opening of 2m x 2.8m opening the inter-storey drift is increased to 14.924mm compared to building with peripheral shear wall. Further the inter-storey drift becomes 14.610 mm for and 3m x 2.1m opening and 17.393mm for 3m x 2.8m opening.

4.2.3 Stress concentration pattern

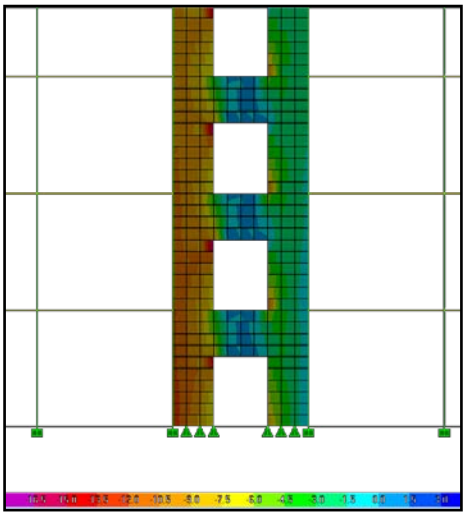
Fig. 12 shows the stress concentration patterns in the shear walls having different size of opening. The stress concentration is maximum for load combination of 1.5(DL + FF ± $EQ_{X/Y}$) Maximum direct stress in 30 storey building having different size of openings are shown in table 6.

Table 6: Stresses in Shear Wall

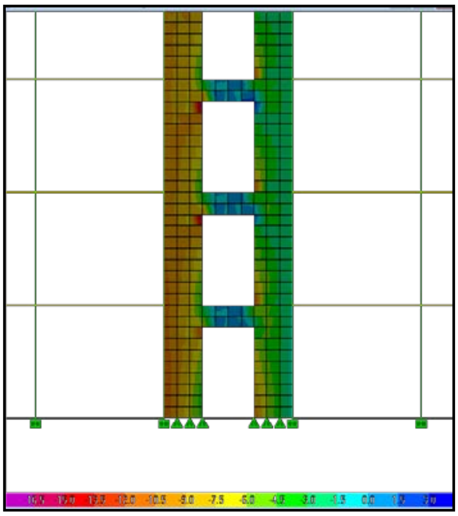
Size of opening	Direct Stress (N/mm^2)
2m x 2.1m	17.34
2m x 2.8m	17.76
3m x 2.1m	19.07
3m x 2.8m	17.44

Table 7: Time period comparison of 30 storey buildings

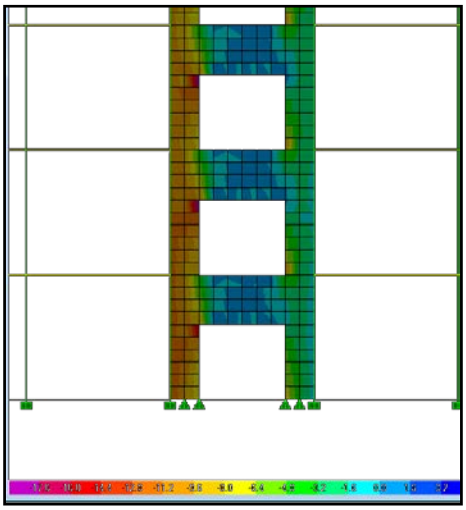
Sr. No.	Building Type	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
1	Bare frame	4.399	4.399	3.668	1.535	1.535
2	Peripheral shear wall	3.614	3.614	2.659	1.109	1.109
3	2m x 2.1m opening	3.628	3.628	2.660	1.119	1.119
4	2m x 2.8m opening	3.691	3.691	2.722	1.185	1.185
5	3m x 2.1m opening	3.631	3.631	2.661	1.141	1.141
6	3m x 3.8m opening	3.791	3.791	2.823	1.253	1.253



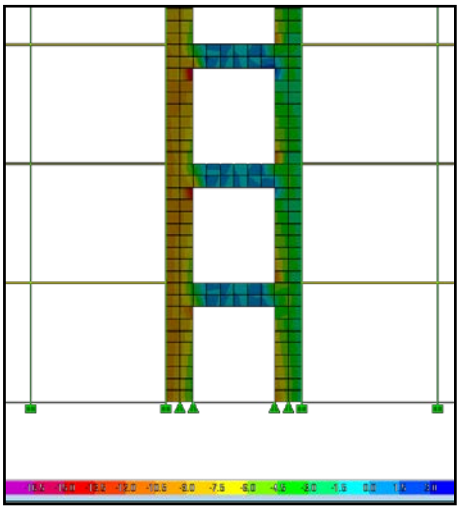
(a): 2m x 2.1m Opening



(b): 2m x 2.8m Opening



(c): 3m x 2.1m Opening



(d): 3m x 2.8m Opening

Figure 12 Stress concentration patterns in the shear walls

The time period of first five modes of considered 30 storey buildings is shown in table 7.

5 Conclusion

In the present study a 30-storey building having shear walls having different size of openings are analyzed, one in which volume of shear wall is reduced due to provision of openings and other in which volume of shear wall reduced is incorporated by increasing the dimensions of adjacent boundary elements, using Response Spectrum and Time History methods.

The provisions of openings in shear walls without incorporating the volume of shear wall reduced due to opening, decreases the stiffness of the building in lateral direction and in turn the lateral displacement and inter-storey drift of the building increases. It was observed that displacement and drift are not only dependent on the size of opening, but shape of opening also plays a major role when the aspect ratio is large. The overall lateral displacement of the buildings increases from 0.58 % to 20.95 % and inter-storey drift increases about 1.04 % to 23.63 % due to the provisions of different size of openings in shear walls as compared to buildings without openings in shear walls.

Moreover in second case, in which volume of shear wall reduced due to opening is incorporated by increasing the size of the adjacent boundary elements, stiffness tends to increase compared to the first case. Thus overall lateral displacement and inter-storey drift of the buildings decreases by 0.13 % to 17.65 % and 0.34 % to 21.45 % respectively as compared to first case.

The provision of openings in shear walls introduces high local vertical stress and shear stress concentrations around the corners of the openings.

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