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ORIGINAL ARTICLE

Seismic response of shear walls with staggered openings

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Abstract

Analyzing civil engineering issues numerically requires the use of the finite element method. In order to examine the behaviour of shear walls with apertures under seismic stresses, finite element analysis is attempted to be applied in this article. Shear walls are typically utilised in high rise structures nowadays as a vertical structural feature to resist lateral stresses brought on by the effects of wind and earthquakes. Because doors and windows are functional necessities, a shear wall may include several openings. These apertures may have a significant impact on the structure's total seismic response. With the use of the finite element programme ETABS and the Response Spectrum approach, a seven storey frame-shear wall building is the subject of this research. The comparison of the data revealed that the positioning of the apertures affects the time interval, displacement, base shear, and stress distribution around the openings. Last but not least, it is recommended that the staggered arrangement of apertures in shear walls be used in practise since it meets both the architectural and the seismic criteria.

1. Introduction

Shear walls are vertical structural components that can withstand lateral stresses that may be brought on by earthquakes and wind. One of these is a shear wall, a structure whose only source of resistance to horizontal loading. Shear walls are an effective structural way to strengthen a structure because they provide it the lateral stiffness and strength it needs to resist horizontal forces. Shear walls often begin at the foundation level and continue up the height of the structure. The majority of the time, they are situated at the sides of buildings or grouped in the shape of a core and are offered along both the length and breadth of the structure. One or more apertures may be present in shear walls for practical purposes. Shear walls must be precisely the right size and placement. To lessen the impact of buildings twisting, they must be symmetrically placed in the layout. structures with proper planning and detail during previous earthquakes, with shear walls have performed well. Strong earthquakes that have occurred throughout the world in the past have also demonstrated that the damage and specific modes of failure of shear walls depend on a number of variables, including the site's conditions, the type of earthquake, and strain rates. These variables include the shape of the plan, the sizes of the walls and openings, the placement of reinforcement, and the dimensions and layout of the openings. There are still several failure mechanisms that need more investigation, despite the fact that they have already received a lot of attention. Shear walls with spaced-apart apertures are an example of one such situation.

There have been several studies that suggest sheer walls with apertures. The impacts of apertures in core type shear walls with a thickness of 203 mm were examined by Sharmin Reza Chowdhury, M.A. Rahman, M.J. Islam, and A.K. Das using an ETABS model of a six story frame-shear wall structure. The size and placement of apertures in shear walls have an impact

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on the structure's stiffness and seismic reaction, according to their study. After the major earthquakes between 2009 and 2011, Mosoarca Marius examined the seismic behaviour of shear walls with regular and staggered apertures. He statically subjected them with alternating cyclic horizontal loads after modelling a three-story shear wall with a thickness of 120 mm at a scale of 1/3. He came to the conclusion that the walls with staggered openings developed a ductile failure with the same amount of reinforcement and layout, whereas the walls with regular openings developed a brittle failure; additionally, the shear walls with staggered openings are more rigid and required less reinforcement. R.C. structural walls with staggered door openings were explored by Aejaz Ali and James K. Wight by modelling four samples at a size of 1/5 with five storeys. A hydraulic actuator was used to test by delivering cyclic lateral load. According to his research, doors that were near to the edge of the boundary column caused early shear-compression failure, whereas walls with staggered apertures displayed ductile flexural behaviour. Studying the seismic behaviour of R.C. walls with square apertures of various sizes and arrangements under reversed cyclic stress was done by Yanez F.V., R. Park, and T. Paulay. According to the findings, the size of the apertures, not their horizontal positioning, determines the rigidity of walls. In order to determine the maximum strength of a shear wall with openings under lateral stress, Lin C.Y. and C.L. Kuo performed an experimental research and finite element analysis. The test programme showed how shear behaviour of R.C. walls behaved when apertures of various sizes and shapes were present, as well as varied patterns of reinforcing around the opening. The conclusion reached was that the depth of apertures has an equal impact on the section's shear capacity as their breadth.

In this study, the response spectrum approach using ETABS is used to perform finite element analysis on a seven story frame-shear wall building without openings, with vertical openings, and with staggered openings. In terms of the seismic reaction, the goal of this study is to investigate the behaviour of shear walls with staggered apertures and compare it to vertical openings.

2. Model Description

Using the finite element method, a seven story, 4 x 5 bay, frame-shear wall structure with a span of four metres in each direction and a floor height of 3.5 metres was modelled without opening, with a vertical opening, and with staggered opening in the shear wall. ETABS software All three versions utilised a typical floor layout with measurements of 16 m x 20 m. The shear wall's thickness was estimated to be 300 mm. A thin shell element served as the representation of the shear wall. Columns and beams were designed to measure 300 mm x 600 mm in dimension. The slab's thickness was determined to be 150 mm, and it was also shown as a shell element. In Figures 1 and 2, respectively, the building's elevations with vertical and staggered apertures in the shear wall are depicted. The apertures' dimensions in both situations were held constant at 1.2 x1 m. The breadth of the shear wall surrounding the gap thickens to indicate the stiffening of the shear wall. To get results with more precision, the model was meshed. The seismic analysis was carried out using the response spectrum technique, and the earthquake loads and load combinations were applied in accordance with IS 1893 - 2002. For analysis, seismic zone II was used. The shear wall was created utilising the limit state approach and was specifically described in accordance with IS 456 (2000) and IS 13920 (1993), respectively.

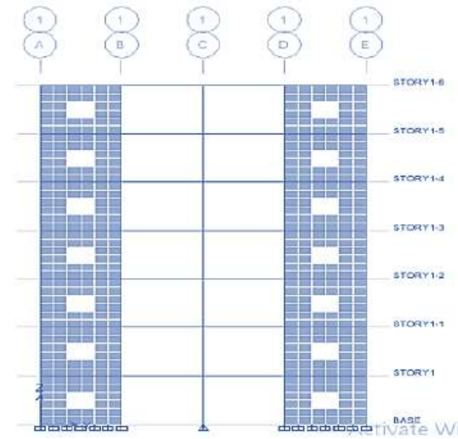

Figure 1: Elevation of the frame-shear wall building with vertical openings

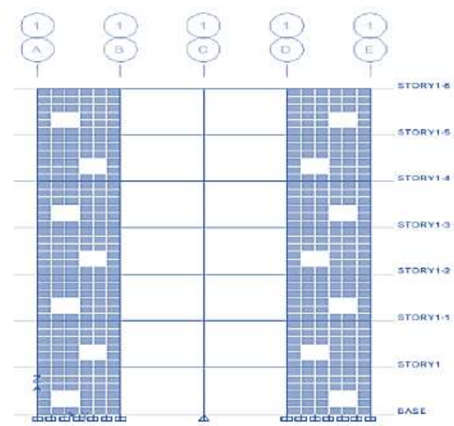

Figure 2: Elevation of the frame-shear wall building with staggered openings

3. Results and Discussion

3.1 Time Period

Because of the vibratory motion of the building, the reaction of a structure may be described as a mixture of several mode forms. However, the first mode or basic time period, which is a built-in feature of the building, is the most important one for seismic analysis. As a result of the investigation, the time period for each of the three models is displayed in Fig. 3. When compared to vertical openings, it can be noted that staggered apertures showed a greater value of time period, which suggests that the shear wall with staggered openings will function better during seismic activity.

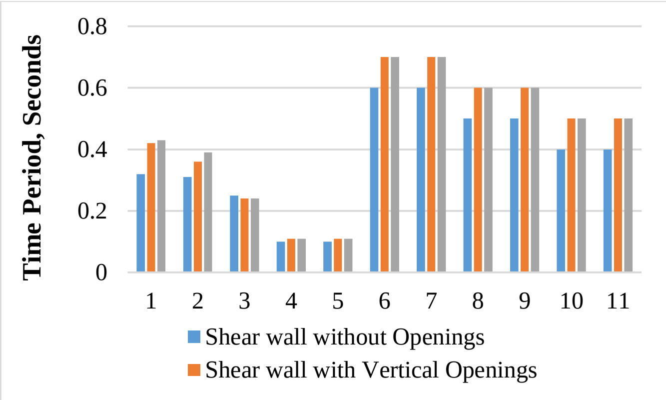

Figure 3: Mode number versus Time period

3.2 Story Displacement

The term "displacement" describes how far the seismic waves have displaced certain spots on the earth from where they were before. In line with each direction, the displacement fluctuates. The tale displacement graph is shown in Figs. 4 and 5, which show it in the X- and Y-axes, respectively. It is clear that the displacement of the top narrative is more X-than Y-directed.
Due to the fact that structures with a long natural period will have lower accelerations but bigger displacements, the shear wall with staggered apertures suffers a higher displacement than vertical openings.

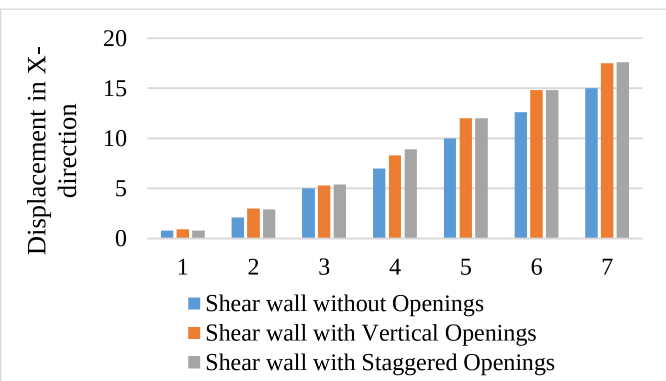

Figure 4: Story versus Story Displacement in X-direction

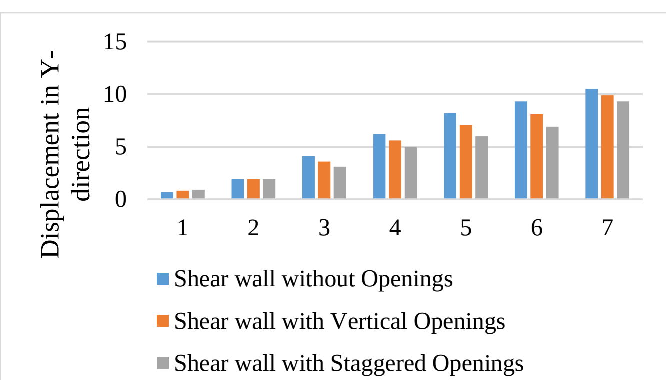

Figure 5: Story versus Story Displacement in Y-direction

3.3 Story Drift

Story drift is the shifting of one level in relation to the level above or below it. Additionally, drift might change depending on the direction. Figures 6 and 7 demonstrate the tale drift in the X- and Y-directions, respectively, in relation to the story level. Additionally, compared to tale drift in Y-direction, X-direction story drift is substantially higher. The story drift for buildings is only allowed to be 0.004 times the story height, which was not exceeded in our analytical analysis for all three models, in accordance with IS: 1893 (Part I) - 2002. The shear wall with vertical as well as staggered arrangement of apertures exhibits no discernible difference in terms of tale drift.

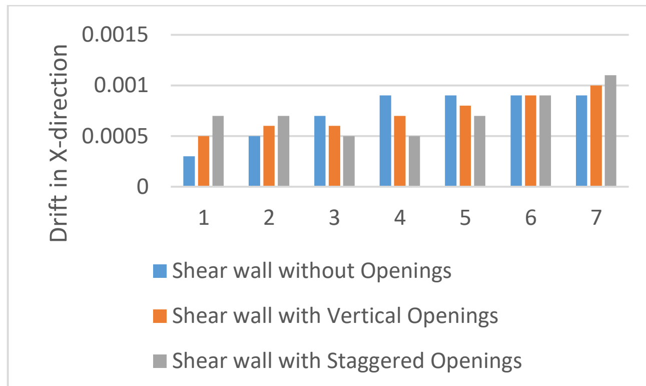

Figure 6: Story versus Story Drift in X-direction

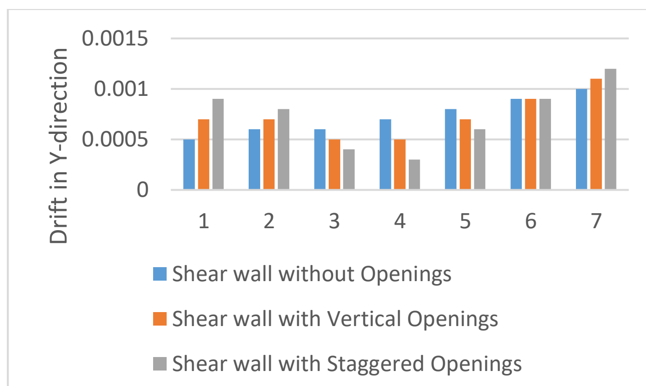

Figure 7: Story versus Story Drift in Y-direction

3.4 Story Shear

The total design lateral forces at all levels above the story under consideration are referred to as story shear. When compared to Y-direction, it is discovered to be greater for X-direction. Fig. 8 depicts the tale shear graph corresponding to the X-direction, and Fig. 9 depicts the story shear graph corresponding to the Y-direction.
When compared to shear walls with vertical apertures, the base shear for shear walls with staggered openings is significantly lower in both directions. The shear wall with staggered apertures will be less prone to damage when the base shear is

decreased. However, the base shear is dependent on the site's current soil conditions, which need to be examined in actual work situations.

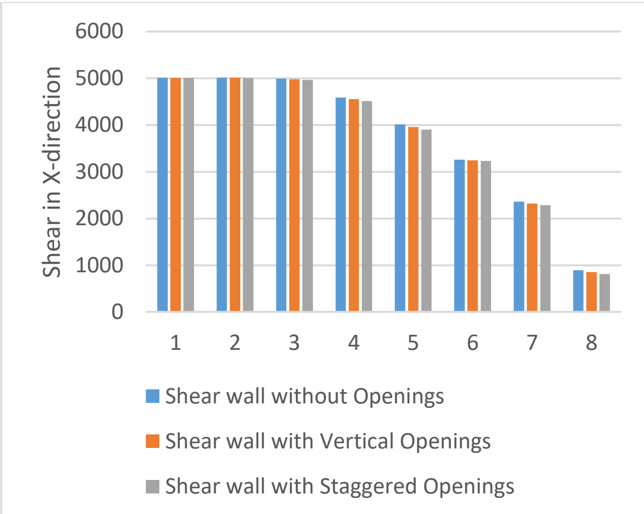

Figure 8: Story versus Story Shear in X-direction

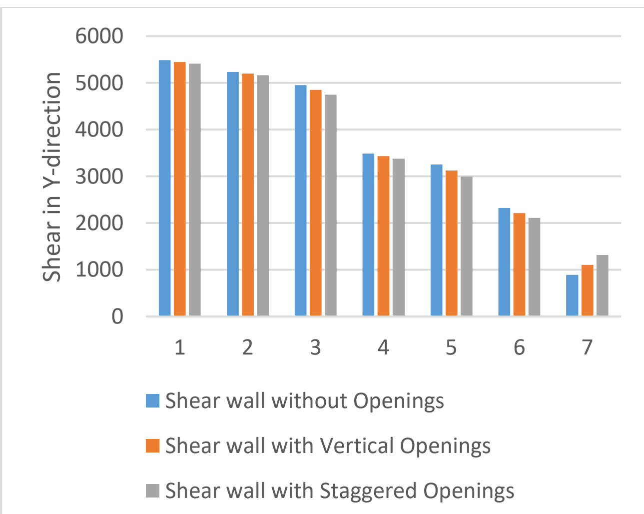

Figure 9: Story versus Story Shear in Y-direction

3.5 Stress Distribution

To pinpoint the locations where more stress is accumulating and to determine the pattern of stress in shear walls with openings, the stress distribution of shear walls with vertical openings and those with staggered openings was examined. Figure 10 depicts the stress distribution for shear walls with vertical apertures, whereas Figure 11 depicts the stress distribution for shear walls with staggered openings. As can be seen, the stress pattern around a shear wall with staggered apertures is substantially less intense than the stress pattern surrounding a shear wall with vertical openings.

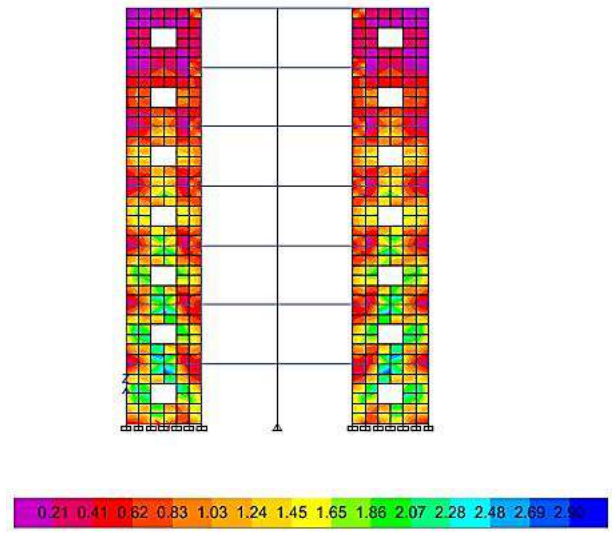

Figure 10: Stress distribution in shear wall with vertical openings

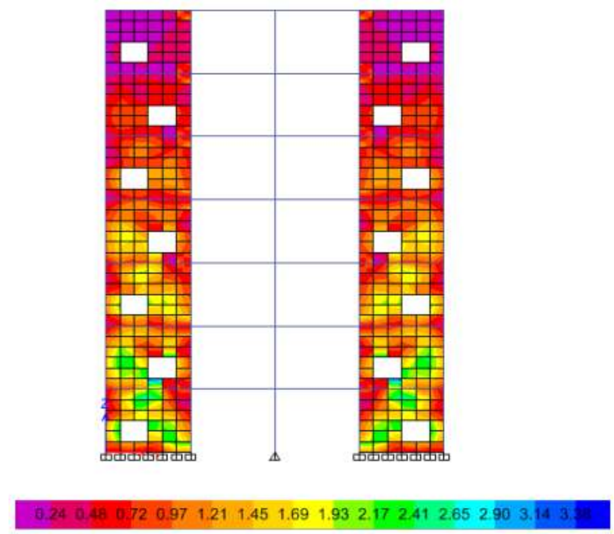

Figure 11: Stress distribution in shear wall with staggered openings

4. Conclusions

According to the results of this study, the position of the apertures in the shear wall has an impact on the time period, displacement, drift, base shear, stress distribution, and overall seismic response of the structure. The analysis produced the following results. Shear walls with staggered openings were found to be far more favourable than those with vertical apertures, and they were also shown to offer superior lateral resistance. When compared to holes that are arranged vertically, the increase in tensions caused by staggered openings is quite minimal. In comparison to vertical apertures, the displacement and drift in staggered openings agreed rather well. While the shear wall with vertical apertures appears to become brittle, the shear wall with staggered openings appears to be more robust and to exhibit a ductile behaviour. In contrast to shear walls with vertical apertures, those with staggered openings experience substantially less base shear. The size of the apertures as well as their position affect the building's seismic behaviour. Compared to shear walls with vertical apertures, shear walls with staggered openings required significantly less reinforcing. In order to better understand the failure process of shear walls with openings and to develop a suitable design code for use in practise, shear walls with various opening sizes and reinforcing patterns can be further examined.

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