Behavior of R.C. Shear Wall with Staggered Openings under Seismic Loads

Aarthi Harini T[1] and G. Senthil Kumar[2]

[1]M.Tech Structural Engineering, SRM University, SRM Nagar, Kattankulathur – 603203, Kancheepuram District, Tamil Nadu, India
[1]harini6792@gmail.com
[2]Assistant Professor, Department of Civil Engineering, SRM University, SRM Nagar, Kattankulathur – 603203, Kancheepuram District, Tamil Nadu, India
[2]senthil.pg2@gmail.com

ABSTRACT

Finite Element Method is an essential approach in analyzing civil engineering problems numerically. In this paper, an effort is made to apply the finite element analysis in exploring the behavior of shear wall with openings under seismic loads. In modern high rise buildings, shear walls are generally used as a vertical structural element for resisting the lateral loads that is induced by the effect of wind and earthquakes. A shear wall may contain many openings due to the functional requirements such as doors and windows, which may largely affect the overall seismic response of the structure. This study is carried out on a seven story frame-shear wall building, using linear elastic analysis, with the help of finite element software ETABS, using Response Spectrum method. The comparative results showed that the time period, displacement, base shear and stress distribution around the openings depend on the arrangement of openings. Finally, the staggered arrangement of openings in shear walls is suggested to be applied in practice, since it satisfies both the architectural and the seismic requirements.

Keywords — Shear Wall, Staggered Openings, Seismic Loads, Finite Element Analysis, Response Spectrum Method, ETABS.

1. INTRODUCTION

Shear walls are vertical structural elements for resisting the lateral loads that may be induced by the effect of wind and earthquakes. Shear wall is a structure considered to be one, whose resistance to horizontal loading is provided entirely by them. Introduction of shear walls in a building is a structurally efficient solution to stiffen the building because they provide the necessary lateral strength and stiffness to resist horizontal forces. Shear walls generally start at the foundation level and are continuous throughout the building height. They are generally provided along both length and width of the building and are located at the sides of the buildings or arranged in the form of core. Shear walls may have one or more openings for functional reasons.

The size and location of shear walls is extremely critical. They must be symmetrically located in plan to reduce the effect of twisting in buildings. Properly designed and detailed buildings with shear walls have shown good performance in past earthquakes. Also the strong earthquakes recorded worldwide in the past have shown that the damages and certain failure mechanisms of shear walls depend on a series of factors such as, the shape in plan, dimensions of the walls and openings, reinforcement and the openings layout, site condition, type of earthquake and strain rates. Even if failure modes have been extensively researched, there are still certain failure modes which have to be investigated further. One such is the case of shear walls with staggered openings.

Shear wall with openings has been discussed in number of papers. Sharmin Reza Chowdhury, M.A. Rahman, M.J. Islam and A.K. Das modeled a six story frame-shear wall building using ETABS and studied about the effects of openings in core type shear wall of thickness 203 mm. Their study revealed that stiffness and seismic response of the structure is affected by the size of openings and location of openings in shear walls.

Mosoarca Marius analyzed the seismic behavior of shear walls with regular and staggered openings after the strong earthquakes between 2009 and 2011. He modeled a three story shear wall of thickness 120 mm on a scale of 1/3 and statically loaded them with alternating cyclic horizontal loads. He concluded that, with the same amount of reinforcement and layout, the walls with staggered openings developed a ductile failure, whereas the ones with regular openings developed a brittle failure; and the shear walls with staggered openings are more rigid and needed less reinforcement. Aejaz Ali and James K. Wight studied R.C. structural walls with staggered door openings by modeling four specimens with a scale of 1/5 with five floors. They tested by applying cyclic lateral load through a hydraulic actuator. His study stated that the walls with staggered openings exhibited ductile flexural behavior and the door openings located close to the edge of the boundary column triggered early shear-compression failure. Yanez F.V., R. Park and T. Paulay studied on seismic behavior of R.C. walls with square openings of different size and arrangement under reversed cyclic loading. It was concluded that the stiffness of walls is dependent on the size of the openings and not on their horizontal locations. Lin C.Y. and C.L. Kuo conducted finite element analysis and experimental work to study the ultimate strength of shear wall with openings under lateral load. The test program demonstrated the shear behavior of R.C. walls with different sizes of openings and reinforcing patterns around the opening. It was resolved that the shear capacity of the section is not only affected by the width of openings but also affected by the depth of openings as well.

In this research, finite element analysis is performed on seven story frame-shear wall building: without openings, with vertical openings and with staggered openings, using response spectrum method with ETABS 2013. This study aims to analyze the behavior of shear wall with staggered openings and compare them with vertical openings, as far as the seismic response is considered.

2. MODEL DESCRIPTION

For this study, a seven story, 4 × 3 bays frame-shear wall building with 4m span in both directions and floor height of 3m was modeled without opening, with vertical opening and with staggered opening in shear wall, using the finite element software ETABS. Typical floor plan with dimensions 16m × 12m was used for all three models. The thickness of the shear wall was taken as 250 mm. Shear wall was represented as a thin shell element. The size of beams and columns were adopted as 250 × 500 mm. The thickness of slab was taken as 150 mm and it was also represented as a shell element. Elevations of the building with vertical and staggered openings in shear wall are shown in Fig. 1 and Fig. 2 respectively. The size of the openings in both the cases were maintained as 1.34 × 1 m. Stiffening of the shear wall around the opening is represented by thickening the width of shear wall around the opening. The model was meshed in order to obtain results with higher accuracy. The earthquake load and load combinations were applied as per IS 1893 – 2002 and the seismic analysis was done by response spectrum method. Seismic zone II was embraced for analysis. The shear wall was designed using limit state method and was detailed as per IS 456 – 2000 and IS 13920 – 1993 respectively.

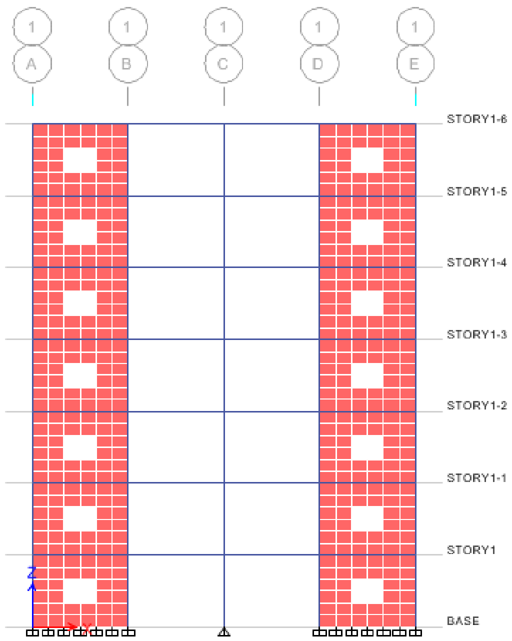

Fig-1: Elevation of the frame-shear wall building with vertical openings

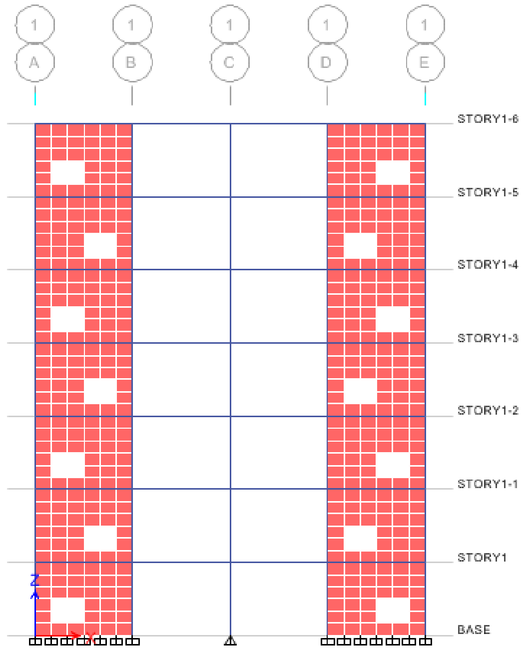

Fig-2: Elevation of the frame-shear wall building with staggered openings

3. RESULTS AND DISCUSSION

3.1 Time Period

The response of a structure can be defined as a combination of many mode shapes, resulting due to the vibratory motion of the building. But for seismic analysis, the first mode or the fundamental time period is the most significant, which is the inherent property of the building. The time period obtained from the analysis for all three models is shown in Fig. 3. It can be seen that the staggered openings exhibited a higher value of time period when compared to vertical openings, which indicates that the shear wall with staggered openings can perform better during seismic action than the vertical openings.

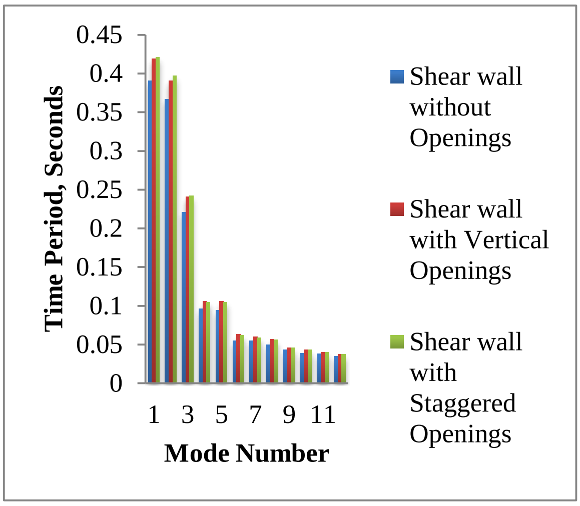

Fig-3: Mode number versus Time period

3.2 Story Displacement

The displacement refers to the distance that points on the ground are moved from their initial locations by the seismic waves. The displacement varies accordingly in each direction. Fig. 4 and Fig. 5 displays the story displacement graph in both X-direction and Y-direction respectively. It is evident that the top story displacement is more in X-direction than in Y-direction. The shear wall with staggered openings experiences a higher displacement than vertical openings due to the fact that, in the case of buildings with a long natural period, the buildings will experience lower accelerations but larger displacements.

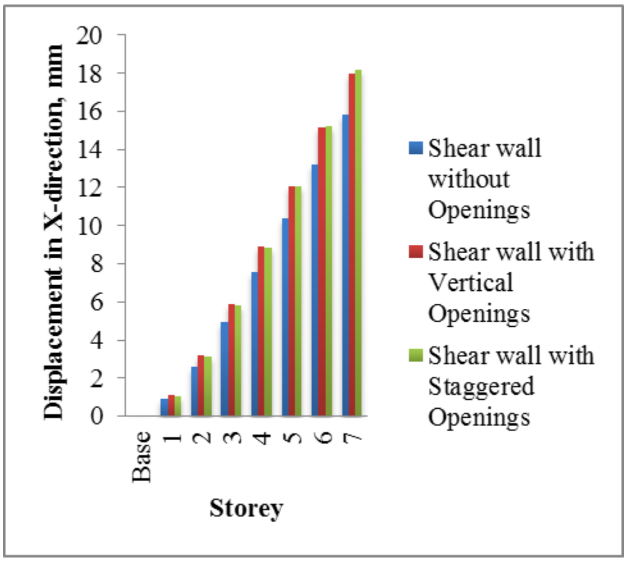

Fig-4: Story versus Story Displacement in X-direction

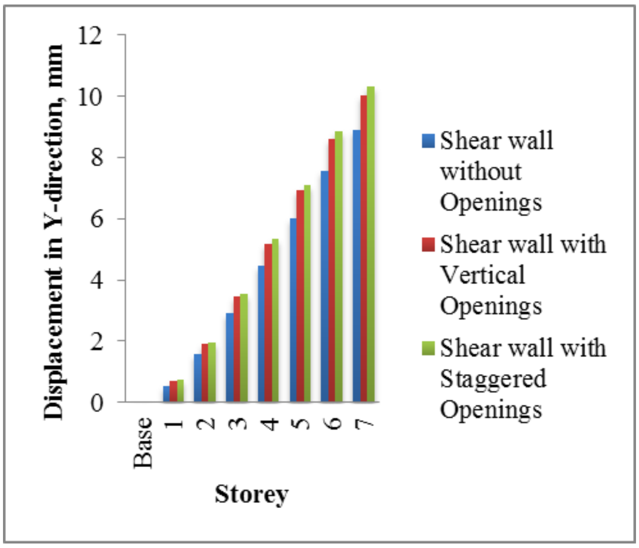

Fig-5: Story versus Story Displacement in Y-direction

3.3 Story Drift

Story drift is defined as the displacement of one level relative to the other level above or below. Drift can also vary according to each direction. Fig. 6 and Fig. 7 shows the story drift corresponding to the story level in X-direction and Y-direction respectively. Also, the story drift in X-direction is relatively higher than the story drift in Y-direction. According to IS: 1893 (Part I) - 2002, the story drift for buildings is limited to 0.004 times the story height, which was not exceeded in our analytical study for all three models. In case of story drift, the shear wall with vertical as well as staggered arrangement of openings shows no significant difference.

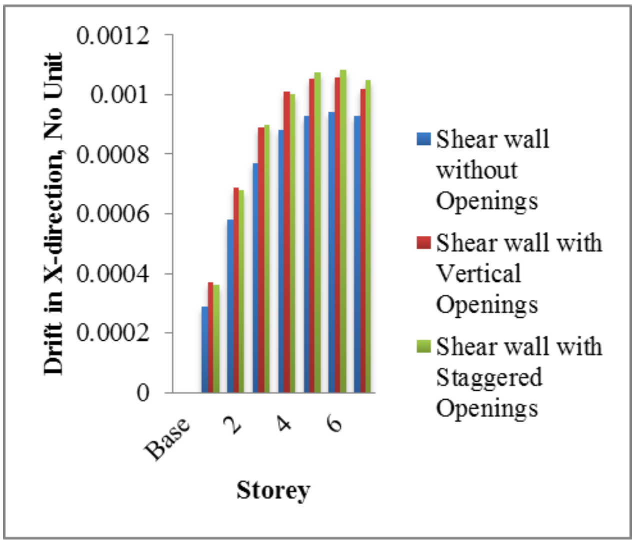

Fig-6: Story versus Story Drift in X-direction

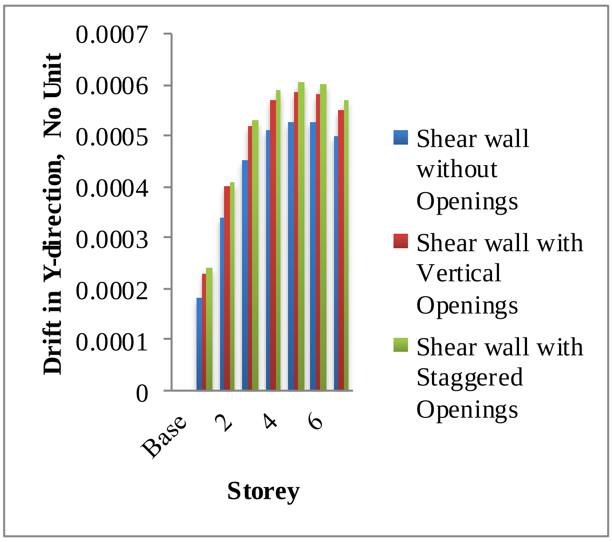

Fig-7: Story versus Story Drift in Y-direction

3.4 Story Shear

Story shear is defined as the sum of design lateral forces at all levels above the story under consideration. It is found to be higher for X-direction when compared with Y-direction. Fig. 8 shows the story shear graph pertaining to X-direction and Fig. 9 shows the story shear graph corresponding to Y-direction. The base shear is found to be much lesser for shear wall with staggered openings when compared to shear wall with vertical openings, in both the directions. As the base shear is reduced, the shear wall with staggered openings will be less susceptible to damage. However, the base shear depends upon the existing soil condition at the site, which must be investigated in real practice.

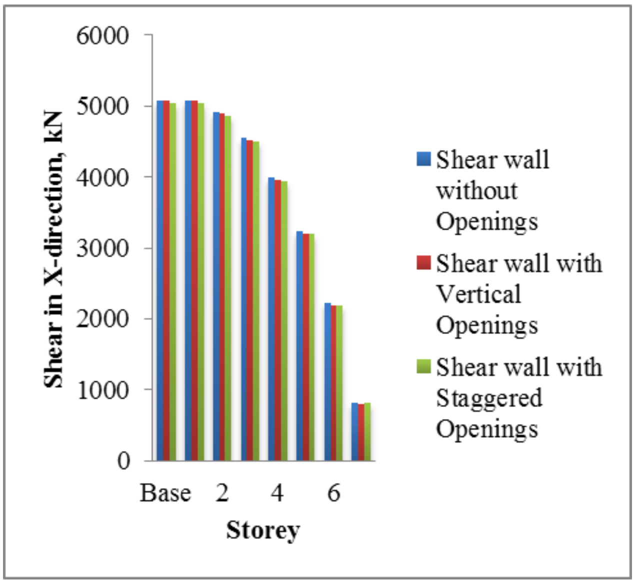

Fig-8: Story versus Story Shear in X-direction

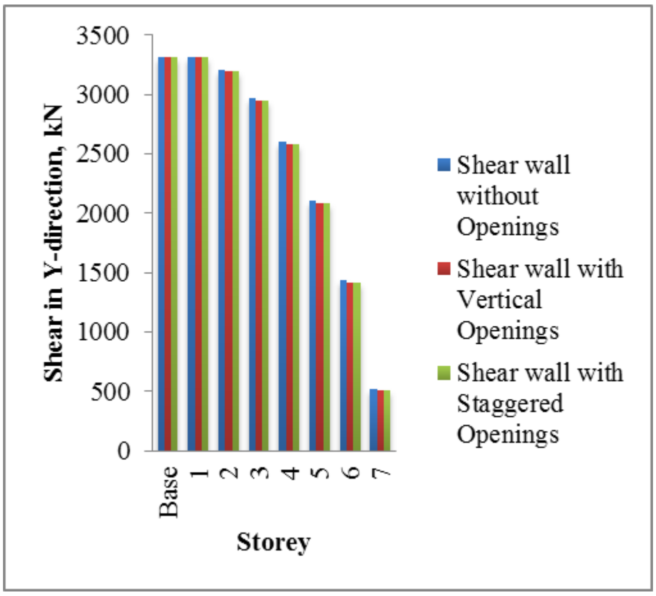

Fig-9: Story versus Story Shear in Y-direction

3.5 Stress Distribution

The stress distribution of the shear wall with vertical openings and with staggered openings was studied to identify the points of higher stress accumulation and stress pattern in shear wall with openings. The stress distribution for shear wall with vertical openings is shown in Fig. 10 and the stress distribution for shear walls with staggered openings is shown in Fig. 11. It can be clearly seen that the stress in shear wall around the staggered openings is of much lesser intensity when compared with the stress pattern around the shear wall with vertical openings.

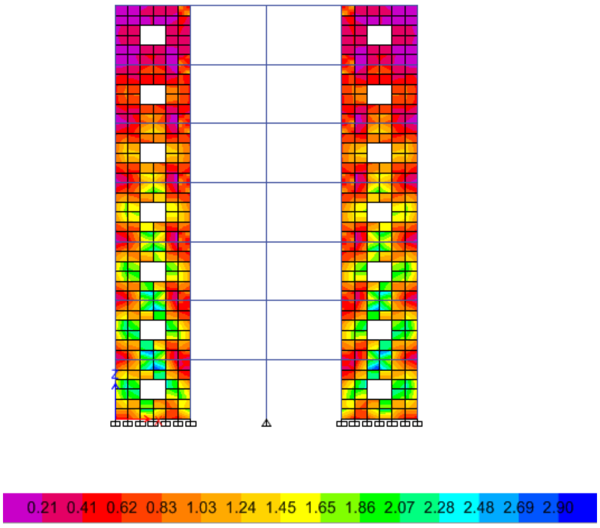

Fig-10: Stress distribution in shear wall with vertical openings

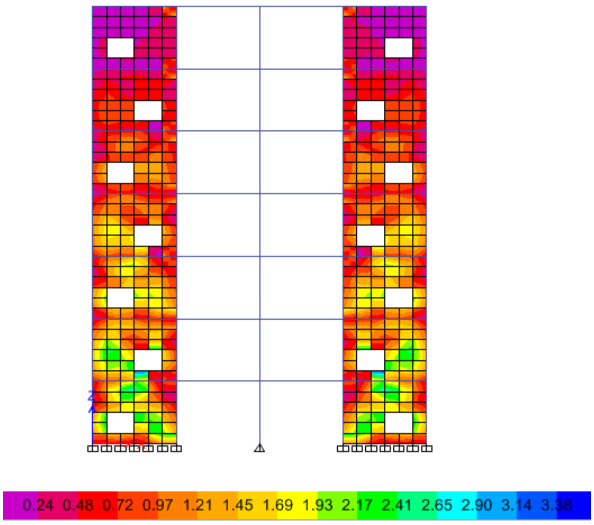

Fig-11: Stress distribution in shear wall with staggered openings

4. CONCLUSIONS

This study reveals that the time period, displacement, drift, base shear, stress distribution and the overall seismic response of the structure is affected by the location of openings in shear wall. The analysis led to the following conclusions. Staggered openings in shear wall proved to be highly advantageous and they were found to provide better lateral resistance than shear walls with vertical openings. The increase of stresses in staggered openings arrangement is small when compared to vertical arrangement of openings. The displacement and drift in staggered openings agreed quite well than that of vertical openings. The shear wall with staggered openings is more rigid and seems to develop a ductile behavior, whereas the shear wall with vertical openings seems to develop a brittle behavior. The base shear in shear wall with staggered openings is much lesser when compared to shear wall with vertical openings. The seismic behavior of the building not only depends on the location of openings but also on the size of openings. The shear walls with staggered openings needed much less reinforcement than the shear walls with vertical openings. Shear walls with different opening sizes and different reinforcing patterns can be further analyzed for future research work, so that the failure mechanism of shear walls with openings can be understood in a better way and a proper design code can be formulated for practice.

ACKNOWLEDGEMENT

The authors appreciate the support of the pro-vice chancellor, director (E&T), head of the department, the project coordinator and other faculty members of SRM University for successfully carrying out the research work. The article could not have reached this level without the professional recommendations and advice of the reviewers of this journal. Views and findings reported in this paper are solely those of the authors.

REFERENCES

[1] Aejaz Ali and James K. Wight, “R.C. structural walls with staggered door openings”, Journal of Structural Engineering, Vol. 117, No. 5, pp. 1514–1531, May. 1991.

[2] Hamdy H.A. Abd-el-rahim and Ahmed Abd-el-rahim Farghaly, “Influence of requisite architectural openings on shear walls efficiency”, Journal of Engineering Sciences, Assiut University, Vol. 38, No. 2, pp. 421–435, Mar. 2010.

[3] IS: 13920 - 1993 “Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces – Code

of Practice", Bureau of Indian Standards, New Delhi, India.

[4] IS: 1893 (Part I) - 2002 "Criteria for Earthquake Resistant Design of Structures", Bureau of Indian Standards, New Delhi, India.

[5] IS: 456 - 2000 "Code of Practice for Plain and Reinforced Concrete", Bureau of Indian Standards, New Delhi, India.

[6] Lin C.Y. and C.L. Kuo, "Behavior of shear wall with openings", in Proc. Ninth world conference on Earthquake Engineering, Japan, 1988, paper, p. 535–540.

[7] Mosoarca Marius, "Seismic behavior of reinforced concrete shear walls with regular and staggered openings after strong earthquakes between 2009 and 2011", Engineering Failure Analysis, Vol. 34, pp. 537–565, 2013.

[8] Pankaj Agarwal and Manish Shrikhande, "Earthquake Resistant Design of Structures", 1st ed., Asoke K. Ghosh, PHI Learning Private Limited, Delhi, India, 2014.

[9] Sharmin Reza Chowdhury, M.A. Rahman, M.J. Islam and A.K. Das, "Effects of openings in shear wall on seismic response of structures", IJCA, Vol. 59, No. 1, pp. 10–13, Dec. 2012.

[10] The IITK website. [Online]. Available: http://www.iitk.ac.in/nicee/

[11] Yanez F.V., R. Park and T. Paulay, "Seismic behavior of walls with irregular openings", in Proc. Tenth world conference on Earthquake Engineering, Rotterdam, 1992.

