HBRP PUBLICATION

Journal of Engineering Analysis and Design
Volume 7 Issue 1
e-ISSN: 3048-7579

Enhancing Seismic Performance of High-Rise Buildings: A Review of Shear Wall Implementation

Md. Mahmudul Haque Ovi[1*], Baria Obaed Bintu[2], Sharmin Reza Chowdhury[3], Zakaria Hossain Rafi[4], Abdullah Al Hojaifa[5]

[1,2,4,5]Graduate in Civil engineering, Department of Civil Engineering, Ahsanullah University of Science and Technology, Dhaka, Bangladesh

[3]Professor, Department of Civil Engineering, Ahsanullah University of Science and Technology, Dhaka, Bangladesh

****Corresponding Author***
E-Mail ID: mahmudulhaqueovi2580@gmail.com

ABSTRACT

The construction of high-rise buildings is increasing day by day in urban areas. Those high-rise buildings face significant challenges in resisting lateral forces such as earthquakes and wind loads. So it is necessary to comprehensively understand their behavior under those loading conditions. Shear walls are an essential component of lateral force-resisting systems, plays an important role in enhancing the stability and resilience of those high-rise buildings. Strategically designed and placed shear walls within a structure would serve very effectively in resisting lateral stresses induced during seismic or wind loads. Studying a regular and irregular high-rise structure with and without a shear walls allowed researchers to understand better on the impacts of shear walls implementation on displacement, story drifts, time period, overturning moments, and base shear. The performance of shear walls on seismic activities can be evaluated by various methods such as static equivalent, response spectrum analysis, time history analysis, and pushover analysis method. In this review paper a comprehensive study has been undertaken on the optimum placement and type of shear walls for enhancing seismic performance of high-rise buildings. It also discusses on the effectiveness of different configurations of shear walls and how openings in shear walls affect their contribution to seismic resistance.

Keywords: *Shear wall, seismic load, response spectrum analysis, time history analysis, ETABS*

INTRODUCTION

In recent times, there has been a significant migration of people from rural to urban areas. As more people move to urban areas the demand for land increases. This leads to a shortage of available land and subsequently rises land prices. The cost of land is not affordable for middle-class people. To accumulate this scenario urban planners and developers grapple with the challenge of balancing population growth with limited space. As a result, for densely populated cities multi-storied buildings are a pragmatic solution which allows more people to reside within a confined footprint.

High-rise buildings are defined as the buildings that are above 10 stories or 33 meters in height, excluding appearances like water tanks and communication towers [1]. The design of high-rise buildings needs careful consideration of structural integrity and cost-effectiveness. Shear wall (SW), as an integral component of lateral force-resisting systems, plays an important role to ensuring the stability and safety of these structures, especially in earthquake-prone regions [2]. Without the strategic placement of shear walls (SWs), high-rise buildings would require significantly larger beam and column sections to withstand lateral forces imposed by wind or seismic events. This increase in member size causes higher material consumption, increased foundation loads, and ultimately, a more expensive construction process. On the other hand, Irregularity exists in the structure because of its aesthetic looks, available land, and many other reasons. Many researchers have confirmed by their research that irregularity in structure significantly reduces the performance of that structure, so that it should be considered during analysis and designing [3]. The intensity of lateral loads such as wind and seismic forces increases dramatically with the increases of building's height. These intensity of lateral loads can significantly compromise the structural integrity of high-rise structures. These lateral forces can induce sway, also known as lateral displacement of the building. The effective control measures must be needed on lateral displacement to ensure the safety and integrity of the structures. The combined use of SWs with other structural members such as moment frames and bracing systems can effectively resist the lateral forces and also ensures their uniform load distribution throughout the building.

OBJECTIVE AND SCOPE OF THE RESEARCH

The purpose of this research is to comprehensively review on the impact of implementing SWs in high-rise buildings under seismic loading conditions. The key objectives of this review paper are as follows:

- To investigate the impact of the SWs locations on structural behavior and performance of high-rise buildings.
- To evaluate the optimum location of SWs which enhances the maximum structural stability and resilience against seismic activities.
- To assess the performance of SWs at different shaped reinforced concrete (RC) frame structures.
- To analyze the ductility of RC frame structures with SWs while considering horizontal forces.
- To investigate the impact of using different types of SW on the seismic response of high-rise buildings.
- To evaluate the performance of SW with various types of openings under seismic loading.

REVIEW OF LITERATURE OVER NUMERICAL ANALYSIS

A unique design method was proposed by Khan and Sbarounis [4] to minimize the effect of soft stories during seismic events. Their approach was using frames and SWs for soft story buildings.

Han-Seon Lee and Dong-Woo Ko [5] conducted an investigation to evaluate the seismic behavior of high-rise structures containing RC bearing-walls. In their analysis they provide three types of irregularities at the lower stories. Their investigation revealed that SWs can significantly minimize the shear deformation but their effects on overturning moment, overturning deformation, and base shear are negligible.

To investigate the seismic performance of a 7-story irregular hospital building with the optimum position of SWs a research was carried out by Lamichhane et al. [3] by using ETABS. Their analysis further observed that constructive utilization of SWs decreased story displacement and the story drift in allowable limit which enhances the comprehensive seismic performance. The reduction in story displacement has shown in Figures 1 and 2. According to their analysis, it was noticed that the coefficient of base shear for structures with SWs as per NBC 105:2020 applies higher to IS 1893:2016. In their study they conclude that the location and placement of SWs play a vital role in retrofitting irregular buildings to improve their resistance due to seismic events and also reduce potential damages.

Fig. 1: *Maximum Story Displacement: with SWs vs. without SWs* [3].

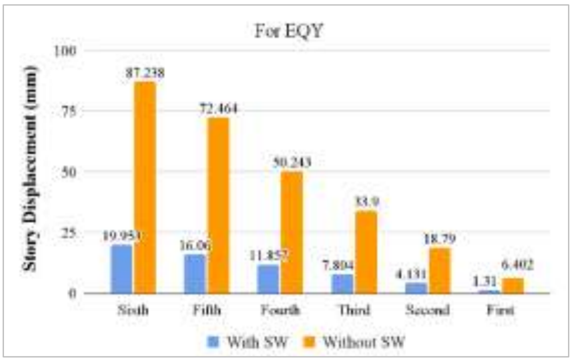

Fig. 2: *Maximum Story Displacement: with SWs vs. without SWs* [3].

To evaluate the seismic behavior of 13-story high-rise buildings Paul et al. [6] conducted an investigation by using both static and dynamic analysis methods with various plan irregularities. In their investigation they mainly focused on the impact of re-entrant corners and torsional effects. By utilizing Response Spectrum Analysis (RSA) method their investigation revealed that the implementing SW can significantly minimize stress concentration across all building shapes (Regular, H-shaped, C-shaped, and L-shaped). Even with this improvement in L-shaped buildings displayed the highest levels of story drift and displacement. According to BNBC 2020 the story drift and displacement exceeded the allowable limits. Maximum story displacements and drifts obtained from their research has been shown in Figures 3 and 4. Their investigation confirmed that the vulnerability of L-shaped buildings to seismic events occurs primarily due to their torsional irregularity. They concluded that buildings with regular shapes tend to perform best under seismic loading. On the other hand, for irregular buildings seismic performance generally follows the order of H-shaped > C-shaped > L-shaped.

HBRP
PUBLICATION

Journal of Engineering Analysis and Design
Volume 7 Issue 1
e-ISSN: 3048-7579

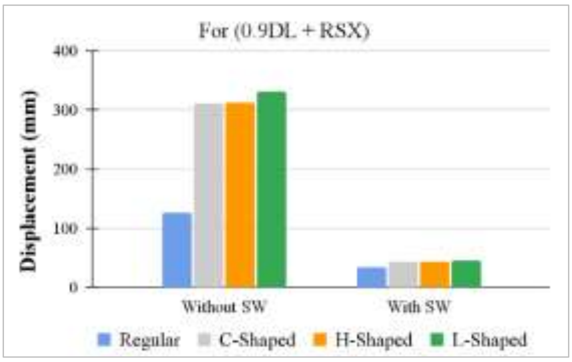

Fig. 3: *Maximum Displacement for Different Shaped Buildings: without SWs vs. with SWs* [6].

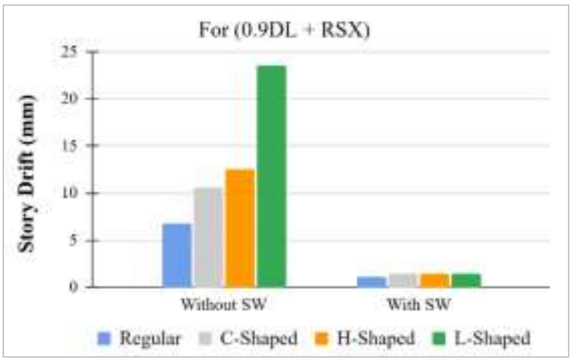

Fig. 4: *Maximum Story Drift for Different Shaped Buildings: without SWs vs. with SWs* [6].

Nallasivam and Shukla [7] used ETABS and RSA method to assess the impact of SW placements on the seismic behavior of 31-story high-rise buildings. Their research demonstrated that after implementing SWs in their models, the stiffness of the models increases while the natural time period decreases. When the SWs were placed at the central core of the building there was a higher time period decrement observed compared to SWs placed at other locations. They concluded that placing SWs at the center core or edges of buildings always shows better performance under lateral loads compared to SWs placed at the corners of a building.

Vijayan et al. [8] conducted research to analyze the seismic behavior of 21, 22, and 52 story irregular high-rise buildings with respect to various types of SWs by using the RSA method in ETABS. Their study disclosed that different types of SWs affect the story displacement, story drift and story shear. Among them composite SWs are more efficient to reduce the story drift and story shear rather than normal RC SWs. The further outcome of the analysis consists of composite SWs efficiently minimizing the seismic effects because it reduces around 60% displacement. In addition their analysis also compares that the use of composite SWs in high-rise buildings provides more seismic resistance and as well as remarkably minimizes the story drift rather than normal RC SWs.

Journal of Engineering Analysis and Design
Volume 7 Issue 1
e-ISSN: 3048-7579

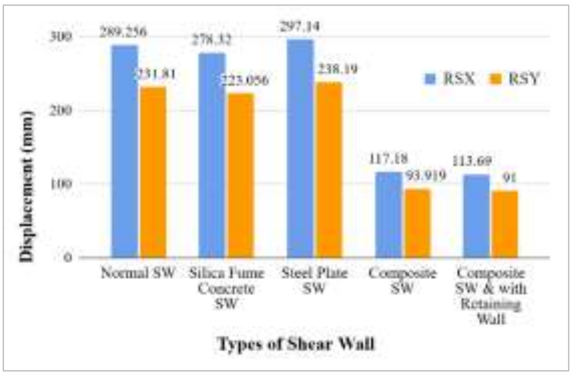

Fig. 5: *Maximum Displacement of 52-Story High-rise Buildings* [8].

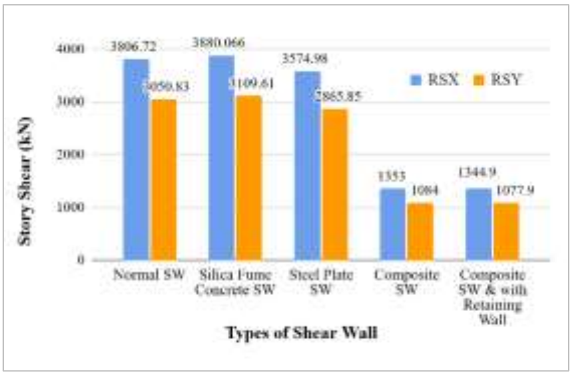

Fig. 6: *Maximum Story Shear of 52-Story High-rise Buildings* [8].

Bhandari et al. [9] explored the effects of implementing SWs on the seismic behavior of 10-story irregular high-rise buildings in Kathmandu by using the RSA method and ETABS. In their study they found that SWs notably reduce the deflection, inter story drift, structure's time period. In contrast, implementing SWs increases the base shear. The use of SWs at full height of buildings with thickness of 200mm, 250mm and 300mm shows a reduction in modal time period are 10.52%, 10.87%, and 11.04% respectively. The result of the modal time period obtained from their investigation has shown in Figures 9, 10, and 11. They also found in their study that when the height of the SW was reduced the deflection and drift above the reduced SWs are slightly increased. They concluded in their study that implementing SWs at full height of their analyzed buildings may not be necessary to reduce the torsional irregularity.

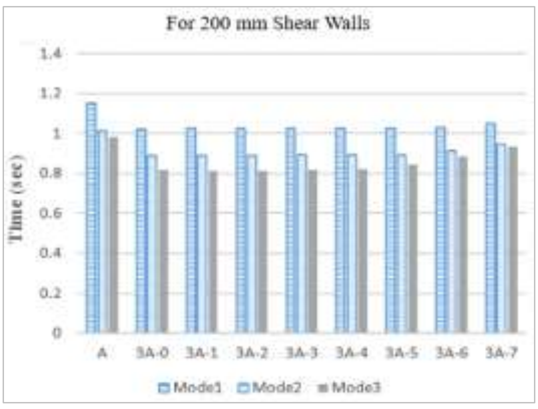

Fig. 7: *Modal Time Period of Building* [9].

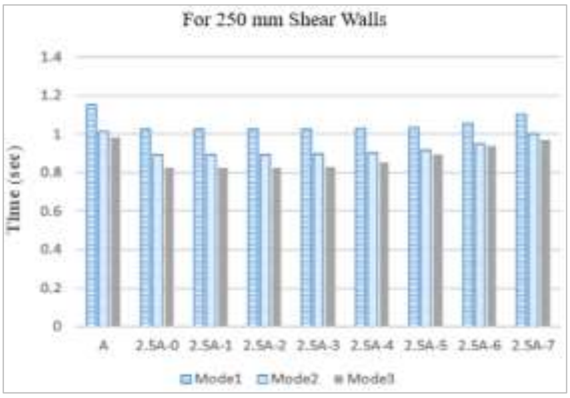

Fig. 8: *Modal Time Period of Building* [9].

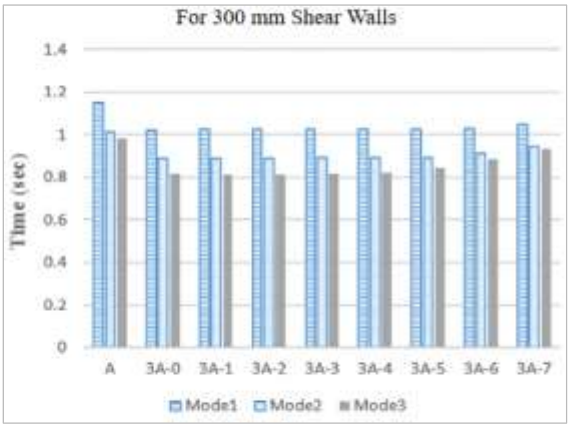

Fig. 9: *Modal Time Period of Building* [9].

Agha et al. [10] conducted a study to assess the seismic performance of 16-story high-rise buildings using dual framed SW system. Their study was completed by using ABAQUS software while considering the interaction between soil and structure. The main purpose of their study was to evaluate the optimum positioning of SWs in the high-rise building. Their study revealed that the most effective position of SWs in a building depends on soil conditions. Where the ground soil is enough hard, there the peripheral SWs at the corners of the buildings minimized the displacement and base shear rather than other positioning of SWs. However, there is a soft soil, and SWs at the central core of the building perform best in reducing these critical structural parameters.

Mohan and Arathi [11] conducted a comprehensive study on the seismic behavior of 11-story high-rise buildings with configuring SWs opening. By using ETABS software and RSA method, they found rectangular, L-shaped, H-shaped, and T-shaped buildings. Their study revealed that using staggered openings in SWs generally resulted in improved structural performance particularly in buildings with regular and H-shaped layouts. This improvement was observed in key measures like how much the building moved, how much each floor tilted relative to the one below, and the overall force at the base of the building. However, in L-shaped buildings, vertical openings shows more effectiveness in reducing displacement and base shear in the Y - direction. Results obtained from their study have been presented in Table 1.

Journal of Engineering Analysis and Design
Volume 7 Issue 1
e-ISSN: 3048-7579

Table 1: *Percentage Reduction in Key Structural Parameters for Staggered vs. Vertical Openings in SWs [11].*

Structural Parameters		**% Reduction**	
		X-Direction	Y-Direction
Regular Building	Displacement	12.92	13.15
	Story Drift	11.176	12.307
L Shape Building	Displacement	11.239	5.4
	Base Shear	0.44	13.37
H Shape Building	Displacement	8.17	7.75
	Story Drift	6.739	6.98
	Base Shear	0.896	0.401
T Shape Building	Displacement	5.99	5.8
	Story Drift	4.65	7.51
	Base Shear	4.676	4.69

Baral and Yajdani [12] investigated how strategic placement of SWs impacts the seismic performance of a 10-story high-rise building in India. They revealed that implementing SWs along the corner edges of the building can significantly reduce the building's fundamental period of vibration. This reduction in the fundamental period of vibration enhances building’s ability under seismic forces. Their investigation also confirmed that SWs also effectively minimized story drift and redistribute internal forces within the structure. The result of fundamental time period and lateral displacements obtained from their investigation are shown in Figures 10 and 11.

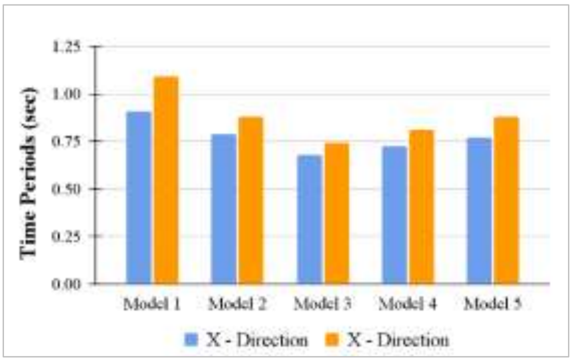

Fig. 10: *Time Period of Different Models* [12].

HBRP PUBLICATION

Journal of Engineering Analysis and Design
Volume 7 Issue 1
e-ISSN: 3048-7579

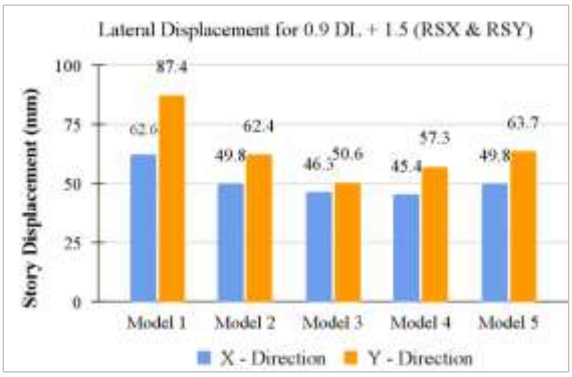

Fig. 11: *Lateral Displacement of Different Models* [12].

Praveen et al. [13] conducted an analysis to assess the effects of SWs location on the seismic behavior of 25-story high-rise buildings. According to their analysis, it has been observed that when the SW is placed at the corners of the buildings, it provides maximum base shear rather than at other locations of the SW. The results of base shear obtained from their study is shown in Table 2. In addition, their study also emphasizes that locating SWs both at the corners and at the center provides more efficient resistance to seismic activity. Their analysis further revealed that these locations of SWs provide more effective resistance compared to the edges of the building. The results of story stiffness obtained from their study are shown in Figures 12 and 13.

Table 2: *Base Shears of Models with SW Variations [13]*.

Models with SWs Variations	Base Shear	
	EQX	EQY
No SW	667	536.2171
SWs at Core of Building	862.9512	819.0693
SWs at Wedges of Building	792.9108	695.8547
SWs at Corner of Building	1211.012	1147.2025
SWs at Corner of Building with Less Volume	769.2996	656.3193
SWs at Re-entrant Corners of Building	831.4465	723.485

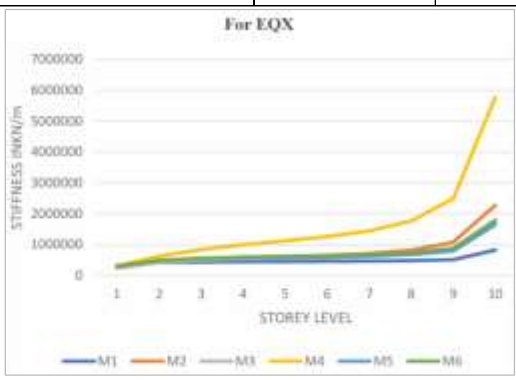

Fig. 12: *Story Stiffness at Different Level* [13].

HBRP PUBLICATION

Journal of Engineering Analysis and Design
Volume 7 Issue 1
e-ISSN: 3048-7579

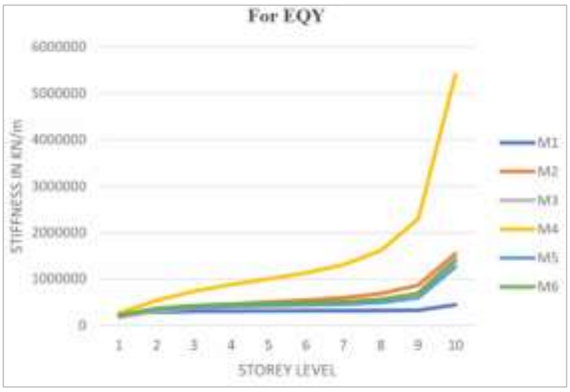

Fig. 13: *Story Stiffness at Different Level* [13].

Venkatesh and Bai [14] investigated the seismic behavior of the 10-story RC moment-resisting frame building by using both external SWs and internal SWs. They found that internal SWs perform better compared to external SWs. They concluded that when it is not possible to evacuate the building for the time of retrofitting, then external SWs can be used as alternatives to internal SWs.

Sanketh and Rao [15] discussed the seismic behavior of irregular buildings with re-entrant corners by using the Time History Analysis method. In their study they assessed how the location of SWs on irregular buildings affects their seismic performance. They found that buildings with SWs effectively reduced story displacement and story drift compared to buildings without SWs. The results of maximum story displacements and maximum story drift ratios obtained from their investigation are shown in Figures 14 and 15. However, they concluded that structural parameters decrease when the SWs are placed closer to the center of mass of the buildings.

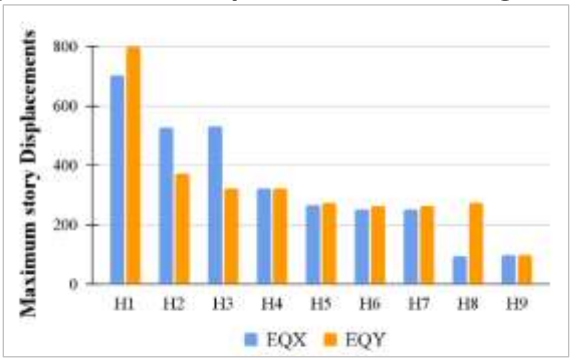

Fig. 14: *Maximum Story Displacements for all Models* [15].

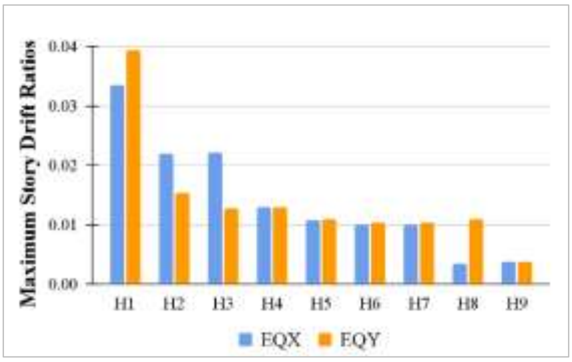

Fig. 15:*Maximum Story Drift Ratios for all Models* [15].

Journal of Engineering Analysis and Design
Volume 7 Issue 1
e-ISSN: 3048-7579

Malik et al. [16] explored the seismic performance of RC framed buildings with curtailed SWs. They concluded that there is a slight effect of the distribution of story shear forces when the SWs height have been reduced up to 50% of total buildings height. Parvez et al. [17] carried out an investigation by using Pushover Analysis method to assess the impact of the opening pattern of SWs of 16-story different plan irregular high-rise buildings. In their investigation they found that placing SWs at the outer girds shows better performance by minimizing story displacement and story drift for both plus and H shaped buildings. The maximum displacement and maximum drift for both plus and H shaped buildings obtained from their investigation are shown in Figures 16 to 19. Ultimately, based on their investigation it can be concluded that the opening pattern and location of SWs significantly affects structural response.

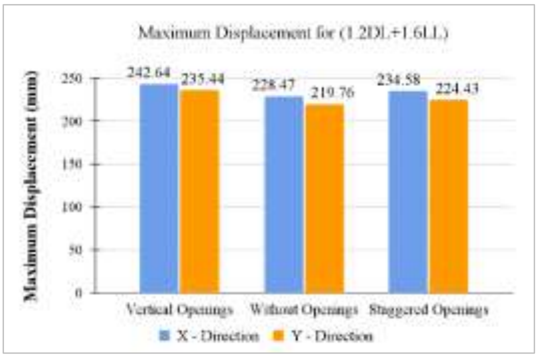

Fig. 16: *Maximum Displacement for Plus Shape Building* [17].

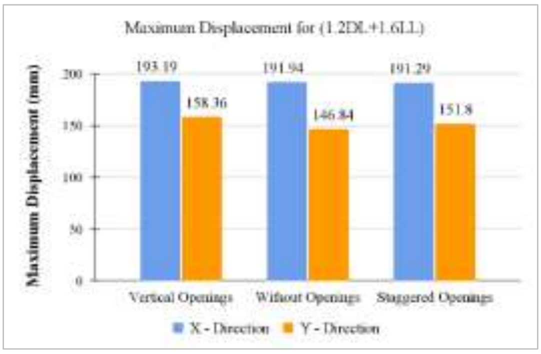

Fig. 17: *Maximum Displacement for H Shape Building* [17].

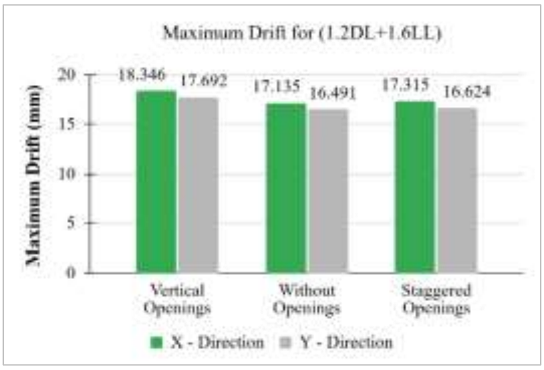

Fig. 18: *Maximum Drift for Plus Shape Building* [17].

HBRP PUBLICATION

Journal of Engineering Analysis and Design
Volume 7 Issue 1
e-ISSN: 3048-7579

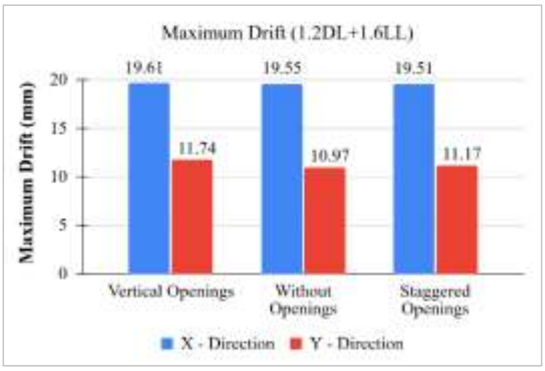

Fig. 19: *Maximum Drift of H Shape Building* [17].

Ismail and Patil [18] explored the complex interaction between SWs and the flat slabs in 13-story high-rise buildings. According to their investigation, the lowest displacements and overturning moments were found for both types of buildings (with and without drop panels) when SWs were placed at the corners of the buildings. In contrast, the maximum story shear and maximum story stiffness were found for SWs that were placed at the corners of the buildings. The results of story stiffness and overturning moments obtained from their investigation are shown in Figures 20 to 23. Ultimately, they concluded that buildings containing flat slab and without SWs exhibits poor seismic performance due to insufficient of lateral stiffness.

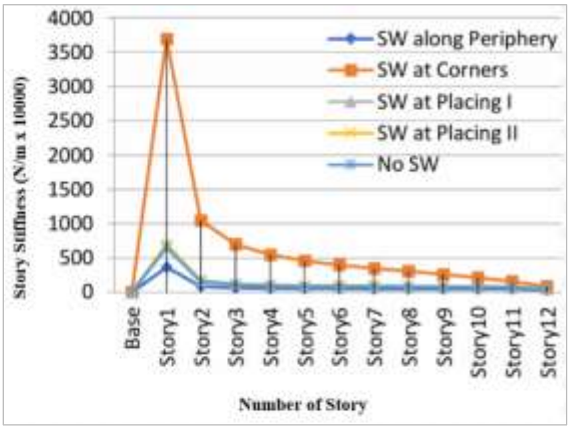

Fig. 20: *Story Stiffness (with Drop Panels) at Different Stories* [18].

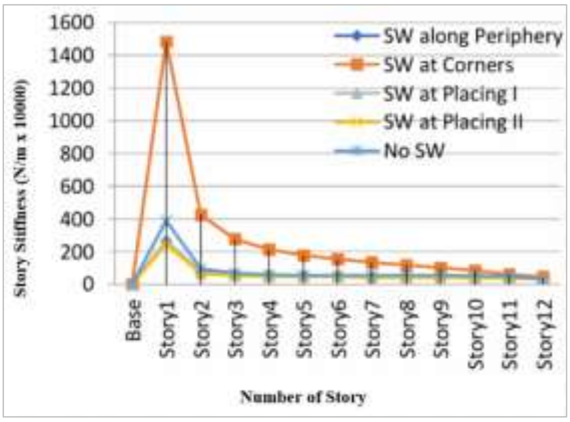

Fig. 21: *Story Stiffness (without Drop Panels) at Different Stories* [18].

Journal of Engineering Analysis and Design
Volume 7 Issue 1
e-ISSN: 3048-7579

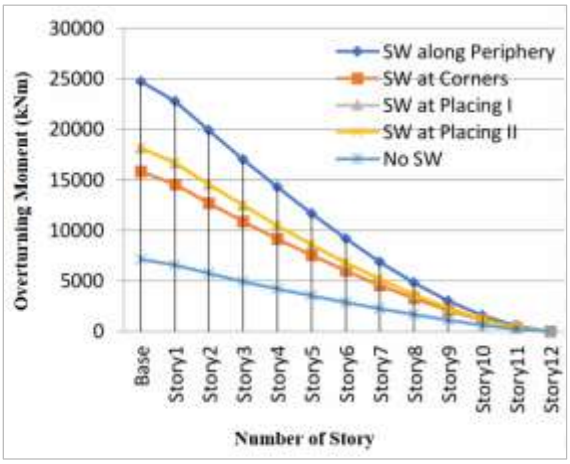

Fig. 22: *Overturning Moments (with Drop Panels) at Different Stories* [18].

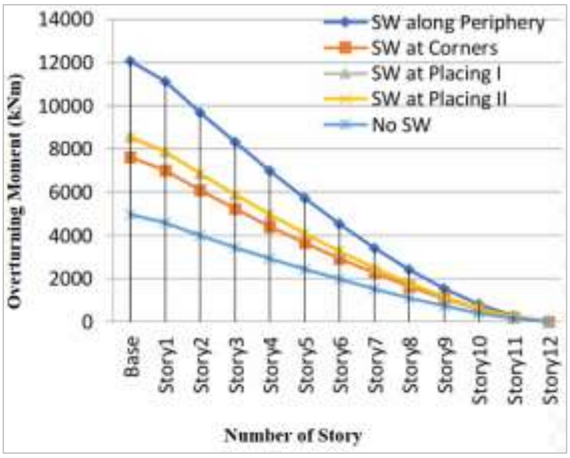

Fig. 23: *Overturning Moments (without Drop Panels) at Different Stories* [18].

Resatoglu and Jkhsi [19] investigated the ductility rate of 4, 8 and 12-story high-rise buildings with varying the location and thickness of the SW by using Non-linear Static Analysis method in ETABS. According to their study it has been observed that the increasing SW's thickness leads to decreasing the ductility rate of structure. Their study further disclosed that increasing the rate SW's thickness also increased the base shear of the buildings. The changing position of SWs from edge to middle caused reduction in ductility rate. The results of ductility value obtained from their research are presented in Figures 24, 25, and 26. The changing location of the SWs from edge to middle also affects the yield displacement as well as increases the value of maximum base shear force for all stories of the buildings.

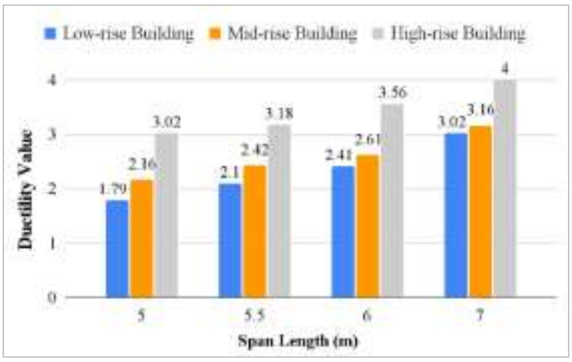

Fig. 24: *Comparison between Ductility Values of Different Storied Buildings* [19].

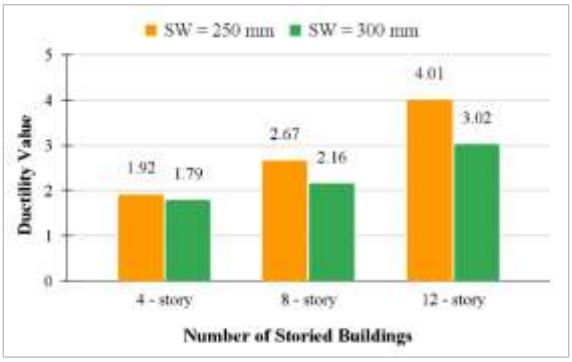

Fig. 25: *Comparison between Ductility Values for Different Thickness of SW* [19].

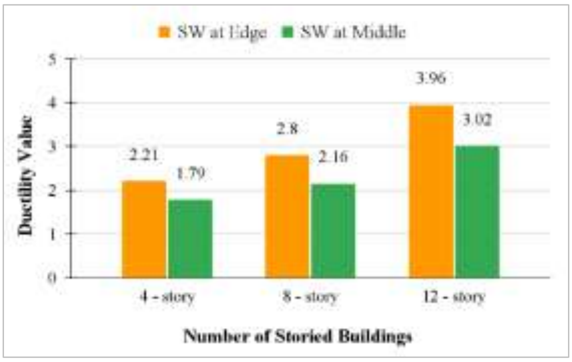

Fig. 26: *Comparison between Ductility Values for Different Positions of SW* [19].

CONCLUSION

After a comprehensive overview on the impact of implementing SWs in high-rise buildings, the following conclusions can be summarized:

- SWs help high-rise buildings to perform better under seismic loading. But the most effective performance of SW heavily depends on its position rather than simply increasing its cross sectional area.
- The implementation of SWs significantly reduces natural time period, story displacement. On the other hand it increases story stiffness which helps to improve the building's resistance to lateral forces.
- Among various plan irregularities, L-shaped buildings are most likely to vulnerable in torsional effects due to their uneven layout. This can causes uneven distribution of seismic forces. To enhance seismic performance, the strategic placement of SWs is essential, which helps to minimize torsional effects and reduces the risk of structural failures.

- SWs located at re-entrant corners and the core of a building exhibit superior performance in minimizing seismic forces compared to those SWs placed at the edges.
- Compared to conventional RC SWs , composite SWs shows a significant reduction in story drift and shear, particularly in high-rise buildings. Composite SWs also exhibit a remarkable ability to reduce seismic effects, with up to a 60% reduction in displacement observed.
- SWs extending the full height of a building may not always be necessary for optimal seismic performance. In some cases, curtailing SWs at higher stories, where their contribution to reducing displacement is less significant, can lead to material savings without compromising the building's ability to resist lateral forces.
- SWs placement is crucial for improving the seismic performance of flat slab structures, particularly when strategically placed at the building's corners rather than placed along the periphery of the buildings.
- The arrangement of openings within a SW can significantly influence its effectiveness in resisting seismic forces. Specifically, staggered openings have been shown to improve the dynamic behavior of SWs compared to vertical openings.

ACKNOWLEDGEMENT
The author expresses sincere gratitude to Professor Dr. Sharmin Reza Chowdhury, Department of Civil Engineering, Ahsanullah University of Science and Technology, for his invaluable guidance, constant encouragement throughout the development of this review article.

REFERENCES
1. Bangladesh National Building Code (BNBC). (2020). *Dhaka, Bangladesh: Housing and Building Research Institute, Ministry of Housing and Public Works, Government of the People's Republic of Bangladesh*.
2. Paulay, T., & Priestley, M. J. (1992). *Seismic design of reinforced concrete and masonry buildings*. A Wiley Interscience Publication.
3. Lamichhan, K., Lamichhane, G. P., Ghimire, K., & Adhikari, K. P. (2021). Analysis of irregular structure with addition of shear walls as per Nepal building code (NBC 105:2020). *International Journal of Engineering Research & Technology (IJERT), 10*(3), 608-612.
4. Khan, F. R., & Sbarounis, J. A. (1964). Interaction of shear walls and frames. *Journal of the Structural Division, 90*(3), 285-335.
5. Lee, H.-S., & Ko, D.-W. (2004). Seismic response characteristics of high-rise RC wall buildings having different irregularities in lower stories. *Journal of Structural Engineering, 130*(2), 271-284.
6. Paul, A., Morshed, Z. A., & Parvez, Z. (2023). Study on seismic responses of plan irregular buildings due to torsional irregularity and re-entrant corners. In *7th International Conference on Engineering Research, Innovation and Education* (pp. 111-116).
7. Shukla, K., & K, N. (2023). Dynamic response of high-rise buildings with shear walls due to seismic forces.
8. Vijayan, V., Santhi, M. H., & Mohan, R. (2020). Seismic performance of high-rise buildings with different types of shear walls. *IOP Conference Series: Materials Science and Engineering, 936*(1).
9. Bhandari, A., Suwal, R., & Khawas, A. (2022). Seismic response of irregular high-rise building in Kathmandu with shear wall. *IOE Graduate Conference, 12*.
10. Agha, W. A., Almorad, W. A., Umamaheswari, N., & Alhelwani, A. (2020). Study the seismic response of reinforced concrete high-rise building with dual framed-shear wall system

considering the effect of soil structure interaction. *Materials Today: Proceedings*, *43*, 2182–2188.

11. Mohan, A., & S, A. (2017). Comparison of RC shear wall with openings in regular and irregular building. *International Journal of Engineering Research & Technology (IJERT)*, *6*(6), 471-476.
12. Baral, A., & Yajdani, D. S. (2015). Seismic analysis of RC framed building for different positions of shear wall. *International Journal of Innovative Research in Science, Engineering and Technology*, *4*(5).
13. P. J., S. J., & Jayachandra. (2024). Effective position of shear wall in a multi-story building with re-entrant corners taking volume into consideration. *International Journal of Innovative Research of Science, Engineering and Technology (IJIRSET)*, *13*(8), 15244-15252.
14. Venkatesh, S. V., & Bai, H. S. (2011). Effect of internal & external shear wall on performance of building frame subjected to lateral load. *International Journal of Earth Sciences and Engineering*, *4*(6), 571-576.
15. Sanketh, P., & Rao, B. M. (2016). Seismic strengthening of plan irregular RC buildings with re-entrant corners using shearwalls. *International Journal of Research in Engineering and Technology*, *5*(2), 21-26.
16. Malik, R., Madan, S., & Sehgal, V. (2011). Effect of height on seismic response of reinforced cement concrete framed buildings with curtailed shear wall. *Journal of Engineering and Technology*, *1*(1), 43-46.
17. Parvez, Z., Morshed, A. Z., & Paul, A. (2023). Pushover analysis of multi-storied plan irregular building having staggered openings in the shear wall. In *7th International Conference on Engineering Research, Innovation and Education*. Sylhet, Bangladesh.
18. Ismail, M. S., & Patil, D. G. (2021). Computational assessment for seismological performance of multi-storey flat slab structures with (at specific positions) and without shear walls. *International Journal of Engineering Applied Sciences and Technology*, *6*(3), 81-87.
19. Resatoglu, R., & Jkhsi, S. (2022). Evaluation of ductility of reinforced concrete structures with shear walls having different thicknesses and different positions. *IIUM Engineering Journal*, *23*(2), 23-44.