

PERFORMANCE-BASED ANALYSIS OF RC SHEAR WALLS WITH OPENINGS UNDER SEISMIC LOADS IN DHAKA

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ABSTRACT

In an active seismic region like Bangladesh, it is necessary to ensure the seismic performance of buildings while considering architectural aesthetics. Introduction of openings in shear walls, one of the basic architectural interventions, can significantly affect the structural response of reinforced concrete (RC) frames under lateral forces such as wind load and seismic load. This research examines the structural behavior of frame structures with reinforced concrete shear walls having varied opening sizes across all soil categories in Dhaka, with the help of finite element modeling and the Bangladesh National Building Code (BNBC) 2020 guidelines. The analysis considered various ten-story building models: (i) without shear walls, (ii) with solid shear walls, shear walls (iii) with 10% and (iv) with 20% openings. The study focuses on critical structural parameters, such as base shear, seismic story drift, torsional irregularity, fundamental period, modal frequencies, and story stiffness. The Equivalent Static Force (ESF) method was applied to compare the models and understand the impact of the shear wall openings. From the analysis, we see that solid shear walls have a significant contribution to seismic resistance, resulting highest base shear (438 kip) and lowest fundamental period (1.01 seconds), reflecting superior lateral stiffness. Although the openings in the shear wall reduce base shear (436-434 kip) and slightly increase the period (1.02-1.04 seconds), all 10% and 20% opening models maintain performance within BNBC-allowed inter-story drift and torsional limits. Stress concentrations around the openings suggest the necessity of careful reinforcement detailing. Moreover, stiffness dropped in lower stories, and stress contours showed high concentrations at opening corners, showing the need for proper reinforcement detailing. Overall, the results indicate that up to 20% openings in the shear walls can be effectively and safely used in earthquake-prone areas without compromising structural stability, with design measures properly implemented. However, opening ratios more than this threshold value lead to undesirable seismic performance. This study draws a balance between architectural functionality and seismic safety in structural design.

Keywords: *Shear Wall Openings, Seismic Performance BNBC 2020, Finite Element Analysis, Reinforced Concrete Structures*

1. INTRODUCTION

Reinforced concrete (RC) shear wall is one of the fundamental structural elements that serves as the backbone for lateral load-bearing capacity in modern structures, as it contributes to the seismic and wind resistance of the structures. (Bashiru, Akinpelu, & Adedeji, 2023). The zones that are prone to seismic events and intense wind forces, these structural elements are important for constructing mid-rise and high-rise buildings. (University, 2023). Architects and structural engineers, based on their design practice, add openings in their designs, including portals, glazed apertures, and service conduits, fulfilling operational needs and architectural aesthetics. Structural uniformity of the wall is disturbed by such openings, thus significantly reducing the stiffness, load-carrying capacity, and seismic response under lateral loads. (Islam, 2024). In rapidly growing cities like Dhaka, Bangladesh, where the effect of earthquakes is considered life-threatening, this issue is particularly critical. (Kanak, Saha, & Islam, 2022). While RC shear walls are now prevalent in the construction of Bangladesh, design approaches still emphasize strength-based provisions over comprehensive performance-based assessment. (Bashiru, Akinpelu, & Adedeji, 2023). Comprehensive structural response is assessed by Performance Based Design (PBD) where deformation limits, energy dissipation, and expected damage states are considered. (Topaloğlu, Uğur, & Erdoğan, 2021). The rate of cracking propagation and localized distress are further induced as stress concentrations are created by the presence of such openings. (Harati, 2020). The position, size, and shape of these openings determine the reduction level of the stiffness and ductility of shear walls. (Islam, 2024). Studies show that when openings are placed asymmetrically or near the base, walls lose a significant portion of their lateral strength. (Scientific.Net, 2014). In Dhaka city, parking or commercial spaces are provided with wall openings on the lower story, and thus, the lateral load transmission can be weakened if proper reinforcement is not applied.

Under earthquakes, RC shear walls lose stiffness and strength under cyclic loads. Ductility is enhanced by well-confined boundary elements. On the other hand, slender walls show flexural failure, and squat walls are susceptible to shear stress. (Harati, 2020). Axial loads contribute to an increase in strength, but deformation is reduced. Moreover, stress distribution is disrupted, and crack propagation is influenced due to openings in the shear wall. (Bashiru, Akinpelu, & Adedeji, 2023; Darvishi & Razavi, 2023; Islam, 2024). Previous numerical modelling studies indicate that up to a 50% reduction in lateral strength may be experienced by slender walls having large openings. (Khan, Ali, & Siddique, 2023), but squat walls are reported to be less affected because of their higher shear capacity (University, 2023). Openings in walls can cause pressure concentration, which causes local stress concentration and deformations. (Shobha Ram, Kumar, & Patel, 2021). However, research that quantifies these effects within a performance-based framework is still very limited, especially for developing regions. PBD is a good solution to connect this gap by linking structural behavior with performance objectives such as Immediate Occupancy, Life Safety, and Collapse Prevention (Chen, Li, & Huang, 2025). Although it has been successful in advanced engineering, PBD has not yet been widely applied to structures with openings, especially for those that are exposed to seismic forces. Furthermore, local factors like local soil classification of Dhaka, construction methodology, and local material properties remain unconsidered in international studies. (Kanak, Saha, & Islam, 2022). This absence of integrated research creates a huge gap in understanding the behavior of RC shear walls with openings under multiple hazards, considering the environmental and urban conditions of Dhaka. This study aims to address this gap through nonlinear performance-based analysis of RC shear walls with various opening configurations that are subjected to seismic loadings. Specifically, how the size, shape, and position of openings influence stiffness and strength, and how these factors affect performance levels such as drift and residual deformation, is shown in this study. The analyses, carried out following NBC 2020, aim to develop design recommendations related to the realities of Bangladeshi construction.

Research gaps like limited experimental data and no local hazard parameters consideration in modeling are critical for advancing both engineering knowledge and design practice in Bangladesh. The importance of this research is in both understanding the performance of shear walls and in the practical construction of these for safe, resilient structures. Considering global PBD principles within Dhaka, the study provides a way for more reliable design and retrofit strategies. Previous research works give importance to confinement, reinforcement, and strengthening (Mahmood & Abbas, 2019; Harati, 2020; Zhou, Feng, & Li, 2022) collectively showed the potential benefits of an integrated performance-based

approach. Performance-based assessment can reduce this gap and improve code calibration for local use. This research's target is to build a comprehensive understanding behavior of RC shear walls with openings under seismic loading. The findings of this research are expected to contribute to code development, ensure design safety, and contribute to resilient and sustainable cities in Bangladesh.

2. METHODOLOGY

The methodological framework starts with problem formulation and performance evaluation. The flowchart on the methodology (Figure 1) illustrates the analytical workflow adopted for assessing the seismic performance of reinforced concrete (RC) shear walls with openings. At first, the quantification of varying opening ratios that influence the structural response of RC shear walls under seismic loading is done. Models were analysed in ETABS, where a 10-story building was created with identical geometry and material properties across models, except for the size of the openings. Material properties were assigned following BNBC 2020 guidelines. Gravity loads (dead and live) and dynamic seismic loads were applied on the models, computed through the Equivalent Lateral Force (ELF) procedure, corresponding to seismic Zone-2 parameters (Table 1). The ELF method determined total design base shear based on seismic weight, response modification factor, importance factor, and spectral acceleration coefficient, while lateral forces were distributed story-wise using height-based weight factors. Figure 2 depicts the typical floor layout and different models carried out in this study. For the analysis, base shear, fundamental time period, and modal frequencies for each configuration are determined. The analysis is followed by a performance evaluation that involved determining story drift, inter-story displacements, and torsional irregularity across floors to identify stiffness degradation due to openings. Stress contours and deformation patterns were extracted to examine stress concentration near the corners of the openings. Models with 0%, 10%, and 20% openings are compared based on their relationship between opening size and reduction in stiffness and strength.

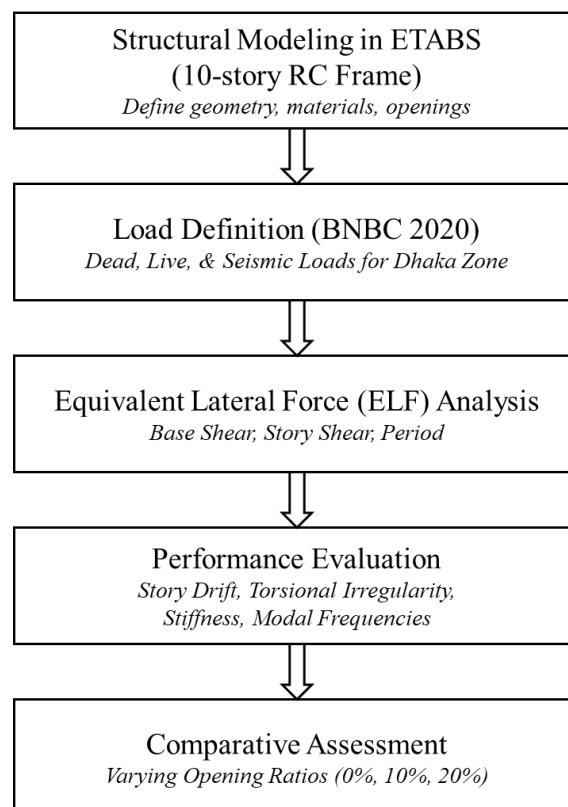


Figure 1: Methodological Flow

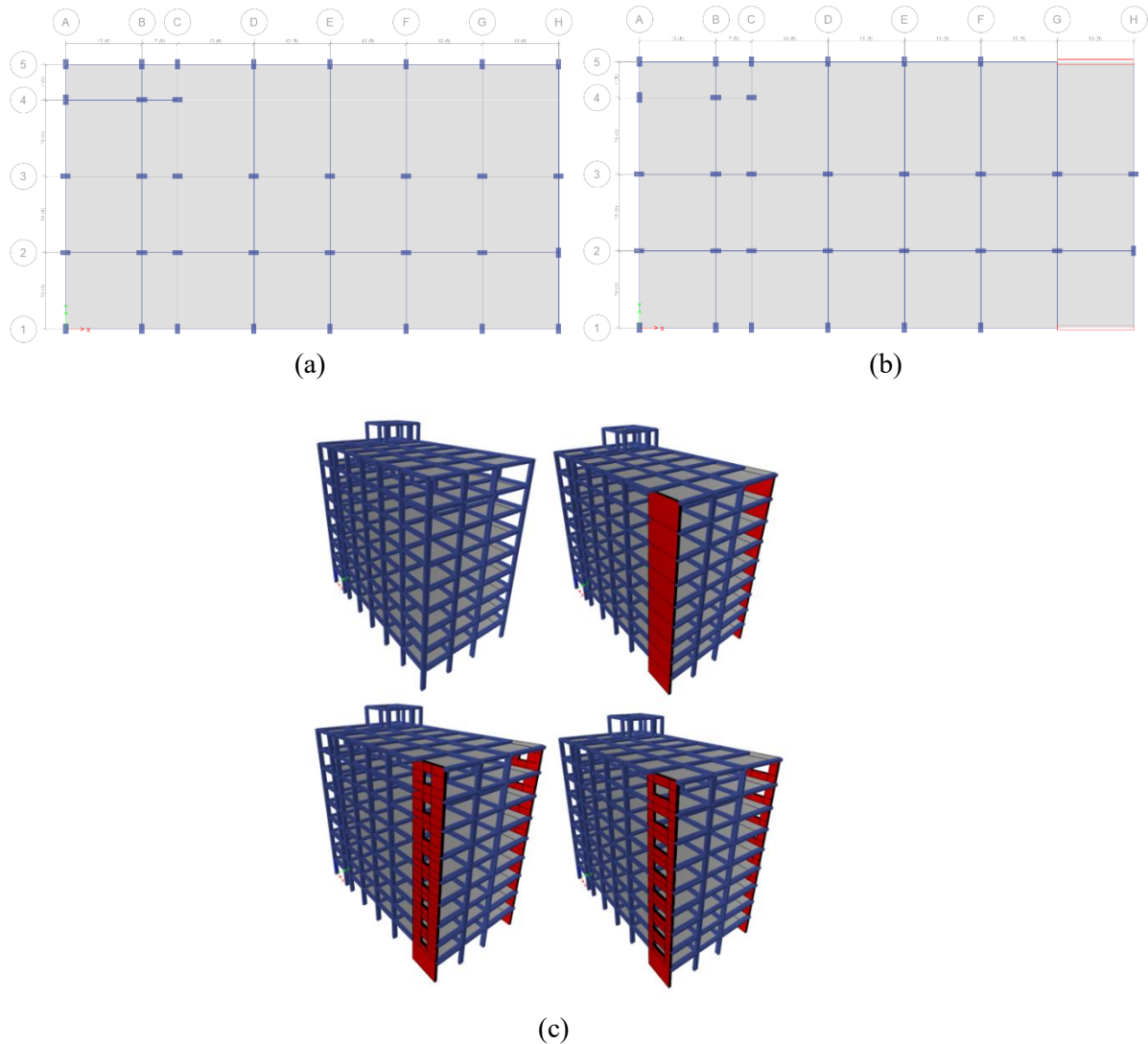


Figure 2: Layout and Finite Element Models

Table 1: Model-wise structure type and seismic parameters

Model Description	Seismic Parameters
C. Moment Resisting Frame Systems (no shear wall)_Special reinforced concrete shear walls	R = 8; Cd = 5.5
B. Building Frame Systems (with shear wall)_Special reinforced concrete shear walls	R = 6; Cd = 5

3. RESULTS AND DISCUSSION

3.1. Base Shear Response

The base shear obtained from the Equivalent Lateral Force (ELF) analysis demonstrates the dominant role of shear walls in enhancing lateral strength. The model with no shear wall and solid shear wall has a base shear of 318 kip and 438 kip, respectively, marking an approximate 38% improvement in overall lateral strength. In the case of models with 10% and 20% openings, base shear slightly decreased to 436 kip and 434 kip, respectively. The marginal 1-2% decrease suggests that limited openings (up to 20%) do not significantly impact global seismic resistance. This minor reduction in base shear indicates the internal forces get redistributed and loss of local stiffness at corners of openings, which can cause drift

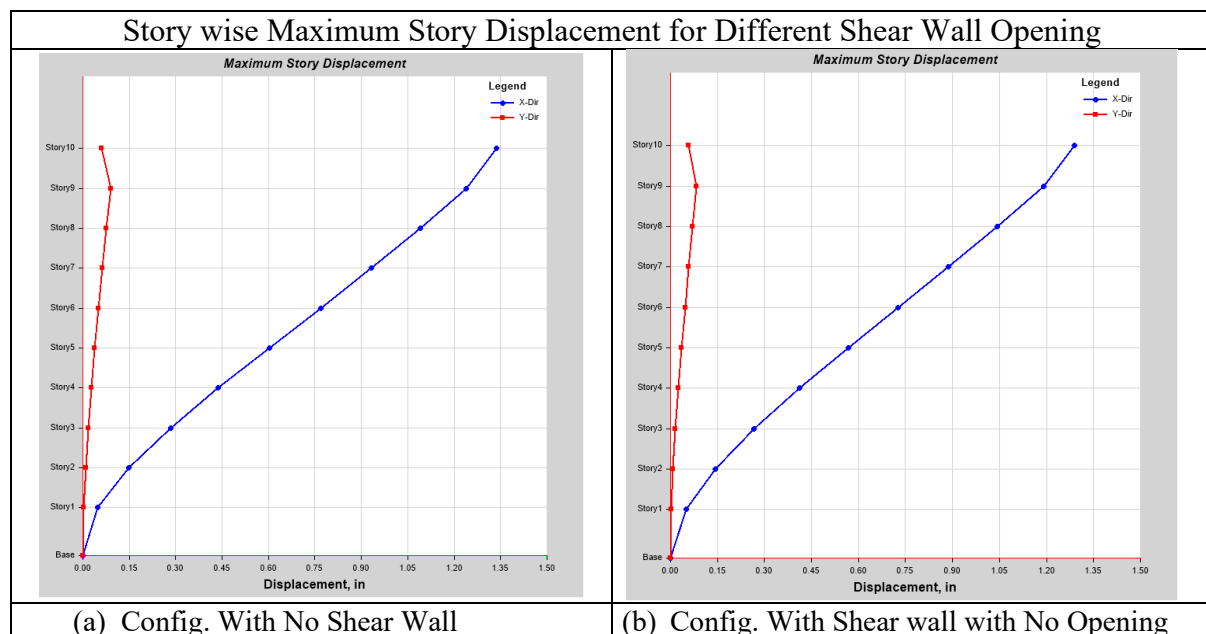
increase and stress concentration. These findings support previous studies showing that moderate openings in shear walls retain the primary load-bearing capacity of the solid shear walls, but larger openings (>25%) can lead to large stiffness loss and uneven lateral load distribution.

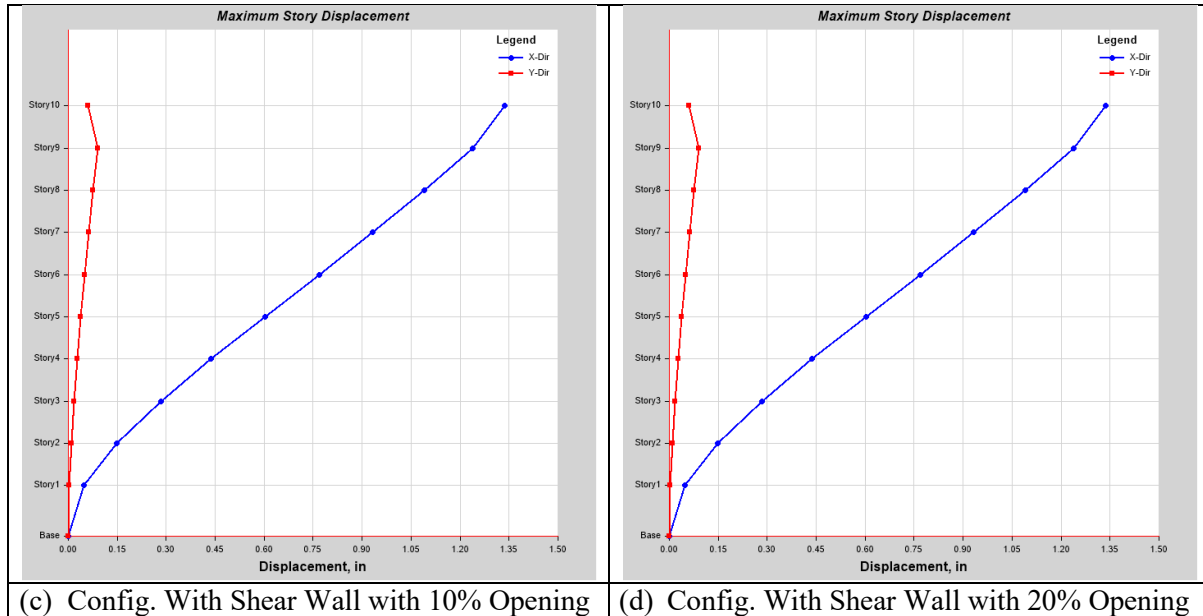
3.2. Time Period and Modal Characteristics

The fundamental period dropped from 1.94 sec (bare frame) to 1.01 sec for the solid shear wall model, reflecting a substantial increase in stiffness. The rise in the period to 1.02 sec and 1.04 sec for models with 10% and 20% opening, respectively, indicates a proportional stiffness reduction and shows strong lateral restraint compared to the model with no shear walls. Modal frequencies also increased for models with shear walls, which shows more rigid behaviour and reduced resonance probability. The results show that the period change due to openings remains within 3%, which means models up to 20% openings do not compromise the global dynamic characteristics of the structure. These findings offer an optimal stiffness–flexibility balance that reduces drift without imposing any excessive design forces.

3.3. Inter-storey Drift Performance

The inter-story drift values across the height of the building show that all shear wall models remain well within BNBC 2020 limits (0.004h). Solid Wall models showed a maximum drift of 0.020 m, which slightly increases to 0.021 m for the model with 20% opening. On the other hand, the model without any shear wall shows a peak drift of 0.099 m, almost five times higher than the models with shear walls. The incorporation of walls reduces lateral deformation of the structures, which limits displacement demands during seismic activity. Drift patterns show that the largest deformation occurs in the mid to upper stories, but the flexural bending is prominent only on the upper stories. The negligible drift variation between models with 10% and 20% openings supports the finding of previous parameters that moderate openings retain sufficient lateral continuity to prevent soft-story formation. Following table shows the Story wise maximum displacement for earthquake loading for each modelling configuration:





3.4. Torsional Irregularity

The torsional irregularity ratio (maximum/average displacement) is within 1.03-1.04 for all models, suggesting excellent torsional symmetry even with openings. For the frame without any shear wall, this ratio reaches 1.27-1.30, showing asymmetric deformation under lateral loads along the Y-direction. The shear walls in the structure can minimize eccentricity between the mass and stiffness centers, which mitigates torsional amplification. These results underline that symmetrical placement of openings, as adopted in this study, prevents rotational response anomalies. Thus, torsional irregularity of all models remains well below the BNBC 2020 critical limit of 1.2, confirming that properly designed openings do not induce torsional instability. Table 2 shows the results of torsional irregularity.

3.5. Story Stiffness Variation

Story stiffness increases with the presence of shear walls, especially at lower stories, where values exceeded 9000 kip/in compared to 447 kip/in for the structure with no shear walls. 10% and 20% openings in shear walls resulted in a minor stiffness decrease of about 3-5%, showing that localized flexibility caused by openings has a limited effect on global rigidity. The model with solid shear walls showed the highest stiffness concentration at the base, gradually decreasing toward the top, which is a typical pattern for a cantilever-type structure. Such consistency in story stiffness across all models suggests that overall deformation patterns remain linear-elastic and free of irregularities, saving from soft-story behavior.

Table 2: Torsional irregularity check

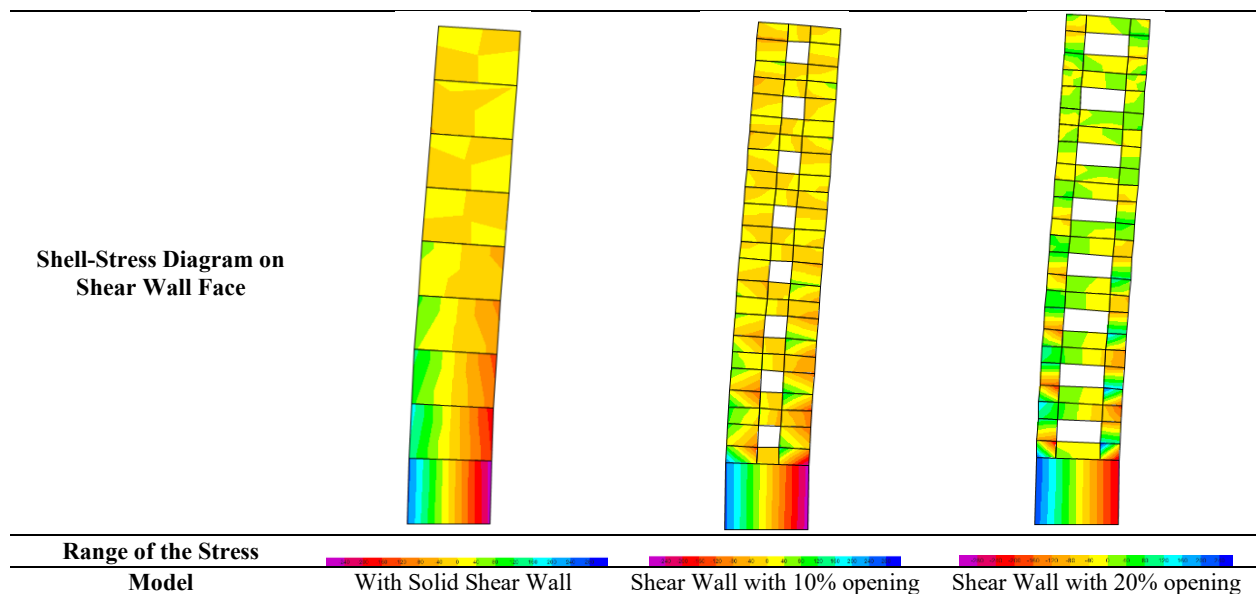
Storey Level	Earthquake in direction X				Earthquake in direction Y			
	Storey Maximum displacement/average displacement							
	Model Without Shear Wall	With Solid Shear Wall	Shear Wall with 10% opening	Shear Wall with 20% opening	Model Without Shear Wall	With Solid Shear Wall	Shear Wall with 10% opening	Shear Wall with 20% opening
Story10	1.01	1.01	1.01	1.01	1.08	1.03	1.03	1.04
Story9	1.02	1.03	1.03	1.03	1.27	1.12	1.13	1.14
Story8	1.02	1.03	1.03	1.03	1.28	1.12	1.13	1.13
Story7	1.02	1.03	1.03	1.03	1.28	1.11	1.12	1.12
Story6	1.02	1.03	1.03	1.03	1.29	1.10	1.11	1.12

Story5	1.02	1.03	1.03	1.03	1.29	1.10	1.10	1.11
Story4	1.02	1.03	1.03	1.03	1.30	1.08	1.09	1.09
Story3	1.02	1.03	1.03	1.03	1.30	1.07	1.07	1.08
Story2	1.02	1.03	1.03	1.03	1.30	1.05	1.05	1.05
Story1	1.02	1.03	1.03	1.03	1.29	1.03	1.03	1.03

3.6. Stress Concentration and Cracking Potential

Stress contour showed that solid shear walls uniformly distribute stress along their height, whereas models with openings displayed strong stress concentrations around the corner edges of the openings. The models with 10% and 20% openings show a notable increment in maximum stress, which indicates localized stress concentration, and this can trigger early cracking if not properly reinforced. Such concentration zones require additional confinement or diagonal reinforcement around the openings. The results (Table 3) show that although global stiffness for the structure is acceptable, localized ductility demands increase with larger openings shows that emphasize should be given to the need for performance-based detailing.

Table 3: Shell stress on different models



3.7. Overall Seismic Performance Interpretation

From the analysis, models with up to 20% openings satisfy immediate occupancy and life safety limits under the design earthquake. Therefore, it shows the threshold beyond which seismic performance begins to degrade substantially. These results show that an optimal balance between architectural flexibility and seismic safety can be achieved, considering that appropriate detailing and reinforcement continuity are maintained.

4. CONCLUSIONS

This study shows that reinforced concrete (RC) shear walls can enhance the seismic resistance of structures, even if openings are introduced within practical limits. We observed that the solid shear wall provides the greatest stiffness and lateral strength through the use of the Equivalent Lateral Force (ELF) method and detailed finite element modelling in ETABS. However, models incorporating up to 20%

wall openings showed marginal reductions in strength and stiffness, with proper implementation of the BNBC2020 provisions. All models have the fundamental period within the acceptable range prescribed by BNBC2020 and hence showed stability under seismic action. Stress concentration at the corners of wall openings displayed the importance of special reinforcement to ensure durability and prevent failure. Shear walls with up to 20% openings meet both occupancy and safety criteria, which means structural safety and serviceability are ensured during earthquakes. Over this limit, significant stiffness reduction and drift increment occur, which can affect the overall seismic stability of the structure. The findings suggest that RC shear walls with openings limited to 20% can be effectively and safely employed in earthquake-prone regions such as Dhaka. When designed with proper detailing and code compliance, such configurations ensure a meaningful balance between architectural flexibility and structural resilience, which is an essential consideration for sustainable development in seismic zones.

5. DECLARATION OF USE OF AI

During the research work, Grammarly and Gemini were used for linguistic assistance, including paraphrasing, grammatical refinement, and spelling correction. The manuscript was further reviewed and revised to enhance clarity and ensure suitability for conference publication.

REFERENCES

- Bashiru, A., Akinpelu, M. A., & Adedeji, A. A. (2023). Performance of reinforced concrete shear walls under lateral loads: A review. *Berkeley Journal of Engineering Research and Development*, 45-60.
- Chen, X., Li, Y., & Huang, Q. (2023). Numerical study on seismic performance of slender RC shear walls subjected to lateral and axial loads. *Advances in Civil Engineering Technology*, 34-48.
- Chen, X., Li, Y., & Huang, Q. (2025). Reliability-based positioning of shear walls to enhance seismic performance considering soil–structure interaction. *Innovations in Infrastructure Journal*, 1-13.
- Darvishi, A., & Razavi, M. (2023). Numerical study on seismic performance of slender RC shear walls subjected to lateral and axial loads. *Advances in Civil Engineering Technology*, 34-48.
- Harati, P. (2020). Reinforced concrete shear walls against lateral loads: State-of-the-art review.
- Islam, M. A. (2024). Finite element modeling and analysis of RC shear walls with cutting-out openings. *Applied Structural Mechanics*, 68-79.
- Kanak, M. H., Saha, T., & Islam, N. (2022). Analysis of wind load on high-rise residential building according to BNBC: A case study from Bangladesh.
- Khan, R., Ali, M., & Siddique, S. (2023). Influence of aspect ratio and opening size on seismic response of RC shear walls. *International Journal of Civil Structures*, 210-225.
- Mahmood, H., & Abbas, T. (2019). Strengthening of reinforced concrete shear walls with openings using carbon fiber reinforced polymers. *International Journal of Advanced Structural Engineering*, 171-182.
- Scientific.Net. (2014). Investigations of RC shear wall–frame structures with various openings in walls under earthquake loading. *Applied Mechanics and Materials*, 242–249.
- Shobha Ram, S., Kumar, R., & Patel, P. (2021). Effects of openings on different shapes of shear wall in RC buildings under seismic and wind excitations. *Current Trends in Civil Engineering and Technology Studies*, 120–129.
- Topaloğlu, M. A., Uğur, S., & Erdoğan, T. (2021). Machine learning–based assessment of energy behavior of RC shear walls.
- University, Z. (2023). Shear walls against lateral loads: A review. *Zagazig Journal of Engineering Research*, 233–248.
- Wang, L., & Zhang, H. (2023). Wind-induced responses and wind loads on a super high-rise building with various cross-sections and high side ratios: A case study. *Buildings*, 485.
- Yadav, D. N., & Rai, P. R. (2020). Analysis of wind load on a tall RC frame building with a shear wall in coastal regions. *Proceedings of the National Conference on Emerging Trends in Structural Engineering*.

Zhou, Y., Feng, J., & Li, M. (2022). Seismic performance of steel fiber reinforced concrete shear walls with window openings. *Buildings*, 1550.