

SEISMIC RESPONSE ANALYSIS OF A HIGH-RISE RC BUILDING IN SYLHET: INFLUENCE OF SHEAR WALL PLACEMENT BASED ON BNBC 2020

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ABSTRACT

Seismic design is extremely crucial for tall buildings, especially when located in areas with a high seismic hazard. One of the useful approaches of seismic design is response spectrum analysis because it can estimate peak values of structural response for a number of vibration modes. It provides insight into dynamic behavior by measuring pseudo-spectral acceleration, velocity, or displacement as a function of structural period for a given time history and level of damping. This study provides a comprehensive seismic response analysis of a 20-storey reinforced concrete building located in Sylhet, Bangladesh, a site critically important as it falls within the high-risk seismic Zone 4 as designated by the BNBC 2020 code. The primary aim of the research is to bridge the gap between theoretical code requirements and practical structural performance, specifically investigating how varying the orientation and placement of shear walls influences the building's lateral load resistance, structural stiffness, displacement, and overturning resistance. To achieve this, the research was conducted using ETABS v22 structural analysis software, where five distinct 20-storey models were developed and compared. These models were identical except for the shear wall configuration: Case 1 served as a baseline model with no shear walls, while Cases 2-5 featured shear walls in different arrangements. A Response Spectrum Analysis (RSA) was performed on all models to evaluate the peak seismic response according to the parameters set by BNBC 2020 for Zone 4, focusing on storey displacement, storey shear, storey stiffness, and overturning moment. The analysis yielded significant and conclusive differences, demonstrating that the model without shear walls (Case 1) was dangerously vulnerable, exhibiting the largest top-floor displacement (3.768 inches) and the lowest storey stiffness (4059 kip/in). In stark contrast, Case 3, featuring an "optimally oriented" layout, delivered the best performance, achieving the smallest displacements due to its dramatically enhanced lateral rigidity, registering a maximum stiffness of 44,148.8 kip/in. Because of this high stiffness, Case 3 effectively engaged the lateral forces and attracted the highest base shear (4456.957 kip). It is important to note that Case 4, in which the shear walls were grouped around the middle core, produced the maximum overturning moments (652,350.9 kip-ft) unexpectedly, suggesting that this improper configuration of shear walls might impose destabilizing effects. Thus, this study concludes that for high-rise buildings in high-seismic zones, the placement of shear walls is much more important than their presence. The wall-free model failed to provide adequate safety, while the "optimally oriented" system (Case 3) virtually eliminated displacement risk. This research provides practical, region-specific data for Bangladesh using the new BNBC 2020 code, offering evidence-based proof that an optimized shear wall system is a fundamental necessity for designing safe, resilient structures in earthquake-prone areas.

Keywords: *Shear wall; Seismic performance; Response spectrum analysis; Lateral loads; High-rise structure*

1. INTRODUCTION

The rapid growth of urban places has driven the global demand for high-rise buildings due to constrained space and increasing population. Tall buildings are intricate to design, especially when dealing with lateral loads like earthquakes. In earthquakes, the response of a building relies on the global stiffness, strength, ductility, and energy dissipative behavior (Murty et al., 2012). These parameters have to meet both code and safety-of-life standards to reduce damage and save occupants from seismic activities. Seismic design is crucial in the northeastern region of Bangladesh, specifically in Sylhet, which falls under Zone 4 which is the most severe seismic hazard zone per BNBC 2020. Situated close to active fault lines like the Dauki Fault and Shillong Plateau and with complex geology, it is susceptible to strong earthquakes (Duarah & Phukan, 2011). This study focuses on a 20-storey building in Sylhet to analyze the effects of different shear wall geometries on seismic performance under extreme lateral loads with an aim towards simulating actual real-life high-risk scenarios and helping facilitate safer structural design.

Shear walls are a critical component for increasing the lateral resistance of reinforced concrete buildings. Shear walls are good at resisting seismic forces as well as providing stiffness and stability (Ozkul et al., 2019). Shear walls will control inter-storey drift and limit lateral displacements during earthquakes when placed in the proper locations within a building due to their high in-plane stiffness and strength (Gupta et al., 2016). However, shear walls do not simply enhance resistance based on presence alone. Thoughtful attention to geometric placement and orientation in the structural system is important. Shear walls can introduce torsional and stiffness irregularities if placed incorrectly so that they disrupt the force transfer and therefore, the overall seismic performance (Banarjee & Srivastava, 2020). This study examines the impact of the direction of shear walls on the seismic performance of a 20-storey reinforced concrete building in Sylhet. Five ETABS v22 models were developed, with one being without shear walls and four with different configurations of shear walls. Response Spectrum Analysis (RSA) according to BNBC 2020 and ASCE 7-05 was adopted to examine seismic demands, taking various vibration modes into account in both X and Y directions. The study handled storey displacements, storey shear, storey stiffness, and overturning moments in determining the optimum shear wall system for structural efficiency and resisting lateral loads within safety limits outlined in the code.

The importance of shear wall design in improving seismic behavior has been widely recognized in earlier studies. Harne (2014) and Agrawal & Charkha (2012) demonstrated that buildings having optimally positioned shear walls experience considerable quantities of minimized lateral sway and inter-storey drift during seismic loading. Their study supported that shear walls not only enhance the global stiffness but also act as a primary element for easily transmitting lateral loads to the foundation. Similarly, Ashraf et al. (2008) opined that shear walls, used symmetrically in plan, help achieve even force distribution, reducing torsional irregularities. However, recent studies have also shown that shear wall performance is highly dependent on where in the structural grid the shear walls are located. Tuppad & Fernandes (2015) and Ali & Aquil (2014) pointed out that irregularly or asymmetrically placed shear walls can introduce unwanted torsional effects, even for otherwise regular-geometry buildings. Nevertheless, there is a clear lack of research at the local level. There are still just a few studies at the local level, especially in South Asia, as a seismically active region where both design practice and levels of enforcement are very different. Much of the research that does exist is either targeted at idealized structures or conducted under other countries' design codes, and their immediate applicability to regions like Sylhet, Bangladesh, is low. Ali et al. (2015) examined the effectiveness of shear walls in minimizing lateral drift in 10 to 25-storey medium to high-rise buildings. They established that a 6-inch thick shear wall was a more cost-effective option for drift control compared to a 12-inch thick wall, with significant performance benefits and no overconsumption of material.

This paper presents the seismic performance evaluation of a 20-storey building in Sylhet, seismic Zone 4, per BNBC 2020 codes. It explores, through appropriate industry software, how structural stiffness, displacement, and overturning resistance vary with different configurations of shear walls. The paper intends to address the gap between theory and practice by presenting evidence-based analysis of how positioning the shear wall, particularly in terms of stiffness distribution, affects the structure. The aim

of this research is to provide practical suggestions on design to engineers to enhance structural safety and reduce seismic risk in high-rise buildings.

2. METHODOLOGY

In this study, an analysis of five models of a 20-storey building differing only in shear wall positions has been conducted in seismic zone 4 under earthquake forces. In order to model the building's behavior, ETABS v.22 is used and the loads are assigned to the frame components following the combinations of load cases as per the BNBC (2020) code. But ETABS does not include BNBC (2020) code, so an equivalent code ASCE 7-05 (2005) is considered. ASCE 7-05 is similar to BNBC (2020) code in various aspects, especially in seismic loading provisions.

2.1 Details of Modelled Building

The five models of the 20-storey building are identical except for the position of the shear walls. The following figures (Fig. 1,2,3,4, and 5) illustrate the plan views and 3D models with varying positions of shear walls. Where case 1 represents the model with no shear wall.

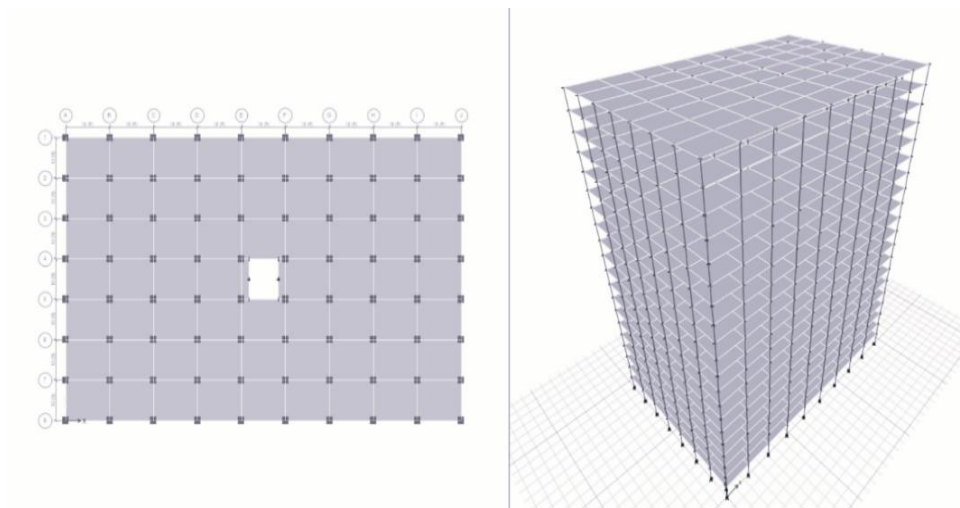


Figure 1: Plan view and 3D model of case 1

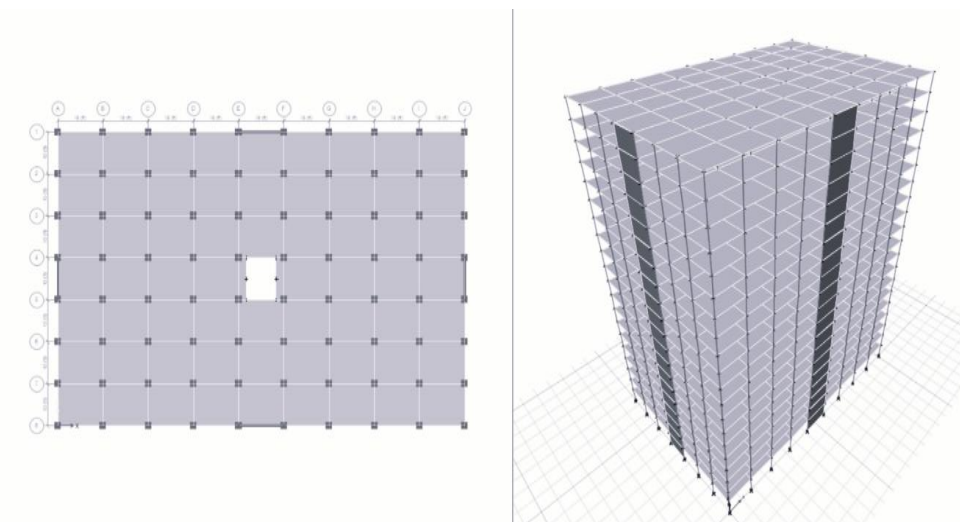


Figure 2: Plan view and 3D model of case 2

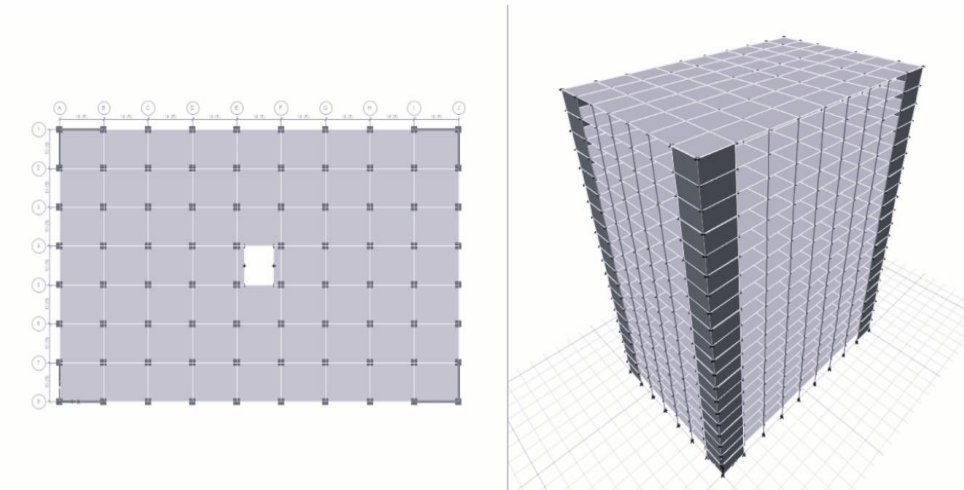


Figure 3: Plan view and 3D model of case 3

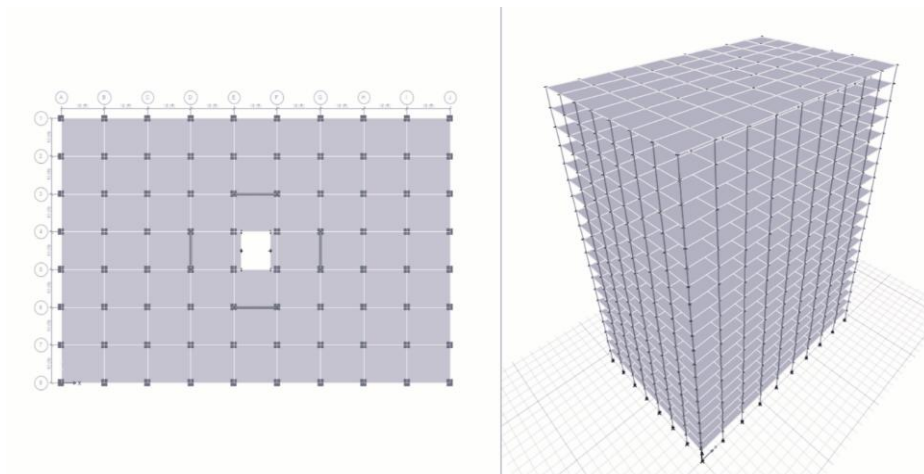


Figure 4: Plan view and 3D model of case 4

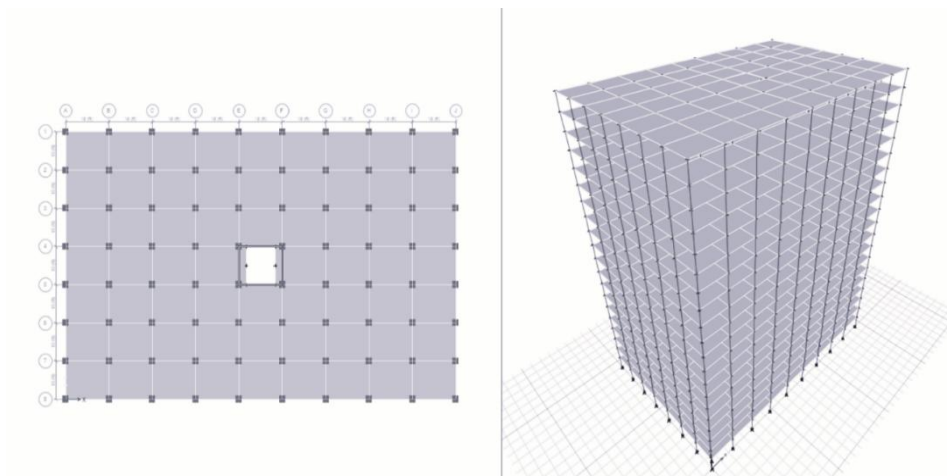


Figure 5: Plan view and 3D model of case 5

The modeled building's support condition is fixed at the column and shear wall base. The basic information of the modeled building is given in Table 1. The dimensions of the structural components and the material specification for steel and concrete used in the identical models are given, respectively, in Table 2 and Table 3.

Table 1: Basic Information of the Modeled Building

Information	Corresponding Data
Structure Type	Reinforced Concrete
No. of Floor	20 storey
Elevation of the Building	200 ft
Storey Height	10 ft
Span Length in X Direction	18 ft
Span Length in Y Direction	15 ft

Table 2: Dimensions of Structural Components

Components	Dimension (inch)
Column Section	30x30
Beam Section	15x20
Floor Slab Thickness	7
Waist Slab Thickness	6
Shear Wall Thickness	6

Table 3: Material Specification of the Modeled Building

Material Properties	Corresponding Data
Concrete Strength	3,500 psi
Yield Strength in Reinforcement	60,000 psi
Yield Strength in Stirrup	40,000 psi

2.2 Load Consideration and Earthquake Parameter

The seismic load E_x and E_y along X and Y axes are evaluated by dynamic analysis with the corresponding load cases considerations and earthquake parameters provided below in Table 4 and Table 5.

Table 4: Load Cases Consideration

	Self Weight	Calculated by ETABS
Dead Load	Floor Finish	10.4 lb/ft ²
	Ceiling Plaster	6 lb/ft ²
	External Wall and Partition Wall Load	0.44 lb/ft ²
Live Load	100 lb/ft ²	

Table 5: Earthquake Parameters

Earthquake Parameters	Adopted Values
Site Classification	F
Zone Coefficient (Zone 4)	0.36
Occupancy Category	II
Importance Factor	1
Seismic Design Category	D
Lateral Force Resisting System	RC Shear Wall
Response Reduction Factor, R	5
System Overstrength Factor, Ω	2.5
Deflection Amplification Factor, C_d	4.25
Site Coefficient, F_a	1.35
Site Coefficient, F_v	2.7
Long period Transition Period	2 sec
0.2 sec Spectral Acceleration, S_s	0.9
1 sec Spectral Acceleration, S_1	0.36
SD_s	0.81
SD_1	0.648
Time Period	1.06 sec

Table 6: Load Combination

Sr. No.	Load Combination	Sr. No.	Load Combination
1.	1.4D	11.	1.27D-0.3R _x -R _y +L
2.	1.2D+1.6L	12.	0.823D+R _x +0.3R _y
3.	1.2D+L	13.	0.823D+R _x -0.3R _y
4.	1.27D+R _x +0.3R _y +L	14.	0.823D-R _x +0.3R _y
5.	1.27D+R _x -0.3R _y +L	15.	0.823D-R _x -0.3R _y
6.	1.27D-R _x +0.3R _y +L	16.	0.823D+0.3R _x +R _y
7.	1.27D-R _x -0.3R _y +L	17.	0.823D+0.3R _x -R _y
8.	1.27D+0.3R _x +R _y +L	18.	0.823D-0.3R _x +R _y
9.	1.27D+0.3R _x -R _y +L	19.	0.823D-0.3R _x -R _y
10.	1.27D-0.3R _x +R _y +L		

2.3 Response Spectrum Analysis

Response spectrum analysis estimates the response of a particular structure under seismic loading. In this analysis, ETABS v.22 is utilized to investigate the response of the five models of the same building, varying only the positions of shear walls. Instead of using the time-history analysis, RSA uses pre-made earthquake spectrums. In response to these spectrums, the peaks (maximum responses) are calculated by the software. As all modes do not peak at the same time, the estimated total response is obtained by adding the peak responses. Bangladesh's four seismic zones. Modal selection for response spectrum analysis should prioritize modes contributing at least 90% of the total effective mass, ensuring a comprehensive capture of the structural response (BNBC 2020). To capture the dominant dynamic behavior of the structure, a set of 60 mode shapes (two translational and one rotational per storey) has been selected, resulting in a cumulative modal mass participation ratio of 99%. The P-Δ effect and a damping ratio of 5% have been considered for this study. Types of primary types of loads that are used in the analysis:

- I. Dead load (self-weight of structure)
- II. Live load (for residential building)
- III. Response spectrum function (in both X and Y directions)

3. RESULTS AND DISCUSSION

3.1 Storey Displacement

The lateral displacement of each storey relative to the foundation is known as storey displacement. Plotted in Figure 6, storey displacement along the X-direction changes significantly with the variations in shear wall layouts in the five building models.

When compared to other models, the results demonstrate that Case 1, which has no shear walls, achieves the largest storey displacement (3.768 inches) at the top floor. In contrast, Case 3, which has shear walls oriented optimally, provides the smallest storey displacement (0.109573 inches) at the ground floor. The displacement seems to be decreasing from the roof to the ground floor if the complete

trend is examined. The models with well-oriented shear walls have shown this increase in comparatively more significant magnitudes. Hence, shear wall configuration plays an immutably decisive role in the lateral rigidity and seismic action enhancement in the X-direction.

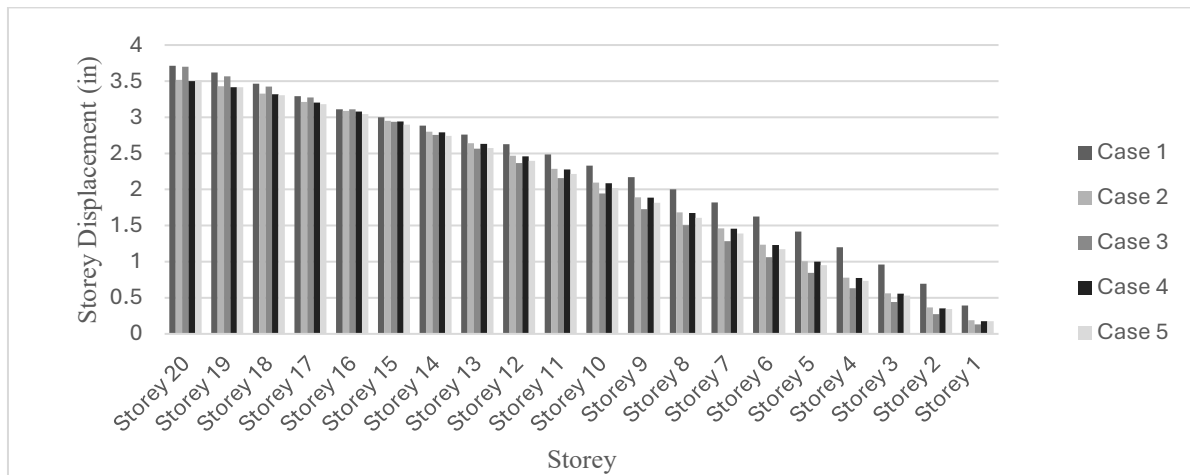


Figure 6: Variation of Storey Displacement in X direction

As with the X-direction, storey displacement in the Y-direction exhibits a comparable pattern and is depicted in Figure 7. The significance of strategically putting shear walls in both primary directions is seen in Case 1, which once again has the largest displacement value (3.714 inches) at the top floor. The least amount of displacement (0.1322 inches) is seen in Case 1 at the ground floor. In every instance, the displacement from roof to base is plainly reduced, and the proportionate increase in displacements with shear walls is also evident. Together, the findings from both figures show that shear wall placement is important and will affect how tall buildings with lateral loads are displaced.

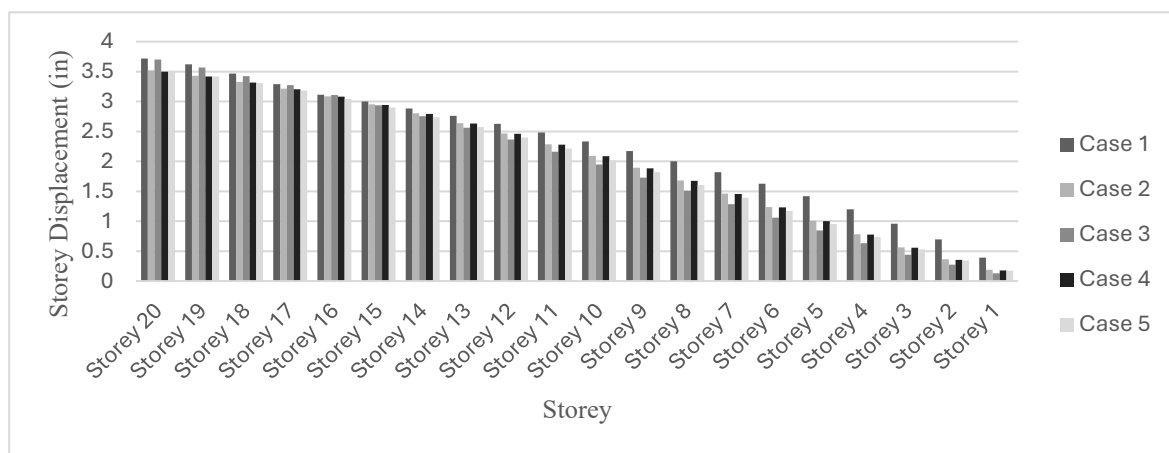


Figure 7: Variation of Storey Displacement in Y direction

3.2 Storey Shear

Storey shear is the cumulative lateral forces that act on every storey (i.e. earthquake, wind, etc). Storey shear is a property that decreases with the height of the building, plotted in Figure 8. Storey shear along the X-direction changes significantly with the variations in shear wall layouts in the five building models. When compared to other models, the results demonstrate that Case 3, which has shear walls oriented optimally, achieves the largest storey shear at base (4456.957kip). In contrast, Case 1, which has no shear walls, provides the smallest storey shear at the top floor (359.59 kip). The shear seems to be decreasing from the base to the top floor if the complete trend is examined. The models with well-

oriented shear walls have shown this increase in comparatively more significant magnitudes. Hence, shear wall configuration plays an immutably decisive role in the lateral rigidity and seismic action enhancement in the X-direction.

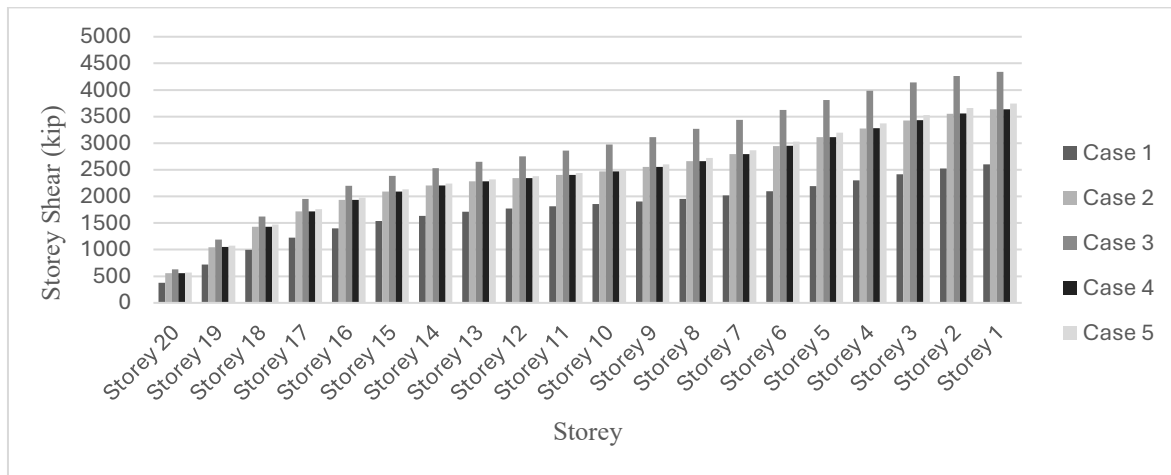


Figure 8: Variation of Storey Shear in X direction

As with the X-direction, storey shear in the Y-direction exhibits a comparable pattern and is depicted in Figure 9. The significance of strategically putting shear walls in both primary directions is seen in Case 3, which once again has the largest shear value (4341.258 kip) at the base. The least amount of shear at base (2601.15 kip) is seen in Case 1, and the smallest shear is 376.28 kip at the top floor of Case 1. In every instance, the shear from roof to base is plainly increased, and the proportionate increase in shears with shear walls is also evident. Together, the findings from both figures show that shear wall placement is important and will affect how tall buildings with lateral loads affect shear forces.

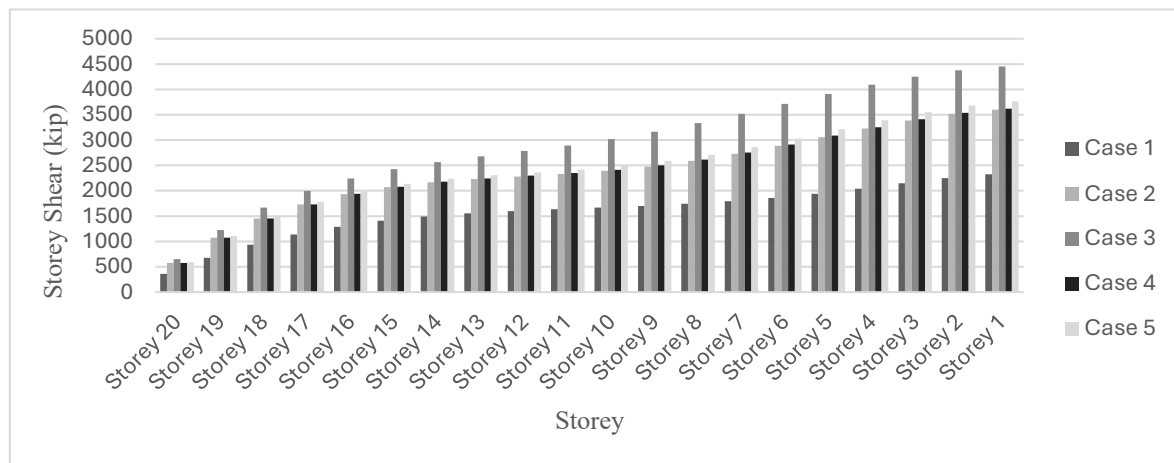


Figure 9: Variation of Storey Shear in Y direction

3.3 Storey Stiffness

Storey stiffness along the X-direction, as plotted in Figure 10, varies considerably with the variations in shear wall arrangements in the five building models. The results show that Case 3, with shear walls optimally oriented, attains maximum storey stiffness in all storeys (44148.8 kip/in for storey 1) when compared to other models. Whereas Case 1, which does not have shear walls at all, gives the minimum storey stiffness on every single floor (4059 kip/in for storey 20). If one looks at the entire trend, it appears that the stiffening requests ameliorated as we come down from the uppermost storeys toward the lowermost storeys. This improvement or increase has been brought about in relatively more significant magnitudes in the models with well-oriented or larger magnitude shear walls. Hence, shear

wall configuration plays an immutably decisive role in the lateral rigidity and seismic action enhancement in the X-direction.

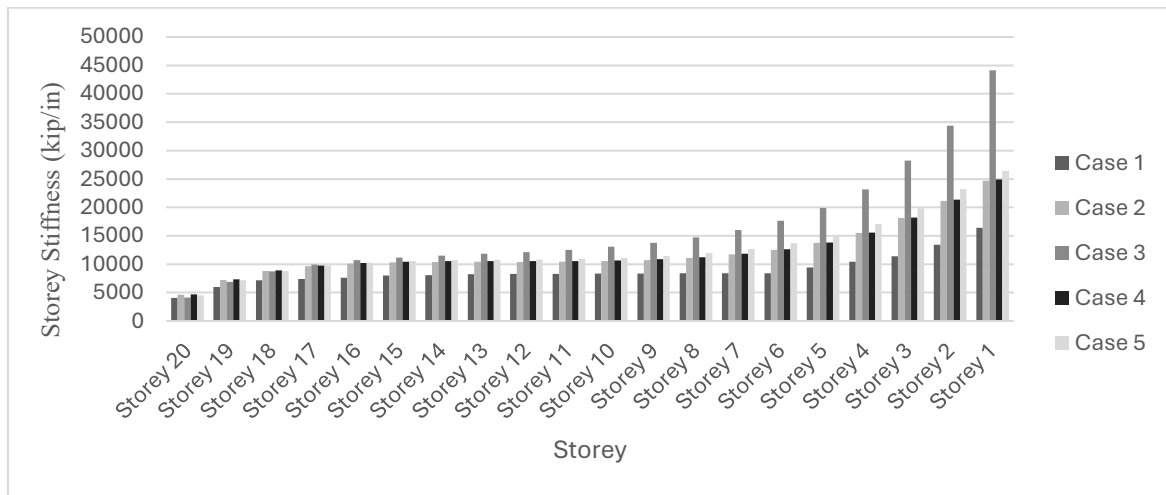


Figure 10: Variation of storey stiffness along the X-direction

Storey stiffness in the Y-direction, similar to the case of the X-direction, shows a similar pattern and is illustrated in Figure 11. Case 3 again has the most stiffness in all storeys (36812.6 kip/in for storey 1), demonstrating the benefit of placing shear walls in strategic locations for both principal directions. Case 1 has the least stiffness (4201 kip/in for storey 20), highlighting how susceptible tall buildings are to lateral forces where shear walls are lacking. The reduction in stiffness from the roof to the base is clearly observed in all cases, and the relative improvements with shear walls provide significant measures of improvement. Collectively, the results from both figures demonstrate that the placement of shear walls matters and will improve the storey stiffness of tall buildings with lateral loads.

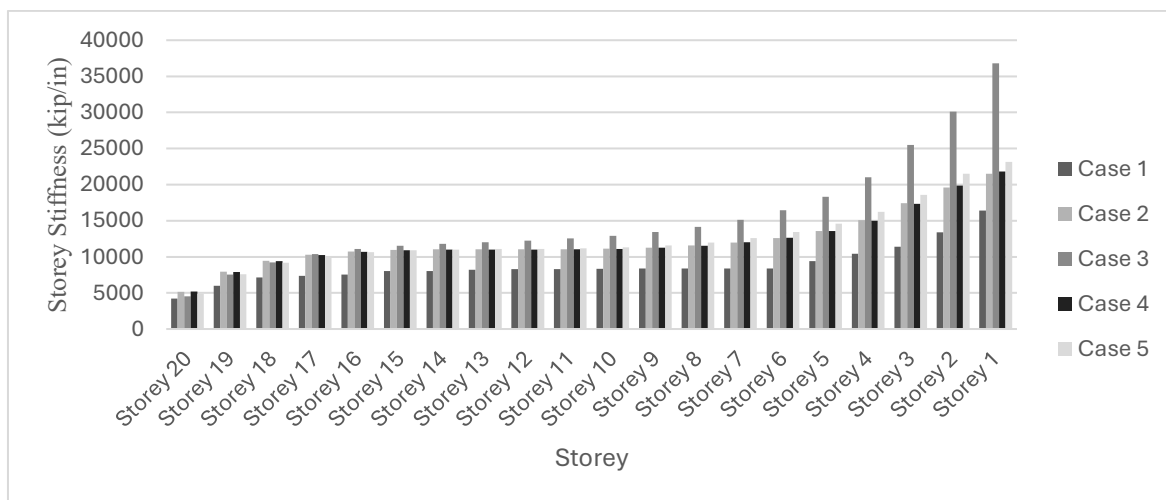


Figure 11: Variation of storey stiffness along the Y-direction

3.4 Overturning Moment

The overturning moment profiles along the X-direction for all 20 storeys of the five building cases are shown in Figure 12. The information included shows that Case 4 recorded the highest overturning moments for every storey (431588.3 kip-ft for storey 1). This is due to reduced lateral stiffness of the structure, causing greater lateral displacements and thus, more overturning effects. Locations/occurrences of shear walls, particularly in Cases 2 and 3, illustrated the greatest reductions from Case 4. In general, Case 3 recorded the lowest overturning moment values for all the storeys (27241.1 kip-ft for storey 20), indicating the best configuration to resist lateral seismic forces along the

X-direction. The major observation is that the shear wall configuration, including presence and orientation are secondary consideration in limiting overturning moments: the highest and lowest moment values were very similar, but these differences were greatest at the lower storeys.

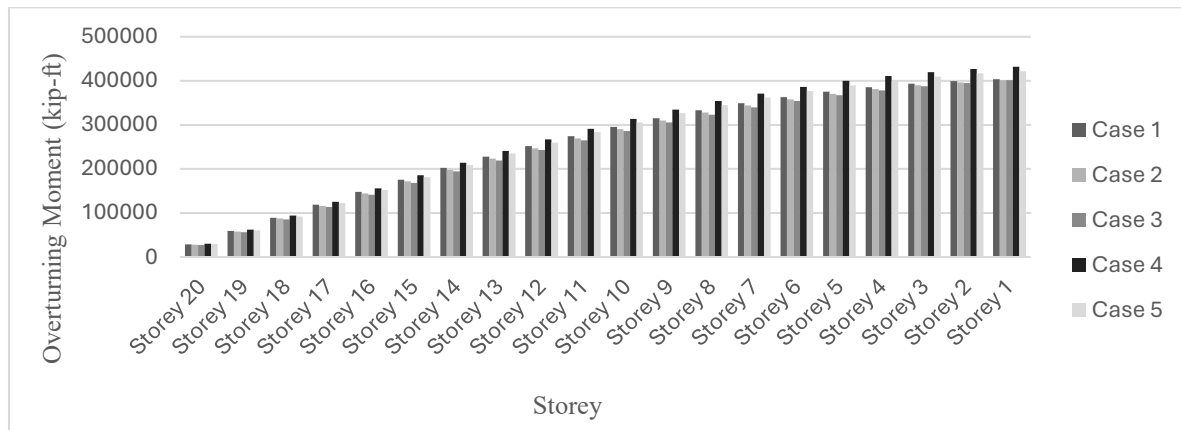


Figure 12: Variation of overturning moment along the X-direction

Along the Y-direction, as shown in Figure 13, a similar trend is observed. Case 4 again consistently produces the largest overturning moments across all floors (652350.9 kip-ft for storey 1), confirming its vulnerability due to the absence of shear walls. Case 3 generally presents the minimum values (41998.6 kip-ft for storey 20), especially at the bottom storeys where overturning demand is greatest (597745.63 kip-ft for storey 1). This trend underscores the protective effect of well-oriented shear walls, as building models with enhanced lateral force-resisting systems experience substantially reduced seismic overturning effects. The comparative analysis in both principal directions highlights that adopting appropriately oriented shear walls is essential for optimizing the seismic performance of tall buildings by effectively reducing overturning moments.

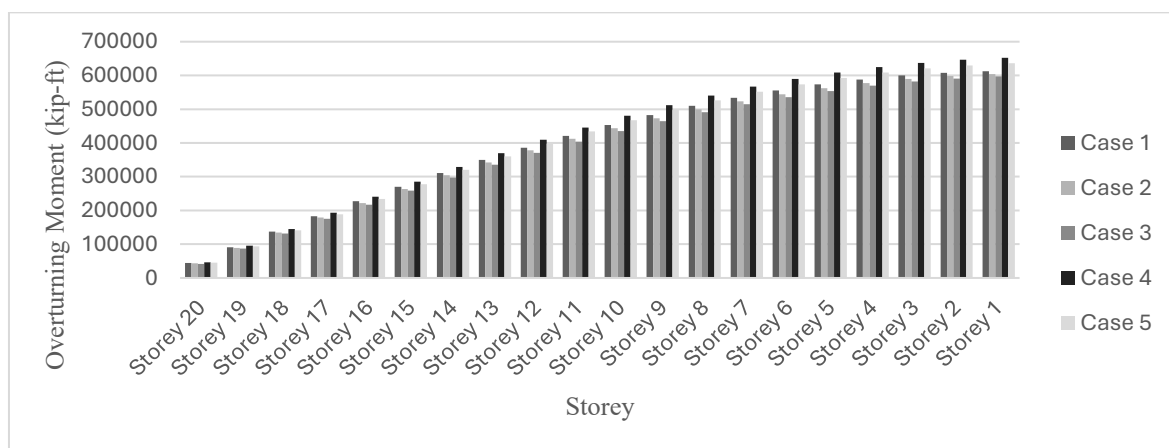


Figure 13: Variation of overturning moment along the Y-direction

4. CONCLUSION

This study demonstrates that the strategic placement of shear walls is far more critical than their mere presence for high-rise buildings in high-risk seismic zones. By analyzing five different 20-storey models in ETABS under the BNBC 2020 code for Sylhet, a Zone 4 area, the performance differences were found to be significant. The baseline model without shear walls, Case 1, was dangerously vulnerable, exhibiting a maximum top-floor displacement of 3.768 inches. In contrast, Case 3, with an "optimally oriented" layout, virtually eliminated this risk by achieving the smallest displacements. This success is

a direct result of dramatically improved lateral rigidity: Case 3's layout provided a maximum base stiffness of 44,148.8 kip/in, making it more than ten times stiffer than the most flexible part of the wall-free model (4059 kip/in). This immense stiffness allowed Case 3 to properly engage and resist the lateral forces, which is why it also attracted the highest base shear (4456.957 kip), it was effectively doing the work it was designed for. In Case 4, with walls clustered around the central core, unexpectedly generated the highest overturning moments (652,350.9 kip-ft), which suggests that this layout could introduce torsional irregularities or destabilizing effects. However, case 3 performed the best in this metric as well, resisting the building's tendency to topple. This research is particularly important for the civil engineering field because it fills a critical gap, providing practical, region-specific data for Bangladesh using the new BNBC 2020 code, where such local studies are scarce. It moves beyond theory to evidence-based proof that an optimized shear wall system, like that in Case 3, is a fundamental necessity for designing safe, resilient structures in earthquake-prone areas.

DECLARATION OF USE OF AI

AI tools were limited to a helping hand during the making of this document. More precisely, the language assistance of AI was applied to improve the writing style, making the text grammatically correct, coherent, and academic, and it was also made easier for the reader. All technical content, data analysis, modeling, interpretations, results, and conclusions were entirely developed by the authors. The authors take full responsibility for the content, accuracy, and originality of the paper.

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