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Structural Response of Concrete Buildings to Seismic and Wind Loads in Bangladesh Using ETABS and BNBC 2020

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Abstract

Rapid urbanization in Bangladesh has led to an increasing demand for multi-storey buildings, necessitating robust structural design to resist lateral loads from both earthquakes and wind. This study analyzes the seismic and wind load performance of G+8 reinforced concrete (RC) building located in four different seismic zones of Bangladesh, using ETABS 2017 in compliance with the Bangladesh National Building Code (BNBC) 2020. The structure was evaluated under both seismic (EQX, EQY) and wind (WX, WY) loads. The structural analysis revealed that wind loads (WX and WY) consistently govern the lateral design for this structure, as evidenced by storey shear (peaking at 45 Kip at the base in Zone 4 and storey displacement (WX peaking at 8 in) and drift (WX peaking at 0.09 in) being substantially higher than seismic demands. Although base shear linearly increased almost threefold from Zone 1 (33.28 Kip) to Zone 4 (99.84 Kip) due to rising seismic zone coefficients, the wind forces dominate the serviceability checks. Maximum storey displacement and drift were concentrated in Zones 3 and 4, with the latter exhibiting the highest drift (0.065 in WX) and extreme torsional irregularity, peaking at 7.82 in WX. The analysis confirms that both seismic and wind effects significantly influence building performance, with seismic forces dominating in higher zones and wind-induced displacements being critical in specific directions. This underscores the importance of region-specific design considerations to ensure structural safety and serviceability in Bangladesh's diverse seismic landscape.

Keywords: Analytical Analysis, ETABS, Multi-Storey Building, BNBC 2020, Concrete

INTRODUCTION

High-rise construction is required in Bangladesh due to its expanding population and constrained horizontal space, but it presents structural issues like stiffness, displacement, and lateral loads. Understanding these forces and their effects is essential because wind loads and earthquakes both have an impact on high-rise structures. Natural catastrophes that cause a great deal of damage and fatalities are earthquakes [1]. Bangladesh is extremely vulnerable to large earthquakes because it is located in an active tectonic zone close to the Himalayas [2]. Particularly at risk are Dhaka and places like Sylhet, Mymensingh, Rangpur, and Chittagong. Only two of the seven significant earthquakes that have struck the nation in the last 150 years have epicenters [3]. Moreover, earthquakes that result from volcanic activity or fault line movements cause significant loss of life and property. Despite their low intensity, previous tremors indicate the possibility of a significant earthquake in the future [4]. In some areas wind loads may surpass earthquake loads depending on the location and code-defined zone factors. Thereafter, wind must be carefully considered because, as moving air, it applies varying pressure to building surfaces over time. It creates forces perpendicular to both internal and external surfaces. For light and dynamic structures, as well as for vertical components like walls, columns, and beams, wind effects are especially important [5]. While seismic effects depend on tectonic activity, soil conditions, and building importance, wind is a dynamic force that is dependent on exposure and speed [2,6].

Static analysis is still widely used in Bangladesh and other developing nations because of a lack of sophisticated modelling and computational capabilities. Hence, safety regulations seek to strike a balance between security and efficiency, particularly in seismically active regions [6]. In order to guarantee safety, the Bangladesh National Building Code (BNBC) was created in 1993, put into effect in 2006, and then revised in 2017 and 2020 [3]. Therefore, to improve safety and performance under a variety of circumstances, BNBC 2020 adds more stringent load combinations and new parameters, like vertical seismic and wind effects, along with improved serviceability criteria, and reflects contemporary practices and international standards [5,7].

A number of studies were assessed for lateral load analysis in Bangladesh as well as overseas. To evaluate seismic responses, including lateral load, storey drift, displacement, and stiffness, across various Indian seismic zones, a G+10 structure was examined in three dimensions using ETABS. In another study a G+9 building was used to evaluate maximum storey displacement, drift, stiffness, and shear, forming a basis for structural comparison by the response spectrum method [7]. F. Abdullah et al. [8] compared BNBC 1993 and BNBC 2020 for a 10-storey residential building across four areas in Bangladesh by examining factors like tremor and wind forces, storey drift, shear, and beam/column moments. Again, shear walls and retrofitting under BNBC 2020 effectively reduced additional displacements in RC structures, according to another recent study. Md. O. Hossain et al. [2] used ETABS and the ESF method in their study to analyse a 10-storey RC building by comparing BNBC 2006 and 2020. They discovered significant variations in inter-storey drift, lateral displacement, base shear, and storey shear. In another study, F. Abdullah et al. [8] used BNBC 1993 and BNBC 2020 to compare the effects of lateral loads on a 10-storey residential building, examining how these loads affected structural behavior in various districts in Bangladesh. Furthermore, by examining lateral loads and building configurations, Shohag and Mozumder [9] shed light on how seismic and wind forces affect tall buildings. Furthermore, seismic base shear values across different versions of BNBC revealed significant discrepancies. For instance, the seismic base shear for an 8-storey hospital building in Sylhet was found to differ markedly comparing BNBC 1993 and BNBC 2017 [10]. It was observed that BNBC 2017 required less reinforcement, making it more economical than BNBC 1993 [11]. Other research compared BNBC with international codes such as NBC-India (2005) [12] and ASCE 7-05 [13], showing that BNBC 1993 yielded the lowest base shear values among them [14].

Wind was also evaluated for various regions in Bangladesh, which affects high-rise buildings, and compared with global code provisions [15]. A combined lateral load analysis, considering both wind and seismic effects, revealed that for low-rise buildings, seismic effects dominated, whereas wind loads became more significant in taller structures [16,17]. Another study showed that overturning moments and storey displacements followed similar trends, with the seismic overturning moment exceeding that of wind as building height increases [18]. Furthermore, studies had shown that in tall buildings, lateral load effects were negligible in the lower storeys but became more pronounced towards the top. The inclusion of shear walls had been found to reduce displacements and increase stiffness [19]. Again, nonlinear static analysis had demonstrated that the storey drift ratio peaks near the middle storey, while axial forces remained consistent across both linear and nonlinear models [20]. Further studies showed ground motion selection remained a crucial factor in determining seismic zone coefficients [17]. Therefore, to better reduce the effects of earthquakes, more comparative study across seismic zones is still needed for important parameters like sway, drift ratio, storey share and base shear [6].

In order to evaluate the lateral load behavior, this paper aims to analyse seismic and wind loads of a multistoried (G+8) residential building located in multiple seismic zones of Bangladesh. This paper’s primary goals were to evaluate the main responses of lateral loads using ETABS analysis, such as base shear, storey shear, storey drift, storey displacement, and torsional irregularity for buildings of varying heights outlined in BNBC 2020. The study offers design insights to improve seismic resilience, especially for irregular tall structures in Bangladesh.

Materials and Methods

This study investigated the structural behavior of a typical reinforced concrete (RC) building subjected to seismic and wind loads using ETABS 2017, in accordance with the Bangladesh National Building Code (BNBC) 2020. The analysis encompasses four distinct seismic zones: Zone I (Rajshahi), Zone II

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(Dhaka), Zone III (Rangpur), and Zone IV (Sylhet) across Bangladesh to evaluate variations in structural performance.

Building Description

The modelled structure is irregular, a typical G+8 storeyed RC frame building (57 ft x 33.3 ft) located in Chattogram City. Each storey had a uniform floor height of 3 meters, with rigid diaphragms assumed for floor slabs. The building was assumed to be fixed at the base. The plan layout was developed using AutoCAD 2018 (Figure 1), and structural modelling and analysis were performed in ETABS 2017.

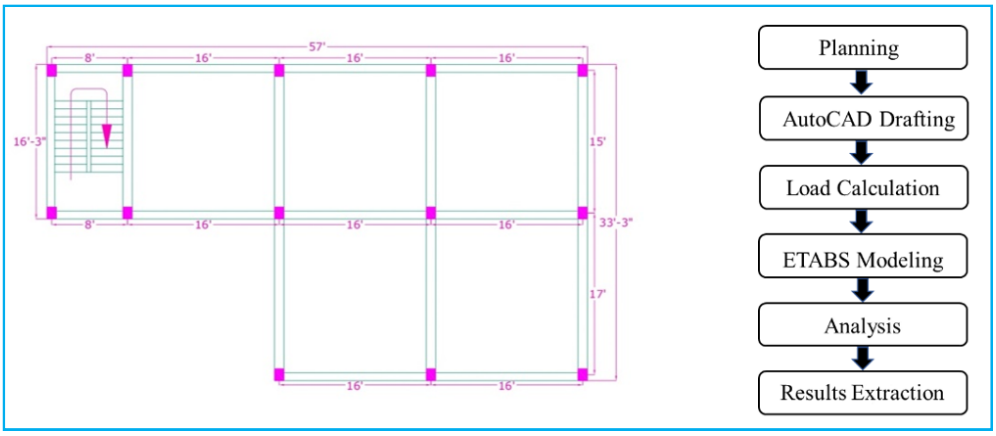

Figure 1. Floor plan for the study (left); the methodology adopted in the study (right)

Structural Components and Design Properties

Table 1 summarised the key structural components and their dimensions. The modulus of elasticity for reinforced concrete is taken as per the BNBC 2020, and all materials and properties used in the model adhere to ACI 318-19 and BNBC 2020 guidelines. Concrete strength and steel yield strength were assumed to be 4000 psi and 60000 psi, respectively.

Table 1. Design data of different components

Component	Size
Beam	12″ × 18″
Column	12″ × 15″
Grade Beam	15″ × 20″
Stair Beam	12″ × 18″
Base Height	7′
Floor Height	10′
Slab Thickness	5″
Stair Slab	6″

Load Considerations

The loads considered in the analysis included dead, live, wind, and earthquake loads. Static loads were applied according to BNBC 2020 for four seismic zones in Bangladesh, in alignment with local seismic activity and building design requirements. The following loads were considered in the analysis:

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- Dead Load: Dead loads per BNBC 2020 included 16.4 psf for floor finish, 9.99 psf for roof slab, and 39.9 psf for partition walls.
- Live Load: Live loads per BNBC 2020 were 41.78 psf for floor slabs, 60.58 psf for roof slabs used as promenades, and 100.27 psf for stairs.
- Seismic Load: Applied using zone-specific seismic coefficients (0.12: Zone I), (0.20: Zone II), (0.28: Zone III), (0.36: Zone IV), and the response reduction factor: (3: Zone I), (5: Zone II), (8: Zone III), and (8: Zone IV), and the deflection amplification factor: (2.5: Zone I), (4.5: Zone II), (5.5: Zone III), and (5.5: Zone IV), site class (Fa = 1.15, Fv = 1.725) for all zones, and important factor: 1 for all Zone; the long period transition period, TD: 2 sec for all zones, system over strength: 3 Omega for all zones, 0.2-sec spectral accel, Ss: 0.9 for all zones per BNBC 2020.
- Wind Load: Derived according to BNBC 2020, incorporating wind speed of 49.2, 65.7, 65.3, and 61.1 m/s for Zone I, Zone II, Zone III, and Zone IV, respectively, and exposure category: A, important factor: 1, gust factor: 0.85, directionality factor Kd: 0.85, topographic factor, Kzt: 1, espouse height: top to the ground floor, windward coefficient:0.8 for all zones, and leeward coefficient: X direction: 0.5, Y direction: 1.34.

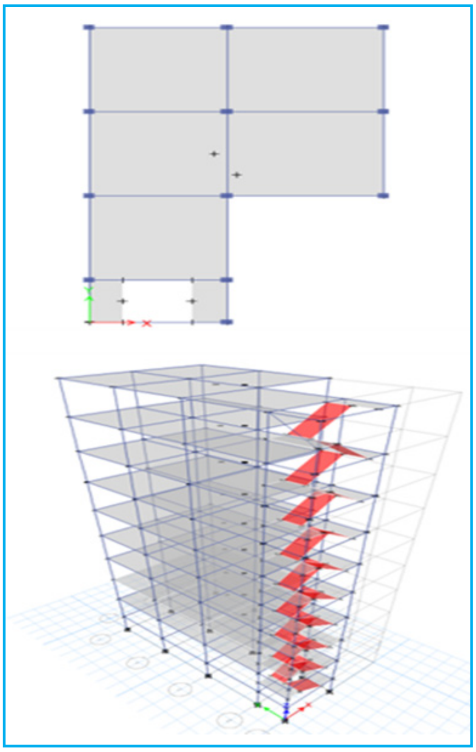

Figure 2. Modelled a G+8 multistory building in ETABS

Modeling and Analysis in ETABS

ETABS 2017 was used for three-dimensional structural modelling and analysis as per plan and structural details (Figure 2). A fixed base condition was assumed, indicating a rigid foundation, and no soil-structure interaction effects were considered in this analysis. The building was assumed to fall under

Importance Category II (Ordinary Occupancy) as per BNBC 2020, suitable for standard residential or commercial use. The following procedure were followed step by step during the modelling:

1. Creating New File – Setting up grid, storey height, and initialisation.
2. Defining Materials – Inputting concrete and reinforcement properties.
3. Defining Sections – Adding beam, column, slab, and wall sections (Table 1).
4. Drawing Elements – Modelling structural components on the grid.
5. Assigning Supports – Applying fixed restraints at column bases.
6. Assigning Loads – Distributing loads on slabs, beams, and stairs per BNBC 2020.
7. Defining Earthquake & Wind Loads – Adding EQX (earthquake load in x direction), EQY (earthquake load in y direction), WX (wind load in x direction), WY (wind load in y direction), and using ASCE 7-05.
8. Defining Mass Source – Setting source, including lateral and lumped mass.
9. Defining Load Cases & Patterns – Adding all necessary load types.
10. Running Analysis – Checking the model and executing structural analysis.
11. Exporting Results – Displaying and exporting tables for key outputs (base shear, storey shear, storey drift, storey displacement, and torsional irregularity).

Results and Discussions

To evaluate the influence of seismic zoning on building response, the structural parameters including storey shear, base shear, storey displacement, storey drift, and torsional Irregularity were extracted from ETABS and analyzed. The seismic and wind loads were applied based on BNBC 2020 provisions for different seismic zones.

Storey Shear

BNBC 2020 states that for all seismic zones, the combined storey shear increased from roof to base, with higher seismic intensity and wind resulting in greater shear. Storey shear had been assessed for different shapes model following BNBC codes [4].

Based on the provided figures (Figure 3a for Zone 1, 3b for Zone 2, 3c for Zone 3, and 3d for Zone 4), the combined storey shear for all four zones consistently demonstrated that the forces from wind loads (WX and WY) were significantly higher than those from equivalent static earthquake loads (EQX and EQY) across all stories, from the base up to the roof. For both load types, the maximum shear force was observed at the base of the structure, and it progressively decreases with increasing height, reaching its minimum value at the Roof. In Zone 1

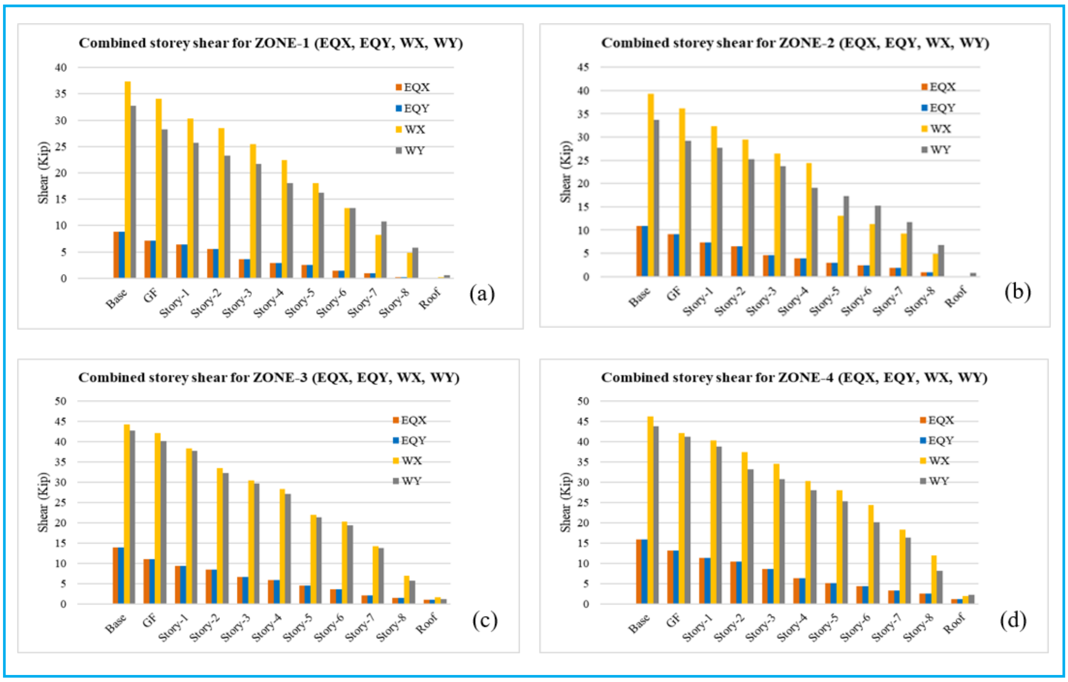

Figure 3. Storey shear distribution for EQX (earthquake in X direction), EWY (earthquake in Y direction), wind load WX (wind in X direction), and WY (wind in Y direction), for Zone 1 (a), Zone 2 (b) Zone 3 (c), Zone 4 (d)

(Figure 3a), the peak shear was about 37 Kip (WX at base), while in Zones 2, 3, and 4 (Figures 3b, 3c, and 3d), the peak wind shear was notably higher, reaching approximately 45 Kip at the Base (WX in Zone 4, Figure 3d).

Conversely, the earthquake shear components (EQX and EQY) were relatively small, typically remaining under 15 Kip even at the base for all zones. The pattern of shear reduction from the base to the roof is characteristic of lateral load distribution in multi-story buildings, confirming that wind loads were the governing lateral load case for the storey shear design in all four zones. These findings demonstrate that wind and seismic forces both increase with zone severity, necessitating strong design and detailing for both serviceability and safety.

Base Shear

In a study, due to updated zone coefficients, lower response modification factors (R), and the inclusion of a 25% live load in seismic weight, BNBC 2020 introduced higher seismic base shear than BNBC 1993 [8]. Furthermore, analysis of Dhaka, Chattogram, Khulna, and Sylhet revealed that base shear increases with building height, with BNBC 2020 forecasting lower values, a wider gap for taller buildings, and a noticeably steeper increase in Sylhet [21].

According to analysis, the base shear for the building steadily rose with seismic zone intensity, as seen in Figure 4a. The recorded values showed a nearly threefold increase from Zone 1 to Zone 4, with values of 33.28 Kip (Zone 1), 55.47 Kip (Zone 2), 77.66 Kip (Zone 3), and 99.84 Kip (Zone 4). The direct impact of rising seismic zone coefficients (Z) on structural demand was reflected in this linear escalation. In order to guarantee stability, structures in higher zones, particularly Zone 4, need to be designed with increased lateral resistance and improved ductile detailing. The increasing base shear values highlighted the fact that, in order to ensure sufficient seismic safety, load-resisting structures and foundations in high-risk areas must be up to three times as strong as those in lower zones.

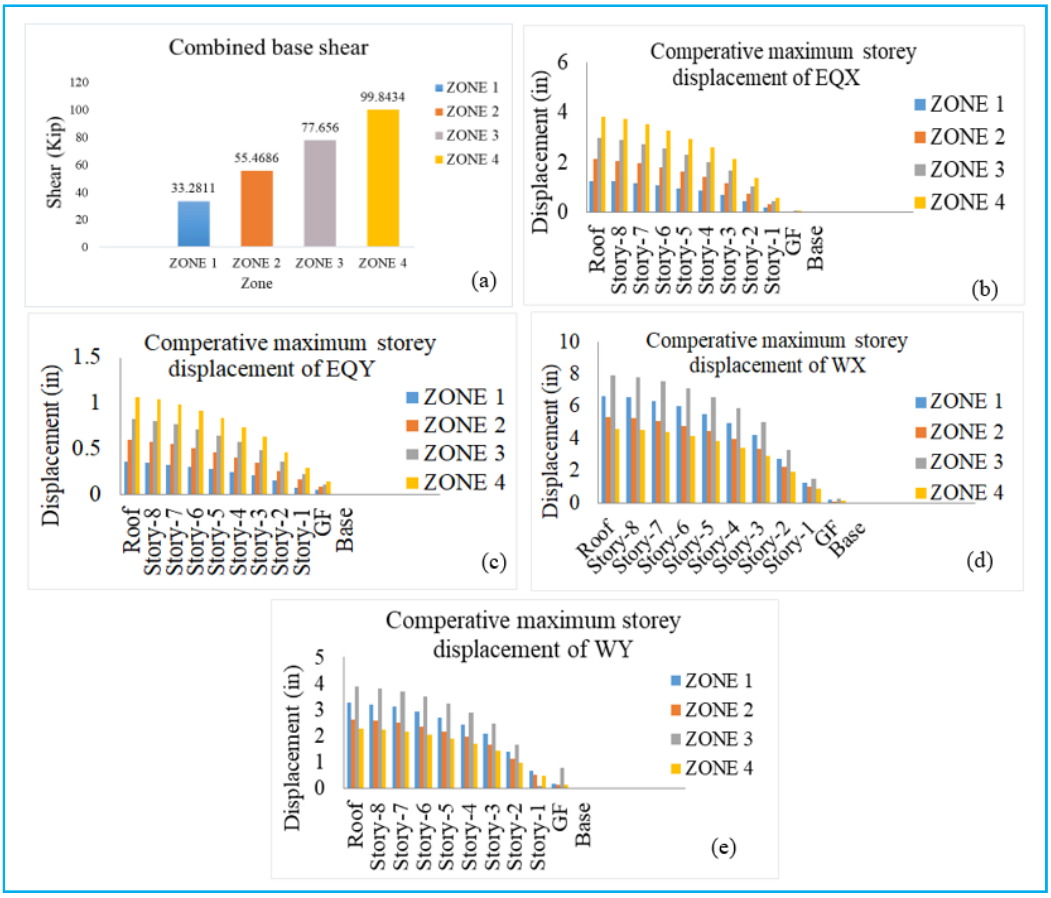

Figure 4. (a) Combined base share in different zones; combined storey displacement for earthquake (b) EQX (earthquake in X direction), (c) EWY (earthquake in Y direction), (d) wind load WX (wind in X direction), and (e) WY (wind in Y direction), for different zones

Storey Displacement

The displacements caused by wind loads were significantly higher than those caused by earthquake loads. For WX, the maximum displacement at the roof reached nearly 8 (in) in Zone 3 (Figure 4d, WX). For WY (Figure 4e), the maximum was close to 4 (in) in Zone 3. Again, earthquake-induced displacements were much smaller. For EQX (Figure 4b), the maximum was around 3.8 in at the Roof, predominantly in Zone 4. For EQY (Figure 4c), the maximum was the lowest of all, peaking at about 1 (in) in Zone 4. For all load types, Zone 3 (WY, WX) and Zone 4 (EQX, EQY) generally exhibited the largest displacements, suggesting these zones represent conditions (higher wind speed or higher seismic acceleration) that induced greater structural flexibility or lateral movement. Conversely, Zone 1 typically showed the lowest displacement across all load cases. This difference highlighted that lateral stiffness requirements or load demands are critically dictated by wind in these building zones.

Results indicated that BNBC 2020 produced higher lateral displacement than BNBC 2006, indicating increased seismic response under the updated code. Lateral displacement happened when soil movement is caused by earthquake vibrations [2]. Several model shapes were examined in a study where displacement rose from the ground to the top storey. The L-shaped model had the highest displacement, followed by the W-shaped, square, and rectangular models, while the addition of shear walls significantly decreased displacement in all directions and storeys [4].

Storey Drift

Wind, seismic loads, building orientation, column size, reinforcement, and irregularities all affected storey drift, which is the lateral displacement of one floor with respect to another. Although wind sway and structural details may cause slight increases in lower floors, newer designs typically reduce drift by 45% to 53%. Additionally, irregular slabs and Grade V irregularity result in higher plinth-level drift. Building height and wind pressure both steadily increase drift.

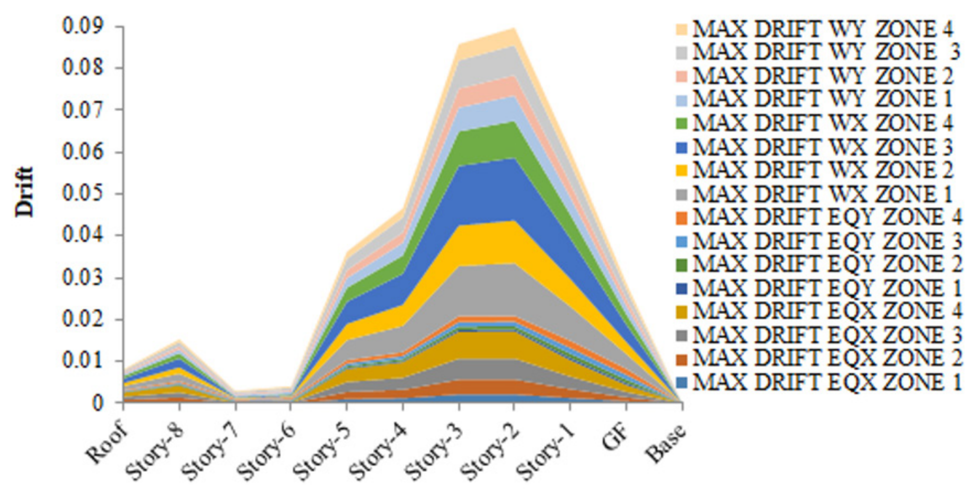

Figure 5. Combined storey drift (EQX, EQY, WX, WY) comparison between selected different seismic zone

Based on the provided stacked area (Figure 5) chart showing maximum storey drift for different zones (1-4) and load cases (EQX, EQY, WX, WY), the drift values (in) were concentrated in the mid-height of the structure, specifically between Story-1 and Story-5, peaking around Story-2 and Story-3 at nearly 0.09in. The contribution of Wind Loads (WX and WY) clearly dominated the overall storey drift compared to the smaller contribution from Earthquake Loads (EQX and EQY). Among the wind loads, Zone 4 and Zone 3 consistently showed the highest maximum drift values, while Zone 1 generally exhibited the lowest drift. When dimensions and reinforcement were changed, maximum drift happens equally in the X and Y directions. This trend suggested that the structure's lateral stiffness was most critical in the middle stories, and wind load governed the inter-storey drift design.

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BNBC 2020 values were higher [21] than BNBC 2006, but they were still within permissible bounds in both codes. Storey drift, or the lateral movement of a floor in relation to the one below, peaked at mid-height, roughly the second to sixth floors [2]. In comparison to BNBC 1993, BNBC 2020 exhibited about twice as much storey drift, peaking between floors 3 and 5 and following a semilunar trend with zone stiffness. All values, however, stayed within code limits [8]. According to a study, the L-shaped model had the most drift, followed by the W and square-shaped models, and the rectangle model had the least. Drift in L, W, and Square shapes was almost the same in both directions, and ground-level drift was comparable across models. In a study, story 2 had the most storey drift, while story 9 had the least [4].

Torsional Irregularity

Uneven plans and an uneven distribution of mass or stiffness amplify stress concentrations, particularly at re-entrant corners and edges. Torsional irregularity is the result of a building rotating unevenly during an earthquake due to eccentricity between its center of mass and center of stiffness. Uneven stress distribution, localized vulnerabilities, increased inter-storey drift in flexible components, and, if torsional moments surpass design limits, an increased risk of partial or total structural collapse These are all consequences of torsional irregularity that can materially impair seismic performance [22].

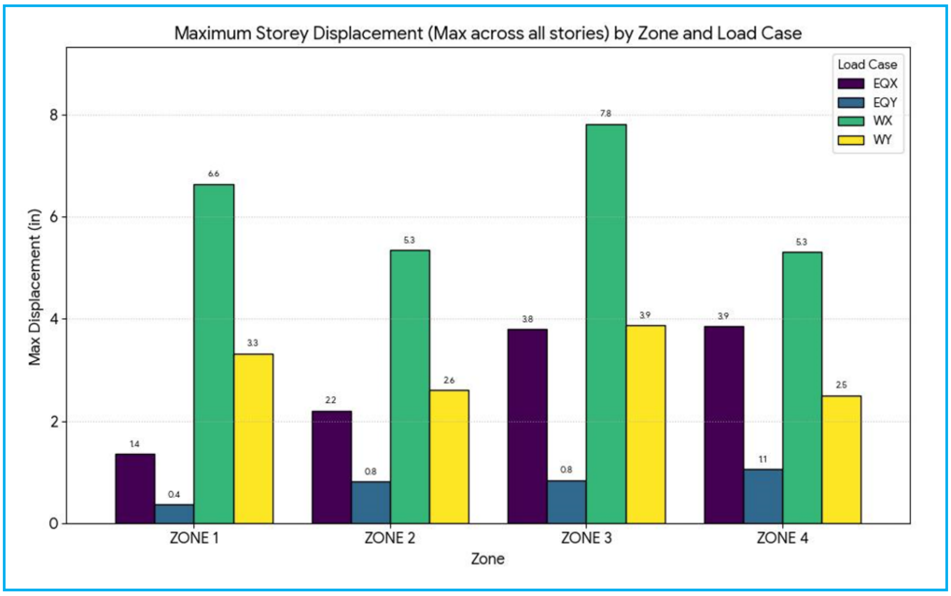

Figure 6. Torsional irregularity for maximum storey displacement of different zones under various loads

Based on the bar charts (Figure 6, 7) summarizing the maximum displacement and drift, a clear pattern emerged regarding the structural performance under various loads. The first bar chart (Figure 6), illustrating maximum storey displacement, showed a significant disparity between wind and seismic forces. The wind in the X-direction (WX) consistently produced the highest displacements, peaking at 7.82 (in) in Zone 3, followed closely by wind in the Y-direction (WY), which reaches 3.87 in, also in Zone 3. In contrast, the seismic forces (EQX and

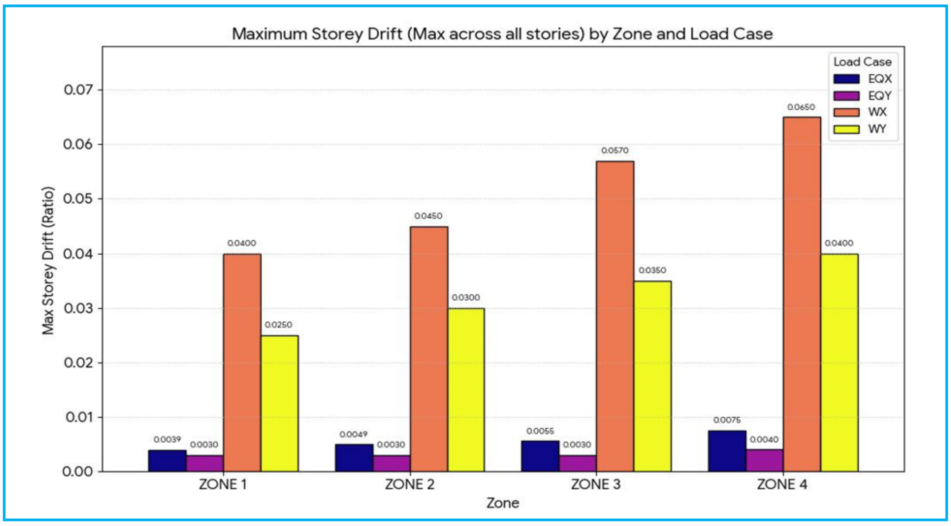

Figure 7. Torsional irregularity for maximum storey drift of different zones under various loads

EQY) yield much smaller displacements, with EQX peaking at 3.85 in and EQY remaining below 1.1 in across all zones. This highlighted that wind loads govern the displacement requirements for this structure, with Zone 3 generally being the most susceptible to large lateral movements.

The second bar chart (Figure 6), detailing maximum storey drift, confirmed the governing nature of the wind loads. Drift, which is critical for preventing non-structural damage, also peaked dramatically under the WX load case, reaching a maximum ratio of 0.065 in Zone 4. This value was substantially higher than the maximum drift under EQX (0.0075) and EQY (0.004). The distribution of the maximum drift across the zones was also revealing, with Zone 4 exhibiting the highest drift under both WX and WY, suggesting a geometric or stiffness asymmetry that was particularly vulnerable to lateral deformation. The design must therefore prioritize strengthening the structure's resistance to wind-induced drift, especially in Zone 4, to ensure the building meets serviceability requirements.

Conclusion

This study has comprehensively evaluated the seismic and wind performance of a G+8 irregular RC building across four seismic zones in Bangladesh using ETABS 2017, following BNBC 2020 guidelines. The key Findings are:

a. Storey shear: The analysis of storey shear across all four zones consistently revealed that wind loads (WX and WY) were the governing lateral forces, peaking at 45 Kip at the base in Zone 4, while seismic forces (EQX and EQY) remained significantly lower (15 Kip), confirming the need for robust design against increasing wind and seismic severity with higher zone numbers.

b. Base shear: Base shear values escalated nearly threefold and linearly from Zone 1 (33.28 Kip) to Zone 4 (99.84 Kip), directly reflecting the impact of rising seismic zone coefficients and necessitating significantly increased lateral resistance in higher-risk areas.

c. Storey displacement: Wind loads (WX, peaking at 8 in) were the dominant factor governing storey displacement requirements, which were highest in Zones 3 and 4 across all load types, while the maximum seismic displacement (EQY, 1 in) was significantly lower.

d. Storey drift: Based on the stacked area chart analysis, wind loads (WX and WY) overwhelmingly governed storey drift, which peaked around stories 2-3 at nearly 0.09 in, with Zones 3 and 4 showing the highest drift values, although all reported values remained within the permissible bounds of both BNBC 2006 and BNBC 2020 codes.

e. Torsional irregularity: The structural analysis concluded that wind loads (WX and WY) govern the design for both storey displacement (peaking at 7.82 in WX, Zone 3) and storey drift (peaking at 0.065 in WX, Zone 4), necessitating structural stiffening, particularly in Zone 4, to meet serviceability requirements against wind-induced lateral deformation.

f. Zone-specific design necessity: The overall findings highlight the importance of incorporating both seismic and wind considerations in structural design, with tailored reinforcement strategies for higher-risk zones and upper storey levels. For different parts of Bangladesh, the seismic zone coefficient varies.

RECOMMENDATION

The study's four primary recommendations are as follows:

- Comprehensive Structural Analysis: To obtain a more accurate evaluation of seismic and wind performance, future research should incorporate soil-structure interaction, nonlinear dynamic analysis, column axial forces, and bending moments.
- Height and Unpredictability Consideration: For upper stories, where displacement, drift, and torsional irregularities were more noticeable, stiffness and reinforcement distribution should be optimized, especially when subjected to wind loads.
- Zone- and Occupancy-Specific Design: Structural design should be tailored to various seismic zones and occupancy types (I, II, and IV). Higher-risk zones, such as Zone 4, should have more robust reinforcement and detailing.
- Broader Application and Adjacency Effects: Future research should consider how nearby structures affect seismic and wind behavior, and similar analyses should be expanded to other building types, such as steel, masonry, and regular moment-resisting frames.

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Conflicts of Interest

The authors declare no competing interest.

Author Contributions

Mohammad Abdul Aziz: conceptualization, writing - original draft, investigation. **Sajedur Rahman:** supervision. **Avishek Ghosh:** writing - original draft. **Mohammad Hasan Mahmud Mazumdar:** writing - original draft. **Akramul Haque:** resources. **Fahmida Khanam Ovi:** visualization.

Data Availability Statement

The article contains the data that was used to bolster the study's conclusions.

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