Effects of Wind Loads on High-Rise Rc Buildings with Different Shapes in a Coastal Region

Md Abu Sufian, Towhid Ahmed and Bhaskar Deb

January 10, 2025

EFFECTS OF WIND LOADS ON HIGH-RISE RC BUILDINGS WITH DIFFERENT SHAPES IN A COASTAL REGION

Md Abu Sufian, Towhid Ahmed, Bhaskar Deb

Sylhet Engineering College, Sylhet-3100, Sylhet, Bangladesh;

Abstract

In this study, a High-rise (G+12) RC building is investigated with respect to its different shapes due to lateral wind loads in a coastal region. The high-rise RC buildings often seem vulnerable to wind action. For desirable performance, we require a better understanding of the interaction between building and coastal gust wind. BNBC (2020) is the standard code of practice for designing loads of buildings and structures. Further; all these shapes were analyzed using ETABS 2016. Each building is a 13-storeyed building with a storey height of 10 ft summing upto a total of 130 ft. For the purpose of analysis, the plan area and stiffness of columns were kept equal. Dead loads and Live loads were calculated using the code BNBC (2020) and ACI 318-08 respectively. Parameters like Storey drift, Joint displacement, Intensity, and Bending moment are used for the assessment. Based on this study it can be established that the shape of a structure plays a vital role in resisting wind loads. **Limitation:** Tornadoes have not been considered in developing the basic wind-speed distributions.

Keywords: Wind Load, Lateral Loads, Gust Factor, High Rise Buildings, Shape, Storey Drift, Story Displacement, Intensity, Topographic Factor

Introduction

The wind load on high-rise buildings is one of the most significant factors affecting their structural design and stability. Various parameters, including the shape of the building, the local weather patterns, and the environmental conditions, influence the wind loads on high-rise buildings.

The focus of this thesis is to investigate the wind load effects on high-rise multi-story buildings of different shapes in the coastal region of Bangladesh. The study aims to comprehensively understand the impact of wind loads on the structural design and stability of high-rise buildings. The findings of this research will help architects, engineers, and building designers make informed decisions regarding the coastal region's design and construction of high-rise buildings. The results of this research will also be helpful for policymakers and stakeholders, who can use the findings to develop regulations and guidelines for the construction of high-rise buildings in the coastal area of Bangladesh.

In conclusion, this thesis will provide a thorough understanding of the wind load effects on high-rise buildings with different shaped profiles in the coastal area of Bangladesh.

Background of the Study

The construction of high-rise buildings in coastal regions poses several challenges due to the impact of wind loads on their structures. Coastal regions are often characterized by higher wind speeds and more variable wind conditions than other regions, making it crucial for engineers complex process that requires a thorough understanding of wind behavior and its effect on structures.

The Bangladesh National Building Code (BNBC-2020) provides guidelines for the calculation of wind loads on buildings in Bangladesh. However, due to their complex geometry, applying these guidelines to the buildings remains a challenge for engineers. As a result, there is a need for an in-depth analysis of wind loads on high-rise buildings in coastal regions to determine the adequacy of the BNBC-2020 guidelines in this specific context.

In recent years, there has been a growing interest in the study of wind loads on high-rise buildings, particularly in coastal regions. However, there is still a gap in the knowledge regarding the behavior of wind loads on these buildings in these regions. This is due to the need for more data on wind loads in coastal regions and the complex nature of the calculations required to assess wind loads on buildings.

This research will be significant for several reasons: Firstly, it will contribute to understanding the behavior of wind loads on high-rise buildings in the coastal region, which is an area of limited attention in the literature.

Secondly, the results of this study will inform the development of more accurate guidelines for the design and construction of high-rise buildings in coastal regions, making them safer and more resilient to wind loads.

Finally, this research will provide valuable insights for engineers and practitioners involved in designing and constructing high-rise buildings in coastal regions, helping them make informed decisions about the application of wind loads on the structures.

In conclusion, 'The Analysis of Wind Loads on High-rise Buildings in a Coastal Region According to BNBC-2020' is a crucial area of research that has the potential to contribute significantly to the understanding of wind loads on these structures and inform the development of more accurate guidelines for their design and construction

Selection of Building:

For this section of the investigation, five distinct shapes have been selected, namely U, N, T, I, and L, for a 12-story high-rise building. The building falls under occupancy category II and is located in Cox's Bazar. The soil type at the site is classified as C, and the seismic design category is D. Other parameters, sections, and material properties are given below:

- Height 130 ft
- Total number of floors: G+12
- Story Height: 10 ft
- Length: 96 ft
- Width: 72 ft
- Grid size: 12 ft x 12 ft
- Column size: 18” x 18”
- Beam size: 16” x 20”
- Concrete grade in columns: 4000 psi
- Concrete grade in beams and slab: 3500 psi
- Steel rebar grade: 72.5 G
- Slab thickness: 5”
- Outer wall thickness: 10”

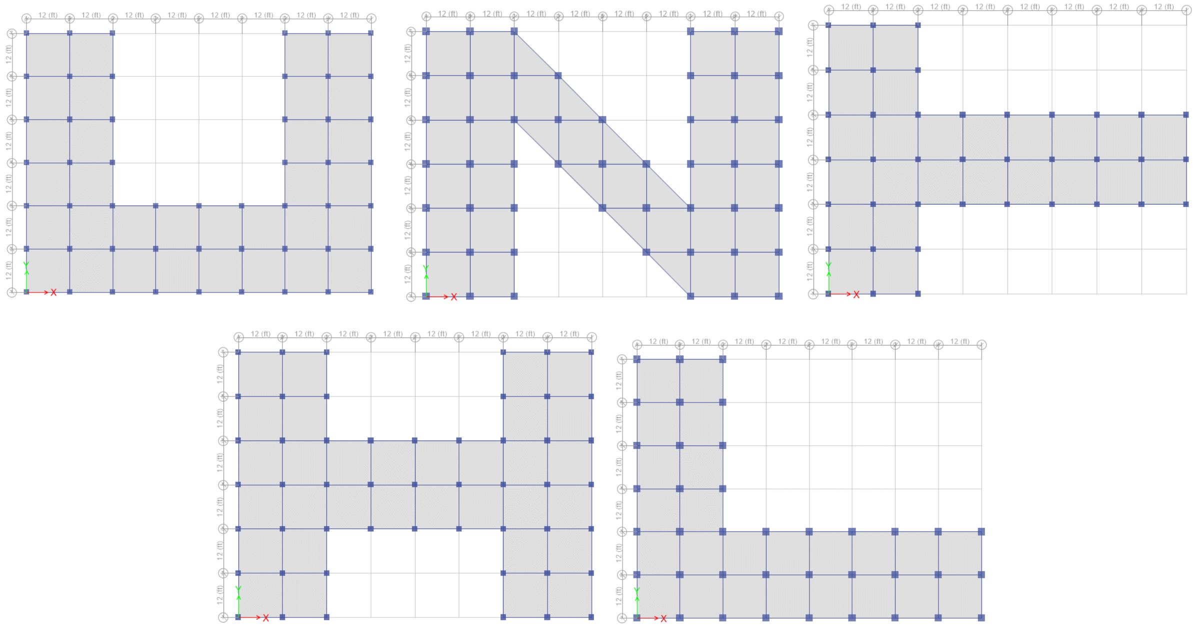
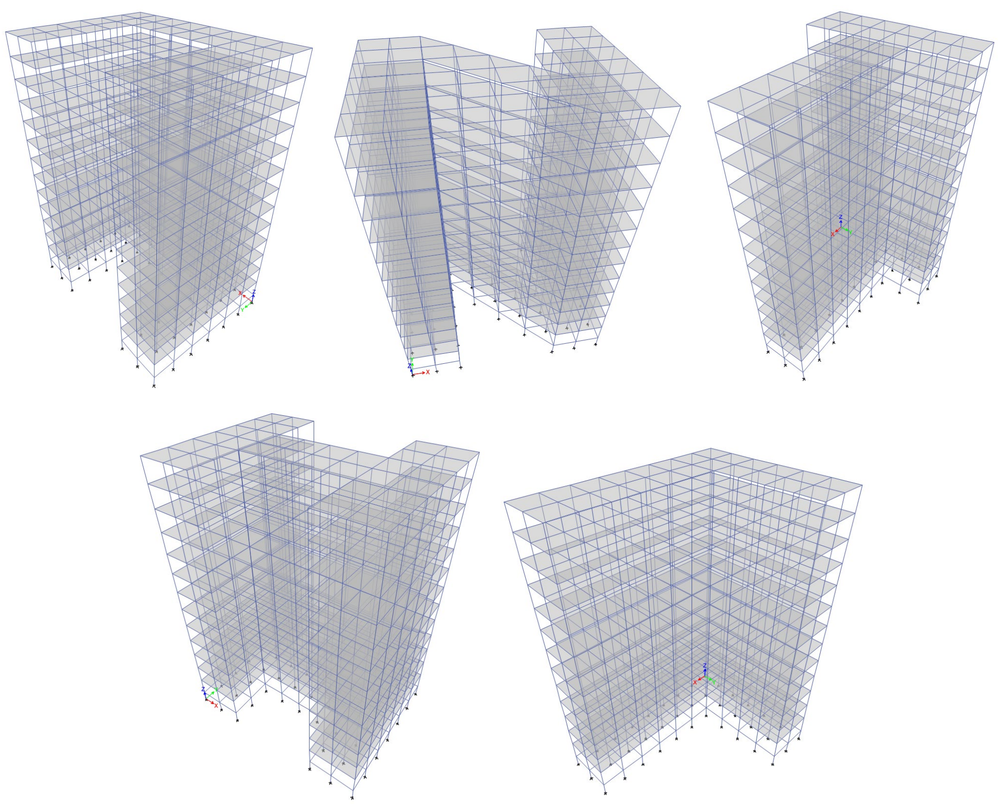


Fig 1: Plan View of Different Shaped Buildings



Load Considerations:

Self-weight: The self-weight of each structural element is calculated automatically by the program.
Floor finish: In addition to self-weight, 25 PSF of floor finish is considered. [BNBC-2020 table-6.1.1]
Partition wall: 30 PSF [BNBC-2020 section 2.3.6]
Floor live load: 50 PSF [BNBC-2020 table- 6.2.2]
Roof live load: 60 PSF [BNBC-2020 section 2.3.8]
Stair live load: 100 PSF [BNBC-2020 table- 6.2.2]

Wind Load Calculation:

Based on expert opinion, a (G+12) storied irregular building is assumed crucial along the coastal wind. To assess the effect of the wind loadings, some calculations and analysis must be required.

Windward Coefficient: Windward Coefficient in any direction is taken as, Cpw= 0.8

Leeward Coefficient:

Along X-axis,

Cpl = 0.451;

Along Y-axis,

Cpl = 0.5;

Importance Factor: 1

Topographical Factor: 1

Directionality Factor: 0.85

Wind Speed, V: 80 m/s

Time Period, T:

$T = C_t\,(h_n)^m$

h_n = 130' = 39.63 m

C_t = 0.0466; m = 0.9

$T = C_t\,(h_n)^m$

=1.278 > 1..........[Flexible Structure]

For flexible or dynamically sensitive structures (natural period greater than 1.0 second), the gust-effect factor shall be calculated by,

$$G_f = 0.925\left(\frac{1+1.7I_{\bar{z}}\sqrt{g_Q^2Q^2+g_R^2R^2}}{1+1.7g_vI_{\bar{z}}}\right)$$

Gust Factor Calculation:

$\bar{b}$ = 0.80 and $\bar{\alpha}$ = 1/9.0 [Table 6.2.10; BNBC-2020]

$\bar{z}$ = 0.6h = (0.6)(39.63) = 23.78 m

Mean hourly wind speed at $\bar{z}$ height, $\bar{V}_{\bar{z}}$

$\therefore \bar{V}_{\bar{z}} = 0.80\left(\frac{23.78}{10}\right)^{1/9.0} x\ 80$ = 70.47 m/s

Building natural frequency, $n_1 = \frac{1}{T}$ = 0.782

For Wind along the X-axis,

$$\eta_L = {15.4n_1L}/{V\bar{z}} = 5.004$$

$$\eta_B = {4.6n_1B}/{V\bar{z}} = 1.121$$

$$\eta_h = {4.6n_1h}/{V\bar{z}} = 2.024$$

$$R_l = \frac{1}{\eta_L} - \frac{1}{2\eta_L^2}(1-e^{-2\eta_L}) = 0.179$$

$$R_B = \frac{1}{\eta_B} - \frac{1}{2\eta_B^2}(1-e^{-2\eta_B}) = 0.536$$

$$R_h = \frac{1}{\eta_h} - \frac{1}{2\eta_h^2}(1-e^{-2\eta_h}) = 0.374$$

The integral length scale of turbulence at the equivalent height, $L_{\bar{z}}$ [Table 6.2.10; BNBC-2020]

$$L_{\bar{z}} = l\left(\frac{\bar{z}}{10}\right)^{\epsilon} = 198.12\left(\frac{23.78}{10}\right)^{\frac{1}{8.0}} = 220.78$$

$$N_1 = \frac{n_1L_{\bar{z}}}{V_{\bar{z}}} = \frac{0.782x220.78}{70.82} = 2.45$$

$$R_n = \frac{7.47N_1}{(1+10.3N_1)^{\frac{5}{3}}} = \frac{7.47x2.45}{(1+10.3x2.45)^{\frac{5}{3}}} = 0.079$$

Hence, the resonant response factor, R

$$R = \sqrt{\frac{1}{\beta}R_nR_hR_B(0.53+0.47R_L)}$$

= 0.441

The value g_Q and g_v shall be taken as 3.4 and g_R is given below,

$$g_R = \sqrt{2\ln(3600n_1)} + \frac{0.577}{\sqrt{2\ln(3600n_1)}}$$

$$= \sqrt{2\ln(3600x0.782)} + \frac{0.577}{\sqrt{2\ln(3600x0.782)}}$$

$$= 4.13$$

Now,

The background response, Q

$$Q = \sqrt{\frac{1}{1+0.63\left(\frac{B+h}{L_{\bar{z}}}\right)^{0.63}}} = \sqrt{\frac{1}{1+0.63\left(\frac{21.95+39.63}{220.78}\right)^{0.63}}} = 0.88$$

The intensity of turbulence, $I_{\bar{z}}$

$$I_{\bar{z}} = c\left(\frac{10}{\bar{z}}\right)^{1/6} = 0.15\left(\frac{10}{23.78}\right)^{1/6} = 0.13$$

Now,

The projected Gust Effect Factor, G_f

$$G_f = 0.925\left(\frac{1+1.7I_{\bar{z}}\sqrt{g_Q^2Q^2+g_R^2R^2}}{1+1.7g_vI_{\bar{z}}}\right)$$

$$= 0.925\left(\frac{1+1.7x0.13\sqrt{3.4^2x0.88^2+4.13^2x0.441^2}}{1+1.7x3.4x0.13}\right)$$

$$= \mathbf{0.938}$$

Similarly,

The Gust Effect Factor for Wind along the Y-axis,

G_f = **0.929**

Load Combinations

Load Combinations were considered as per BNBC – 2020

Result Analysis:

Joint Displacement

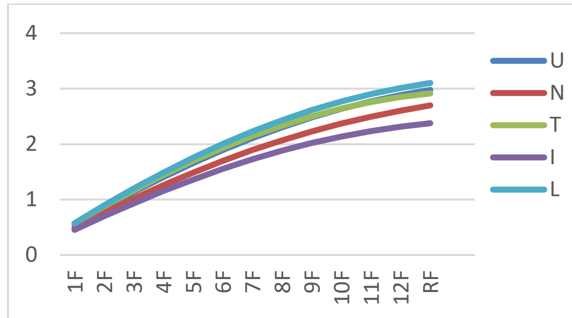


Fig 28: X-axis Displacement Graph

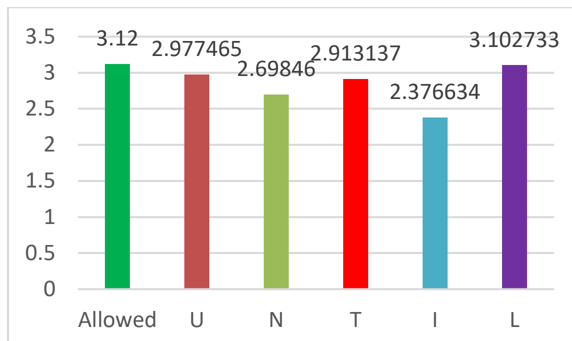


Fig 28: X-axis Displacement Bar

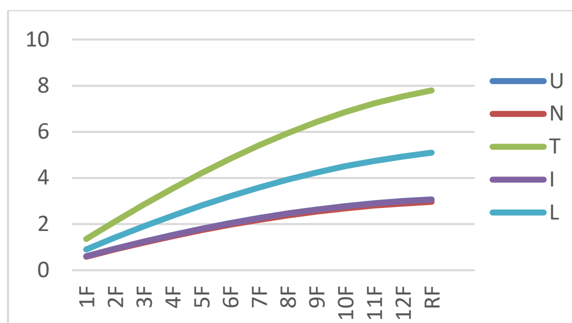


Fig 40: Y-axis Displacement Graph

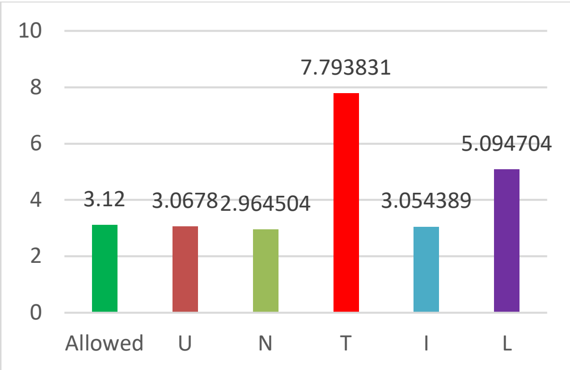


Fig 41: Y-axis Displacement Bar

Story Drift

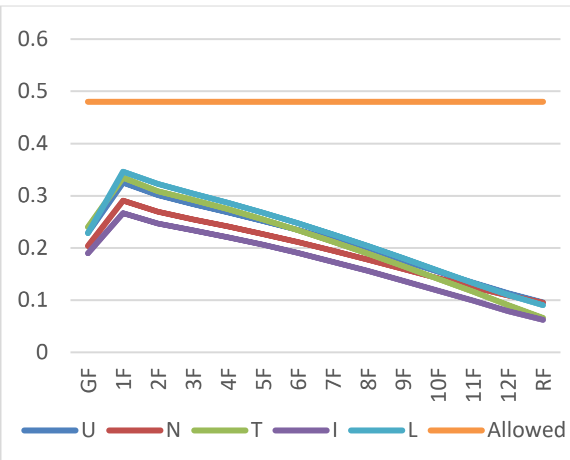


Fig 42: X-axis Story Drift

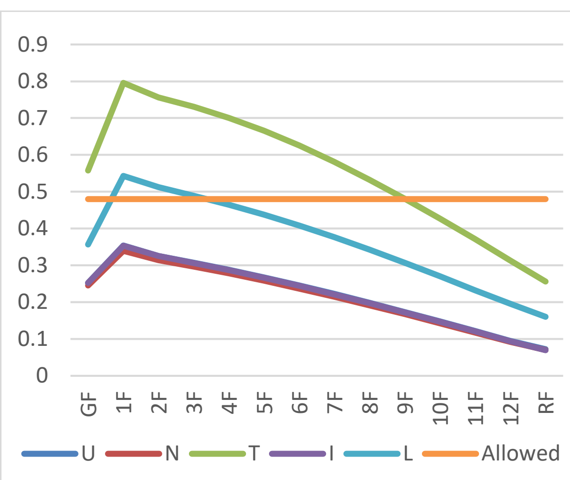


Fig 43: Y-axis Story Drift

Discussion:

From this study, a lateral wind analysis was conducted to examine the displacement and drift of a 13-storied building with a height of 130ft with various shapes under wind load. Results showed that the N and I-shaped building configurations displayed the lowest displacement and story drift compared to T and L-shaped buildings.

In terms of story displacement along the X-axis, the I-shape possesses the least story displacement, being more resilient to wind-induced forces than T and L-shaped structures.

On the other hand, displacement findings along the Y-axis are more challenging, exceeding the allowable limit line for T and L-shaped buildings. Whereas the rest slightly edges the limit.

Now, in terms of story drift along the X-axis, all models rest underneath the safe zone, making the I-shaped building the safest.

Moreover, the drift along the Y-axis is also quite crucial, failing two models, T and L, by exceeding the line of the allowable limit.

In conclusion, these findings suggest that N and I-shaped building designs may be more adaptable to wind-induced forces than T and L-shaped structures.

Comments:

Shape Characteristics on Buildings

The U-shaped building has an open center, which makes it vulnerable to wind loads from any direction. The open center creates a large, unsupported span, which can result in significant lateral displacement and bending.

The N-shaped building has two wings and an open center, similar to the U-shape. Also has a diagonal spine, similar to I-shaped, which makes them enduring enough to wind loads. However, the wings provide some wind resistance and stability.

The T-shaped building also has a strong central spine and a wide base, which helps to resist wind loads. But making it vulnerable to the loads directly perpendicular to the central spine. Thus, the shape struggles to provide stability in both directions, making it quite unfitting for high-rise buildings in coastal windy environments.

I-shaped building has a strong central spine and also a large cross-section, which makes them very susceptible to lateral loads from wind from any direction.

L-shaped buildings have a corner that projects out from the main structure, creating an exposed area that can be susceptible to wind loads. This can lead to significant bending and twisting, which can cause discomfort for occupants.

Conversely, buildings shaped in T and L are considered the most hazardous, as they show the highest level of displacement and story drift, surpassing the acceptable limit.

Limitations

1. The building is located in the Coastal region. Yet, flood and surge loads have been ignored in the analysis.
2. Salt in the air and seawater can cause corrosion of steel reinforcement in concrete, reducing the strength and durability of the structure over time.

Future Scopes

1. As in future studies, shear walls may be placed in weaker directions to reduce lateral displacement.
2. The concept of using bracing is one of the advantageous concepts that can be used to strengthen the structure.
3. In coastal areas where soil conditions are not very favorable for high-rise structures, a deep foundation is compulsory.
4. For further precise and more specific study, the Wind Tunnel Method is highly utile.
5. The corrosive environment in coastal regions requires frequent maintenance to protect the structure from further damage.

References:

[1] A. N. M. Mominul, I. Mukut, and M. M. Alam, "Analysis of Wind Characteristics in Coastal Areas of Bangladesh ANALYSIS OF WIND CHARACT ERIST ICS IN COAST AL AREAS OF BANGLADESH."

[2] "Bangladesh Geography - Banglapedia." https://en.banglapedia.org/index.php?title=Bangladesh_Geography (accessed Jan. 31, 2023).

[3] A. O. Dawood and D. Abbas Oda, "Certified Organization) Website: www," International Journal of Innovative Research in Science, Engineering and Technology (An ISO, vol. 3297, 2007, doi: 10.15680/IJIRSET.2017.0607001.

[4] M. Kalra, P. Bajpai, and D. Singh, "Effect of Wind on Multi Storey Buildings of Different Shapes," Indian J Sci Technol, vol. 9, no. 48, Dec. 2016, doi: 10.17485/ijst/2016/v9i48/105705.

[5] A. M. Hameed and S. Shaikh, "EFFECTS OF WIND LOAD ON RC BUILDINGS BY USING GUST FACTOR APPROACH," JETIR, 2019. [Online]. Available: www.jetir.org

[6] K. R. C. Reddy and S. A. Tupat, "The effect of zone factors on wind and earthquake loads of high-rise structures." [Online]. Available: www.iosrjournals.org

[7] R. K. P, N. S. Kumar, and K. Nayaz Khan, "Effect of Wind Pressure on R.C Tall Buildings using Gust Factor Method." [Online]. Available: www.ijert.org

[8] D. N. Yadav and A. Rai, "Study of Wind Load on Tall RC Frame Building with Shear Wall in Coastal Region." [Online]. Available: http://www.krishisanskriti.org/Publication.html

[9] A. U. Weerasuriya and M. T. R. Jayasinghe, "Wind Loads on High-Rise Buildings by Using Five Major International Wind Codes and Standards," 2014.