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Aerodynamic Effects of Wind on Multi-Story Structures: A Height- and Terrain-Based Analysis

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Abstract

Wind loads are a critical consideration in the structural design of buildings, with direct implications for safety and serviceability. This study investigates the aerodynamic behavior of reinforced cement concrete (RCC) buildings under varying heights and terrain conditions, in accordance with IS: 875 (Part 3): 2015. 12 structural models representing 20 m, 35 m, and 50 m tall buildings were analyzed using extended three-dimensional analysis of building system (ETABS) across four terrain categories in wind zones II to replicate a range of environmental scenarios. Static wind responses were examined, focusing on key parameters including overturning moment and displacement. Results demonstrate that terrain roughness and building height significantly affect wind-induced structural responses. The study emphasizes the importance of site-specific wind zoning and terrain classification in design and validates the applicability of Indian Standards through numerical simulation. These findings provide actionable insights for structural engineers aiming to improve wind resistance and optimize RCC building design.

Keywords: Wind load, ETABS, IS:875 (Part 3), terrain category, structural stability, aerodynamics

INTRODUCTION

The structural integrity of buildings is significantly influenced by environmental forces, among which wind plays a dominant role, particularly in high-rise and exposed structures. As urban development expands into diverse terrains, ranging from coastal regions to dense urban centers, the need for accurate wind load estimation has become increasingly critical. Wind can induce substantial lateral forces and vibrations that affect both the safety and serviceability of reinforced cement concrete (RCC) structures.

The Indian Standard IS: 875 (Part 3): 2015 provides comprehensive guidelines for evaluating wind loads on buildings, considering factors such as terrain category, building height, and wind zone. These parameters directly influence the distribution of wind pressure across a structure. In particular, variations in terrain, such as open ground, suburban layouts, or heavily built-up areas, can significantly alter wind characteristics, thereby impacting the design response of the building.

India is experiencing rapid development, ranking among the fastest-growing nations both economically and in terms of infrastructure. With increasing urbanization, the availability of horizontal land has become limited. To address this spatial constraint, vertical expansion through the construction of high-rise buildings has gained preference over traditional low-rise structures. These tall buildings help optimize land use by utilizing vertical space more efficiently.

However, high-rise structures are more vulnerable to lateral forces, particularly those

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caused by wind. Wind loads have become critical design consideration in such buildings owing to their greater exposure and height. In accordance with IS: 875 (Part 3) 2015, wind loading varies based on the surrounding terrain and is categorized into four distinct types.

1. *Terrain category 1:* Areas with open surroundings and minimal obstructions, where the average height of nearby objects was less than 1.5 meters. This category typically includes airfields and open plains.
2. *Terrain category 2:* This refers to regions with open surroundings but scattered obstacles, such as small buildings or trees. The general height of these obstructions ranges between 1.5 m and 10 m. Such terrain is commonly found in semi-urban and sparsely developed areas.
3. *Terrain category 3:* This category includes areas with a dense concentration of buildings or other structures. These obstructions are usually spaced close together and typically do not exceed 10 m in height. It may also include a few isolated tall structures. Urban residential zones and small commercial districts usually fall into this category.
4. *Terrain category 4:* Areas under this category have numerous tall and massive structures placed close together, such as densely populated urban centers or industrial zones. A high level of obstruction significantly alters wind flow, reducing its direct impact on individual buildings and increasing turbulence.

IMPACT OF WIND LOAD ON BUILDINGS

The velocity profile of wind in the atmospheric boundary layer typically rises with altitude, beginning at a ground level close to zero and peaking at a height called the gradient height. Although it can occur as altitude increases, the Ekman effect of a tiny change in wind direction is usually overlooked in design guidelines.

The surrounding terrain category had the largest impact on the wind speed variation with height. Wind speed varies over time and is not constant at any given height. It is feasible to break down the instantaneous wind speed into two parts for engineering analysis: a mean (or average) component and a fluctuating (or gust) component. Depending on meteorological conditions, the mean wind speed may vary from a few seconds to several minutes. This was determined during a given average period. Shorter averaging intervals increased the significance of the gust component, which represents wind turbulence, suggesting greater variability and short-duration wind speed peaks.

DESIGN WIND SPEED

The design wind speed (Vz) at a specific height above the ground level for any structure was derived by modifying the basic wind speed (Vb) provided in the wind map (IS: 875 Part 3). These modifications account for various site-specific and structural factors to reflect the wind pressures that a structure may experience more accurately.

The adjusted design wind speed, Vz, incorporates the following factors:

- *Risk level factor (k1)*: Accounts for the probability of occurrence based on the importance and expected life of the structure.
- *Terrain, height, and structure size factor (k2)* reflects changes in wind speed due to terrain roughness, building height, and size.
- *Topography factor (k3)*: Considers the influence of local topographic features such as hills, ridges, and escarpments that may amplify wind speeds.
- *Importance factor (k4)*: An additional factor considered in cyclone-prone regions for critical structures to enhance safety.

Mathematically, the design wind speed at height z is expressed as:

$$Vz = Vb \times k1 \times k2 \times k3 \times k4$$

- Vz = Design wind speed at height z(m/s)

- Vb = Basic wind speed (m/s)
- k1 = Risk coefficient
- k2 = Terrain, height, and structure size factor
- k3 = Topography factor
- k4 = Importance factor for cyclonic regions (if applicable)

This equation provides a comprehensive approach for determining wind speeds suitable for design, ensuring the structural integrity and safety of buildings under wind loading conditions.

LITERATURE REVIEW

The research highlights that in a G+5 building model, story drifts remain constant up to the 2nd story but drop to the 1st story, suggesting a reduced wind impact on low-rise structures. For medium- and high-rise buildings, story drift consistently decreases from top to bottom, with terrain category 1 showing the highest drift and category 4 the lowest. Similarly, the building torque is greatest in terrain category 1, and the fixed support conditions at the base help reduce this twist from the sixth floor to the first floor. Shear forces and bending moments also peak in terrain category 1 and decrease along the height of the building. In all cases, terrain category 1 experienced the highest forces, whereas category 4 had the lowest, underscoring that those structures in terrain type 4 were less susceptible to wind effects [1].

The aerodynamic characteristics of different two-dimensional (2D) terrain configurations were determined using numerical simulations and wind tunnel experiments. Under sheared inflow conditions, a good agreement was observed between the computational and experimental results for the pressure coefficients and wind speed ratios, supporting the reliability of the numerical approach. For idealized 2D terrains subjected to uniform flow, the distribution of the wind pressure was found to be strongly influenced by the slope angle. Significant negative peak pressure coefficients were observed at the escarpment due to flow separation, particularly on steep uphill (40°) and downhill (30°) slopes. The streamwise wind speed ratios above the terrain also varied with slope: uphill slopes showed a reduction in speed above the slope and an increase near the escarpment, peaking at 40°; downhill slopes displayed a similar pattern, with maximum ratios at 30°. This study provides valuable aerodynamic insights that can enhance wind field modelling, particularly in typhoon-prone regions [2].

This study underscores the importance of accounting for terrain effects and wind incidence angles when evaluating wind loads on structures. It was found that suburban terrain conditions reduce pressure and force coefficients by 10–20% compared to open terrain, whereas uniform flow conditions generally align with Indian and international codal standards at a 0° wind incidence. However, codal values often underestimate pressures at a 90° incidence in boundary layer flow, suggesting the need for updates to better reflect site-specific exposure conditions. These findings emphasize that relying solely on codal values may lead to unsafe designs under complex aerodynamic and terrain scenarios. Consequently, wind tunnel testing remains a crucial tool for accurately predicting wind-induced forces and ensuring structural safety [3].

A wind tunnel study was conducted to explore the across-wind dynamic forces on 15 tall building models with aspect ratios ranging from four to nine and various cross-sectional shapes. The research focused on how the terrain type, aspect ratio, side ratio of the cross-section, and corner modifications influence these forces. Using high-frequency force balance tests, the authors developed new empirical formulas for the power spectral density of across-wind forces as well as for base moment and shear force coefficients. These formulations were validated using the data from previous studies. Furthermore, an aeroelastic test was performed on a square building model with an aspect ratio of six to assess the across-wind response and aerodynamic damping. A strong agreement was found between the aeroelastic test results and calculated responses, underscoring the importance of aerodynamic damping and confirming the accuracy of the proposed formulas [4].

Wind tunnel experiments were conducted on a rectangular building model (10 cm × 15 cm plan, 70 cm height) at a 1:300 scale under suburban conditions for 12 wind angles (0°–90°) at 16 m/s. The mean pressure and force coefficients were derived using pressure taps along eight vertical levels and MATrix LABoratory (MATLAB) processing. The results showed that the mean pressure coefficients on the windward face remained consistent across levels, whereas the leeward suction coefficients were similar at 0° but differed at 90°, reflecting geometric symmetry effects. The top level (Level 8) consistently recorded lower pressure coefficients owing to the wake turbulence and 3D flow effects. Experimentally determined drag coefficients at 0° and 90° (1.4 and 2.1°) exceed IS:875 values (1.4 and 1.5), highlighting the influence of the boundary layer. The mean lift coefficients were nearly zero at 0° and 90°, as expected owing to symmetry, and torsional moment coefficients reached maximum and minimum values (+0.15 at 15° and -0.25 at 60°), indicating significant rotational behavior at specific angles [5].

This paper reviews how new insights into hurricane surface wind profiles and turbulence spectra affect the along-wind buffeting responses of high-rise buildings. Using three sample buildings with varying aspect ratios and natural frequencies, it was found that the Kaimal and Model B spectra produced peak base moment spectra at higher frequencies than Model A. Base moment RMS responses closely matched those of NALD for Model B (2–9% difference) but differed more for Kaimal (14–23%) and Model A (47–52%). Vickery's wind profile generated up to 11% higher base moment RMS than ASCE 7-10. The buffeting displacements were notably larger for Model A owing to less aerodynamic admittance filtering. The analysis showed that the influence of Model A grew with building height as the resonant contributions increased. The gust effect factors were similar for the Kaimal and Model B spectra but up to 15% higher for Model A, indicating a more conservative design approach. Finally, the Model A spectrum led to higher displacement exceedance probabilities, while Model B caused higher acceleration exceedance probabilities [6].

A comparative analysis of wind speeds across various terrain categories (TC1–TC4) was conducted, and the flow characteristics within the sub-layer over rough surfaces were examined. Utilizing design wind pressure data alongside STAAD.Pro V8i software to assess nodal displacements, the study revealed that terrain category IV (TC4), characterized by the highest surface roughness, exhibited the lowest wind speeds at a height of 10 m. Interestingly, the findings also indicated that tall buildings situated in TC4 experienced the highest wind speeds and pressures at their uppermost levels owing to the influence of the "Gust Effect." This highlights that although rough terrains can mitigate wind impact at lower elevations, they tend to intensify wind loads on the upper floors of high-rise structures [7].

This six-year study of surface wind characteristics across four meteorological stations in Hong Kong revealed that the surrounding terrain and topography significantly influence wind speed and direction, with notable effects such as hilly shielding and valley effects. Periodic patterns were observed in wind, temperature, and pressure, along with trends of increasing wind speed and temperature, and decreasing pressure at certain stations. Fractal dimension analyses showed consistent fluctuation patterns with temperature and pressure variations linked to the local terrain heat capacities. The gust factors under tropical cyclones and monsoons followed similar trends, with a stable linear relationship found between the gust factor and turbulence intensity despite varying terrain and wind types. Spectral analysis highlighted deviations from classic von Karman spectra at higher frequencies, particularly for lateral wind components, whereas turbulence integral length scales varied with terrain roughness. Overall, the study provided comprehensive empirical models for gust factors and turbulence characteristics, which are vital for accurate wind load assessments in complex terrains [8].

MERIT DEM (Multi-Error-Removed Improved-Terrain DEM), a refined digital elevation model with reduced errors, improves global terrain classification by minimizing DEM inaccuracies. Using multiresolution segmentation and combining geometric features, such as slope and local convexity, with surface texture data, the authors applied k-means clustering to create 40 initial terrain clusters, which were later grouped into 15 meaningful terrain categories through hierarchical clustering and comparison with Japanese thematic maps. The classification successfully distinguished key landforms, such as bedrock mountains, hills, plateaus, terraces, and plains, and was validated with data from California and Australia, suggesting global applicability. Improvements over previous models included better representation of terraces and small landform features, although challenges remained in classifying narrow plains and metropolitan areas owing to DEM resolution limits. This study highlights the potential of refined terrain classification to enhance the understanding of natural hazard susceptibility and support land development in regions lacking geological data, with future work aimed at improving geometric signature tuning and cluster groupings [9].

A study on the aerodynamic optimization of a 2D airfoil using Computational Fluid Dynamics (CFD) and a genetic algorithm (SMOGA) showed that the airfoil shape, particularly the lower surface, greatly affects lift, drag, and stability. The research demonstrated a trade-off between lift and stability, where straight lower surfaces improved lift and reduced drag but decreased stability, whereas S-shaped surfaces enhanced stability with a slight loss in lift. Although this study focused on air foils, it highlights how aerodynamic behavior is influenced by form and surrounding conditions, supporting the use of CFD and optimization in analyzing wind effects, an approach relevant to the wind analysis of RCC buildings in varying terrain and height conditions [10].

These studies collectively advance our understanding of wind effects on buildings, terrain influences on wind flow, and improved terrain classification techniques. They highlighted the significant impact of terrain roughness and shape on the wind speed, pressure distribution, and dynamic responses of structures, especially tall buildings. Experimental, numerical, and field data emphasize the importance of accurate wind spectra, aerodynamic damping, and terrain categorization in predicting the structural behavior under wind loads. Additionally, the innovative use of high-resolution DEM data and machine learning enables a more precise global terrain classification, which is crucial for assessing natural hazards and guiding land development. The integration of advanced modelling, empirical data, and improved terrain analysis paves the way for safer structural design and better environmental risk management.

AIM AND OBJECTIVES

The principal aim of this study is to examine the impact and fluctuation of wind pressure on structures with variable elevations and environmental conditions. In accordance with the IS 875 (Part 3) Wind Loads criteria, this study focuses on low-rise, medium-rise, and high-rise buildings assessed under various terrain types. The following is an outline of precise goals.

1. Analyze the effect of wind pressure on multi-storied buildings of three height categories: 20 m (low-rise), 35 m (medium-rise), and 50 m (high-rise), subjected to different terrain conditions (Terrain Categories 1 to 4) and located in wind zones 2.
2. Perform a comprehensive static wind load analysis using extended three-dimensional analysis of building system (ETABS) software: the methods recommended in code IS: 875 (Part 3) must be applied to determine realistic wind effects on structural performance.
3. Compare the structural behavior of buildings under varying conditions by evaluating parameters such as overturning moment and displacement, different combinations of building height, and terrain category.
4. Provide analytical insights that can support the development of improved wind-resistant design strategies and contribute to safer and more cost-effective construction practices by Indian Standards.

SYSTEM DEVELOPMENT

This article outlines a systematic approach for modelling 12 distinct structures, each varying in size and located across different terrain types. Figures 1, 2, and 3 visually represent these findings for easier understanding. The structural data specifications for the 20 m, 35 m, and 50 m high buildings are listed in Tables 1, 2, and 3.

- Terrain Category 1
  Model Type 1: Low-rise building
  Model Type 2: Medium-rise building
  Model Type 3: High-rise building
- Terrain Category 2
  Model Type 4: Low-rise building
  Model Type 5: Medium-rise building
  Model Type 6: High-rise building
- Terrain Category 3
  Model Type 7: Low-rise building
  Model Type 8: Medium-rise building
  Model Type 9: High-rise building
- Terrain Category 4
  Model Type 10: Low-rise building
  Model Type 11: Medium-rise building
  Model Type 12: High-rise building

LOADING CONDITIONS

Dead Load

Self-weight of structural elements such as slabs, beams, columns, staircases, and parapet walls (if applicable) is automatically calculated by ETAB based on member dimensions and material density (Figure 4).

Table 1. Low-rise building specification.

No. of stories	G+7
Structure	RCC
Floor height	3 m
Grade of concrete	M 30
Grade of Steel	Fe 500
Slab thickness	150 mm
Plan size	20 m × 20 m
Foundation to plinth	2 m

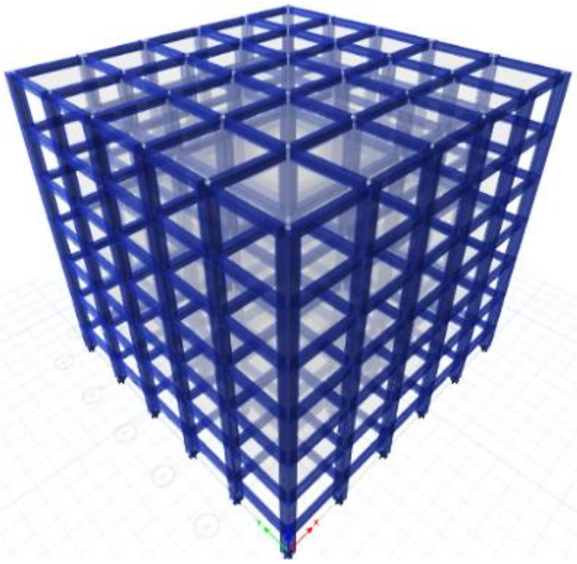


Figure 1. A 20 m high building.

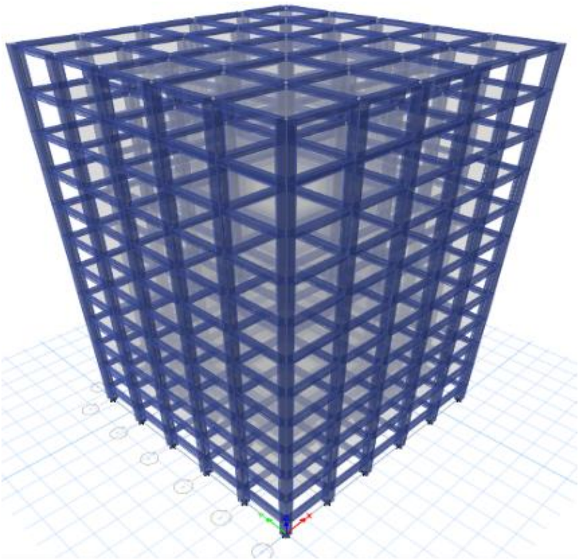


Figure 2. A 35 m high building.

Table 2. Medium-rise building specification.

No. of stories	**G+12**
Structure	RCC
Floor height	3 m
Grade of concrete	M 30
Grade of steel	Fe 500
Slab thickness	150 mm
Plan size	20 m × 20 m
Foundation to plinth	2 m

Table 3. High-rise building specification.

No. of stories	**G+17**
Structure	RCC
Floor height	3 m
Grade of concrete	M 30
Grade of steel	Fe 500
Slab thickness	150 mm
Plan size	20 m × 20 m
Foundation to plinth	2 m

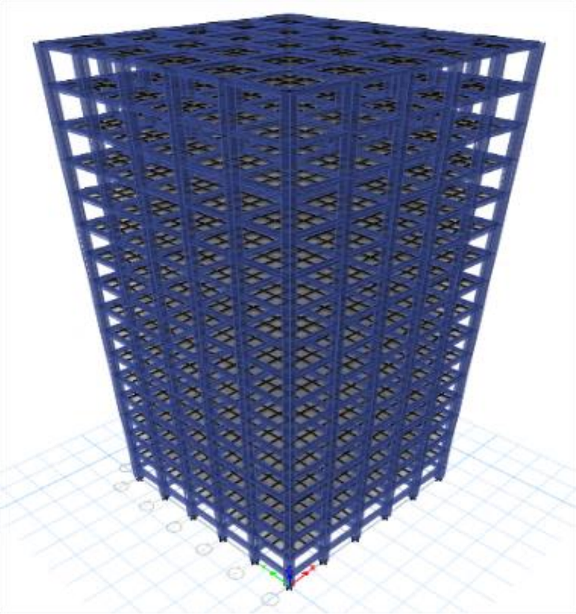


Figure 3. A 50 m high building.

Wall Load

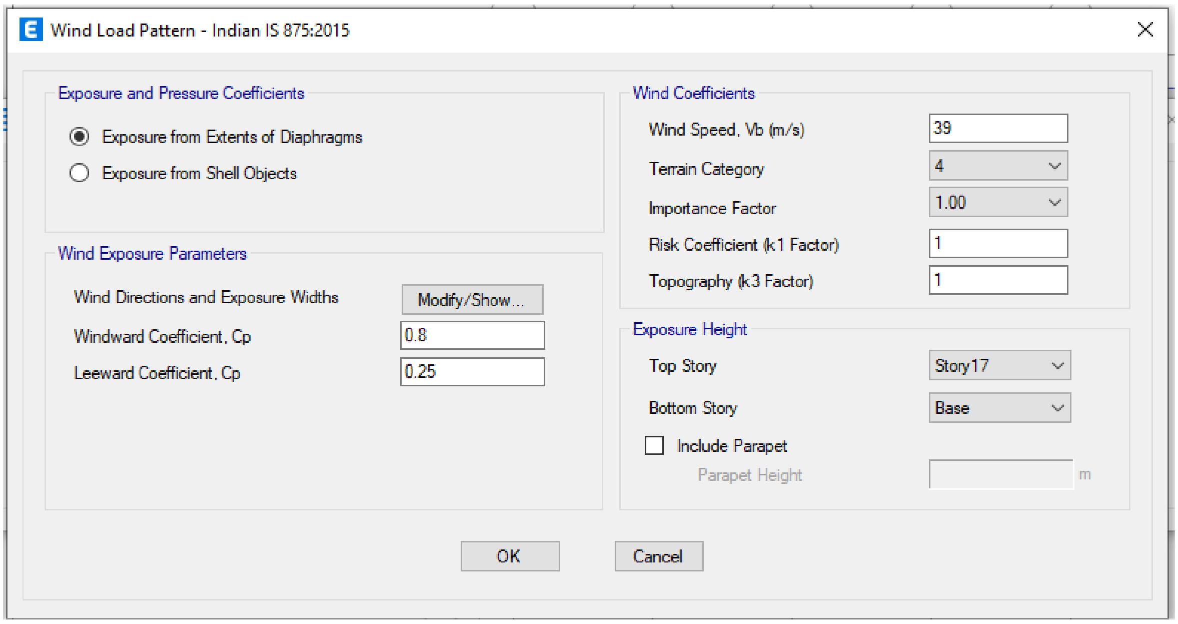
Wall thickness = 230 mm
Wall height = 3 m
Wall load=13.5 kN/m

Floor Finish Load

Thickness = 50 mm (0.05 m)
Density ≈ 20 kN/m³
Load = 1 m×1 m×0.05 m×20 kN/m³ = 1.0 kN/m² (with factor) =1.5 kN/m²

Live Load (IS 875 Part 2: 1987)

Commercial floors: 4 kN/m²



● Exposure from Extents of Diaphragms
○ Exposure from Shell Objects

Windward Coefficient, Cp: 0.8
Leeward Coefficient, Cp: 0.25

Wind Speed, Vb (m/s): 39
Terrain Category: 4
Importance Factor: 1.00
Risk Coefficient (k1 Factor): 1
Topography (k3 Factor): 1

Top Story: Story17
Bottom Story: Base
☐ Include Parapet
Parapet Height: m

Figure 4. Wind load data.

Wind Load (IS 875 Part 3: 2015)

Basic wind speed (Vb): 39 m/s

Design wind speed (Vz)

$$Vz = Vb \times k1 \times k2 \times k3 \times k4$$

Where:

- *k1* = Risk coefficient (based on building importance)
- *k2* = Terrain, height, and structure size factor
- *k3* = Topography factor
- *k4* = Importance factor

Design Wind Pressure

$$Pz = 0.6 \times Vz^2 \ (\text{N/m}^2)$$

RESULTS AND DISCUSSION

Overturning Moment

Figure 5 reveals that the overturning moments for the 20 m high low-rise building increase significantly from top to base across all terrains. Terrain 1 consistently showed the highest overturning moments, whereas Terrain 4 showed the lowest. The maximum base moment in Terrain 1 reaches 4376.0 kN-m, indicating that more exposed terrain imposes higher demands on structural stability. This highlights the significant role of terrain in the design of low-rise buildings for wind loading.

Figure 6 shows that for the 35 m medium-rise building, the overturning moment increased consistently from the top down to the base across all terrains, similar to the patterns observed in the low- and high-rise structures. Terrain 1 consistently exhibited the highest moments, followed by Terrains 2, 3, and 4.

The maximum overturning moment at the base reached 14,724 kN-m in Terrain 1, indicating the significant influence of terrain roughness on structural demands. These results highlight that terrain exposure is a crucial factor in the design of medium-rise buildings that are subjected to wind loading.

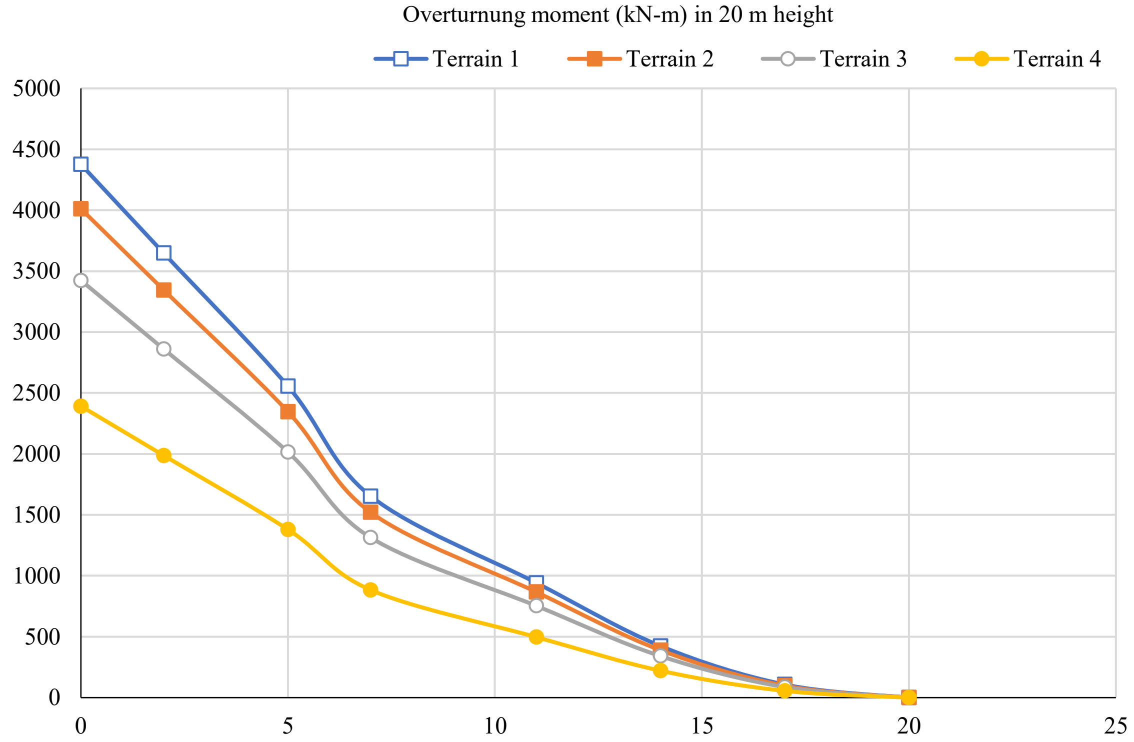


Figure 5. Low-rise building overturning moment.

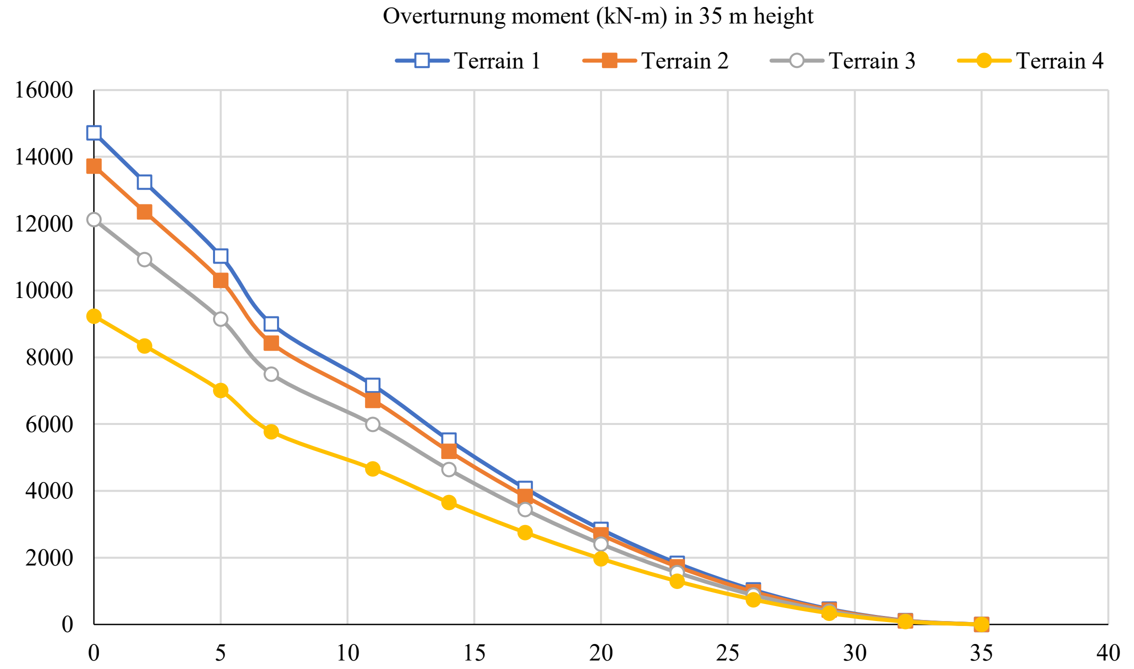


Figure 6. Medium-rise building overturning moment.

Figure 7 reveals the data that shows the overturning moments increase significantly from the top (zero) to the base across all terrains. Terrain 1 (open terrain) consistently had the highest moments, whereas Terrain 4 (most sheltered) had the lowest. The maximum base overturning moment reaches 31804.9 kN-m in Terrain 1, highlighting the need for a more robust structural design in open terrains. This underscores the importance of terrain classification in determining the effects of wind loads on structural stability.

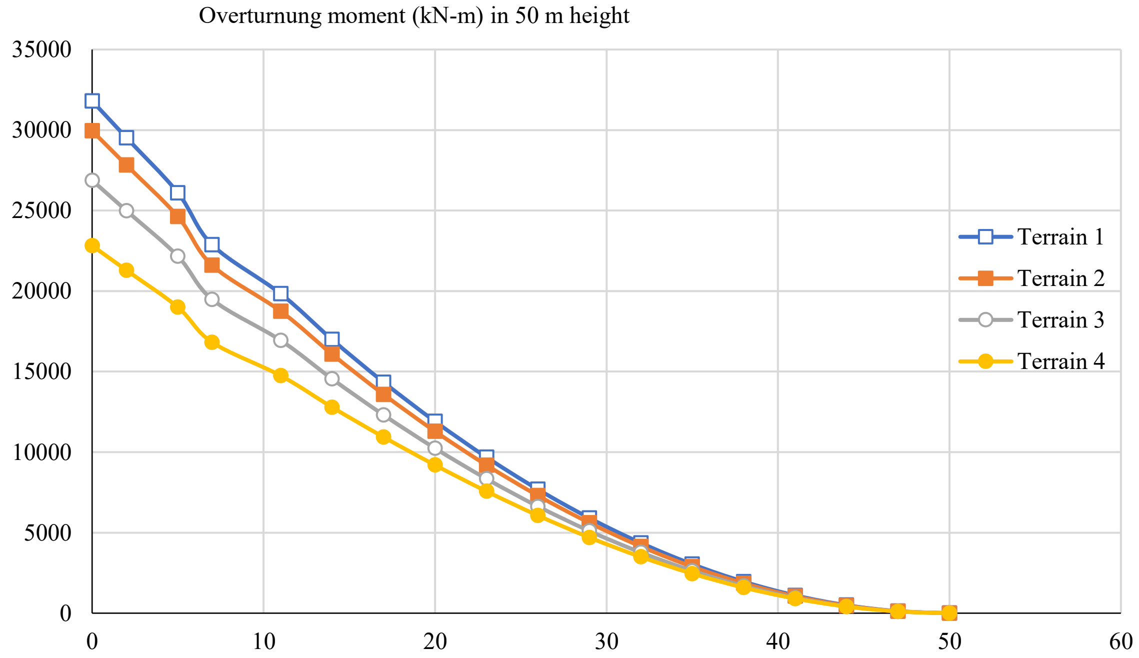


Figure 7. High-rise building overturning moment.

The overturning moments in the analyzed buildings consistently increased from the top stories to the base, reflecting the cumulative wind forces acting along the height. Terrain 1 consistently yielded the highest overturning moments owing to its low surface roughness, followed by Terrains 2, 3, and 4.

In terms of magnitude, high-rise (50 m) buildings experienced the largest overturning moments at the base (~32,000 kN-m in Terrain 1), whereas medium-rise (35 m) structures exhibited lower base moments (~14,700 kN-m), and low-rise (20 m) buildings had the smallest base moments (~4,400 kN-m). This emphasizes the significant impact of terrain roughness on the magnitude of overturning moments and highlights the base stories as the most critical zones for ensuring structural safety and stability. Wind tunnel data and refined wind loading models, particularly for high-rise structures, may further enhance the design safety and economy, as evidenced by the significant differences observed across terrains.

Displacement

- Displacement increases with building height, indicating that taller structures experience significantly higher wind-induced lateral movements.
- For all heights, Terrain 1 (open terrain) resulted in the highest displacements, whereas Terrain 4 (urban terrain) showed the lowest displacements owing to increased surface roughness and wind shielding.
- At a height of 20 m (Table 4 and Figure 8), the maximum displacement was 2.639 mm in Terrain 1, which reduced to 1.438 mm in Terrain 4.
- At 35 m height (Table 5 and Figure 9), it increases to 13.24 mm in Terrain 1 and 8.343 mm in Terrain 4.
- At a height of 50 m (Table 6 and Figure 10), the displacement further increased to 30.605 mm in Terrain 1 and to 22.117 mm in Terrain 4.
- Terrain roughness significantly affects lateral displacements, which can affect non-structural elements and serviceability limits.
- Critical attention must be paid to high-rise buildings in Terrain 1, which experienced the largest lateral displacements, potentially requiring enhanced drift control measures (e.g., stiffer lateral force-resisting systems and dampers).

Table 4. Low-rise building displacement (mm). Displacement (mm) in 20 m height.

Stories	Story height (m)	Terrain 1	Terrain 2	Terrain 3	Terrain 4
Story 7	20	2.63	2.41	2.06	1.43
Story 6	17	2.51	2.30	1.96	1.37
Story 5	14	2.27	2.08	1.77	1.24
Story 4	11	1.9	1.74	1.48	1.04
Story 3	7	1.39	1.28	1.08	0.77
Story 2	5	0.79	0.72	0.61	0.44
Story 1	2	0.18	0.17	0.14	0.10
Base	0	0	0	0	0

Table 5. Displacement (mm) in 35 m height.

Stories	Story height (m)	Terrain 1	Terrain 2	Terrain 3	Terrain 4
Story 12	35	13.24	12.35	10.92	8.34
Story 11	32	12.99	12.12	10.72	8.17
Story 10	29	12.57	11.72	10.36	7.87
Story 9	26	11.95	11.14	9.84	7.44
Story 8	23	11.12	10.36	9.14	6.88
Story 7	20	10.08	9.38	8.27	6.20
Story 6	17	8.84	8.21	7.23	5.40
Story 5	14	7.40	6.87	6.03	4.50
Story 4	11	5.77	5.36	4.69	3.50
Story 3	7	4.00	3.71	3.24	2.42
Story 2	5	2.15	1.99	1.74	1.30
Story 1	2	0.49	0.45	0.39	0.29
Base	0	0	0	0	0

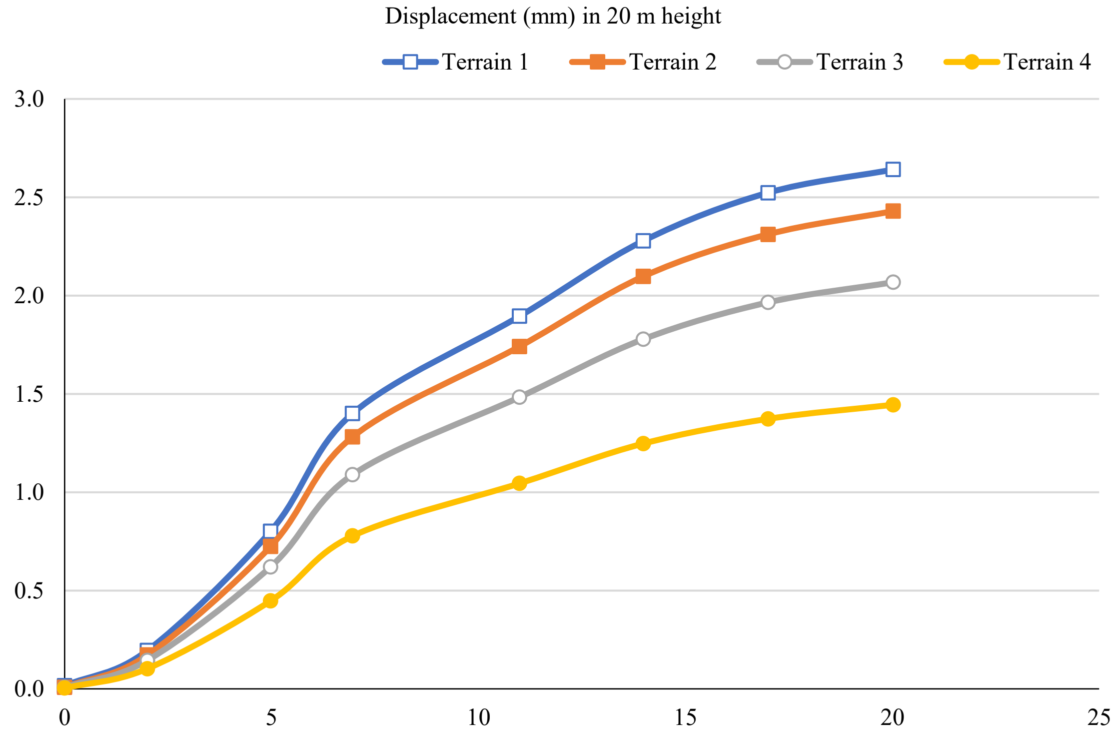


Figure 8. Low-rise building displacement.

- The results emphasize the need to consider both the overturning moment and displacement limits when designing for wind, especially in flexible structures.
- These results highlight the importance of terrain-specific wind loading when assessing the serviceability and comfort of the occupants.
- The trend shows a nonlinear increase in displacement with height and highlights the need for additional structural stiffness in taller buildings, particularly in open terrains.
- These results underline the importance of considering terrain category and height in the structural design of wind loads.

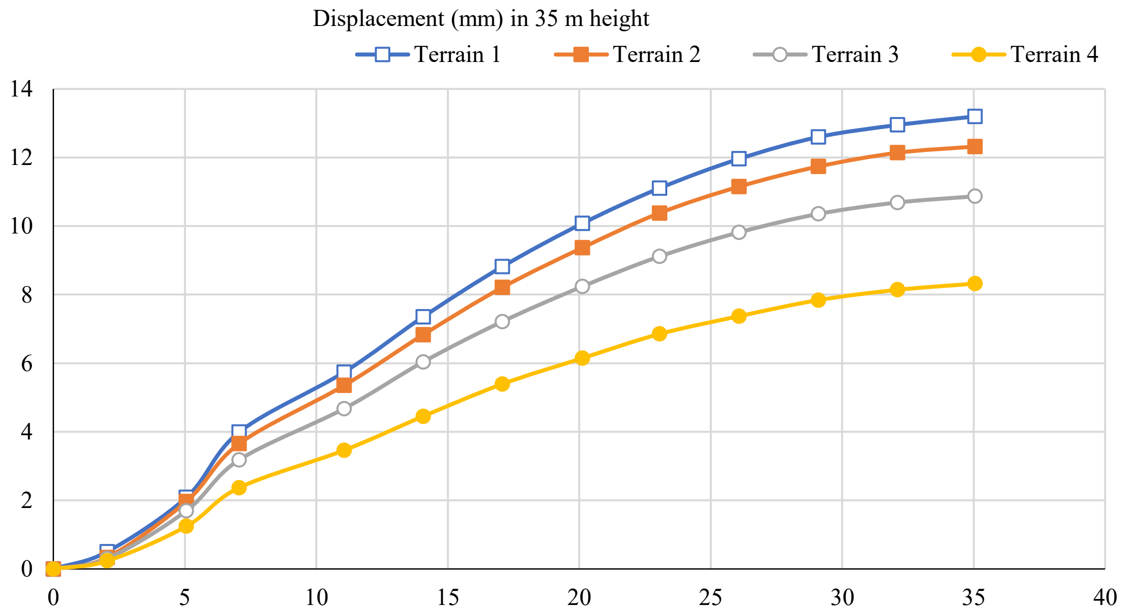


Figure 9. Medium-rise building displacement.

Table 6. High-rise building displacement (mm).

Displacement (mm) in 50 m height					
Stories	***Story height (m)***	***Terrain 1***	***Terrain 2***	***Terrain 3***	***Terrain 4***
Story 17	50	30.60	28.84	25.92	22.11
Story 16	47	30.23	28.49	25.60	21.82
Story 15	44	29.69	27.97	25.13	21.39
Story 14	41	28.92	27.25	24.47	20.78
Story 13	38	27.93	26.31	23.61	19.99
Story 12	35	26.71	25.15	22.56	19.03
Story 11	32	25.27	23.78	21.32	17.90
Story 10	29	23.61	22.20	19.89	16.62
Story 9	26	21.73	20.42	18.28	15.19
Story 8	23	19.64	18.44	16.49	13.63
Story 7	20	17.34	16.27	14.53	11.95
Story 6	17	14.85	13.92	12.42	10.17
Story 5	14	12.17	11.41	10.15	8.29
Story 4	11	9.33	8.73	7.76	6.32
Story 3	7	6.36	5.95	5.28	4.29
Story 2	5	3.37	3.16	2.80	2.27
Story 1	2	0.76	0.71	0.63	0.51
Base	0	0	0	0	0

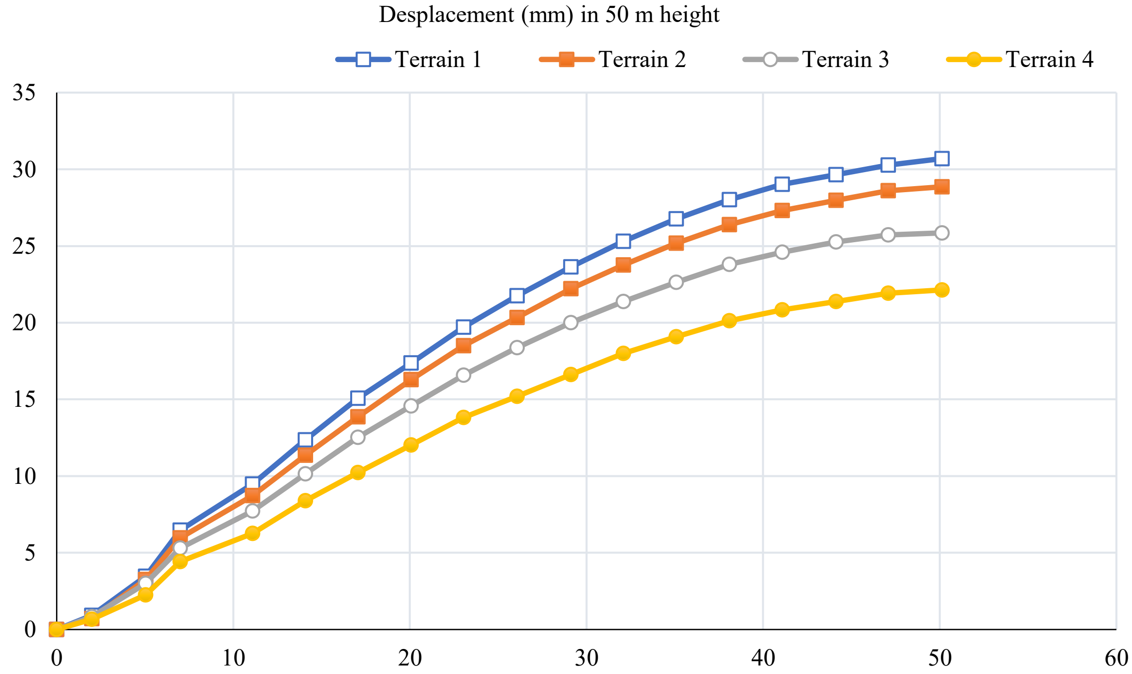


Figure 10. High-rise building displacement.

CONCLUSION

- The effects of terrain category and building height on the wind-induced response of RCC structures were thoroughly analyzed through the overturning moment and displacement results. Both parameters showed a strong correlation with the terrain roughness and structure elevation.
- The overturning moment increased nonlinearly with height and was highest at the base of the building in all terrain categories. For instance, the base moment increased from 4376.03 kN-m (Terrain 1, 20 m height) to 31804.90 kN-m (Terrain 1, 50 m height), clearly indicating the cumulative impact of wind loads on taller structures.
- Terrain 1 consistently produced the highest overturning moments and displacements because of its minimal surface roughness and higher wind exposure. Terrain 4, being the roughest, resulted in the lowest values, demonstrating the dampening effect of the terrain obstructions.
- The displacement patterns revealed a progressive increase with height, with the top stories experiencing the maximum deflection. This trend is more pronounced in open terrains, reinforcing the need for effective lateral load-resisting systems in such environments.
- The results highlight the critical importance of terrain classification during the structural design phase. Ignoring terrain effects can compromise safety or lead to uneconomical designs, particularly in tall structures.
- Despite the increased forces and displacements, all responses remained within the permissible limits prescribed by the design codes (IS 875 and IS 456), validating the structural adequacy under wind action. However, the observed trends indicate the necessity of adopting enhanced stiffness measures, such as shear walls, bracings, or core walls in high-rise designs, particularly for Terrain 1 and 2 locations.
- In conclusion, this study confirms that terrain type is a decisive factor in the wind load behavior of tall RCC structures, and its accurate consideration is essential for safe and optimized structural design. Future research may integrate turbulence, dynamic amplification, and real-time wind simulations for more robust modelling.

REFERENCES

1. Jadhav S, Vishwanath K. Wind load impact upon tall structures in diverse terrain categories. J Sci Res Technol. 2023;1:2583–8660.

2. Fang P, Zheng D, Li L, Ma W, Tang S. Numerical and experimental study of the aerodynamic characteristics around two-dimensional terrain with different slope angles. Front Earth Sci. 2019;13:705–20. DOI: 10.1007/s11707-019-0790-8.
3. Iwahashi J, Kamiya I, Matsuoka M, Yamazaki D. Global terrain classification using 280 m DEMs: segmentation, clustering, and reclassification. Prog Earth Planet Sci. 2018;5. DOI: 10.1186/s40645-017-0157-2.
4. S CG, P H, S SR. Effects of upstream terrain characteristics on aerodynamic coefficients of structures. Arch Civ Mech Eng. 2017;17:776–85. DOI: 10.1016/j.acme.2017.02.005.
5. Amirinia G, Jung S. Along-wind response of high-rise buildings subjected to hurricane boundary layer winds. J Struct Eng. 2017;143. DOI: 10.1061/(ASCE)ST.1943-541X.0001816.
6. Okafor CV, Okolie KC, Echefuna CM, Okafor CP. Analysis of wind effect on high-rise building for different terrain category. Eur J Eng Technol Res. 2017;2(12):23–30. DOI: 10.24018/ejers.2017.2.12.550.
7. Sarath Kumar H, Rajan SS, Andrew AJ, Babu GR, Srinivasa Rao N, Guru Jawahar J. Aerodynamic coefficients for a rectangular tall building under sub-urban terrain using wind tunnel. Asian J Civ Eng. 2016;17:325–33.
8. Lee SH, Lee J. Aerodynamic analysis and multi-objective optimization of wings in ground effect. Ocean Eng. 2013;68:1–13. DOI: 10.1016/j.oceaneng.2013.04.018.
9. He YC, Chan PW, Li QS. Wind characteristics over different terrains. J Wind Eng Ind Aerodyn. 2013;120:51–69.
10. Gu M, Quan Y. Across-wind loads of typical tall buildings. J Wind Eng Ind Aerodyn. 2004;92:1147–65. DOI: 10.1016/j.jweia.2004.06.004.