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Critical Comparative Study of Dynamic Wind Response of Tall Buildings Using Gust Effectiveness Factor Method

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Abstract - The advent of low-density high strength construction materials, along with advancements in computer and analysis techniques, has led to the emergence of tall and flexible structures that are vulnerable to the influences of dynamic wind loading. The second edition of the Indian wind loading codal regulations, namely IS 875 (Part 3) 2015, incorporates the gust factor approach to effectively consider the dynamic characteristics of wind in relation to flexible structures. An endeavour is undertaken to evaluate and contrast the reactions of different stresses exerted on high-rise structures. The gust factor approach, as specified by IS 875-2015, is employed for the determination of dynamic wind load. The methodology employed in this study was the determination of the static wind load, dynamic wind load, and static equivalent earthquake load in order to ascertain the magnitude of force exerted on each individual story. This comparative study utilizes four models with varying aspect ratios derived from the G+20 and G+40 narratives. The outcomes are shown in relation to tale drift, story force, and story displacements. Furthermore, the analysis is conducted on structures situated on inclined terrain, featuring square and rectangular floor plans. This comparative study demonstrates that the dynamic wind load response of a building exhibits a non-linear parabolic relationship with an increase in the number of stories. In contrast, the response of the static wind load is linear in nature. The ETABS program is utilized. The investigation has revealed that the categorization of terrain has a significant influence in determining the suitability between the two methodologies. The work has indicated that in terrain category 4, the static technique is deemed more crucial when compared to the dynamic approach. Conversely, in terrain category 2, the dynamic approach is considered more vital than the static approach.

Key Words: ETABS, IS 875 (Part 3) 2015, dynamic wind load, terrain category, story drift, story displacements.

I. INTRODUCTION

The construction of enormous structures emerged because of the imperative need for both public well-being and economic prosperity, within the context of certain temporal and spatial conditions. During the 1880s, the United States witnessed the development and erection of its inaugural high-rise buildings. The phenomenon of vertical expansion in urban areas emerged primarily as a response to the increasing demand for space-efficient constructions in the face of escalating land costs and growing populations. The objective of each nation and city is to build a distinct and recognisable skyline on a global scale, thereby solidifying their geographical presence. The city's reputation is enhanced, and visitor attraction is increased due to the unique characteristics of the destination. These structures act as powerful symbols of authority and rank, embodying the highest achievements in engineering and architecture. Additionally, they function as iconic monuments that provide a sense of comfort and reassurance. Furthermore, they stand as enduring testaments to the indomitable human spirit, while also serving as effective tools for fostering positive public relations. Throughout history, humans have consistently demonstrated a desire to construct increasingly elevated edifices. Throughout the course of human history, the construction of towering structures has captivated the curiosity and fascination of individuals. The Egyptian Pyramids, which are part of the Seven Great Pyramids, may be traced back to the third millennium B.C. Constructed in the year 2600. The residence exhibits signs of being outdated. These structures function as a dual purpose, providing a form of safeguarding while also serving as a manifestation of individuals' achievements. The Indian subcontinent is significantly vulnerable to a range of natural disasters, such as earthquakes, droughts, floods, cyclones, landslides, avalanches, and various others. These catastrophic events present a substantial and imminent danger to the region. Most nations and union territories are susceptible to one or several catastrophic events. Annually, these natural calamities lead to numerous human casualties and extensive property damage. A considerable region inside India is susceptible to the potential risks and consequences associated with seismic activities. Hence, it is imperative for researchers to prioritise and advance effective disaster mitigation strategies while investigating the response of structures to wind and seismic events, to assure their continued functionality. The population growth rate in India is a cause for concern. The significant populace necessitates not alone employment opportunities, but also enough housing and infrastructure. The relocation of numerous companies to urban areas, particularly middle-class and big cities, can be attributed to the implementation of industrial policies. As a result, a significant portion of the population is relocating to these urban areas. Consequently, urban areas want a substantial quantity of infrastructure and edifices. The exponential growth in population will exert significant pressure on agricultural regions located in proximity to big and mid-sized urban centres. To address the issue of urbanisation, it is necessary to consider the implementation of medium or high-rise structures. Due to the anticipated scarcity of land, it will be imperative for middle-sized municipalities to expeditiously construct additional multi-story structures. The present urban centres are experiencing diverse forms of horizontal expansion, although the limited availability of land necessitates the adoption of vertical growth strategies. Preserving agricultural land for the purpose of food production holds significant importance. Consequently, the concept of multi-story constructions or high-rise buildings is conceived.

The population is experiencing rapid growth in contemporary society. Urban growth is significantly influenced by the presence of tall structures. The impact of wind loads on tall buildings is significant. The impact of wind on buildings and their coverings is characterised by the application of force over time. The movement of air both within and outside the building is commonly referred to as wind pressure. The fan may experience significant damage at the entry of wind due to its inherently unpredictable characteristics. Consequently, the process of designing structures and their surrounding areas entails the assessment of airflow patterns. While it is uncertain whether the construction code explicitly mandates the minimum wind speed threshold for the lifespan of a residential structure, it is worth noting that towering edifices possess inherent flexibility and can easily oscillate in the three orthogonal directions, namely the x, y, and z axes. These entities are responsible for the initiation of premature damage and exhibit significant levels of localised absorption. Contemporary high-rise constructions exhibit enhanced flexibility and heightened sensitivity to wind-induced vibrations in comparison to their predecessors, owing to the persistent utilisation of robust and weighty materials. Wind loads and wind-induced fields are widely accepted in the field. When considering the design of tall buildings, it is of utmost importance to consider the presence of strong wind conditions in the surrounding area. Tall structures exhibit the presence of torque as well as two wind components, namely the upwind and crosswind components.

The wind factor methodology enables a theoretical examination of the dynamic behaviour of tall buildings in response to changes in wind direction. In contrast, the analytical methodology encounters significant difficulty in accurately predicting the crosswind direction and torque response resulting from wind due to inherent technical limitations. Various models have been proposed to predict the occurrence of lateral wind and torsional moments, utilising data obtained from experimental wind conditions. However, it is worth noting that current empirical models possess certain limitations. In the wind-resistant construction process, structural engineers employ their design and technical expertise to ascertain the dimensions of individual building components. Subsequently, drawing upon the distinctive architectural blueprint, they proceed to determine the dynamic behaviour of towering structures. Boundary layer wind testing is essential for the determination of wind loads in buildings that are sensitive to wind. Due to the multitude of factors at play, accurate weather predictions for high-rise buildings assume paramount importance.

The objective of this study is to explore and analyse the dynamic wind load analysis of buildings, considering various factors and unique conditions. The investigation will employ suitable finite element modelling software for this objective. The objective of this study is to undertake a comparative analysis on the performance of reinforced concrete (RCC) structures at different heights (low, mid, and high-rise) when subjected to static and dynamic wind loading conditions.

II. WIND ANALYSIS FOR MULTI-STOREY BUILDINGS

The emergence of new generation models can be attributed to the progress made in contemporary materials and building methods, resulting in more flexibility, less damping, and diminished wear. There exists a substantial body of evidence indicating that these models exhibit sensitivity to the passage of wind. During the construction process, wind turbulence has the potential to induce vibrations in different structural components. The consideration of dynamic response is crucial in the design phase when there is an expectation of significant vibrations. Wind is generated by the flow of air from areas of high atmospheric pressure to regions of lower atmospheric pressure. Due to the Earth's rotation, wind frequently circulates about areas of high and low pressure, as opposed to moving directly from regions of high pressure to those of low pressure. This phenomenon is characterised by the deflection of air to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The Eiffel Tower is an architectural structure that exhibits remarkable resilience in the face of strong wind forces. When wind enters a structure, the side facing the wind, known as the windward side, encounters an increase in pressure, while the side opposite to the wind, referred to as the downwind side, receives a decrease in pressure. The occurrence of adverse side effects is contingent upon the structural composition of the building. The pressure exerted on the wall differs from that exerted on the surface, however it is not always uniform.

Therefore, it is imperative for a designer to possess a comprehensive understanding of the potential hazards associated with this transverse pressure. The magnitude of the pressure exerted on surfaces is determined by the square of the wind speed. Various factors influence wind load, including geographical location, elevation, exposure level, closeness to neighbouring structures, building height and size, prevailing wind direction and velocity, as well as the positive or negative pressure arising from architectural design components. The determination of the lateral loads acting on the facade takes into consideration each of these components.

Hence, there is a need for methodologies that enhance the ability of designers to accurately predict wind velocities with a higher level of confidence compared to previous assumptions. Engineers aim to ensure the satisfactory performance of structures exposed to wind throughout their expected lifespan by implementing safety regulations and providing technical assistance. The aerodynamic forces exerted on the model are aligned with the direction of airflow. Specifically, the drag force is directed downstream and acts in the same direction as the wind, while the lift force is oriented perpendicular to the wind's direction at the inlet. Extensive study has been conducted to investigate the climatic patterns of different models in response to the significant impact of storms on human casualties and property damage throughout many global locations, including India. Ventilation in buildings is commonly assessed and modelled based on the ventilation of buildings with similar geometry. An example of this can be observed in the Indian Standard IS875-Part3-2015, which outlines various industrial models along with rectangle, square, and cylindrical shapes. Conducting research within a wind tunnel is crucial for assessing the wind pressure exerted on structures that deviate from the prescribed geometries outlined in established regulations and standards.

A) The Impact of Wind on Stationary Structures:

When a structure is in a static state, the flow merely makes touch with the external surface of the structure. A "static" model refers to a structural design that exhibits a high degree of rigidity and minimal deformation when exposed to external forces, such as wind-induced stresses. The limited availability of energy to induce resonances in the spectrum of atmospheric turbulence can be attributed to the high frequencies of the lowest mode. The primary design load parameter of utmost importance is the maximum load that the object will sustain over its lifespan. The evaluation of manufacturing encompasses several critical areas, namely physical performance, body length measurement, loading time, and design assessment.

B) The Influence of Wind on Dynamic Structures:

Dynamic models incorporate supplementary interactions with the mobility of the model. The response of a structure to wind loads is of paramount importance in its design when the structure exhibits a significant level of flexibility. The comprehensive investigation of the response of small structures can be achieved by decomposing their dynamic behaviour into distinct vibration patterns, known as normal modes. These modes are defined based on specific criteria, enabling a full examination of the reaction. The initial three factors to consider are the structural model, sample size, stiffness, and damping. Utilise the following settings to provide the desired parameters.

III. WIND LOAD EVALUATION BY IS 875:

A) Static Wind Load Analysis

This method gives the force F in specified direction. This force is calculated as follows.

$$F = C_f \times A_e \times P_d$$

A_e is the frontal area

C_f is total wind load on building or structure

P_d is the force coefficient for the building

Wind pressure P_z at any height above mean ground level can be obtained by,

$$P_z = 0.6 \times V_z^2$$

V_z wind pressure at height z, in N/m^2

$$V_z = V_b \times k_1 \times k_2 \times k_3 \times k_4$$

V_b = Basic wind speed

k_1 = Risk coefficient factor

k_2 = Terrain or Height factor

k_3 = Topography factor

k_4 = Importance factor for cyclonic region.

The design wind pressure Pd can be obtained as,

$$P_d = P_z \times k_a \times k_d \times k_c$$

k_d = wind directionality factor

k_a = area averaging factor

k_c = combination factor

3.2. Dynamic Wind Load Analysis (Gust Factor Method)

a) Along the Wind Response

With the help of this, you can determine the impact of windward loads on the floors of the building or structure. The level and overall height h of the building both affect the wind coefficient.

$$F_x = C_{fz} \times A_z \times \bar{P}_d \times G$$

F_x = design peak along wind load

G = Gust Factor

C_{fz} = drag force coefficient

A_z = Effective frontal area of building

$\bar{P}_d$ = design hourly mean wind pressure

$$\bar{P}_d = 0.6 \times \bar{V}_{z,d}^2$$

Design hourly mean wind speed at height z

$$\bar{V}_{z,d} = \bar{V}_z \times k_1 \times \bar{k}_{2,i} \times k_3 \times k_4$$

$\bar{k}_{2,i}$ =hourly mean wind speed factor for ith category terrain

$$\bar{k}_{2,i} = 0.1423 \left[in \left(\frac{Z}{Z_{0,i}} \right) \right] \left(Z_{0,i} \right)^{0.0706}$$

Z = height above ground

$Z_{0,i}$ = Aerodynamic roughness height

Gust factor and is given by,

$$G = \sqrt{\left[g_v^2 B_s (1+\varphi)^2 + \frac{H_s g_R^2 S E}{\beta} \right]}$$

Where;

Background factor

$$B_s = \frac{1}{\left[1 + \frac{\sqrt{0.26(h-s)^2 + 0.46 b_{ph}^2}}{L_h} \right]}$$

$$L_h = 85 \left(\frac{h}{10} \right)^{0.25}$$

$$\varphi = \frac{g_v I_{v,i} \sqrt{B_s}}{2}$$

Height factor for resonance response

$$H_s = 1 + \left(\frac{s}{h} \right)^2$$

$$S = \frac{1}{\left[1 + \frac{3.5 f_a h}{V_{h,d}} \right] \times \left[1 + \frac{4 f_a b_{o,h}}{\bar{V}_{h,d}} \right]}$$

Spectrum of turbulence in the approaching wind stream

$$E = \frac{\pi N}{\left(1+70.8N^2\right)^{5/6}}$$

$$N = \frac{f_a L_h}{\vec{V}_{h,d}}$$

Peak factor for resonant response

$$g_R = \sqrt{2\times In\left(3600\, f_a\right)}$$

Where;

r = roughness factor

g_v = peak factor for upwind velocity fluctuation,

= 3.0 for T.C. 1 and 2

= 4.0 for T.C. 3 and 4

ϕ = factor to account for the second order turbulence intensity

β = damping coefficient of the building/structure

B) Across the Wind Response

This section describes how to calculate the centre crosswind return time and air conditioning balance for rectangular-shaped tall structures. Lattice towers do not require solutions from solutions. It is important to identify the side wind direction that causes the top-to-bottom bending moment Mc of structures and towers:

$$F_{z,c} = \left(\frac{3M_c}{h^2}\right)\times\left(\frac{z}{h}\right)$$

$$M_c = 0.5 g_h p_h b h^2 (1.06-0.06k)\sqrt{\frac{\pi C_{fs}}{\beta}}$$

$$g_h = \sqrt{2\times In\left(3600\, f_a\right)}$$

Where;

$F_{z,c}$ = across wind load per unit height at height z

M_c = across wind design peak base bending moment

g_h = a peak factor

p_h = hourly mean wind pressure at height h

b = breadth of the structure normal to the wind

h = the height of the structure, in m

C_{fs} = Across wind force spectrum coefficient

β = damping coefficient of the building

z = mode shape power exponent

IV. 3D BUILDING SYSTEMS

To study the effect of the dynamic wind on high rise building, a building situated in Chennai region is considered. The basic wind speed for the region is 44 m/s as per IS875-Part3-2015 and all four terrain categories are considered. To perform dynamic wind analysis Gust Factor method is used as specified in code. The building falls in seismic zone III as per IS1893-Part1-2016 and medium or type B soil is considered. The plan area for the building is 1200 m2,1225 m2 and 1250 m2. The plan for rectangular building is 40m x 30m, 35m x 35m. two models that is 20 & 40 storied buildings are considered for analysis. The buildings are fixed at the base. The floor-to-floor height is kept constant and is taken as 3m. Shear wall are used in the interior core region of stairs and lifts and at exterior to control the lateral deflection of wind.

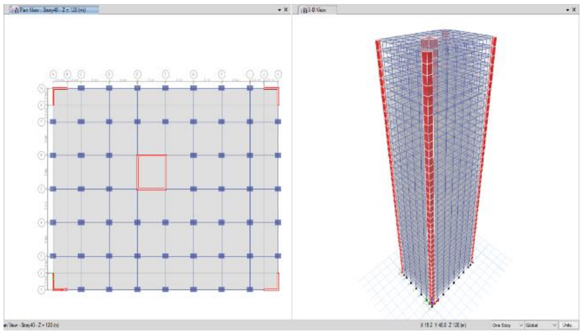


Fig. 1. Snip of rectangular frame building (Plan and 3D view) in ETAB Software

Table.1 Details of the different models

Model No	Floors	Height (m)	Plan Dimension (m)	Plan Area (m^2)	Aspect Ratio
1	G+20	60	40 x 30	1200	1.3
2	G+20	60	35 x 35	1250	1.0
3	G+40	120	40 x 30	1200	1.3
4	G+40	120	35 x 35	1250	1.0

The fundamental wind speed is recorded as 44 meters per second. Terrain Categories: Classifications I, II, III, and IV. The soil type is classified as Type II. The significance factor is assigned a value of 1, while the values for K1 and K3 are also set to 1. The seismic zone is classified as Zone III, with a corresponding seismic zone factor of 0.16. The soil type is categorized as Type II. The importance factor is assigned a value of 1, indicating a standard level of importance. The response reduction factor is determined to be 5.

The live load exerted on the floor is 2.0 kN/m^2, while the floor finish contributes an additional load of 1.0 kN/m^2. The internal wall load is measured to be 6.09

kN/m, whereas the external wall load is measured to be 9.34 kN/m.

Table 2. Member Sizes and Properties High Rise Structure

Model	No of stories	Beam size	Column size	Slab thickness	Shear wall thickness
1	G+20	300 x 750	1000 x 750	150	250
2	G+20	300 x 750	1000 x 750	150	250
3	G+40	400 x 750	1000 x 750	150	250
4	G+20	400 x 750	1000 x 750	150	250

Selection of terrain categories shall be made with due regard to the effect of obstructions which constitute the ground surface roughness. The terrain category used in the design of structure may vary depending on the direction of wind under consideration.

Category 1 – Exposed open terrain with rare or no obstructions and in which the average height of any object surrounding the structure is less than 1.5 m.

Category 2 – Open territory with well scattered obstructions having heights generally between 1.5 to 10 m.

Category 3 – Territory with several closely spaced obstructions having the size of building-structures up to 10 m in height with or without a few isolated tall structures.

Category 4 – Terrain with several large high closely spaced obstructions. This category includes large city centres, usually with obstructions above 25m and well-developed industrial complexes.

V. RESULTS AND DISCUSSION

This research investigated how static wind loads, dynamic wind loads, various building aspect ratios, and planned rectangular and square buildings on sloping ground responded to increasing building height. Also contrasted with changes in the parent list is the model's reaction. Calculating dynamic wind loads involves using the wind coefficient approach. ETABS was used to do the analysis. Use force layer, transform layer, and transform layer to finish. This section displays the outcomes of finite element modelling of tall structures subject to lateral loads.

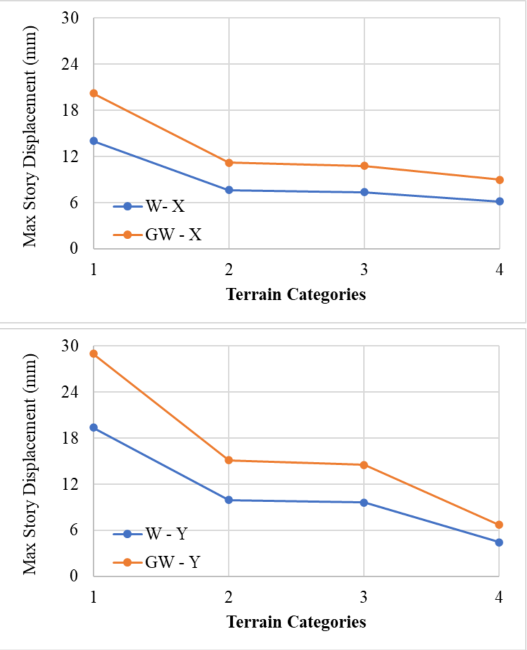
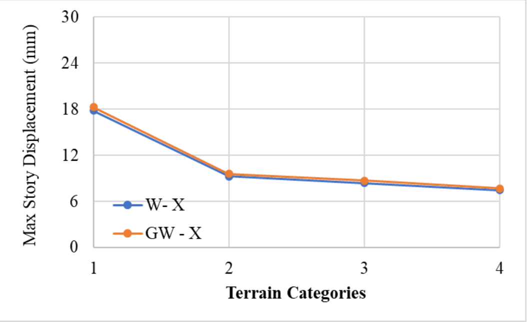


Fig. 2. Story displacement of G+20 (Model-1)

The figure 5.1 illustrates the displacement outcomes of Model 1, a G+20 story building, using static and dynamic analyses conducted on both the X and Y axes. The displacements are measured for various terrain classifications, and both static and dynamic analyses indicate a range of 30% to 40% displacement. The provided graph illustrates the displacement outcomes of Model 2, a G+20 story building, using static and dynamic analyses conducted on both the X and Y axes. The displacements are categorised based on different terrain conditions, and the results indicate a range of 10% to 15% displacement. The provided graph illustrates the displacement outcomes for the G+40 Story building's Model 3, considering static and dynamic analyses for both the X and Y axes. The displacements are measured for various terrain categories, and the results indicate a range of 40% to 45% variation in displacement values



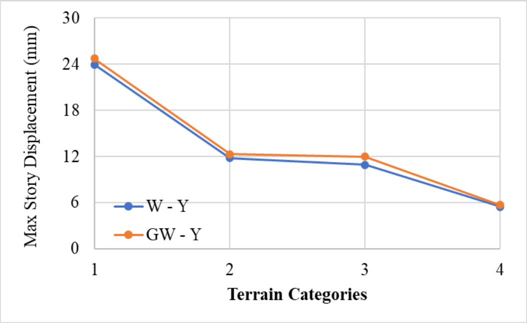


Fig. 3. Story displacement of G+20 (Model-2)

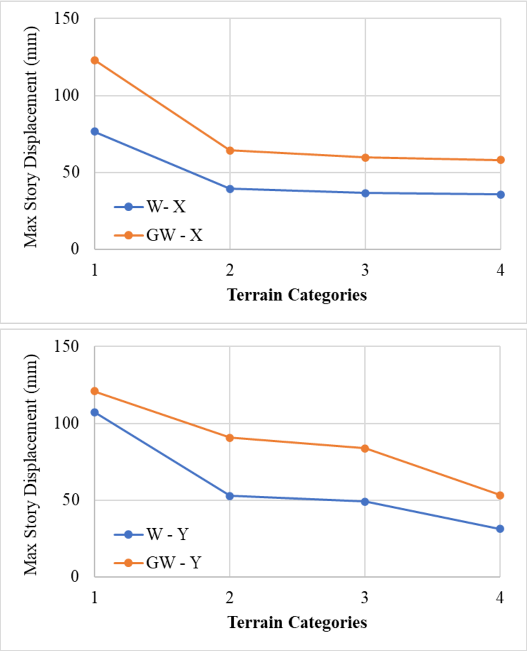


Fig. 4. Story displacement of G+40 (Model-3)

The provided graph illustrates the outcomes of Story Displacement analysis conducted on Model 4 of a G+40 Story building. The analysis was performed for both the X and Y axes, considering various terrain classifications. The results encompassed both static and dynamic analysis, with a variation ranging from 30% to 40%. As the aspect ratio and story height grow, the resulting displacement outcomes are likewise expected to vary, specifically in terms of an increase, contingent upon the terrain type. In the first terrain type, the wind force is higher, thereby leading to greater displacement outcomes. The graph illustrates a positive correlation between wind force and the decline in terrain category.

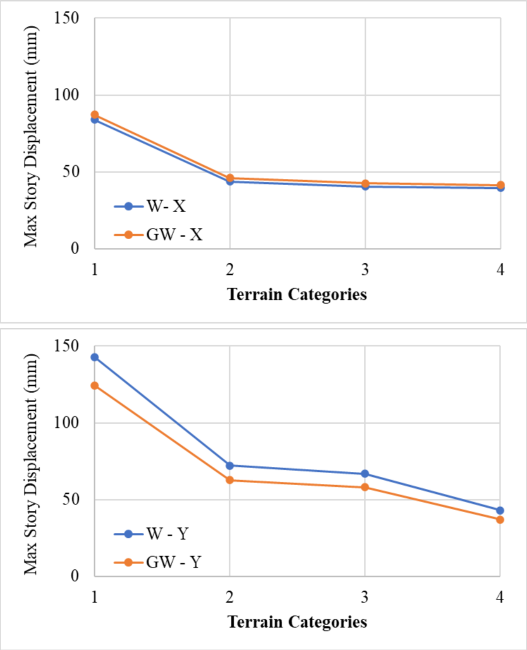


Fig. 5. Story displacement of G+40 (Model-4)

VI. CONCLUSIONS

1. The dominating load operating on tall buildings is the dynamic wind load in the along-wind direction, surpassing all other forces.
2. The dominance of static equivalent wind load is observed in low rise and mid-rise buildings, but its significance decreases as the height of the building increases.
3. The rate at which the story displacements rise with changes in terrain category for dynamic wind loads (along) is greater than that for static wind loads.
4. As the aspect ratio increases, there is a corresponding increase in both displacement and story drift values.
5. As the terrain category increases, there is a significant reduction in the values of tale drift and displacement.
6. In accordance with the codal provisions, it is necessary to consider the impact of gust wind on high rise and midrise buildings since it exhibits diverse variations in its behaviour.

REFERENCE

[1] Anupam Rajmani, Priyabrata Guha (2015), “Analysis of Wind & Earthquake Load for

Different Shapes of High-Rise Building", International Journal of Civil Engineering and Technology, Volume 6, Issue 2, pp. 38-45.

[2] Aslam Hussain, Rajiv Gandhi (2014), "Wind Analysis of Building Frames on Sloping Ground", International Journal of Science and Research Publications, volume 4, issue 5.

[3] B. Shobha, H. Sudarsana Rao, Vaishali G. Ghorpade (2018). "Effect of Wind Load on Low, Medium, High Rise Buildings in Different Terrain Category", International Journal of Technical Innovation in Modern Engineering & Science, Volume 4, Issue 02.

[4] Fabio Minciarelli, Massimiliano Gioffre, Mircea Grigoriu, Emil Simiu, (2001), "Estimates of extreme wind effects and wind load factors: influence of knowledge uncertainties", Elsevier Engineering Structures.

[5] H. Valer, L. Costin, Mircea Degeratu (2006), "Numerical and Experimental Investigation of Wind Induced Pressures on a Tall Building in Bucharest", The 13th International Conference on Fluid Flow Technologies Budapest, Hungary, September 6-9, 2006.

[6] I Srikanth, Vamsi Krishna (2014). "Study on the Effect of Gust Loads on Tall Buildings", International Journal of Structural and Civil Engineering Research, vol. 3, no. 3.

[7] Krushna Kishor Shahane, L. G. Kalurkar (2020), "Response of Multistorey Structure with and Without of Expansion Gap for Wind Loading and Dynamic Analysis", International Journal of Engineering Research & Technology, ISSN: 2278-0181, Vol. 9, Issue 07.

[8] Lin-lin Zhangb, Jie Lia, Yongbo Pengb (2008), "Dynamic response and reliability analysis of tall buildings subject to wind loading", Elsevier, Journal of Wind Engineering, and Industrial Aerodynamics 96 (2008) 25–40

[9] Megha Kalra, Purnima Bajpai, Dilpreet Singh (2011), "Effect of Wind on Multi Storey Buildings of Different Shapes", Indian Journal of Science and Technology, Vol 9(48).

[10] Oguz Uzol, Ozgur Kurc (2012), "Estimation of Wind Loads on Tall Buildings through Wind Tunnel Testing", Structural and Earthquake Engineering Laboratory, Department of Civil Engineering, METU, Ankara, Conference Paper.

[11] Sarita Singla, Taranjeet Kaur, Megha Kalra, Sanket Sharma, (2012) "Behaviour of R.C.C. Tall Buildings Having Different Shapes Subjected to Wind Load", Proc. of Int. Conf. on Advances in Civil Engineering 2012, DOI: 02. AETACE 3.17

[12] Seungho Lee, Sooyong Kim, Soon-Duck Kwon (2020), "A Comparative Study of Wind Tunnel Tests and Design Codes in Evaluation of Along Wind Effects on Towers", Hindawi research journals & papers, Volume 2021, Article ID 8818057.

[13] Shaikh Muffassir, L.G. Kalurkar (2016), "Comparative Study on Wind Analysis of Multi-story RCC and Composite Structure for Different Plan Configuration", IOSR Journal of Mechanical and Civil Engineering, ISSN: 2320-334X, Volume 13, Issue 4.

[14] Shivendra Nath Mishra, M.C. Paliwal, (2019) "Wind Load Analysis for Different Configuration of Structures", p-ISSN: 2395-0072, Volume: 06 Issue: 11.

[15] Tharaka Gunawardena, Shiromal Fernando, Priyan Mendis, Bhathiya Waduge, Dilina Hettiarachchi (2017), "Wind Analysis and Design of Tall Buildings, the State of the Art", 8th International Conference on Structural Engineering and Construction Management, 2017.

[16] Yi Liu, Gregory A. Kopp, Shui-fu Chen (2019), "Effects of plan dimensions on gust wind loads for high-rise buildings", Elsevier, Journal of Wind Engineering & Industrial Aerodynamics 194 (2019) 103980