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DESIRABLE SHAPES OF BUILDING TO RESIST WIND LOAD IN CYCLONIC REGION

Ms. Tanmayee V. Dixit[*1], **Dr. V.S. Rajamanya**[*2]

[*1]Student, M.B.E.S. College Of Engineering, Ambajogai, India.

[*2]Professor, M.B.E.S. College Of Engineering, Ambajogai, India.

ABSTRACT

The study explores the resilience of various building shapes—square, rectangular, C-shape, T-shape, L-shape, and hollow rectangular—against wind loads in cyclonic regions. Using IS 875 (Part 3)-1987, wind load calculations were performed and applied to software models for analysis. The research aims to determine the most structurally stable shapes by evaluating parameters such as displacement, storey drift, base shear, time period, and frequency. Results indicate that square-shaped buildings exhibit the lowest displacements and storey drifts in both X and Y directions, outperforming other shapes. Specifically, the square shape shows a 21.88% reduction in X-direction displacement compared to rectangular shapes, and a 15.60% reduction in Y-direction displacement. Additionally, square buildings demonstrate a lower time period and higher base shear, indicating superior stability. The findings suggest that while square shapes provide the best overall wind load resistance, non-rectangular shapes like C and T shapes also offer significant performance improvements. This study underscores the importance of selecting appropriate building shapes in cyclone-prone areas to enhance structural integrity and occupant safety.

Keywords: Wind Load Resistance, Cyclonic Regions, Building Shapes, Structural Stability, Displacement, Storey Drift.

I. INTRODUCTION

In this study, the focus lies on designing buildings capable of withstanding wind loads in cyclonic regions. Cyclones pose significant threats to infrastructure, necessitating careful consideration of architectural and engineering factors to mitigate potential damage. Various architectural strategies and structural considerations are explored to enhance a building's resilience to cyclonic winds. Through a comprehensive analysis of desirable building shapes, including form, roof design, and structural connections, insights into effective design practices are provided. Understanding the principles behind wind-resistant architecture empowers architects and engineers to implement measures to safeguard buildings and their occupants against cyclonic forces. This study aims to contribute valuable knowledge to the field of architectural design in cyclonic regions, fostering the creation of safer and more resilient built environments. By studying the characteristics of cyclonic winds and their effects on buildings, designers can develop innovative solutions that prioritize safety and structural integrity. Different building shapes offer varying levels of resistance to wind loads, with some forms proving more effective in deflecting and dissipating wind forces than others. Through this research, aim to identify the most desirable building shapes that can withstand cyclonic winds while minimizing the risk of structural failure. By incorporating these findings into architectural practices and building codes, we can enhance the resilience of structures in cyclonic regions, ultimately reducing the potential for damage and loss of life during extreme weather events. Additionally, this study underscores the importance of interdisciplinary collaboration between architects, engineers, meteorologists, and policymakers to develop holistic approaches to cyclone-resistant building design.

1.2 Structure of wind

Wind is randomly varying dynamic phenomenon and a trace of velocity verses time for wind will be typically as shown in figure 1.1. The wind velocity V can be seen as a mean plus a fluctuating component responsible for creating 'gustiness. Within the earth's boundary layer, both components not only vary with height, but also depend upon the approach terrain and topography, as seen from figure 1.2. While dealing with rigid structures, the consideration of the equivalent static' wind is adequate. However, in dealing with wind-sensitive flexible structures, the consideration of wind-energy spectrum, integral length scale, averaging time and the frequencies of the structure become important. The determination of wind velocity for a certain geographical location is essentially a matter of statistical reduction of a given measured data. On this depend the various wind zones. Another important decision involved is the averaging time is concerned, it may be anywhere from 2-3 seconds to 10 minutes to an hour. The influence of averaging time on velocity is seen in figure 1.3

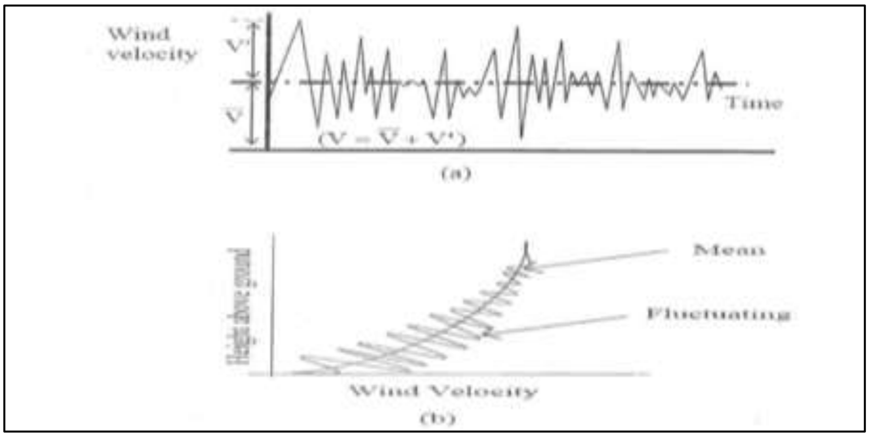


Fig 1: Variation of wind velocity with (a) Time (b) Height

1.2.1 Influence of terrain and topography

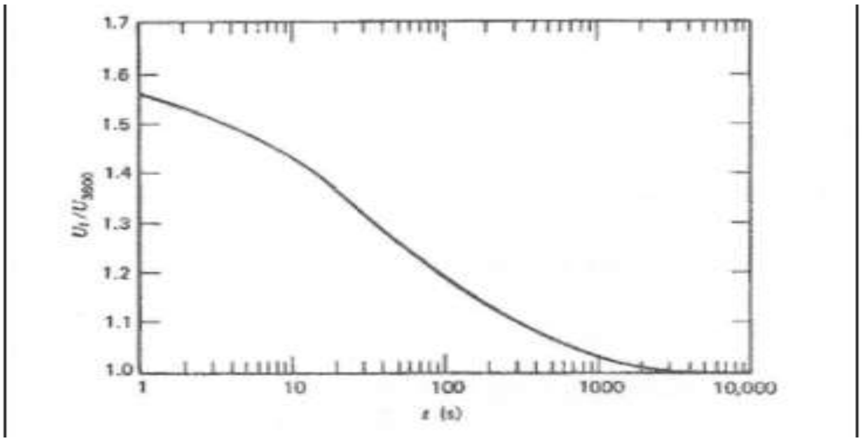


Fig 2: Ratio of probable maximum speed averaged over period 't' to that averaged over one hour

1.3 Effects of wind on structures

A typical wind force operates on a structure. This mean wind force is calculated using the mean wind speed and the fluctuating wind force generated by the fluctuating flow field. The influence of a fluctuating wind force on a building or part of a structure relies not only on the characteristics of the fluctuating wind force, but also on the size and vibration characteristics of the building or portion of the building. To estimate the design wind load, it is required to assess the features of varying wind forces and the building's dynamic properties. For the majority of structures, the influence of varying wind force caused by wind turbulence predominates. In this situation, along-wind horizontal wind strain on structural frames is crucial. However, horizontal wind loads on structural frames in the crosswise wind and torsional directions should not be disregarded for moderately flexible structures with a high aspect ratio. The separation of flow in non-bluff, sharp-edged bodies is well-defined, and the size of the building parallel to the flow influences the reattachment of the split flow and, therefore, the suction forces on the leeward side. Suction pressures may rise for thin bodies and decrease for thick bodies due to turbulence. Buildings and other civil engineering structures are three-dimensional entities with a wide range of geometries and complicated flow patterns, resulting in diverse pressure distributions. In addition to the geometry of conventional buildings, topographical factors and other nearby structures also contribute to the complexity of wind flow.

1.3.1 Wind sensitive structures

Tall and slender buildings are elastic and display a dynamic wind response. Tall structures vibrate in the wind owing to the turbulence inherent to the wind as well as the turbulence caused by the structure itself as a result of flow separation. Thus, there is a mean and variable wind response. The dynamic forces operate not only in the direction of wind flow, but also in a direction almost perpendicular to it, causing tall buildings to display an across wind response.

II. LITERATURE REVIEW

Kiran Kumar.J et.al (2018) emphasize the pivotal role of buildings amidst burgeoning populations, where preferences for personal space propel demand for constructions. As available land diminishes, tall buildings become essential, optimizing occupancy within minimal space. However, tall structures face challenges, particularly against wind and seismic activities. The study underscores the importance of building shapes, favoring non-angular configurations for superior wind resistance. Shapes resembling circles, such as octagons and hexagons, exhibit commendable performance. This research delves into architectural intricacies, mitigating structural vulnerabilities while accommodating urban population growth. **Shreyas Ashok Keote et.al (2015)** tackle significant challenges posed by tropical cyclones in India, proposing mitigation strategies for coastal areas. Acknowledging inevitable natural disasters, the paper stresses adapting construction practices to minimize impact. It recommends resilient building requirements to withstand cyclonic forces and explores techniques for reducing cyclone intensity. The study critiques existing design provisions, advocating for enhanced cyclone resilience through improved planning and development standards. Specific protective techniques for structural elements are discussed, supported by illustrative figures. This comprehensive approach aims to minimize cyclone devastation in coastal regions. **J.D. Holmes et.al (2010)** offer rational approaches for designing structures in regions prone to tropical cyclones. Examining windstorm event characteristics, the paper scrutinizes structural safety and reliability principles in extreme wind environments. The authors propose variations of wind speed with return period, highlighting uncertainties, particularly in high-wind regions crucial for structural design. Recent data insights offer valuable but limited information. The paper underscores that in cyclone-prone regions, primary uncertainties lie in wind speed, influencing structural safety and reliability. This highlights the need for robust design strategies to mitigate cyclonic impacts effectively.

S. Fawzia, A. Nasir et.al (2011) address the global necessity for taller structures, despite challenges like material costs and timelines. Focusing on high-rise construction complexities, the study explores deflection minimization and frequency control, crucial for cyclonic wind impacts. Findings emphasize plan dimensions' role in structural rigidity, with taller buildings exhibiting reduced lateral stiffness. The research underscores the necessity for additional bracing systems like belt trusses and outriggers to meet serviceability limits. This study provides tailored strategies for varying building heights, enhancing stability and minimizing deflections in high-rise constructions. **Naveen Suthar et.al (2021)** present a comparative analysis of wind loads in high-rise construction using two Indian standards. The study underscores the imperative of cost-effective designs prioritizing safety. Highlighting vulnerability to high wind speeds, particularly in coastal areas, the research reveals significant differences between old and new building codes. The new code demonstrates higher safety levels and cost-effectiveness. Lateral deflection remains within permissible limits, affirming structural integrity. This study contributes valuable insights, emphasizing the importance of adhering to updated building codes for enhanced safety and efficiency. **Sachin Jadhav et.al (2024) evaluate wind load responses of tall structures, focusing on story drift, shear, and support** responses across varying building heights and terrain categories. Findings indicate differing impacts on low, medium, and high-rise buildings, influenced by terrain types. The study underscores the importance of considering terrain in wind load responses to ensure structural serviceability and occupant comfort. By assessing wind-induced oscillations' effects, the research highlights the need for tailored design considerations based on terrain characteristics. **Megha Kalra et.al (2016)** analyze wind load effects on various building shapes to identify the most structurally stable shape for multi-storey structures. Using rigorous calculations and software analysis, the study evaluates stability across different shapes and heights. Plus and Non-uniform shapes emerge as the most stable, while L-shape and U-shape exhibit lower stability. This research underscores the significance of building shape in wind load resistance, providing valuable insights for designing tall structures amidst population growth and land scarcity.

Barkha Verma et.al (2022) conducted a study on the impact of wind forces on tall buildings with varying horizontal aspect ratios, crucial for addressing land shortages in developing countries like India. Analyzing building models with different aspect ratios, the research compared wind effects on regular and irregular structures. Findings revealed variations in base shear, with square buildings exhibiting the lowest and rectangular buildings the highest shear. This study underscores the importance of aspect ratio in wind load distribution and its implications for tall building design, particularly in regions facing land constraints. **Shreyas A. Keote et.al (2015)** address the severe threat posed by tropical cyclones to India, emphasizing mitigation strategies for coastal areas. Acknowledging the inevitability of these disasters, the paper stresses adapting construction practices to minimize impact. It recommends resilient building requirements and explores techniques for reducing cyclone intensity. Critiquing existing provisions, the study advocates for enhanced cyclone resilience through improved planning and development standards. Specific protective techniques for structural elements are discussed, aiming to minimize cyclone devastation in coastal regions. **Nourhan Abdelfatah et.al (2020)** investigates the aerodynamics of elevated structures in coastal areas to mitigate flooding hazards. Assessing wind pressure on large-scale models of elevated houses, the study identifies variations in pressure coefficients with stilt height. Two-story models exhibit lower pressure coefficients than one-story models, with high negative coefficients at lower wall zones. Computational analyses corroborate wind testing results, highlighting flow separation at elevated house floors. This research provides insights into wind effects on elevated structures, essential for mitigating flooding risks in coastal regions. **Anupam Rajmani et.al (2015)** explore tall building stability under wind and earthquake loads, emphasizing early integration of aerodynamic shaping and structural system selection in architectural design. Analyzing four building shapes, the study identifies performance variations under different loads. Circular shapes are stable under earthquake loads, while rectangular shapes perform best under wind loads. Triangular shapes exhibit the least stability, emphasizing design considerations for wind and earthquake resilience in tall buildings. This research underscores the importance of holistic design approaches to mitigate wind-induced and earthquake-induced responses in modern tall structures.

III. METHODOLOGY

3.1 Introduction

At the starting of any project some preliminary study is required. These preliminary studies are required to know the exact behavior of the structure, to know the property of the structure and various load conditions of the structure. Analyzing the small structure concern to respective project study does these types of studies.In this reserch software modeling, wind load calculations by static and dynamic methods for various shapes of buildings as per IS 875 (part 3)-1987 has been done. Then application to calculated wind loads to software models and analysis is studied.

Following is flowchart of work for Project: -

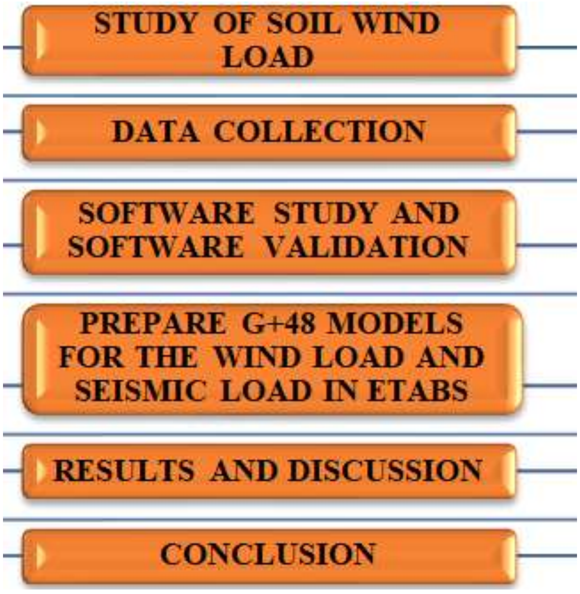


Fig 3: Flowchart.

3.2 Parameters considered for the study

A 50 storied building of different shapes- Square, Rectangular, Circular and Elliptical, having equal plan area and equal stiffness of the columns has been analyzed.

3.3 Design wind speed

Wind speed in the atmospheric boundary layer increases with height from at ground level to maximum at a height called the gradient height. The basic wind speed shall be modified to include risk level, terrain roughness, height of the structure and local topography to get the design wind velocity Vz and is given as:

Vz=Vz.k1.K2.K3 3.1

Where, Vz = Design wind speed in m/s at any height 'z' m

Vb = Basic wind speed for various zones K1 = Probability factor (risk coefficient) K2 = Terrain roughness and height factorK3 = Topography factor.

Risk coefficient (K1): suggested life period to be assumed and the corresponding K_1 factor for different class of structures as per IS: 875 (Part 3)

Terrain and height factor (K2): Selection of terrain categories shall be made with due regard to the effect of obstruction, which constitute the ground surface.

Topography Factor (k3): The effect of topography will be significant at a site when the upwind slope is greater than about 3, and below that, the value of k3 may be taken to be equal to 1.0. The value of k3 is confined in the range of 1.0 to 1.36 for slopes greater than 3º.

IV. MODELLING

Model 1: Square shape building used for linear analysis

Model 2: Rectangular shape building used for linear analysis

Model 3: C shape building used for linear analysis

Model 4: T shape building used for linear analysis

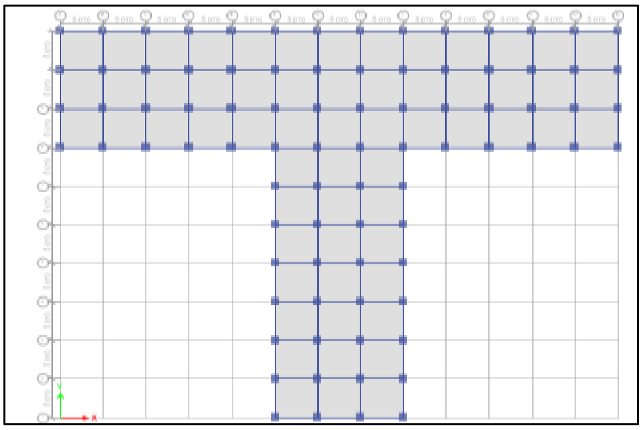


Fig 4: T shape plan view

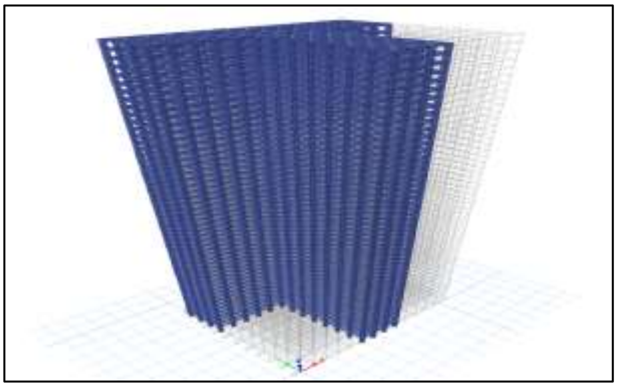


Fig 5: T shape rendered view

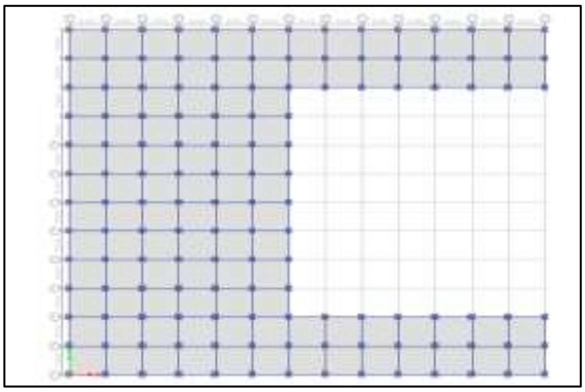


Fig 6: C shape plan view

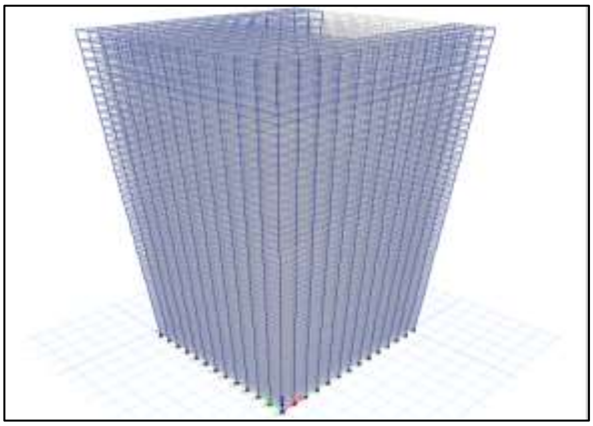


Fig 7: C shape 3D view

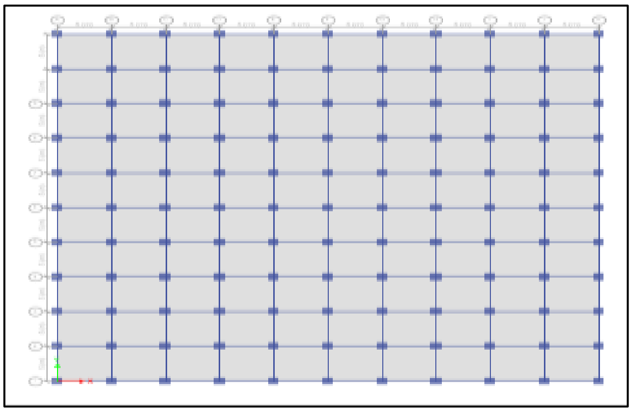


Fig 8: Square shape plan view

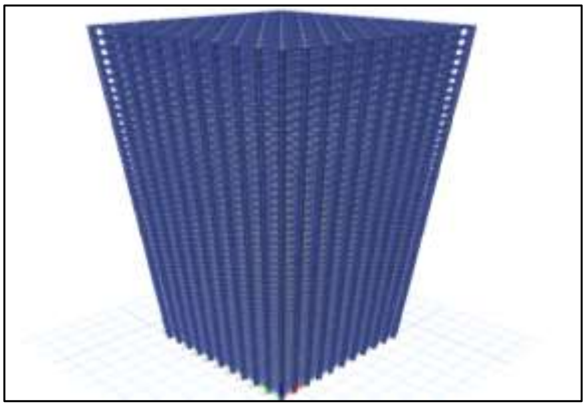


Fig 9: Square shape rendered view

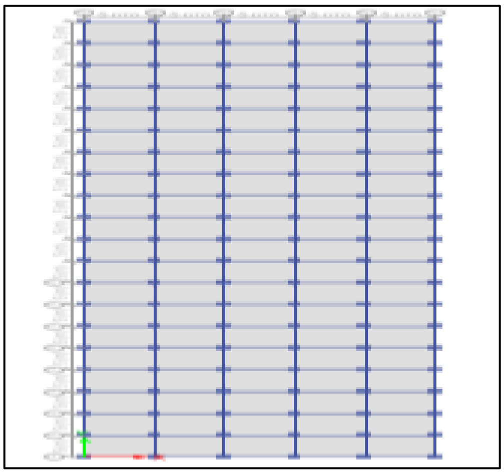


Fig 10: Rectangle shape plan view

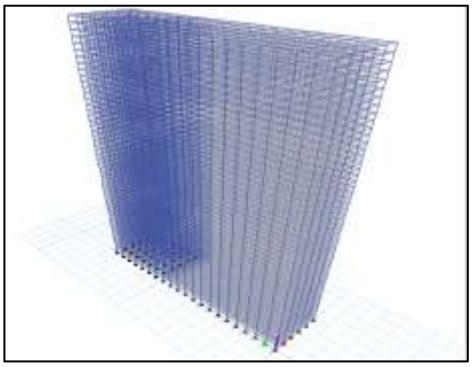


Fig 11: Rectangle shape rendered view

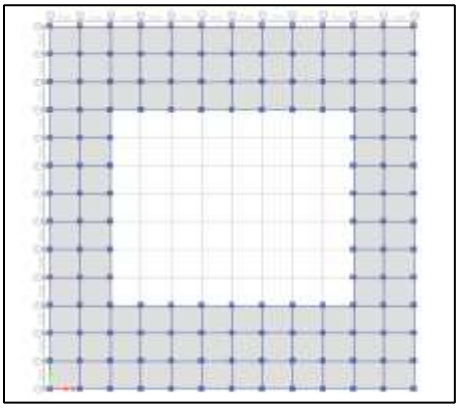


Fig 12: Hollow shape plan view

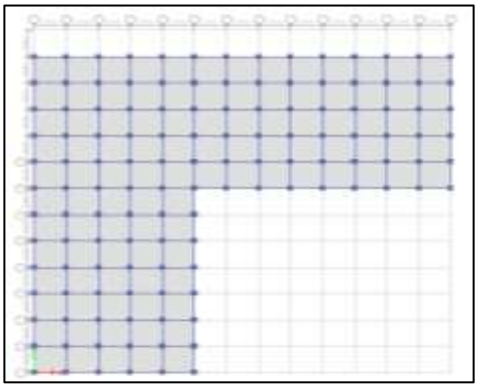


Fig 13: L shape plan view

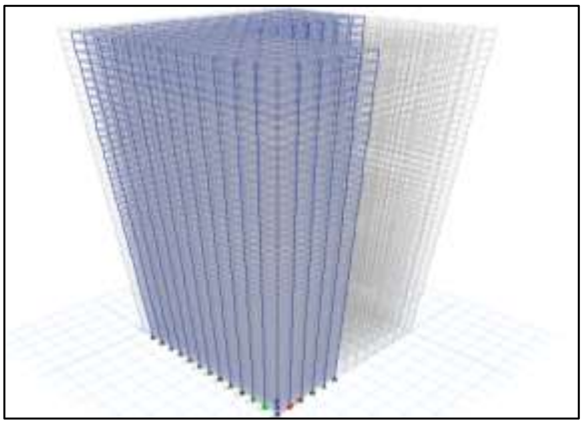


Fig 14: L shape 3D view

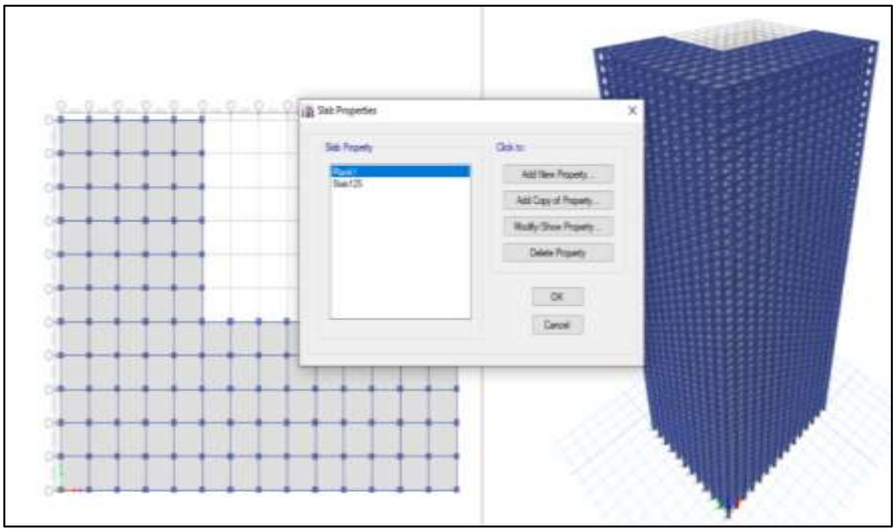
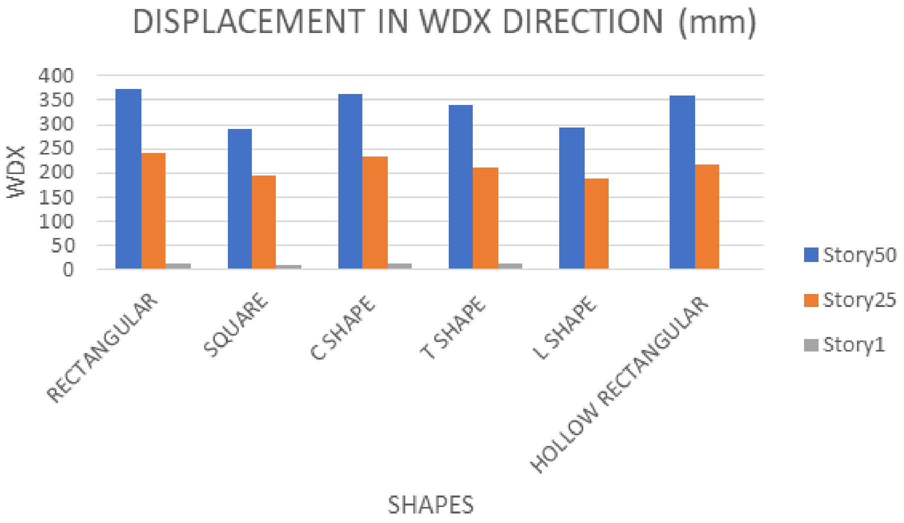


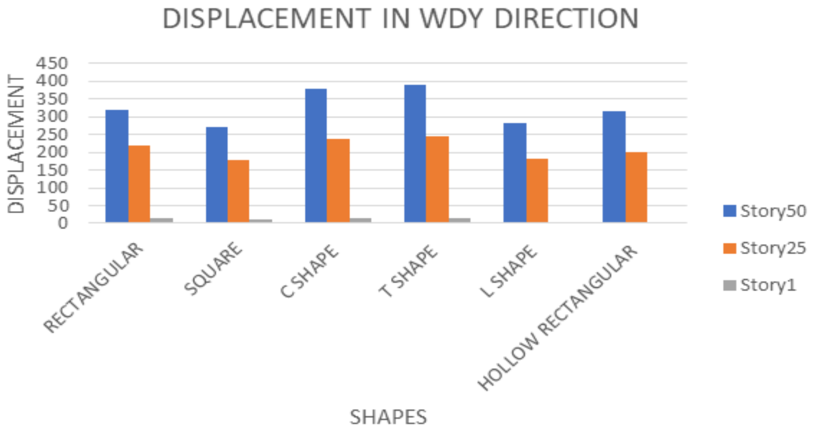
Fig 15: Defining slab sections

V. RESULTS & DISCUSSION



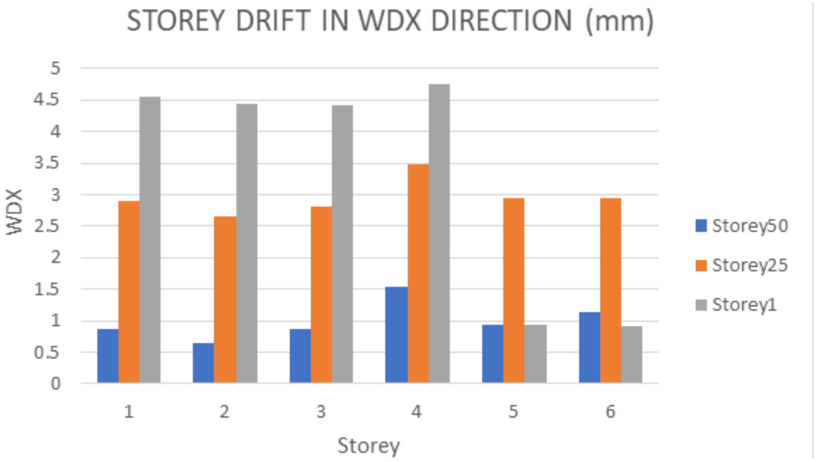
Graph 1: Displacement In X –Direction

The above graph shows displacement in X –direction for square ,Rectangular ,C shape,T shape ,L shape, hollow rectangular building. square shape building has lower displacement than the rectangular shape building by 21.88%, C shape 19.36 % building and T shape building by 14.23%. L shape by 0.95 %, hollow rectangular by 18.71 %.



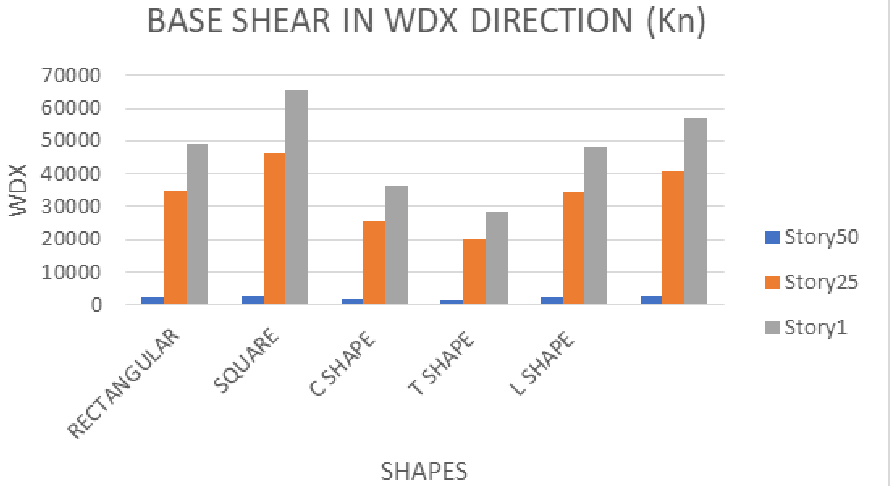
Graph 2: Displacement In Y –Direction

The above graph shows displacement in Y –direction for square ,Rectangular ,C shape,T shape ,L shape, hollow rectangular building. square shape building has lower defirmation than the rectangular shape building by 15.60 %, C shape 28.94 % building and T shape building by 31.11 %, ,L shape by 3.87 % , hollow rectangular by 14.16 %



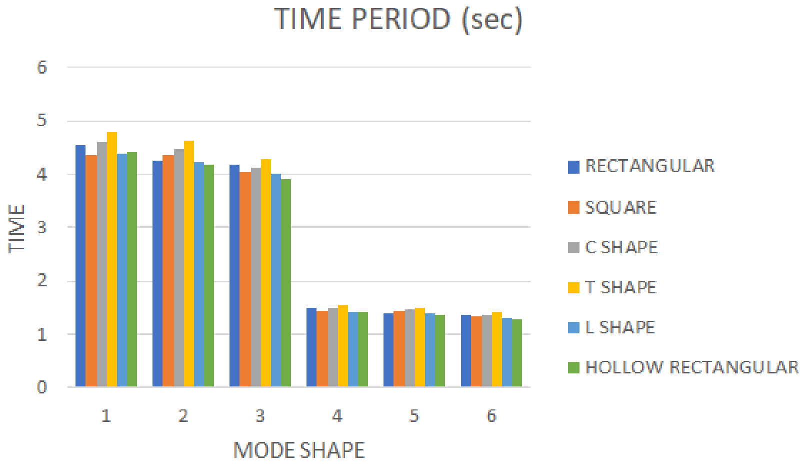
Graph 3: Storey Drift In X –Direction

The above graph shows storey drift in X –direction for square ,Rectangular ,C shape,T shape ,L shape, hollow rectangular building. square shape building has lower storey drift than the rectangular shape building by 25.83 %, C shape 25.14 % building and T shape building by 57.72 % L shape by 30.53 % , hollow rectangular 43.38 by %.



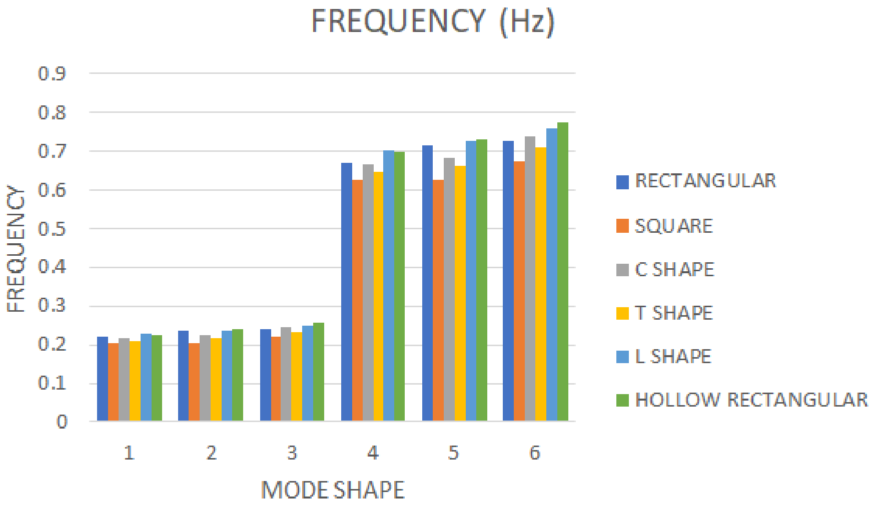
Graph 4: Base Shear In X –Direction

The above graph shows Base shear in X –direction for square ,Rectangular ,C shape,T shape, L shape, hollow rectangular building. square shape building has higher Base shear than the rectangular shape building by 23.80 %, C shape 44.26 % building and T shape building by 54.77 %, L shape by 17.78 % , hollow rectangular by 3.60 %.



Graph 5: Time Period

The above graph shows Time period in direction for square ,Rectangular ,C shape,T shape , L shape, hollow rectangular building. square shape building has lower Time period t than the rectangular shape building by 3.74 %, C shape 5.26 % building and T shape building by 8.85 % ,L shape by 0.41 % , hollow rectangular by 1.22 %.



Graph 6: Frequency

The above graph shows Frequency in direction for square ,Rectangular ,C shape,T shape, L shape, hollow rectangular building. square shape building has lower frequency t than the rectangular shape building by 6.31 %, C shape 5.02 % building and T shape building by 0.91% ,L shape by 9.60 % , hollow rectangular by 8.72 %.

VI. CONCLUSION

The research concludes that building shape significantly influences wind load resistance in cyclonic regions. Among the shapes analyzed, square buildings consistently exhibited the lowest displacements and storey drifts, both in X and Y directions, compared to other configurations. This highlights the superior stability of square shapes under wind loads. Additionally, the square shape demonstrated a lower time period and higher base shear, further validating its effectiveness in withstanding cyclonic forces. Non-rectangular shapes, such as C and T shapes, also showed commendable performance improvements, suggesting their potential suitability in specific design contexts. The study's findings advocate for the strategic selection of building shapes to enhance resilience against wind loads in cyclone-prone areas, emphasizing the square shape as the most desirable configuration. Future research could expand on these findings by incorporating dynamic wind load analyses and exploring the impact of varying building heights and materials. This study provides valuable insights for engineers and architects in designing wind-resistant structures, ultimately contributing to safer and more sustainable urban development in vulnerable regions.

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