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Evaluating the Impact of Wind Vibrations on Building Structures

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Abstract: In recent years, the rapid growth of urbanization and the increasing demand for vertical construction have led to the development of tall and complex building structures. These structures are highly sensitive to lateral loads, particularly wind loads, which significantly influence their stability, safety, and serviceability. Wind is a dynamic and fluctuating load that varies with height, terrain, and environmental conditions, making its analysis essential in the design of high-rise buildings. The present study focuses on evaluating the impact of wind vibrations on building structures with different configurations. In this research, a comparative analysis is carried out on rectangular (regular) and C-shaped (irregular) reinforced concrete buildings with varying heights of 16, 18, and 20 storeys. All models are developed and analyzed using ETABS 2016 software, which allows accurate modeling and simulation of structural behavior under wind loading conditions. The wind load is applied as per the provisions of IS 875 (Part 3): 2015, considering a basic wind speed of 47 m/s for the selected region. The study evaluates key structural response parameters such as time period, storey displacement, storey drift, storey shear, and base shear. The results indicate that the time period increases with building height, showing that taller structures are more flexible. It is also observed that C-shaped buildings exhibit higher time period, displacement, and drift, indicating lower stiffness and greater susceptibility to wind-induced vibrations. On the other hand, rectangular buildings show higher storey shear and base shear, demonstrating better load distribution and structural resistance. The comparative analysis highlights that building shape plays a significant role in wind response behavior. Irregular configurations such as C-shaped buildings experience uneven pressure distribution and higher lateral deformation, which may lead to serviceability issues such as excessive drift and discomfort to occupants. In contrast, regular buildings perform more efficiently under wind load due to their uniform geometry and stiffness.

Keywords: Wind Load, Wind Vibration, Tall Buildings, Storey Drift, Storey Displacement, Base Shear, ETABS, Structural Analysis, Irregular Buildings, IS 875 (Part 3).

I. INTRODUCTION

In the present era of rapid urbanization and continuous population growth, the demand for infrastructure development has increased tremendously. Cities are expanding at a fast pace, and due to the scarcity of land in urban areas, the concept of vertical construction has gained significant importance. As a result, multi-storey and tall buildings are being constructed extensively for residential, commercial, and industrial purposes. Buildings are fundamental structures that provide shelter and facilitate various human activities such as living, working, storage, and recreation. In earlier times, most buildings were low-rise structures constructed with heavy materials, and therefore, the effect of environmental loads like wind was not considered critical in design. However, with advancements in construction technology, modern buildings have become taller, lighter, and more flexible, making them more sensitive to lateral loads such as wind and earthquake forces. Among all environmental loads acting on a structure, wind load plays a very significant role in the design of tall buildings due to its dynamic and unpredictable nature. Unlike dead loads and live loads, which are static and relatively constant, wind load varies with time, direction, height, terrain conditions, and surrounding obstructions.

According to the referenced study, wind has two primary effects on buildings: firstly, it exerts external pressure and suction forces on the structural surfaces, and secondly, it influences the airflow patterns around the building, which affects both external and internal pressure distribution. These effects can lead to various structural responses such as bending, shear, torsion, and vibration. In extreme cases, wind can cause structural damage, failure of cladding elements, and discomfort to occupants due to excessive motion. As buildings increase in height, the impact of wind becomes more pronounced. The wind speed generally increases with height above ground level due to reduced surface friction, which results in higher wind forces acting on the upper portions of the building. Additionally, tall and slender structures tend to have lower stiffness and natural frequency, making them more susceptible to dynamic effects such as oscillations and resonance. Wind-induced vibrations can lead to serviceability issues such as excessive displacement, storey drift, and acceleration, which may not necessarily cause structural collapse but can significantly affect the comfort and safety of occupants. Therefore, it becomes essential to carefully evaluate and analyze wind effects during the design stage of tall buildings.

Another important aspect of wind behavior is its fluctuating nature. Wind does not act as a steady force; instead, it consists of a mean component and a fluctuating component known as gust. The gust component can cause sudden increases in wind pressure, leading to dynamic loading conditions. The response of a building to wind depends not only on the magnitude of wind speed but also on the frequency of fluctuations and the dynamic characteristics of the structure. This makes wind analysis more complex compared to other types of loading conditions. Engineers must consider both static and dynamic wind effects to ensure the safety and performance of structures. The shape and configuration of a building also play a crucial role in determining its response to wind loads. Regular-shaped buildings such as rectangular or square plans generally exhibit more uniform load distribution and better structural performance under wind loading. On the other hand, irregular-shaped buildings, such as L-shaped, T-shaped, or C-shaped structures, tend to experience uneven pressure distribution, increased torsional effects, and higher displacement and drift values. As highlighted in the study , the comparison between rectangular and C-shaped buildings shows that irregular shapes are more vulnerable to wind-induced vibrations due to their geometric complexity. This emphasizes the importance of considering building shape during the planning and design stages.

II. METHODOLOGY

Description of Building:

Table 3.1: Building Parameters

Sr. No.	Parameter	Value
1	Building Type	Residential
2	Plan Dimension	45 m × 80 m
3	Length in X-direction	45 m
4	Length in Y-direction	80 m
5	Bays in X-direction	9 (5 m each)
6	Bays in Y-direction	16 (5 m each)
7	Storey Height	3.3 m
8	Total Height	52.8 m, 59.4 m, 66 m
9	Slab Thickness	150 mm
10	Beam Size	350 mm × 400 mm
11	Column Size	450 mm × 600 mm
12	No. of Storeys	16, 18, 20

Loading Conditions:

Loading conditions are one of the most important aspects of structural analysis, as they represent the actual forces acting on the building during its service life. In the present study, all building models are analyzed under standard loading conditions as per Indian Standard codes. The loads considered include dead load, live load, and wind load, which are applied uniformly to all models to ensure a proper and fair comparison between different building configurations. The dead load consists of the self-weight of structural components such as slabs, beams, and columns, along with additional permanent loads such as floor finishing. In this study, the self-weight of the structure is automatically calculated by the ETABS software based on the defined material density of concrete (25 kN/m³). Additional dead loads such as floor finishing, including tiles and mortar screed, are considered as uniform distributed loads. These loads are taken as approximately 0.20 kN/m² for tiles and 0.21 kN/m² for screeding, as per standard practice. Dead loads remain constant throughout the life of the structure and are an essential component in design. The live load represents the movable or transient loads acting on the structure due to occupancy and usage. These loads vary depending on the type of building and its usage. In this study, the building is considered as a residential structure, and the live load is applied as per IS 875 (Part 2): 1987. The floor live load is taken as 3 kN/m², which is a standard value for residential and commercial buildings. The roof live load is considered as 1.5 kN/m², accounting for maintenance activities and occasional access. Live loads are applied uniformly across all floors to maintain consistency in analysis.

The loads are applied as per Indian Standard Codes:

1. IS 875 (Part 1): Dead Load
2. IS 875 (Part 2): Live Load
3. IS 875 (Part 3): Wind Load

Table 3.2: Load Details

Load Type	Description	Value
Dead Load	Self-weight + finishing	0.20 + 0.21 kN/m²
Floor Live Load	As per IS 875	3 kN/m²
Roof Live Load	As per IS 875	1.5 kN/m²
Wind Load	As per IS 875 (Part 3)	47 m/s

Wind Load Data:

Wind load data is one of the most important inputs in the analysis of tall buildings, as it directly governs the lateral forces acting on the structure. In the present study, wind load is calculated and applied as per the provisions of IS 875 (Part 3): 2015, which is the standard code used in India for determining wind forces on structures. The accuracy of wind analysis largely depends on the correct selection of wind parameters such as basic wind speed, terrain conditions, height factors, and topographical effects. The basic wind speed (Vb) considered in this study is 47 m/s, which corresponds to the selected geographical region (Lucknow) as per the wind speed map provided in IS 875 (Part 3). This value represents the peak gust wind speed averaged over a short duration at a standard height of 10 m above ground level in open terrain. It forms the base value for calculating the design wind speed at different heights of the building.

To determine the actual wind speed acting on the structure at a given height, modification factors are applied to the basic wind speed. These include:

1. Risk Factor (k_1): Accounts for the importance and design life of the structure.
2. Terrain and Height Factor (k_2): Considers the effect of terrain roughness and height above ground level.
3. Topography Factor (k_3): Accounts for the influence of hills, slopes, and surrounding topography.

The design wind speed (Vz) at any height is calculated using the standard equation:

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

Once the design wind speed is determined, the corresponding wind pressure (Pz) is calculated using the following expression:

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

This wind pressure acts on the exposed surfaces of the building and generates lateral forces that are distributed along the height of the structure.

The wind load is calculated as per IS 875 (Part 3): 2015 using the following parameters:
1. Wind Speed = 47 m/s
2. Wind Region = Lucknow
3. Terrain Category = As per code
4. Risk Factor (k1), Terrain Factor (k2), Topography Factor (k3)

3.7 Codal Provisions (Is 875 Part 3)
The wind load is calculated using the following formula:

$$V_z = V_b \cdot k_1 \cdot k_2 \cdot k_3$$

Where:
- Vz = Design wind speed
- Vb = Basic wind speed
- k1 = Risk factor
- k2 = Terrain factor
- k3 = Topography factor

Wind Pressure:

$$P_z = 0.6V_z^2$$

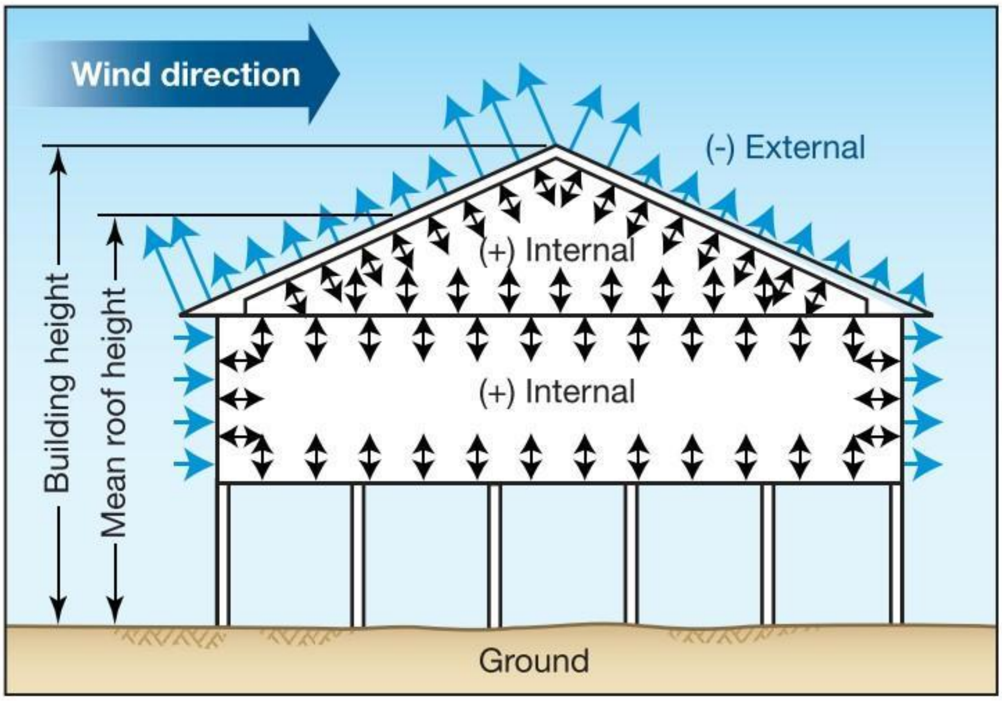

Fig 3.1: Wind Pressure Distribution on Building

Modelling of Building:
The modeling of the building is carried out using ETABS software.

The following steps are followed:
1. Define grid system
2. Define material properties
3. Define section properties
4. Create geometry of structure
5. Assign loads

6. Apply boundary conditions
7. Run analysis

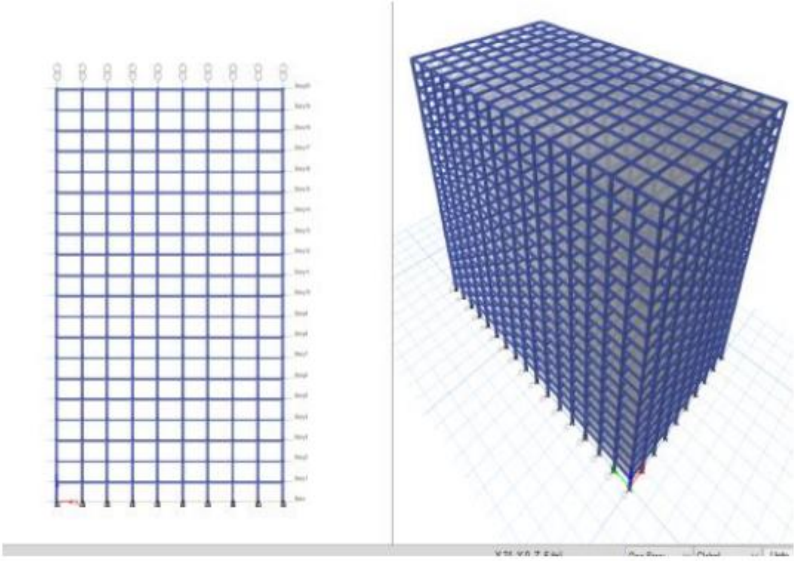

Figure 3.2: Rectangular Model (20 Storey)

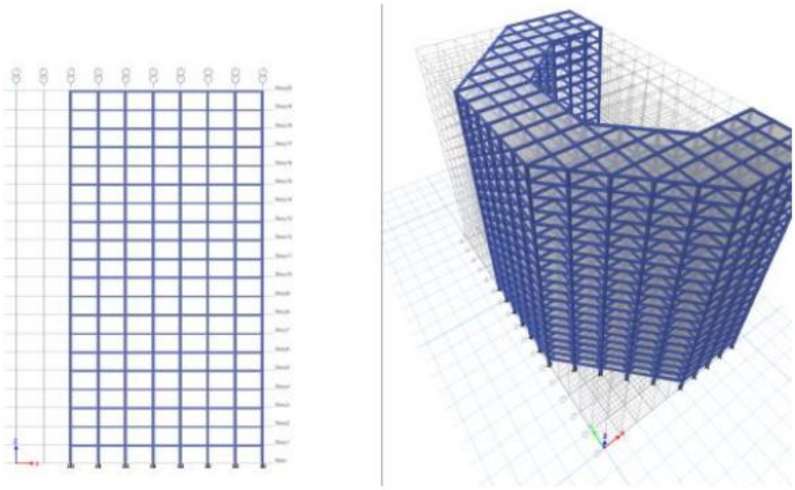

Figure 3.3: C Shape Model (20 Storey)

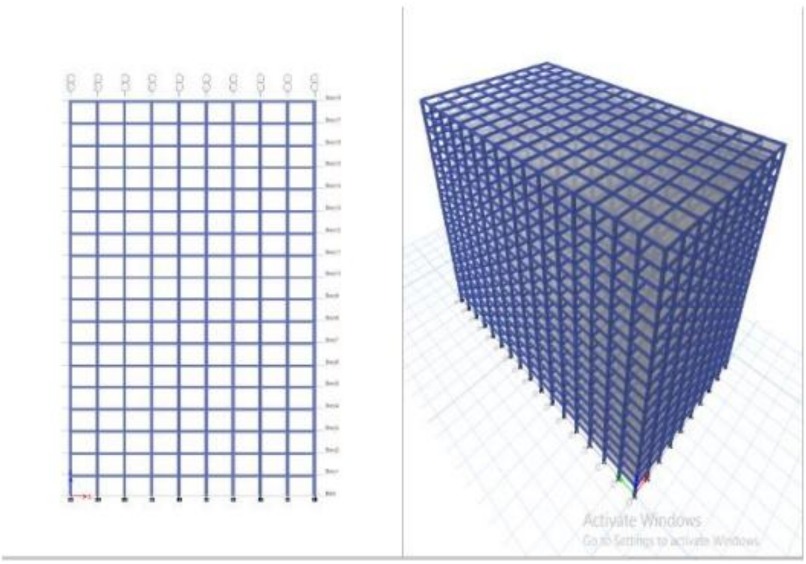

Figure 3.4: Rectangular Model (18 Storey)

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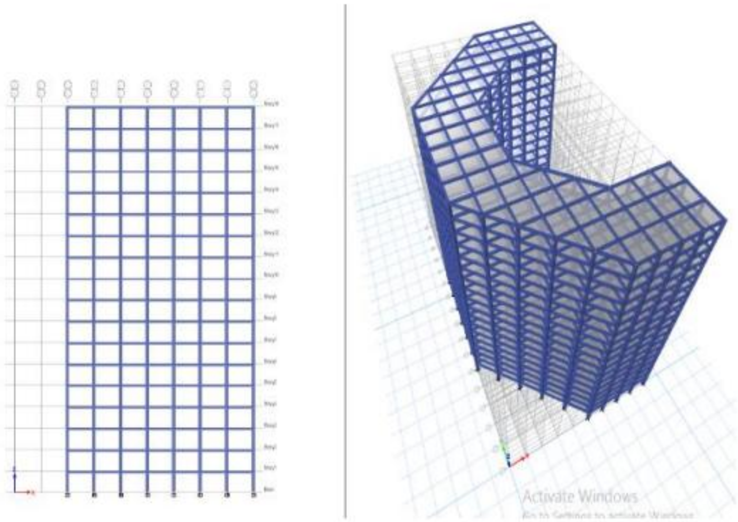


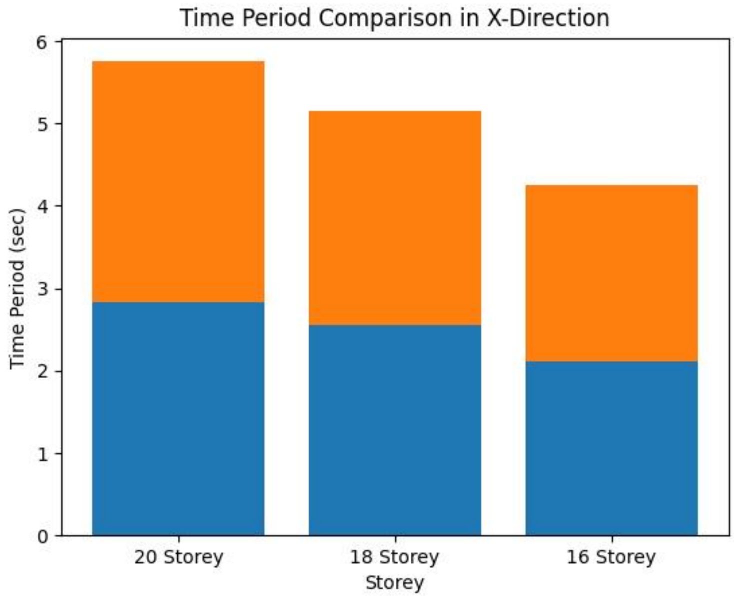
Figure 3.5: C shape Model (18 Storey)

III. RESULTS AND DISCUSSION

Time Period:
The time period represents the dynamic behavior of the structure and indicates its flexibility. Higher time period means more flexibility.

Table 4.1: Time Period in X-Direction (Sec)

Storey	Rectangular Shape (sec)	C Shape (sec)
20 Storey	2.837	2.915
18 Storey	2.547	2.601
16 Storey	2.115	2.141



Graph 4.1: Time Period Comparison

Discussion:

From the results, it is observed that:

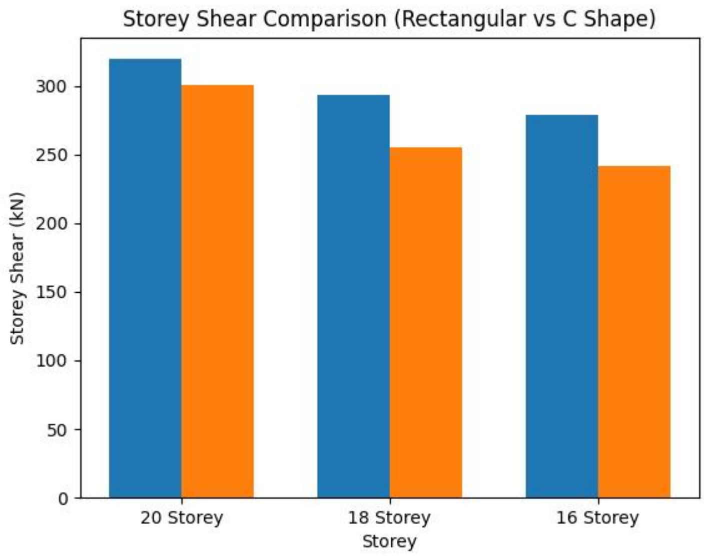
1. Time period increases with increase in building height
2. C-shaped buildings have slightly higher time period than rectangular buildings
3. This indicates that C-shaped buildings are more flexible

Storey Shear:

Storey shear represents the lateral force acting at each level due to wind load.

Table 4.2: Storey Shear (kN)

Storey	Rectangular Shape (kN)	C Shape (kN)
20 Storey	319.3398	300.1193
18 Storey	292.8265	255.5228
16 Storey	278.6192	241.861



Graph 4.2: Storey Shear Comparison

Discussion:

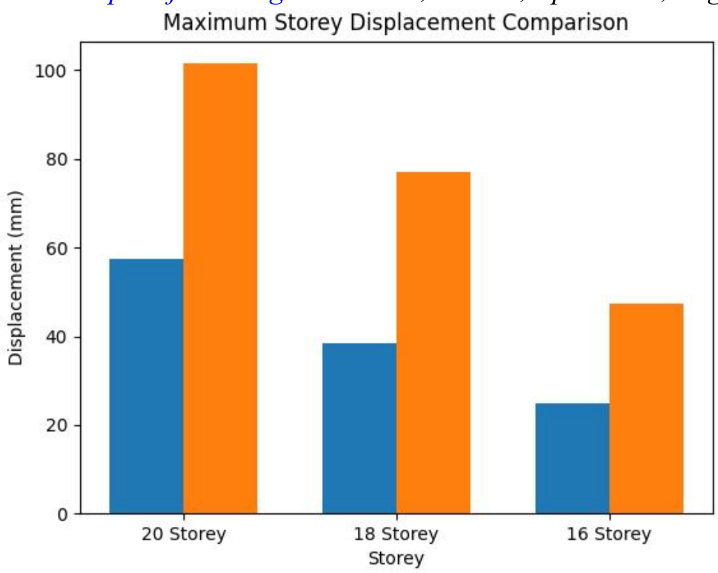
1. Storey shear increases with building height
2. Rectangular buildings show higher storey shear
3. C-shaped buildings have lower shear values
4. This indicates better load distribution in rectangular structures

Storey Displacement:

Storey displacement represents lateral movement of the building due to wind.

Table 4.3: Maximum Storey Displacement (mm)

Storey	Rectangular Shape (mm)	C Shape (mm)
20 Storey	57.451	101.52
18 Storey	38.545	77.12
16 Storey	24.943	47.371



Graph 4.3: Storey Displacement Comparison

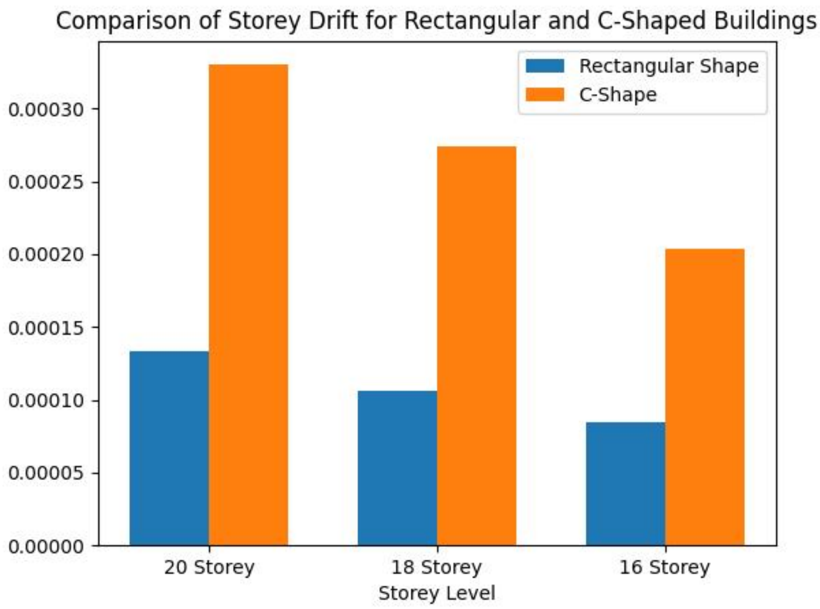
Discussion:
1. Displacement increases with height
2. C-shaped buildings show very high displacement
3. Nearly double displacement compared to rectangular
4. Indicates less stiffness in irregular structures

Storey Drift:

Storey drift is the relative displacement between floors.

Table 4.4: Storey Drift

Storey	Rectangular Shape	C Shape
20 Storey	0.000133	0.00033
18 Storey	0.000106	0.000274
16 Storey	0.000085	0.000204



Graph 4.4: Storey Drift Comparison

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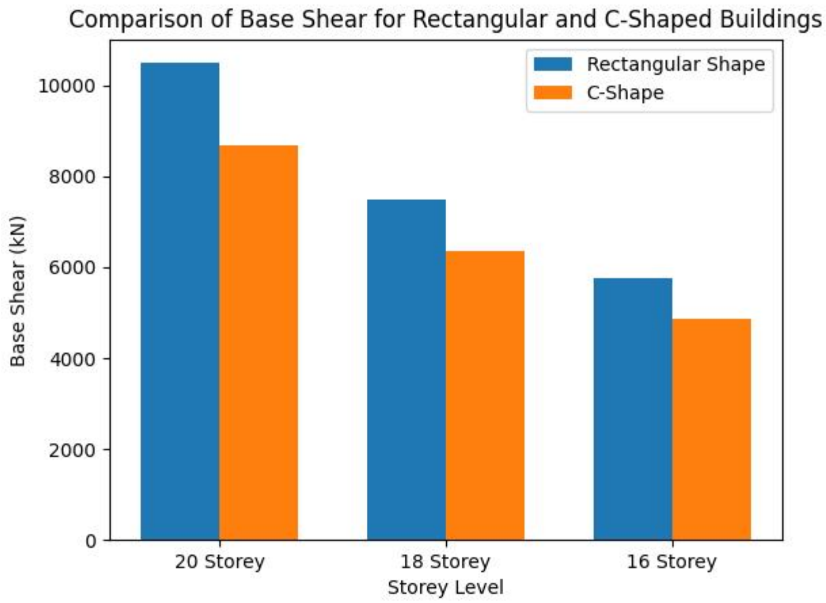
Discussion:
1. Drift increases with height
2. C-shaped buildings show significantly higher drift
3. High drift indicates risk of damage to non-structural elements

Base Shear:

Base shear represents total lateral force at foundation.

Table 4.5: Base Shear (kN)

Storey	Rectangular Shape (kN)	C Shape (kN)
20 Storey	10492.0542	8669.285
18 Storey	7478.5529	6365.1525
16 Storey	5746.9779	4856.4433



Graph 4.5: Base Shear Comparison

Discussion:
1. Base shear increases with height
2. Rectangular buildings have higher base shear
3. C-shaped buildings show lower base shear
4. Indicates less resistance to wind load

CONCLUSION

Based on the detailed wind load analysis carried out using ETABS, it is concluded that building height and structural shape have a significant effect on the behavior of tall buildings under wind forces. As the height of the building increases, the time period and storey displacement also increase, indicating greater flexibility of taller structures. The C-shaped irregular buildings showed higher displacement and storey drift compared to rectangular buildings, which indicates lower stiffness and greater vulnerability to wind-induced vibrations. Rectangular buildings performed better due to their regular geometry, uniform load distribution, and higher base shear capacity. The study also reveals that excessive drift in irregular buildings may lead to cracks, damage to non-structural elements, and reduced occupant comfort. Overall, regular shaped buildings provide better wind resistance, while irregular buildings require special design considerations for safety and stability under wind loading conditions.

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