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Wind Load Response of Tall Buildings of Various Shapes

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Abstract: *Rise in urbanization and due to scarcity in space available on the horizontal ground, there is a need for vertical expansion of cities. For which the high rise constructions are needed. Behaviour of the tall buildings subjected to wind loads along with vertical gravity loads is very much essential due to their vulnerability. This paper tries to explore the shape effect of buildings against the wind load using design software E-TABS. Different wind load patterns are ventured on various shapes of building viz. Square, Circular and Octagonal on direction basis to determine the response of buildings. Buildings of heights G+20 and G+40 are subjected to varying wind speeds of 33m/s, 44m/s and 50m/s to determine the response of the building with varying shapes. The study focuses on maximum bending moment in columns, maximum roof displacement and storey drift. Shapes play an important role in resisting the wind loads and circular shaped building is found to perform the best.*

***Keywords:** Tall building, Wind load, E-TABS, Roof displacement, Inter storey drift, Bending moment*

1. Introduction

Rapid growth of population and non-availability of land space in metropolitan cities all around the world has led to the unprecedented amount of construction of tall buildings. So, to accommodate this large number of world's population in the urban area only space available is vertical so vertical growth is very much essential. Therefore it is mandatory to study the behaviour of high rise buildings. The wind effects on infrastructure may be low, moderate, strong and extremely destructive. The construction of high rise building can be economically attractive only if structural engineer can have comprehensive understanding of the structural behaviour of various systems on the one hand and the practical sense of the construction on the other. Two load cases that governing the high rise construction other than static load case are earthquake load case and wind load case. Present study concentrates on wind load case. The design of a tall building is significantly driven by wind loading since they hinder the free flow of wind, resulting in high wind forces.

Many works are done earlier in the field of wind engineering, which includes wind pressure characteristics, wind flow, dynamic response, interference effect etc. [3] carried out the research on wind- resistant studies on tall buildings. Wind tunnel tests were carried out on 27 typical building models by using wind pressure scanning and HFFB techniques to study on wind loads and responses of tall buildings and structures. [1] Investigated the pressure integration technique for predicting wind-induced response in high-rise buildings, in which author presents a procedure for response prediction in high-rise buildings under wind loads. The advantages of accounting for complex mode shapes, non uniform mass distribution, and interference effects of the surrounding were studied. [6] studied the shape effect of high rise building against the wind load using design software STADD-Pro and the load analysis was done on the basis of FEA method. [4] Studied on the wind induced pressures which would arise due to wind intensity and how the pressure varies according to different shapes of buildings. The intensity of a wind load depends on how fast it varies and also on the response of structure. Ansys Fluent was used for CFD analyses to study the wind induced response. [5] investigated the variation of pressure at the faces of an octagonal plan shaped tall building due to interference of 3 square plan shaped tall building of same height using ANSYS CFX for 0o wind incidence angle. [2] Conducted a comprehensive wind tunnel tests on rectangular building models having the same plan area and height but with different side ratios to investigate the characteristics of wind forces and response of tall buildings.

This paper tries to explore the shape effect of building against the wind load using design analysis software E-Tabs. Eighteen numbers of building models are analyzed of heights G+20 and G+40 of Square, Circular and Octagonal shapes by subjecting to various wind speeds of 33m/s, 44m/s and 50m/s. Wind incidence angle of 0^0 and 90^0 are employed in the study to determine the response of the building.

2. Methodology

Present analysis considers multi-storey reinforced concrete framed buildings of 3 different shapes viz., Square, Circular and Octagonal with different storey heights of G+20 and G+40 each having a storey height of 3 m and plinth level of 1.5m. Buildings are comprised of ordinary moment resisting frames with

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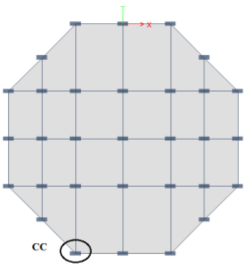
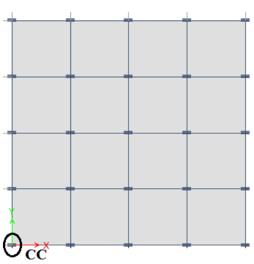
infills. Dimension of building elements were arrived on the basis of structural design following the respective Indian standard codes for design of reinforced concrete structures IS 456:2000. Details of different geometric parameters of building components are as shown in Table 1 and the schematic representation of building plan are shown in Figure1 in which the circled column (CC) represents the critical column which is considered in the study while computing the values of bending moment. Thickness of floor slab at various storey levels and roof slab were taken as 0.15 m and wall thickness as 0.2m. M30 grade concrete were used for beams and columns and M25 grade concrete were used for slabs and Fe500 grade steel were selected as the materials for design of structural elements. The design loads impending on the structures were taken as per IS: 875 (Part 3)-1987.The different parameters considered in the analysis are as shown in Table 2.

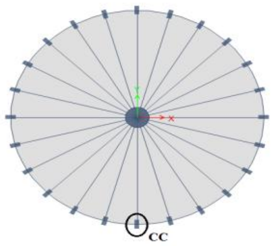
Finite element modeling and analysis were carried out using the finite element software ETABS. The modeling of building frames was done using beam element having three translational and three rotational degrees of freedom at each node. Roof slab and floor slabs at various storey levels were done using membrane element possessing bending capabilities. The three dimensional finite element building model is as shown in Figure 2.



a) Octagonal shape



b) Square shape



c) Circular shape

***Figure 1**. Schematic representation of building plan*

2.1 Estimation of along wind load as per IS: 875(Part3) 1987

Design wind speed (V_z): can be mathematically expressed as:

$$V_z = V_b * K_1 * K_2 * K_3 \quad (1)$$

Where,
V_b =Design wind speed at any height z in m/s.
K_1=Probability factor (risk coefficient)
K_2=Terrain, height and structure size factor and
K_3=Topography factor

Design wind pressure (P_z): The design wind pressure at any height above mean ground level shall be obtained by the following relationship between wind pressure and wind velocity

$$P_z = 0.6\, V_z^{\,2} \quad (2)$$

Where,
P_z = design wind pressure in N/m2 at height z,
V_z = Design wind velocity in m/s at height z.

***Table 1:** Different geometric parameters of building*

Shape	Wind speed (m/s)	G+20 Beam size in m	G+20 Column size in m 1-10	G+20 Column size in m 11-20	G+40 Beam size in m	G+40 Column size in m 1-10	G+40 Column size in m 11-20	G+40 Column size in m 21-30	G+40 Column size in m 31-40
Octagonal	33	0.20x0.45	0.35x0.75	0.30x0.65	0.2x0.45	0.55x1.5	0.5x1.35	0.30x0.75	0.25x0.55
	44	0.20x0.45	0.35x0.75	0.30x0.65	0.2x0.45	0.55x1.5	0.5x1.35	0.30x0.75	0.25x0.55
	50	0.20x0.45	0.35x0.85	0.30x0.65	0.2x0.45	0.55x1.5	0.5x1.35	0.30x0.75	0.25x0.55
Square	33	0.20x0.45	0.35x0.60	0.25x0.60	0.2x0.45	0.55x1.4	0.5x1.30	0.35x0.70	0.25x0.55
	44	0.20x0.45	0.35x0.60	0.25x0.60	0.2x0.45	0.55x1.4	0.5x1.30	0.35x0.70	0.25x0.55
	50	0.20x0.45	0.35x0.60	0.25x0.60	0.2x0.45	0.55x1.4	0.5x1.30	0.35x0.70	0.25x0.55
Circular	33	0.20x0.50	0.35x0.65	0.30x0.70	0.2x0.50	0.35x0.9	0.3x0.70	0.25x0.65	0.20x0.55
	44	0.20x0.50	0.35x0.65	0.30x0.70	0.2x0.50	0.35x0.9	0.3x0.70	0.25x0.65	0.20x0.55
	50	0.20x0.50	0.35x0.65	0.30x0.70	0.2x0.50	0.35x0.9	0.3x0.70	0.25x0.65	0.20x0.55

***Table 2:** Parameters considered for wind analysis*

Parameter		
Wind speed		33m/s 44m/s 50m/s
Incidence angle		X-axis: 00 Y-axis: 900
Structural class		Class C
Terrain		Category 3
Pressure Coefficients	For 0^0	0.80 0.25
	For 90^0	0.80 0.25
Risk Coefficient		K1=1
Topography factor		K3=1

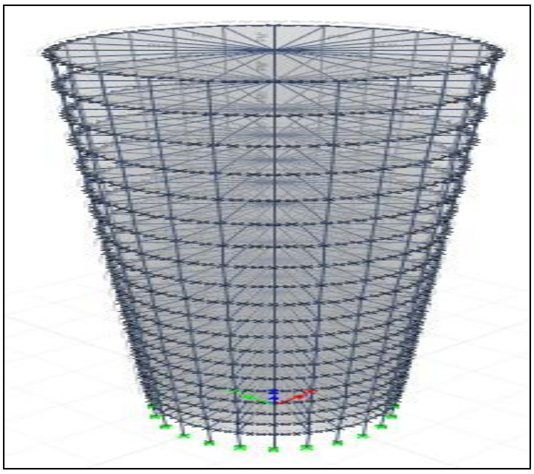


Figure 2: *Three dimensional finite element building model*

3. Results and Discussions

The analytical study of the model as stated before was done using ETABS. Different shapes, heights and wind speeds were considered in the study. Results constitutes maximum roof displacement and inter storey drift of high rise building when the building is subjected to along wind with 0^0 and 90^0 wind incidence angles.

3.1 Roof Displacement

Roof Displacement is the degree to which a structural element at the roof is displaced under load. The maximum displacements at roof for different wind speeds and heights of building are as tabulated in Table 3. From the study it was observed that the displacement will be minimum in case of circular building followed by octagonal and rectangle. It is higher in case of rectangular shape due to more angularity in edges of rectangle hence it possesses high galloping effect near the edges and same is the case with octagonal.

Table3: *Maximum roof displacement*

Shape	Storey No.	Wind Speed	Maximum Displacement (mm)
Octagonal	G+20	33m/s	59.600
		44m/s	105.88
		50m/s	136.70
	G+40	33m/s	195.50
		44m/s	354.77
		50m/s	459.16
Square	G+20	33m/s	68.49
		44m/s	121.75
		50m/s	157.21
	G+40	33m/s	210.00
		44m/s	378.76
		50m/s	490.14
Circular	G+20	33m/s	36.40
		44m/s	64.67
		50m/s	77.16
	G+40	33m/s	166.51
		44m/s	295.99
		50m/s	382.21

3.2 Storey drift

It is the displacement of one level relative of the other level above or below. The storey drifts for different wind speeds and shapes are as shown in figures 3 and 4 respectively. From fig 3and 4 it is observed that storey drift increases with increase in wind speed. Storey drift in circular cross section is the lowest and square cross section is the highest. Also with the increase in storey height there is decrease in storey drift. In case of high rise building with G+40 stories it is observed from fig 4 that the storey drift above 35 stories is higher in case of circular shape buildings than in square and octagonal shape buildings.

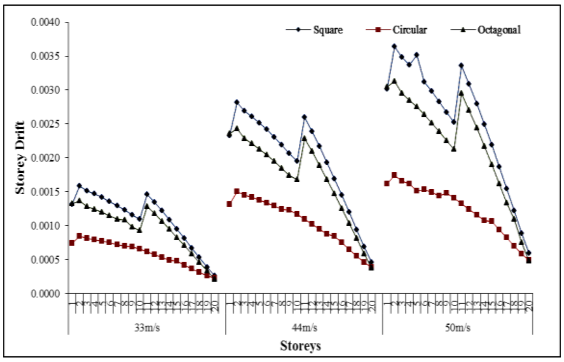


Figure 3. *Storey drift of G+20 building*

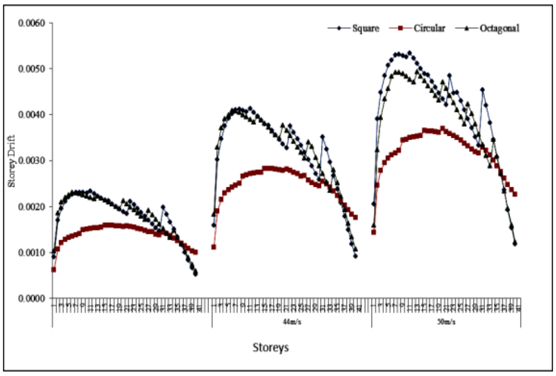


Figure 4. *Storey drift of G+40 building*

3.3 Bending Moment

A bending moment is the reaction induced in a structural element when an external force or moment is applied to the element causing the element to bend. The maximum Bending moment in critical column at the bottom storey for different wind speeds, heights and building shapes are as tabulated in Table 4. From figure5, figure6 and figure7 it is observed that bending moment increases with increase in wind speed and also with increase in height of the building for all shapes building plan considered in the study.

Table4: *Maximum bending moment in critical column*

Shape	Storey No.	Wind Speed	Maximum Bending moment in Critical Column (kN-m)
Octagonal	G+20	33m/s	62.727
		44m/s	95.813
		50m/s	117.844

	G+40	33m/s	234.342
		44m/s	329.286
		50m/s	478.732
Square	G+20	33m/s	72.564
		44m/s	129.807
		50m/s	140.544
	G+40	33m/s	248.592
		44m/s	351.234
		50m/s	524.976
Circular	G+20	33m/s	136.478
		44m/s	152.911
		50m/s	159.040
	G+40	33m/s	273.109
		44m/s	434.113
		50m/s	596.318

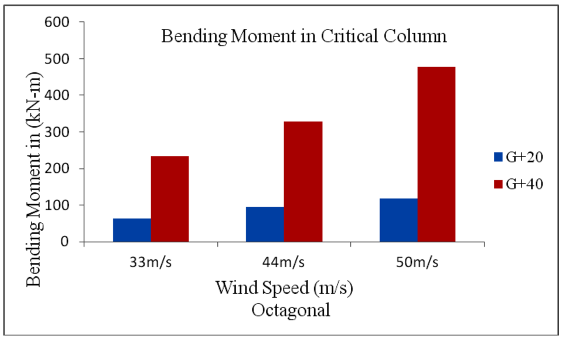


Figure 5. *Maximum bending moment in critical column of octagonal shape building*

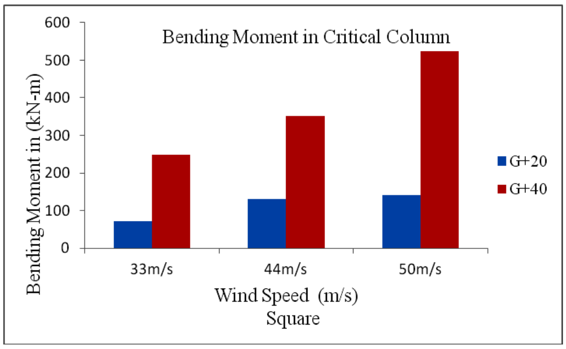


Figure 6. *Maximum bending moment in critical column of square shape building*

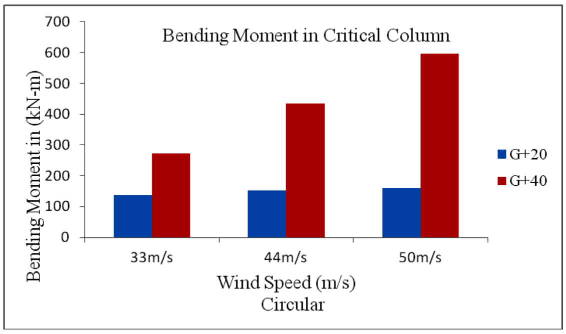


Figure 7. *Maximum bending moment in critical column of circular shape building*

4. Conclusions

Present study focuses on wind load response of tall buildings of various shapes. Variation in maximum bending moment in columns, maximum roof displacement and storey drift were considered for the study. Following are the general conclusions drawn from the study.

- Shape of the structure plays an important role in resisting wind loads.
- Circular shaped building showed the least roof deflection and storey drift followed by octagonal shaped and square shaped buildings.
- With the change in shape of the building from square to circular the lateral displacements and storey drifts decreases.
- Bending moment increases as the wind speed increases and also with increase in height of the building

For storey heights of G+20 and G+40 it is observed that the roof deflection and storey drift in circular cross section is the lowest compared to other shapes.

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