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RESEARCH ARTICLE

SHAPE EFFECTS ON THE WIND INDUCED RESPONSE OF HIGH RISE BUILDINGS

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ABSTRACT

This paper will explore the shape effect of building against the wind load using design software STADD pro and the load analysis are done on the basis of FEA method. For high rise construction needs to know the expected wind loads on the building so that to work out proper resistance systems to counteract the wind loads. The present study looks to examining the wind loading patterns on various shapes of building on direction basis. The computed wind loads are also benchmarked against standards code, IS:875-1987(part-3). In present paper the test models of G+20, G+40, G+60, G+80 with different shapes like square, rectangular, circular, hexagonal are established and then find out their results for maximum displacement and compare software results with manual analysis.

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INTRODUCTION

The continuity of economic prosperity and population increase in the urban areas point toward a future with increased in activity in high rise construction of residential and office building. "In all human history we have reached 3.5 billion of urban settlers and in the next 30 years we are going to have 3 billion more". Rapid growth of population and non-availability of land space in metropolitan cities of India 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 there is not enough space available on the horizontal ground. To accommodate all this population only space available is in vertical space. Therefore it is mandatory to study analysis of high rise building. However, 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 are governing on high rise structure other than static load case. Earthquake load case and wind load case. Here we have concentrated on wind load case. However, the design of tall buildings is still mainly revolving around the wind loading based on the Indian wind loading standard. 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. However, there are also some effects of wind that can make it a friend. One example is the possible use of the building as the platform for wind turbines for generating energy. With the available wind power increasing as wind velocity cubed, the higher winds at the upper levels of tall towers present a potential opportunity to access greater wind energy than is available at ground level. There is also in principle an opportunity to use the amplified winds around tall towers to naturally ventilate the building. In hot climates the increased winds around the tower's base can, in conjunction with shading, provide opportunities to improve the thermal comfort around the building. Shape effects, from a wind engineering perspective, have been investigated by Davenport (1971), via aerodynamic model tests. Hayashida and Iwasa (1990) also examined shape effects on super tall building using rigid models. Corner modifications and their impact on aerodynamic forces were studied in detail by Dutton and Isyumov (1990), Kawai (1998) and Tamura and Miyagi (1999) and the ASCE 7-2005. Zhou *et al*. (2003) suggested that loading data

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accumulated via commercial wind tunnels tests of buildings in their actual surroundings could be used to supplement an overall loading database. It is encouraging to see the use of such databases for preliminary design purposes included in the commentaries of ASCE 7-05 such as *http://aerodata.ce.nd.edu /interface/interface.html*

Wind effects on tall buildings

The wind is the most powerful and unpredictable force affecting tall buildings. Tall building can be defined as a mast anchored in the ground, bending and swaying in the wind. This movement, known as wind drift, should be kept within acceptable limits. Moreover, for a well-designed tall building, the wind drift should not surpass the height of the building divided by 500. Wind loads on buildings increase considerably with the increase in building heights. Furthermore, the speed of wind increases with height, and the wind pressures increase as the square of the wind speed. Thus, wind effects on a tall building are compounded as its height increases. Besides this, with innovations in Architectural treatment, increase in the strengths of materials, and advances in methods of analysis, tall building have become more efficient and lighter, and so, more vulnerable to deflection, and even to swaying under wind loading. Despite all the engineering sophistication performed with computers, wind is still a complex phenomenon, mainly owing to two major problems. Unlike dead loads and live loads, wind loads change rapidly and even abruptly, creating effects much larger than when the same loads were applied gradually, and that they limit building accelerations below human perception. Although the true complexity of the wind and the acceptable human tolerance to it have just begun to be understood, there is still a need to understand more the nature of wind and its interaction with a tall building, with particular reference to allowable defections and comfort of occupants.

Vortex-shedding phenomenon

Along wind and across wind are two important terms, used to explain the vortex-shedding phenomenon. Along wind or simply wind is the term used to refer to drag forces. The across wind response is a motion, which happens on a plane perpendicular to the direction of wind. When a building is subjected to a wind flow, the originally parallel wind stream lines are displaced on both transverse sides of the building (Fig 1), and the forces produced on these sides are called vortices.

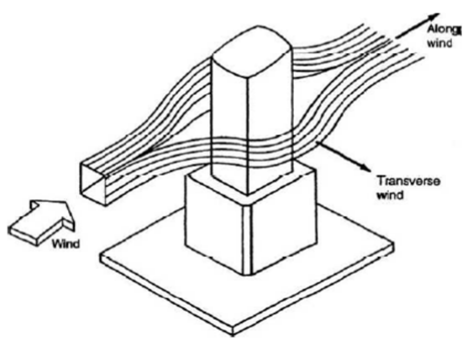

Figure 1. Simplified wind flow

At quite a low wind speeds, the vortices are shed symmetrically on either transverse side of the building (Fig 2 a), and so building does not vibrate in the across wind direction.

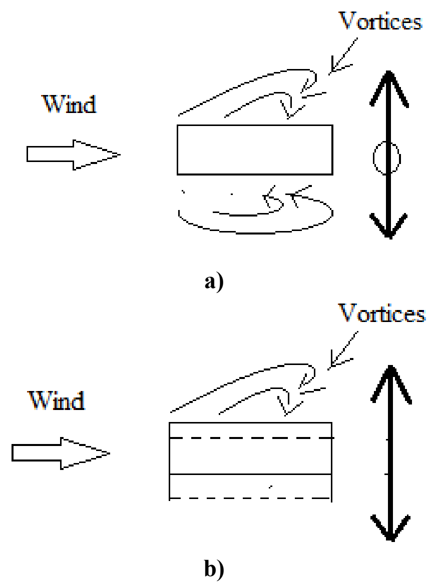

Figure 2. Vortices in different wind speed conditions: (a) vortices in low speed of wind (there is no vibration in the across wind direction); (b) vortices in high speed of wind – vortex-shedding phenomenon (there is vibration in the across wind direction)

On the other hand, at higher wind speeds, the vortices are shed alternately first from one and then from the other side. When this occurs, there is an impulse both in the along wind and across wind directions. The across wind impulses are applied to the left and then alternatively to the right. Therefore such kind of shedding which causes structural vibrations in the flow and the across wind direction is called *vortex-shedding*, a phenomenon well known in fluid mechanics. This phenomenon of alternate shedding of vortices for a rectangular tall building is shown schematically in Figure 2b. These effects are heavily dependent on shape. Hence the current trend towards considering the aerodynamics of the shape very early in the design of the very tall towers. The curtain wall loads also tend to increase with height primarily due to the fact that wind speeds in general increase with height, and the winds at ground level and on terraces or balconies are increased.

Data used and building modeling

In the present study following parameters are considered:

Material Properties

- Density of concrete=25kg/m^3
- Density of steel= 7850 kg/m^3
- Grade of concrete= M_{30}
- Grade of steel= Fe415
- Typical storey height = 3m.
- Typical plinth height =0.9m.
- In X-direction-5 Bays of 5m @25m
- In Z-direction- 5Bays of 5m @25m

Table 1. Parametric values of building

Storey No.	Shape	Beam Size (mm)	Column Size (mm)	Slab Thickness (mm)	Basic Wind Press. (M/Sec)
	Square	500x230	450x450	120	47
G+20	Rectangular	500x230	450x450	120	47
	Circular	500x230	450x450	120	47
	Hexagonal	500x230	450x450	120	47
	Square	500x230	450x450	120	47
G+40	Rectangular	500x230	450x450	120	47
	Circular	500x230	450x450	120	47
	Hexagonal	500x230	450x450	120	47
	Square	500x230	450x450	120	47
G+60	Rectangular	500x230	450x450	120	47
	Circular	500x230	450x450	120	47
	Hexagonal	500x230	450x450	120	47
	Square	500x230	450x450	120	47
G+80	Rectangular	500x230	450x450	120	47
	Circular	500x230	450x450	120	47
	Hexagonal	500x230	450x450	120	47

Loading Consideration

Dead load case- As per IS 875 -1987(Part-1)

Live load case-As per is 875-1987(Part-2)

Wind load case- IS 875-1987(part-3) deals with wind loads to be considered when designing building, structure and components thereof,

a) Basic wind speed (vb):

IS 875(part-3), Fig. 1 gives basic wind speed map of India, as applicable to 10m height above mean ground level for different zones of the country. For the present study as per terrain category II basic wind speed taken as 47m/s.

b) Design wind speed (vz):

It can be mathematically expressed as follows:
Vz = vb*k1*k2*k3
Vb =Design wind speed at any height z in m/s.
k1=Probability factor (risk coefficient)
k2=Terrain, height and structure size factor and
k3=Topography factor

c) Design wind pressure (Pz):

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

$Pz = 0.6\ vz^2$

Where,
Pz = design wind pressure in N/m^2 at height z,
Vz = Design wind velocity in m/s at height z

Problem Statement

For G+20 storey building-
As per IS 875-1987(part-3)

Design wind speed (Vz) = Vbxk1xk2xk3
Where,
Vb=47 m/s
k1 and k3= 1
k2=1.18
Vz= 47x1x1.18x1=55.46 m/s
and
$Pz= 0.6xVz^{2}= 0.6x\ (55.46)^2= 1845.48\ N/m^2$

Modelling:

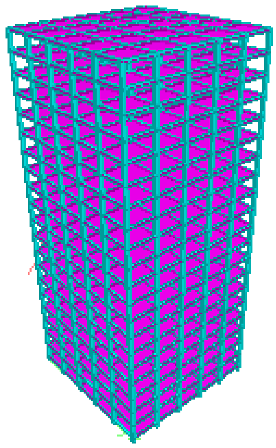

Figure 3. G+20 Square Shape Building

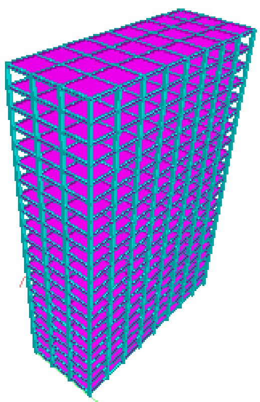

Figure 4. G+20 Rectangular Shape Building

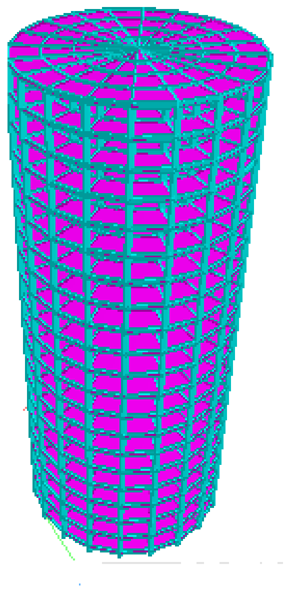

Figure 5. G+20 Circular Shape Building

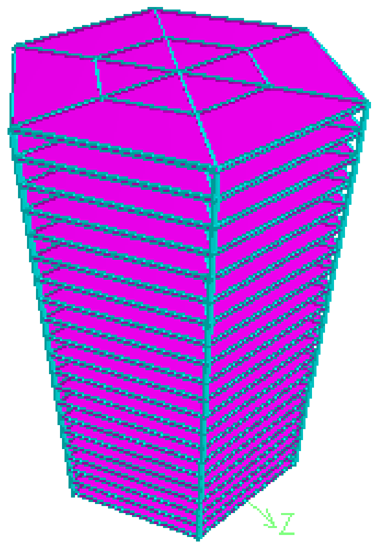

Figure 6. G+20 Hexagonal Shape Building

RESULTS AND DISCUSSION

From the study the results are discussed are as follows:

Table 2. Displacement of Buildings under loading conditions

Storey No.	Shape	Displacement X (Cm)	Displacement Y(Cm)	Displacement Z (Cm)
	Square	7.99083E+03	2.23308E+02	7.99083E+03
G+20	Rectangular	4.47586E+03	4.34177E+02	1.49148E+04
	Circular	8.00295E+02	1.78426E+02	3.17261E+03
	Hexagonal	4.74111E+04	8.19185E+02	9.16894E+04
	Square	4.45776E+04	1.69467E+03	4.45776E+04
G+40	Rectangular	2.24844E+04	3.60132E+03	9.79937E+04
	Circular	9.19005E+03	2.38129E+03	5.56862E+04
	Hexagonal	2.33185E+05	6.54827E+03	4.36191E+05
	Square	1.42887E+05	5.87050E+03	1.42887E+05
G++60	Rectangular	6.41376E+04	1.28787E+04	3.65328E+05
	Circular	5.91005E+03	3.83129E+03	2.86762E+04
	Hexagonal	6.49245E+05	2.21365E+04	1.14754E+06
	Square	3.52352E+05	1.41666E+04	3.52352E+05
G+80	Rectangular	1.27578E+05	3.13860E+04	9.60669E+05
	Circular	3.04671E+05	4.17798E+04	1.35968E+06
	Hexagonal	9.96861E+05	2.74628E+04	1.29239E+06

Table 3. Rotation of Buildings under loading conditions

Storey No.	Shape	Rot X (Rad/Sec)	Rot Y (Rad/Sec)	Rot Z (Rad/Sec)
	Square	1.73807E+00	8.29079E-03	-1.73807E+00
G+20	Rectangular	3.04305E+00	-9.72616E-03	-1.00420E+00
	Circular	4.27462E-01	6.07141E-01	-9.55527E-02
	Hexagonal	1.27528E+01	-1.9135E+01	-1.08989E+01
	Square	4.24811E+00	1.29014E-02	-4.24811E+00
G+40	Rectangular	8.43673E+00	-1.82071E-02	-2.36807E+00
	Circular	3.18146E+00	6.50324E+00	9.00530E-01
	Hexagonal	3.22711E+01	-8.8622E+01	2.59654E+01
	Square	8.38404E+00	1.98140E-02	-8.3840E+00
G+60	Rectangular	2.13523E+01	2.76814E-02	-4.12186E+00
	Circular	4.81146E+00	6.30524E+00	9.350030E-01
	Hexagonal	5.31354E+01	2.17783E+02	-4.37403E+01
	Square	1.55286E+01	2.69646E-02	-1.55286E+01
G+80	Rectangular	4.49482E+01	-3.40370E-02	-5.67995E+00
	Circular	5.11497E+01	2.83909E+01	-1.22808E+01
	Hexagonal	6.96306E+01	-2.8256E+02	-5.12270E+01

Maximum Absolute Stresses

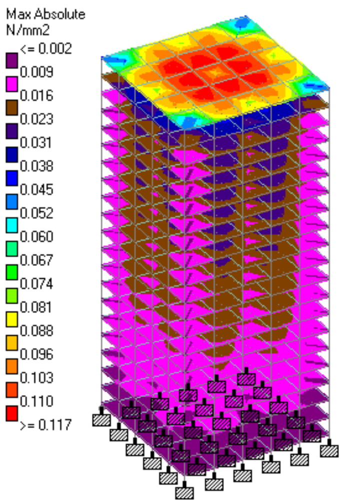

Figure 7. Maximum Absolute stress of G+20 Square Shape Building

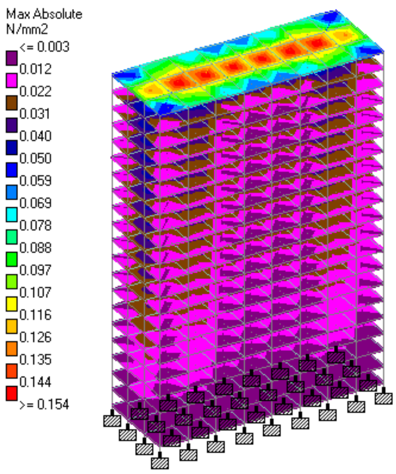

Figure 8. Maximum Absolute stress of G+20 Rectangular Shape Building

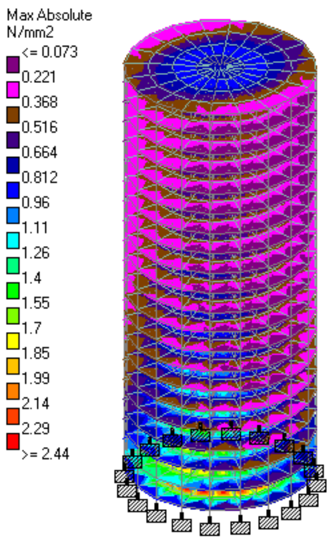

Figure 9. Maximum Absolute stress of G+20 Circular Shape Building

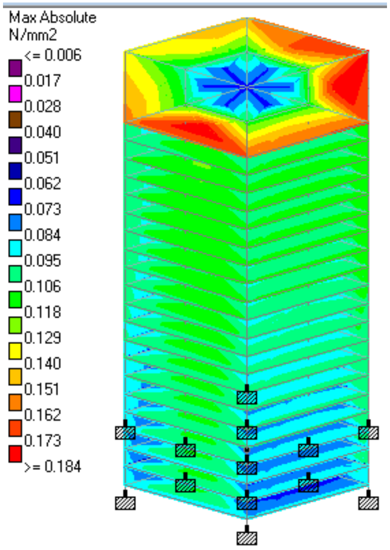

Figure 10. Maximum Absolute stress of G+20 Hexagonal Shape Building

Conclusion

In this Paper wind response of high rise building is studied using design software STADD-pro v8i.Four parameters of shape Square, Rectangular, Circular, and Hexagonal are selected for zone II (Pune region basic wind speed 47 m/s). For storey height G+20, G+40, G+60 & G+80 it was observed that upto 60 storey deflection along windward direction is less in Circularl as compared to other shapes. However for G+80 the rectangular shape gives comparatively less deflection. Because of torsional eccentricity Rotation about X & Z direction is less in square shape, rectangular shape and hexagonal which leads to better performance against torsional moment induced by wind. However less deflection in circular which leads to less stress in building. It can be concluded that for G+ 60 circular shapes should be performed for better wind resistance.

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