A Study of Shape of Tall Building Subjected to Wind Load for RCC and Steel Frame Structures

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Abstract— High rise building are analysed for different shapes i.e. rectangular, circular, Hexagonal and pentagon for different levels. Experimental study involves to explore the shape effect of (G+20) building against the wind load using wind rose diagram and design software STADD pro for RCC as well as for Steel Frames and the load calculations are done on the basis of FEM analysis. Therefore, in order to mitigate such an excitation and to improve the performance of tall buildings against wind loads and earthquake loads, many researches and studies have been performed. Early integration of aerodynamic shaping, and structural system selections play a major role in the architectural design of a tall building in order to mitigate the building response to the wind excitations.

Key words: High-Rise Building, Wind Load Effect, Earthquake Load Effect

I. Introduction

A. Background

Due to industrialization 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 behavior of various systems on the one hand and the practical sense of the construction on the other. Two load case 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.

Wind is often regarded as the foe of tall buildings since it tends to be the governing lateral load. Wind also has some potential beneficial effects particular to tall buildings. One is that, since wind speeds are higher at the heights of tall buildings, the potential for extracting wind energy using wind turbines is significantly improved compared with ground level. Other benefits are to be found in judicious use of natural ventilation, sometimes involving double layer wall systems, and, in hot climates, the combination of tailored wind and shade conditions to improve outdoor comfort near tall buildings and on balconies and terraces. 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.

B. 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.

C. Variation of wind speed with height

An important characteristic of wind is the variation of its speed with height (Figure 1). The wind speed increase follows a curved line varying from zero at the ground surface to a maximum at some distance above the ground. The height at which the speed stops to increase is called the gradient height, and the corresponding speed, the gradient wind speed. This important characteristic of wind is a well understood phenomenon that higher design pressures are specified at higher elevations in most building codes. Additionally, at heights of approximately 366 m from the ground, surface friction has an almost negligible effect on the wind speed; as such the wind movement is only depend on the prevailing seasonal and local wind effects. The height through which the wind Speed is affected by the topography is called atmospheric boundary layer. The wind speed profile within this layer is in the domain of turbulent flow and could be mathematically calculated.

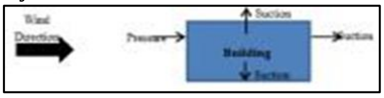

Fig. 1: Effect of wind loads on a structure

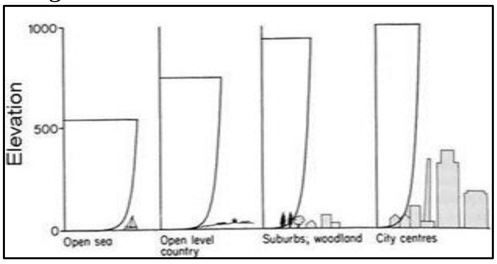

Fig. 2: Mean wind profiles for different terrains.

D. 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 2), and the forces produced on these sides are called vortices.

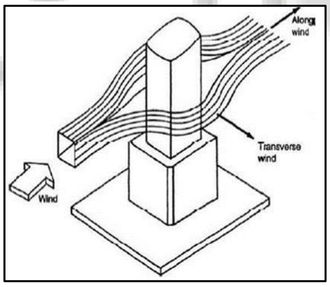

Fig. 3: Simplified wind flow

At quite a low wind speeds, the vortices are shed symmetrically on either transverse side of the building (Fig 3 a), and so building does not vibrate in the across wind direction.

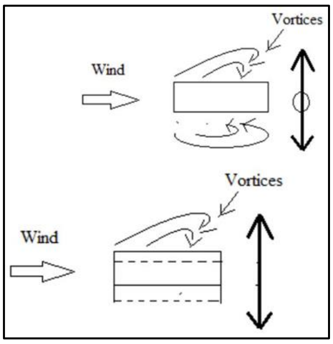

Fig. 4: Vortices in different wind speed conditions: vortices in low speed of wind (there is no vibration in the across wind direction); (b) vortices in high speed of wind – vortex-shedding phenomenon (there is vibration in the across wind direction)

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. All these effects are familiar to experienced developers and designers of tall towers and can be categorized as potential problems to be solved through the use of wind tunnel testing.

Designers need to know the expected wind loads on the building so that they can work out proper resistance systems to counteract the wind loads. Currently, the general trend in India is not to do any special wind tunnel studies and the building design is simply based on the wind load provisions in the IS 875 (1987) Standard believing that the code calculations provide the ultimate answer without knowing the pitfalls hidden in the standard [Suresh Kumar (2011)]. In contrary to the codes/standards, wind tunnel testing does physically simulate and predict the aerodynamic effect of the actual shape of the structure.

The economics of constructing tall buildings are greatly affected by wind as their height increases. To counteract wind loads and keep building motions within comfortable limits can require robust structural systems that drive up costs. Wind tunnel test results are more refined and accurate since it accounts the influence of adjacent structures, site specific wind directionality, and the structural complexity. In the current Indian scenario, it is seen that there is an urge for designers to go for aesthetic looks for tall building design than accounting its wind engineering aspects. Series of wind tunnel tests conducted for various tall buildings with unconventional shapes have shown to adversely impact the wind-induced structural loads as well as building motions. Many considerations to geometry, orientation and structural systems could have been given early in the design process to mitigate the issues. RWDI has database of variety of Indian projects dealing with aerodynamic treatments and structural modifications which are used for this paper as case studies.

Careful aerodynamic design of tall buildings through wind tunnel testing can greatly reduce wind loads and their affect on building motions. To ensure the structure safety in strong winds and control the wind-induced motion of super-tall buildings, aerodynamic optimization is considered to be the most efficient way, because the aerodynamic optimization is aimed at the source of problems. This paper summarizes the effect of building shape on wind induced response of structure through FEM analysis.

Zhou et al. (2003) provided a novel approach to give designers the necessary knowledge to effectively design structures for wind performance. The respective authors compiled a database of high-frequency base balance (HFBB) test data for structures of various heights and footprints. By inputting key building parameters, designers are provided with an estimate of the wind response of the structure. Our research is intended to supplement the information presented by Zhou et al. (2003), and demonstrate general wind loading patterns for common building shapes.

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). The present study looks to examining the wind loading patterns on various shapes on a direction by direction basis. The computed wind loads are also benchmarked against two building standards codes, IS:875-1987 and the ASCE 7-2005.

Zhou et al. (2003) suggested that loading data 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

The present study involves to explore the shape effect of (G+20) building against the wind load using design software STADD pro for RCC as well as for Steel Frames and the load calculations are done on the basis of FEM analysis.

E. Objectives

– To explore the effect of building shape on wind induced response of structure through FEM analysis for RCC and Steel Frames
– To provide base line values for wind load, computed response against the value given in IS 875(1893)
– To compare square, rectangular, circular, pentagon and Hexagoan.
– To analyse the different shapes and their effects on building by using design software.

II. Literature review

Anupam Rajmani & Priyabrata Guha (2) (2015) had done analysis of wind & earthquake load for different shapes of high rise building. According to Authors flexible buildings are very sensitive to wind excitation to the building occupants. Therefore, in order to mitigate such an excitation and to improve the performance of tall buildings against wind loads and earthquake loads, many researches and studies have been performed. Early integration of aerodynamic shaping, wind engineering considerations, and structural system selections play a major role in the architectural design of a tall building in order to mitigate the building response to the wind excitations. In this research work author studied four different shaped buildings namely circular, rectangular, square and triangular. It is difficult to develop simple general rules for the preference of shapes as a tool for reducing wind related problems.

There results shows that the wind tunnel testing is usually the best way for determining project specific wind loads and building motions. For 15 storied building the most stable structure is circular shape and triangular shape for maximum earthquake and maximum wind load respectively, similarly for 30 storied building, rectangular shape is most stable for maximum earthquake and wind load and for 45 storied building circular shape & rectangular shape is most stable for maximum earthquake and wind load respectively. In terms of maximum Mz triangular Shape for 15 storey, rectangular shape for 30 storeys.

III. Methodology

A. General

A (G+20) building with their five study shapes were identified for consideration in this research. While the cross-section of the seed buildings was similar to one of the five study shapes, the height and width of the seed was varied. In order to compare the data and identify loading trends for particular shapes, it was necessary to normalize the data to represent a common building shape.

Common building shapes were selected for inclusion in this study. Figure 1 presents a photo of a seed building for each the shapes studied. Sample seeds were sought to have open surroundings to avoid unique project specific wind effects caused by adjacent structures. From the database, four buildings for each of the five basic building footprints considered were identified.

The study also considered seeds for various Reynold's numbers (Re), which should be acknowledged when considering the results. The variation of Re for the various experiments was limited to ±150,000.

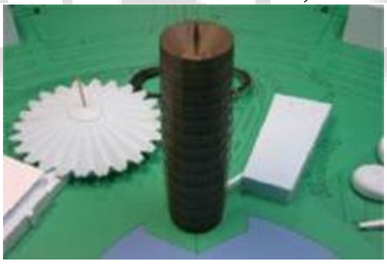
Fig. 5: Circular shape building

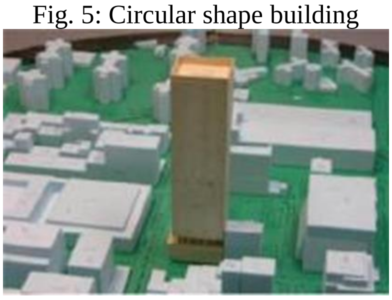
Fig. 6: Square shape building

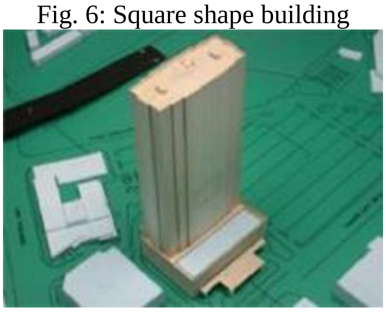
Fig. 7: Rectangular shape building

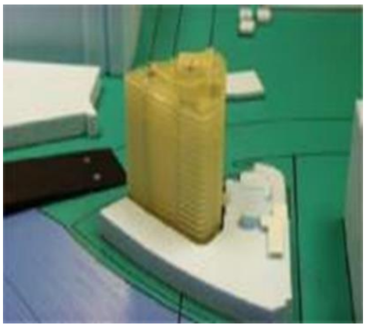

Fig. 8: Triangular shape building

Fig. 9: Elliptical shape building

For the present study loads considered are as:

- Dead Load: Dead loads shall be calculated on basis of unit weights which shall be established taking into consideration the materials specified for construction. This consists of walls, partitions, roofs, floors including the weights of all other permanent structure. It may be calculated on the basis of unit weights of material given in IS 875(PART-I)
- Imposed Loads: Imposed loads are produced from the weight of movable partitions of building, uniformly distributed and concentrated loads. For structure carrying live loads which induced impact and vibration. Imposed loads shall be assumed in accordance with IS 875(PART-2)
- Wind Load: The IS 875(part-3) deals with wind loads to be considered when designing building, structure and components thereof,

1) 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.

2) Design wind speed (vz):

The basic wind speed (vb) for any site shall be obtained and shall be modified to include the following effect of design wind velocity at any height (Vz) for the chosen structure:

a) Risk level

b) Terrain roughness, height and size of Structure and

c) Local topography.

It can be mathematically expressed as follows:

$$z=Vb*k1*k2*k3$$

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

K3= topography factor

As per this study,

V_b=40 m/s, k_1= 1 , k_3=1

3) Design wind pressure

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/M2 at height z, andVz = Design wind velocity in m/s at height z

IV. PROBLEM STATEMENT

A three storey, single bay, commercial building is shown in figure. It has in-filled masonry walls. Design the building as per IS: 1893(part-1)2002 for the following data:

Seismic Zone: Zone IV	
No. of storey Three (G+2)	
Floor to floor height 3.2m	
Impose load roof slab	1.5 KN/ m^2
-Floor slab	4.0 KN/m^2
Floor finish Roof slab	2.0 KN/m2
- Floor slab	1.0 KN/ m^2
Thickness of in-filled wall 250mm (including plaster)	
Beam sizes	250mmX350mm
Column sizes	
Ground floor	250mmx450mm
First floor	250mmX350
second floor 250mmX250mm	
Thickness of slab	140mm
Parapet 1m high and 150mm thick	
Plinth level 1m above ground level (medium soil condition)	
Depth of foundation for column	
1.5m below G.L	
Depth of footing	0.6m

Depth of foundation for wall 1m below G. L. Materials

Concrete (M20), steel (Fe415) Specific weight of concrete 25 KN/m^3

Specific weight of masonary 20 KN/ m^3

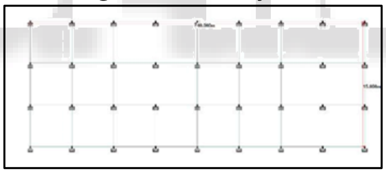

Fig. 10: Foundation

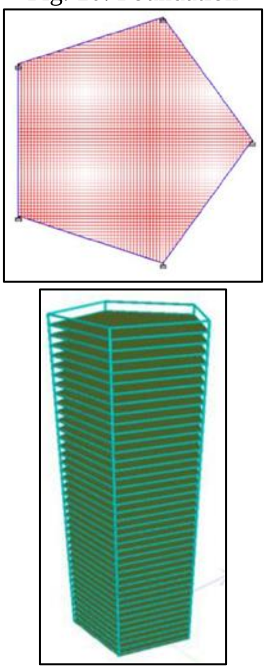

Fig. 11: Plan and elevation

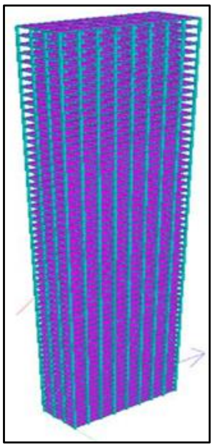

Fig. 12: 3D model (rectangular shape)

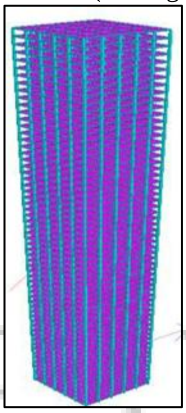

Fig. 13: 3D model (square shape)

V. RESULTS AND DISCUSSION

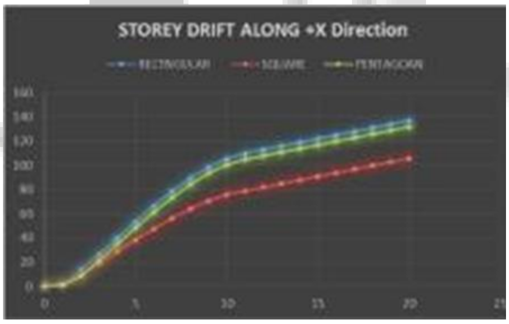

Fig. 4: Result

X-No of storey, Y-Deflection

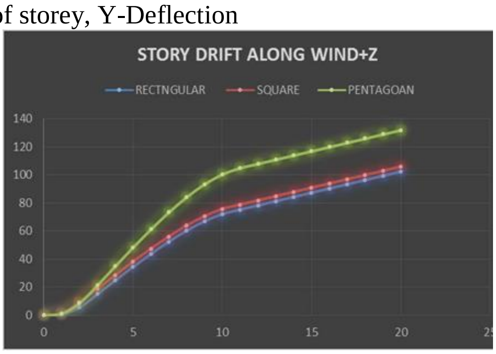

Fig. 5: Result

VI. CONCLUSION

The present study involves to explore the shape effect of (G+20) building against the wind load using design software STADD pro for RCC and the load calculations are done on the basis of FEM analysis. Wind load is calculated in accordance with IS 875: Part-3 and following conclusions can be drawn.

– While applying load along +VE and –Ve X direction displacement is 25% less as compared to rectangular and pentagoan
– Latterly applying load along +VE and –Ve Z direction displacement is 15% less in rectangular as compared to square and pentagon

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