

Shape Effects on Wind Induced Response of Tall Buildings Using CFD

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ABSTRACT: Earlier in 19th century, there were no structures as tall buildings but with the technological advancement and rise in urbanization, there was a need for vertical expansion of cities. During that era, for design purpose, only vertical/gravity loads on buildings were to be considered but with increase in slenderness/height of buildings, lateral loads on structures i.e. wind loads and earthquake loads came into pictures which are more predominant. In 1930s' many high rise buildings were constructed across the world. It was a period of great prosperity for high rise buildings as extensive research work was carried out on wind induced effects on high rise buildings. Unlike the mean flow of wind, which can be considered as static, wind loads associated with gustiness or turbulence rapidly and even abruptly, creating effects much larger than if the same loads were applied gradually. Wind loads, therefore, need to be studied as if they were dynamic in nature. CFD analysis becomes the most popular for such wind induced response studies. This research is mainly concentrate on wind induced pressures which would be arises due to wind intensity and how 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 has been used for CFD analyses to study the wind induced response.

KEYWORDS: Tall buildings, CFD, Ansys Fluent, Wind Analysis, Gust, Dynamic Analysis

I. INTRODUCTION

There is no explicit definition for tall building. It is difficult to distinguish the characteristics of building which categorize it as tall. Building cannot be defined as tall using the term of height or number of floors only. A building is an enclosed structure that has walls, floors, a roof and usually windows. "A tall building" is a multi-storey structure in which most occupants depend on elevators to reach their destinations. The most prominent buildings are called high-rise buildings in most countries. There is no absolute definition of what contributes a tall building. From the structural design point of view, it is simpler to consider a building as tall when its structural analysis and design are in some way affected by the lateral loads i.e. wind or seismic and particularly the sway caused by such lateral loads. As the height increases, the wind forces begin to dominate. Therefore, structural framework for super-tall buildings is developed around concepts associated entirely with resistance to turbulent wind.

In tracing the further developments of wind loading from 1930's to the present, there appear to have been several forces at work. First there have been some radical changes in structural properties-mass, stiffness and damping. The average densities of tall buildings and long span bridges, for example, have fallen to roughly a factor of 2 from around 20 to 10 lb/ft³ in case of buildings and from 200 to 100 lb/ft³ of roadway in case of long span bridges. In parallel, the substantial increase in material strengths (by factor of 2 and 3 in case of structural steel and concrete) has led to reduction in member sizes and consequently stiffness. This has been exaggerated further by the omission of heavy masonry cladding and frame infill and therefore the loss of their contribution to stiffness. To this, we can add the significant improvements in analysis such as plastic analysis and the contribution of the digital computer. Lastly, there have been significant reductions in damping due to extensive use of welding, pre-stressing and the omission of heavy masonry elements. All of these changes in structural form directly increase their susceptibility to wind and hence the need for better models of wind loading. The trend to build taller, larger and lighter structures has highlighted the need for research in providing accurate analysis of wind effect so that the tower is significantly saving in the cost of façade and structure in comparison with the use of estimates from wind standards.

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II. RELATED WORK

In 1st paper, author has adopted standard k- ϵ model to study the effect of different geometric plan configurations like square, circular, swastika, hexagon and octagon of tall building having same plan area and height on force coefficient. To study wind effect, 3-D wind flow condition around tall building was developed using Computational Fluid Dynamics (CFD) code FLUENT and then pressure coefficient and wake region around the building was evaluated by numerical computation. Author found that wind pressure coefficient was maximum in case of square plan shape and minimum in case of circular plan shape of building. Also total drag force was minimum for circular plan shape of building and maximum for swastika plan shape building. Author also found that circular plan shape of building was much better than any other shape in terms of both wind pressure coefficient as well as total drag force on building. In 2nd paper, Author explored the effect of shape of building on the wind induced response of a structure through comprehensive investigation of wind tunnel studies. The study focused on buildings with foot prints of square, circular, triangular, rectangular and elliptical shapes. In 4th paper, different shapes of building of height 150m having equal plan area, equal stiffness and columns were considered for analysis. Authors determined wind loads based on gust effectiveness factor method. Based on analysis of tall buildings, storey displacements, storey drifts, storey shear, axial forces in columns were compared. Author observed that the peak intensity of wind and peak displacement for elliptical building was almost 70% less compared to square building. Author concluded that with the change in shape of building from square to elliptical, the wind intensity, storey drifts, the lateral displacements, storey shear of building decreases and thus wind load is reduced by maximum percentage with an elliptical plan. IS 875(Part 3):1987 clearly gives the idea about gust effectiveness. Code contains coefficients for various shapes (Table 23 PN 42-IS 875(Part 3):1987). In all other papers a lot of study had been done using BLWT and various wind simulation codes.

III. METHODOLOGY

For this study, Total 11 shapes of buildings according to plan has been selected which has been modelled in AutoCAD 3D and commercial CFD software Ansys Fluent 14.5 has been used to simulate full scale flow around building. CFD codes work by solving the governing equations with the use of a turbulence model. Different CFD commercial codes have different discretization methods to solve those governing equations. Fluent code uses finite volume discretisation method to solve the governing equations, that means the region of interest (the domain) is divided into a finite number of cells or control volumes (the mesh or grid). In the simulation the variables are solved at the centre of the cell. The values at other locations are determined by using interpolating those values. In other words, the accuracy of numerical solution will usually improve with an increased number of grid points, especially if the increase is made in spatial regions with complex geometries. For this reason the creation of the mesh (or grid) is one of the most important issues to consider for a successful CFD simulation.

Size of computational domain:

There are no explicit rules for size of domain. The extent of the building area (e.g. surrounding buildings) that is represented in the computational domain depends on the influence of those features on the region of interest. As experience from wind tunnel simulations is that a building with height H_x may have a minimal influence if its distance from the region of interest is greater than 6-10 H_x . Thus, as a minimum requirement, a building of height H_x should be represented if its distance from the studied building complex is less than 6 H_x . For this study, domain has been considered 800X600X400 in X, Y and Z direction respectively.

Shape Geometries:

General shapes have been selected and modelled using AutoCAD 3D. Triangle, Trapezium, Tetragon, Square, Rectangle, Parallelogram, Octagon, Hexagon, Kite, Ellipse, and Circle have been modelled and analysed further. Fig 1 shows circle geometry and in similar way other shape geometries have been modelled. Plan area and height has been kept same for all the shapes i.e. 1225 m² and 110 m respectively.

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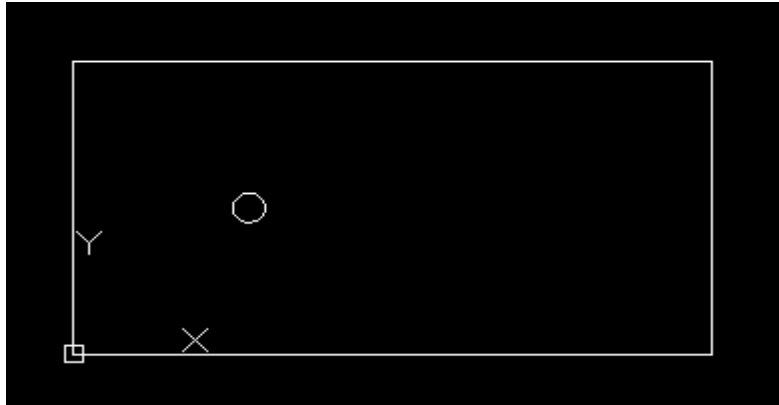


Fig 1 Circle Shape geometry with Domain

Properties of materials:

1. Fluid:

Material around building: Air

Temperature : (300 k)

Density (kg/m³):1.1777

Specific Heat Capacity: (Cp) – J/kg-K 1005

Thermal Conductivity (W/m-K) 0.0262

Kinematic Viscosity (kg/m-s) 1.5761e-05

2. Solid (Building)

Material: RCC

Density: 2500 kg/m³

Elastic Modulus: 28000 MPa

Poisson's ratio: 0.2

Mesh Generation:

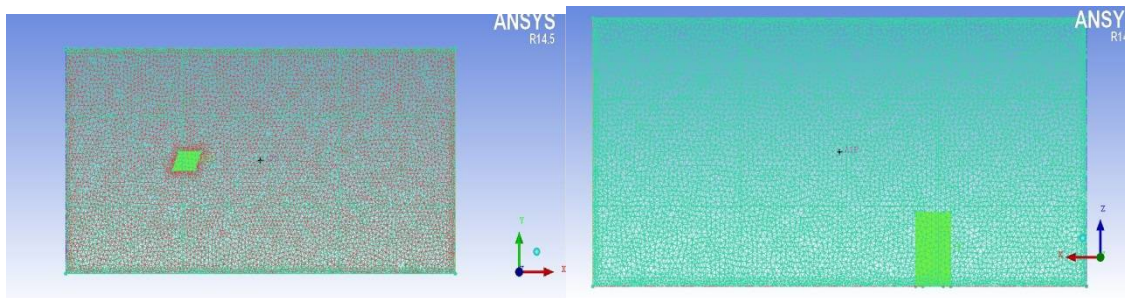
To achieve the desired mesh i.e. with aspect ratio around 10 and orthogonal quality of 0.4, ICEM Mesh tool has been used. Tetragonal unstructured type of mesh has been performed with the following element sizes for particular region:

Size of elements given in ICEM Mesh as shown in Table 1:

Parts	Size of element
Inlet	10
Outlet	10
walls	15
Building	1 with prism layers
Bottom	5
Inner curves	1
Outer curves	1

Table 1 Comparison of Gust load and CFD drag load

Fig 2 shows the complete mesh for all the parts as follows:



Plan

Elevation

Fig 2 Mesh Generation

IV. ANALYSIS AND RESULTS

Analyses have been performed in Ansys Fluent. For analyses, K-ε Realizable turbulence model with standard wall function has been used and Boundary conditions as follows:

- Inlet (velocity inlet) = 44 m/s
- Outlet = Outflow
- Lateral sides, top side and ground: wall
- Building Wall: Wall

After running the calculations till the convergence, results have been checked in CFD Post. Results consists of variation of dynamic pressure, pressure coefficients and drag force on tall building surface due to variation of geometric plan shape of tall building. Dynamic wind force by gust factor method has also been calculated according to IS875: Part 3 and compared with CFD drag force. The plan area for each building geometry is constant i.e.1250 square meter and height of each building geometry is 110 m. the value of force coefficient for each tall building plan shape geometry as well as the total drag force acting on the tall building unit as obtained by CFD code fluent is tabulated in table 1,2 and 3, also by graphically.

Geometry	Gust load(KN)	CFD Drag force(KN)	% Difference w.r.t CFD
Circle	3459.7	4179.08	17.21383654
Triangle	5257.6	5029	-4.545635315
Square	5750.5	5120.23	-12.30940798
Ellipse	1314.4	803	-63.68617684
Hexagon	8056	13506	40.35243595
Octagon	5512.87	4342.56	-26.94977156
kite	7048.4	7164	1.613623674
Trapezium	4038.8	3532.98	-14.31709209
Rectangle	9037	11300.25	20.02831796
Parallelogram	5750.23	5634.52	-2.053591078
Tetragon	6700.02	7018.54	4.538265793

Table 2 Comparison of Gust load and CFD drag load

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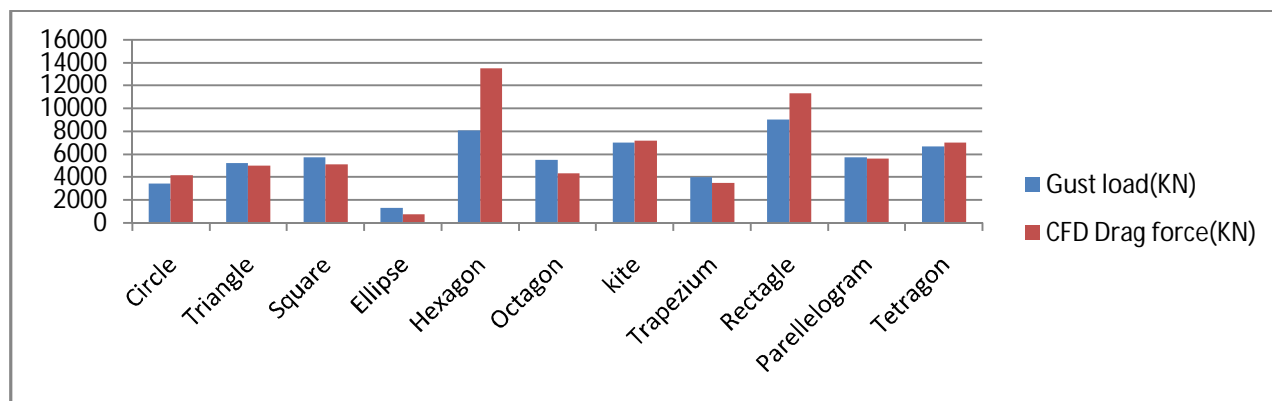
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Geometry	Maximum Dynamic pressure(Pa)	Wind Pressure coeff.	Skin friction coeff.
Circle	4248.34	0.99	3.54E-03
Triangle	2740.18	1.827	6.37E-03
Square	4888.24	1.3	5.80E-03
Ellipse	2315.13	0.988	4.45E-03
Hexagon	5360.54	0.98	5.40E-03
Octagon	3246.68	1.05	2.60E-03
kite	3521.49	1.07	8.90E-03
Trapezium	3843.89	1	9.50E-03
Rectangle	2241.21	1	2.00E-03
parallelogram	2252.89	1.09	3.00E-03
Tetragon	3063.74	1.08	6.25E-03

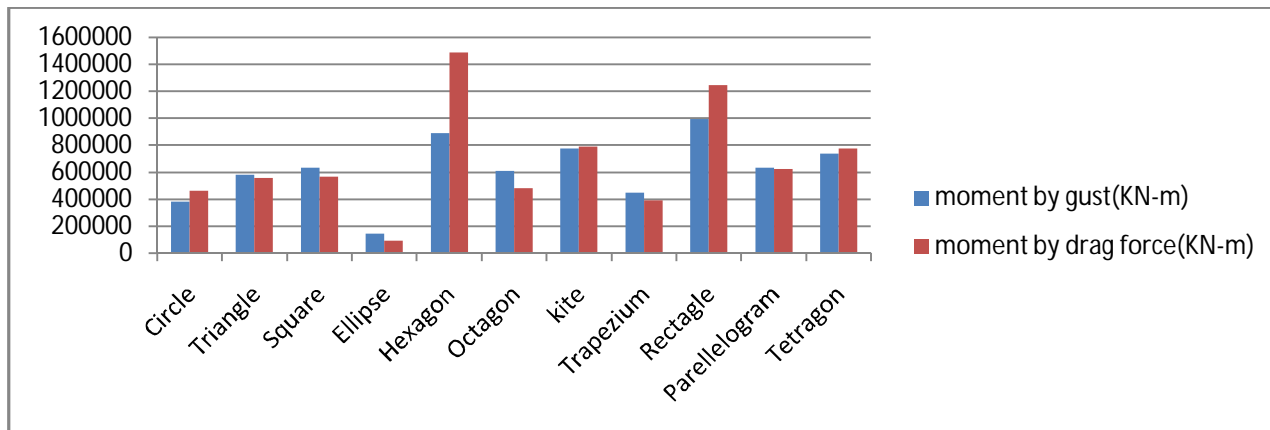
Table 3 Values of dynamic pressure and coefficients

After comparing the forces it has been observed that, Elliptical shape is having very less drag force and gust load. It is higher in case of Hexagon shape due to more angularity in edges of hexagon hence it possesses high galloping effect near the edges near to the inlet and hence has higher drag force. Same happens in case of Tetragon, Rectangle, kite, Octagon. Variation has been shown graphically as follows:

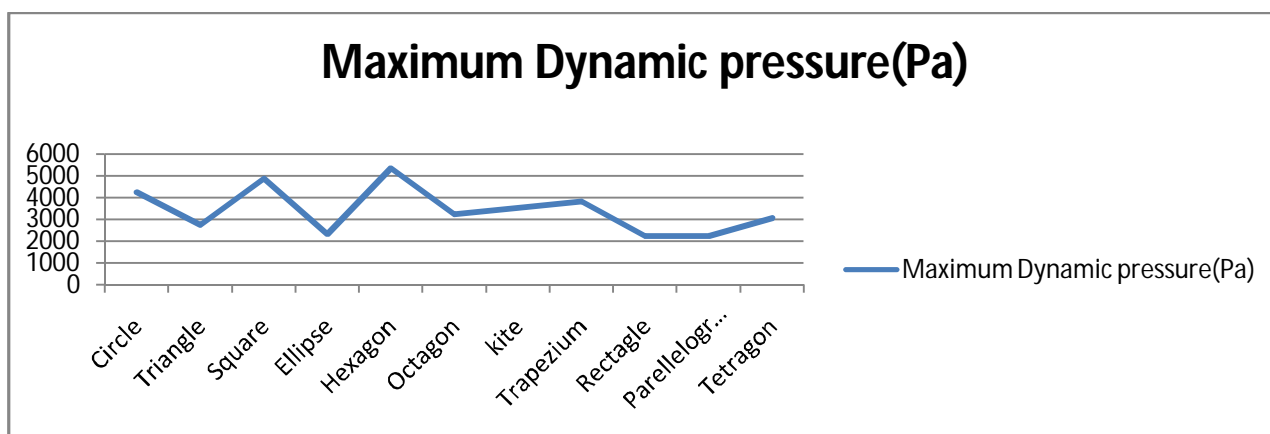


Graph 1 Variation in Wind forces for all shapes

In case of moments and dynamic pressure as vortex shredding and ovaling effects are predominant for hexagon certainly it is higher for hexagon and lesser for ellipse, Values of moments induced due to wind forces are less for ellipse and circle as compared to others. It has been shown in graphs2 and 3 as below:



Graph 2 Variation in Moments for all shapes



Graph 3 Variation in dynamic pressure (From CFD)

V. CONCLUSION

CFD has been proved to be very effective tool for wind load analyses. From the results obtained, it was found that Wind Pressure Coefficient is max in case of square, trapezium, rectangle plan shape and it is minimum in case of circular, hexagon and elliptical plan shape of tall building. The octagonal plan shape of tall building is more effective in reducing wind pressure coefficient than parallelogram and triangle plan shape of tall building. In comparison with octagonal plan shape of building with hexagonal plan shape of building is more effective in reducing the wind pressure coefficient. Trapezium, Rectangle, parallelogram, and Tetragon are more effective in reducing wind pressure coefficients than triangle which has highest wind pressure coefficients. The total drag force will be more in case of hexagon plan shape building compared to all other plan shape of building. Drag force is very less for ellipse. Also in case of max dynamic pressure it is very high for hexagon shape. In brief, the circular and elliptical plan shape of buildings is much better compared to the other plan shape of building in reducing of both Wind Pressure Coefficient as well as Total Drag Force on Building.

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