Study on Wind Flow on a Hexagonal Shaped Tall Building by Means of Drag Coefficients

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Abstract - *With the emerging technology, the buildings are getting taller and unconventional shaped rather than being traditional.Generally shape and orientation of the building are determined on the basis of architectural and practical considerations, but the wind-induced excitation encouraged by bluffness of the building shapes cannot be neglected .Tall buildings are highly susceptible to the effect of wind loads. The speed of wind increases from the street level and goes on increasing with altitude and causes great instability to the structure. Modifying the structure with aerodynamic modifications has found to be an effective approach in mitigating wind induced loads. The aerodynamic modification includes modifications to the corners such as chamfered, recessed, rounded corners as well as modification to the form of the building such as setback, tapering, helical and twisting. A hexagonal shaped building is modelled using the computational fluid dynamics package of ANSYS CFX and the wind flow around the building is analysed. Different aerodynamic modifications such as roundness, recession, chamfering, tapering and setback are applied to the basic hexagonal shape and the wind flow around these formations are analysed based on drag coefficients and pressure coefficients. The best aerodynamic modification is then selected based on the lowest value of drag coefficient.*

Key Words: Wind, Tall building, CFD, Aerodynamic modification, Rounded, Chamfering, Recession, Tapering, Setback

1. INTRODUCTION

With the increase in population along with the decrease in usable land, there arrives the need for vertical construction. With the dawn of urbanization, the cities are being conquered by skyscrapers. These skyscrapers are inevitable as they consumes very less amount of land and they can accommodate more residential or commercial space as compared to a single storied building which would take up the same amount of land. These tall buildings are susceptible to earthquake as well as wind effects. But from the point of view of frequency of occurrence, wind is the most dangerous one and it causes high instability to the building and the occupants. The shape of buildings are now taking a turn from the past conventional configurations. In contrast to the conventional configurations like simple circular, square, rectangular etc, the newest buildings are of different shapes along with different modifications to the building form as well as to the corners. It has been proved that these modifications namely aerodynamic modifications are highly effective in achieving wind resistance. The main effect of wind wind response is the vortex shedding phenomenon on the building. It causes instability to the buildings and the surroundings. Buildings commonly have sharp corners and they causes separation of wind flow and results in large wind induced loads.The aerodynamic modifications has found to be very effective in reducing the vortex shedding as well as along wind and across-wind responses. The vortex shedding causes very severe across wind motion which needs to be mitigated. The process of vortex shedding can thus be suppressed only by modifying the outer surface of the building such that the flow of wind is smooth like as in the case of a streamlined body. The aerodynamic modifications alter the wind flow pattern around the building and helps in achieving smooth wind flow patterns. Thus the aerodynamic shapes stop the formation of alternate vortices from the windward sides of the building and brakes the coherent formation of vortices. The commonly used modifications include minor modifications or corner modifications like chamfering, recessed , and roundness of corners as shown in figure 1 and major modifications viz.form modifications like setback, tapering, twisting, helical, openings etc as shown in figure 2.

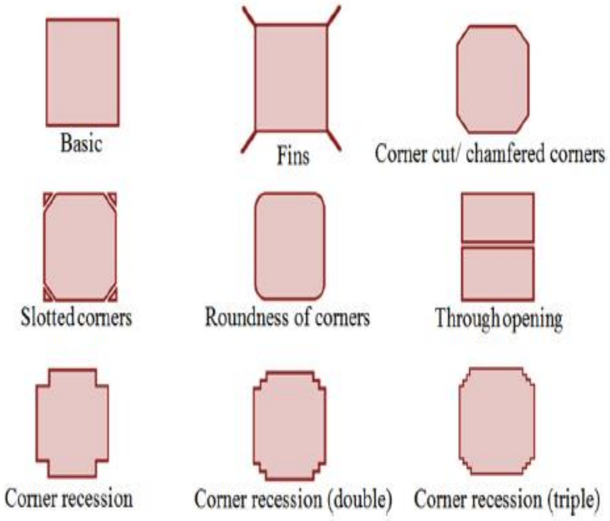

Fig 1: Minor aerodynamic modifications

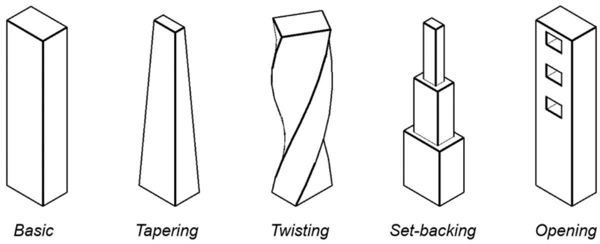

Fig 2: Major aerodynamic modifications

2. PARAMETRIC MODEL

The chosen parametric model of the study is a basic hexagonal shaped building model. Six different models were simulated with different aerodynamic modifications applied to the basic hexagonal plan shape. The three models are as shown in fig 4. The scale of the models are 1:300. The height of the model is 500 mm and sides are 100 mm each with a proportion of B/H=1/5. Where B is the width and H is the height of the building. The six different models are shown in figure 3.

2.1 Solution Methodology

ANSYS CFX package is used for CFD simulations. The computational domain used for the study is as per the recommendations on the use of CFD in wind engineering - 2004[1] as shown in the figure(4).

The inlet and side walls are provided at a distance of 5H from the building face and the outlet is considered at 15H from the building model and the domain roof is at a height of 6H from the domain floor. Such a large domain is provided so that no blockage correction is required.

No slip wall condition is provided for domain floor, and the building including its top. Also, free slip wall condition is given for the side walls and the roof of the computational domain.

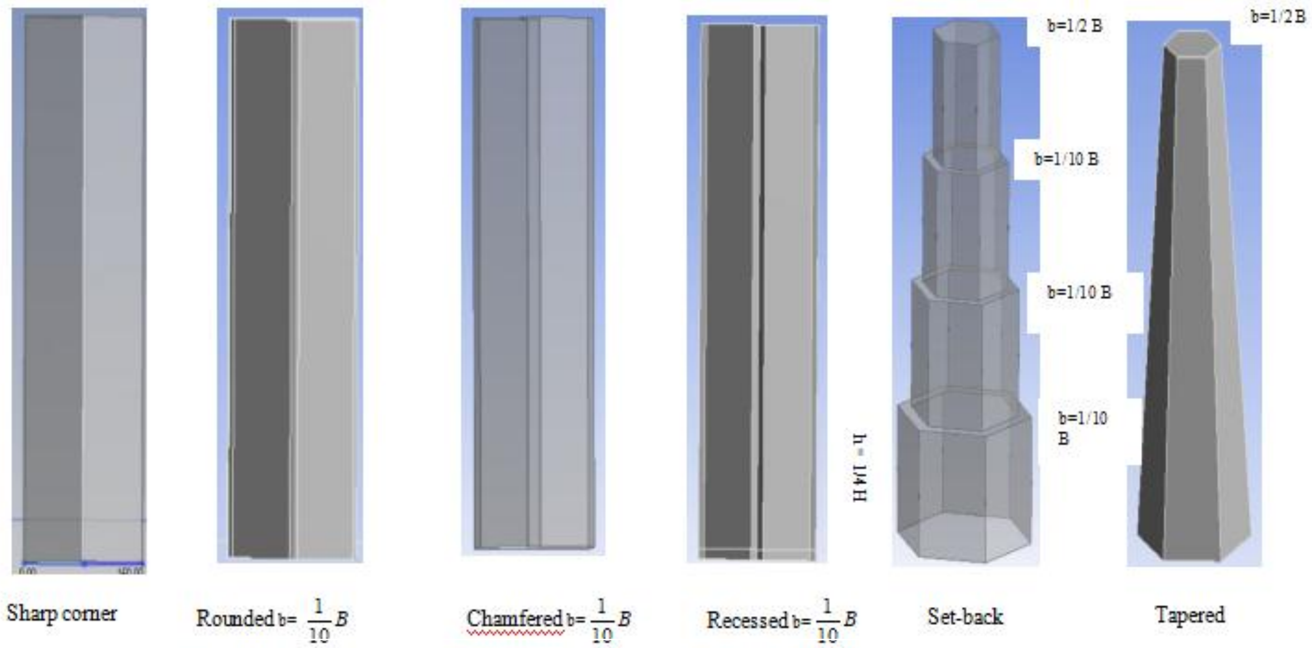

Fig 3: configuration of test models

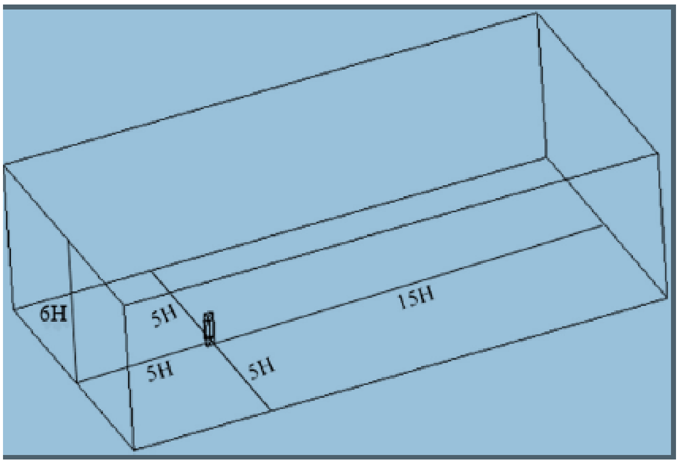

Fig 4: computational domain used for the study

The velocity of wind at the inlet is given as 10 m/s and the pressure at outlet is taken as 0 Pa. The operating pressure at the domain is given as 1 atm.

Tetrahedral meshing was used to mesh the domain as well as the building. And finer mesh were provided on and around the building using inflation.

The wind flow follows a boundary layer profile.Wind velocity is assumed to be zero at ground and increasing with the height. This nature of wind is usually represented by two different models namely logarithmic law and the power law [2]

1. Logarithmic Law

$$\frac{Vz}{V*} \approx \frac{1}{k}\log e\frac{z}{z0}$$

Where *k* is the Von Karman's constant with a value=0.40

And Vz is the velocity at height z above ground, z_0 is the surface roughness parameter,

V* is the friction viscosity= $\frac{\sqrt{\tau_0}}{\rho}$, τ_0 is the skin frictional force on the wall and ρ is the density of air and z is the height above ground.

2. Power Law, is used for this study as it is widely used and is very easy to adjust match with the mean wind velocity profile.

$$\frac{V}{V_0} \approx \left(\frac{z}{z_0}\right)^{\alpha},$$

Where V is the velocity at height z above the ground, V_0 is the wind speed at reference height, z_0 is the reference height above ground which is taken as 1m and α is an exponent whose value varies with the terrain category. The terrain category is taken as 2 and the corresponding value of

α = 0.133.

Numerical modelling is done by *k*-ε turbullence modelling which was found to be most reliable in past studies.

The performance of the building can be explained on the basis of drag coefficients and pressure coefficients. The lower drag coefficient represents lower aerodynamic tension[3].

Drag coefficient $C_d = \frac{2F}{\rho V^2 A}$

Where, F is the aerodynamic force, A is the reference area subjected to the wind, ρ is the density of air and V is the design wind speed and

Pressure coefficient $Cp = \frac{P - P\infty}{0.5\rho V^2}$

Where P is the static pressure at the specified point at which the pressure coefficient is being evaluated

$P\infty$ is the static pressure in the free stream which is taken as zero atm

V is the velocity of the fluid and ρ is the density of the fluid

Pressure coefficient Cp is calculated as a face average value each for each face.

3. RESULTS AND DISCUSSIONS

The analysis of the different models of a hexagonal shaped building with k-ε turbulence modelling has been completed in two phases. Firstly, different aerodynamic corner modifications were applied to the basic model with the same wind flow and orientation and their drag coefficients were then recorded. Then in the second phase, different aerodynamic form modifications namely set-back and tapering were applied to the basic hexagonal plan and their performance in reducing drag coefficient is then analysed.

The wind flow patterns around the building starting from the inlet for the six different models are shown in figure 5.

Symmetrical vortices are formed on either side of the basic hexagonal shaped model. Lesser vortex formation and more smooth flow is observed in the case of recessed corner hexagon. The vortices formation seems to be disrupted in the case of rounded and chamfered models. Also in the case of tapered and set-back formations, the vortex formations appear to be confused and incoherent.

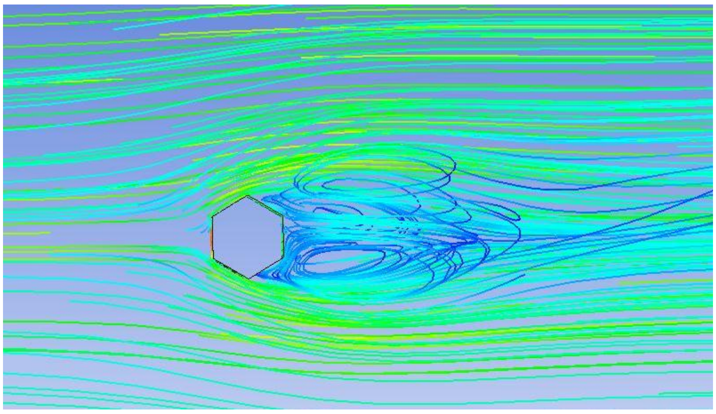

Fig 5 (a):wind flow around basic hexagon

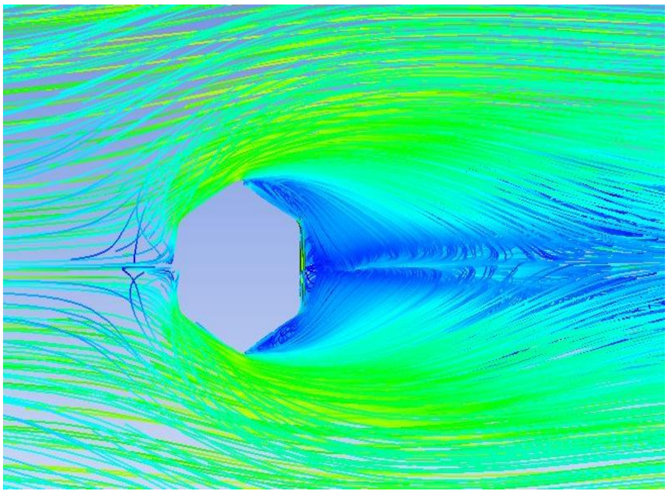

fig 5 (b): wind flow around rounded corner hexagon

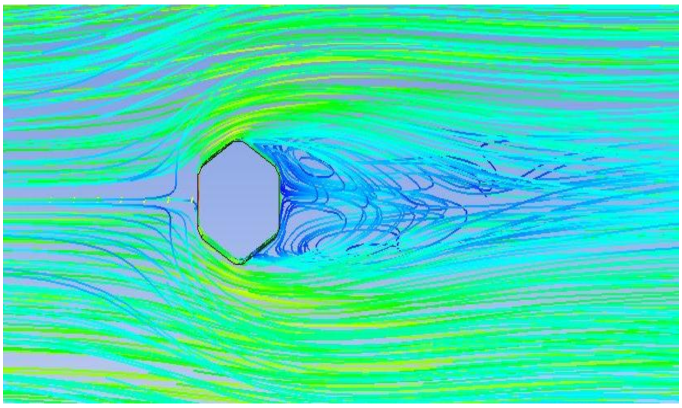

Fig 5(c): wind flow around chamfered corner hexagon

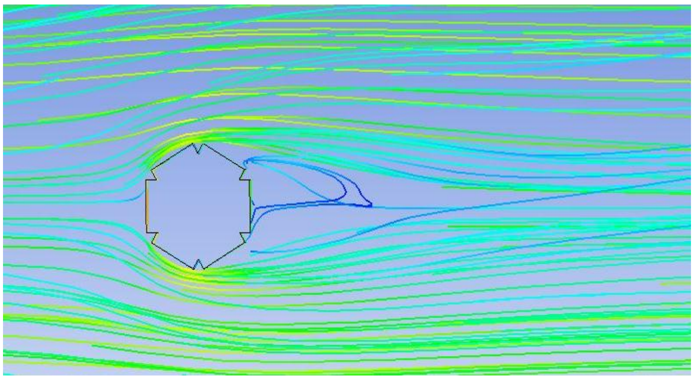

Fig 5(d): wind flow around corner recession

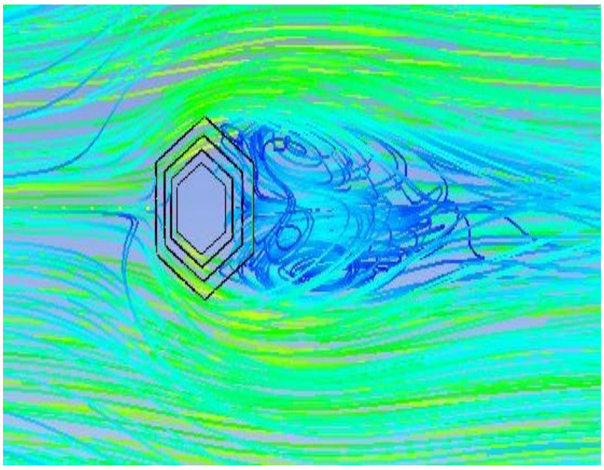

Fig 5(d):wind flow around set-back model

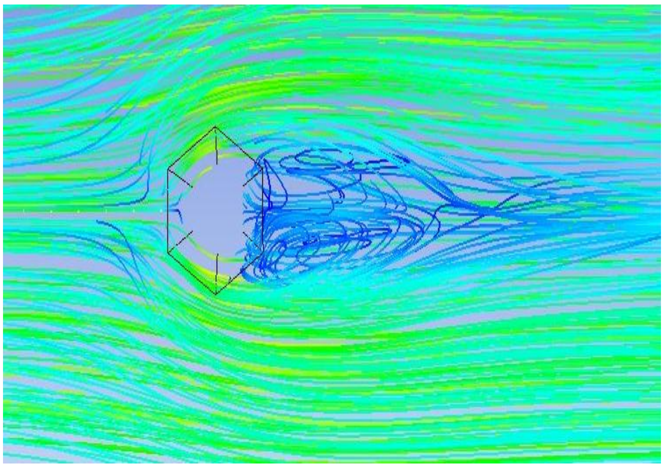

Fig 5 (e): wind flow around tapered model

The calculated drag coefficients of each model are listed in the table 1 .

Model	sharp corner	rounded	chamfered	Recessed	Tapered	Setback
Drag coefficient	0.869	0.683	0.819	0.566	0.716	0.761
% reduction	-	21.4	5.75	34.8	17.6	12.42

Table 1: Drag coefficients

The lowest value of drag coefficient is obtained for corner recession and the highest value for the basic sharp corner hexagon.

The face averaged values of pressure coefficients calculated for different models are listed in table 2

Table 2: Pressure coefficients

Model	Pressure coefficient Cp of different faces											
	A	% reduction	B	% reduction	C	% reduction	D	% reduction	E	%reduction	F	% reductiom
Basic	1.3	-	-1.133	-	-1.133	-	-1.196	-	-1.193	-	-0.795	-
Rounded	0.624	52	-0.861	24	-0.861	24	-0.917	23.32	-0.917	23.1	-0.712	10.4
Chamfered	0.855	34.2	-1.049	7.41	-1.046	7.41	-1.06	11.1	-1.06	11.1	-0.737	7.29
Recessed	0.598	54	-0.669	40.9	-0.669	40.9	-0.889	25.6	-0.887	25.6	-0.616	22.5
Setback	1.081	16.8	-0.517	54.3	-0.517	54.3	-0.997	16.6	-0.997	16.43	-0.694	12.7
tapered	1.007	22.5	-0.573	49.4	-0.579	49.4	-1.04	13.04	-1.095	8.21	-0.504	36.6

Positive pressure coefficients occurred for the windward faces of all the models due to direct wind dissipation and negative(suction) pressure coefficients are observed for the side walls as well as the leeward faces .wake is the region with low negative wind pressure and results in drag forces on the walls of the leeward faces of the building. The highest value of pressure coefficients for all the faces has occurred for the sharp corner hexagon. And the lowest values of pressure coefficients are observed for the recessed corner model.

4. CONCLUSIONS

This study consists of analyzing the wind flow pattern around a hexagonal shaped tall building model with different aerodynamic modifications. The drag coefficients and the pressure coefficients of each model has been found out. The pressure distribution on each face of every model has been studied.On a comparison with the basic corner hexagon model without any modifications, the modified models has showed better performance in reducing drag coefficient. The rounded corner and chamfered corner models has reduced the drag coefficient by 22% and 6% respectively. Where as the recessed corner model has reduced the drag coefficient by 35%. hence, corner recession is selected as the best model among the corner modified models.on comparing the modifications to the form of the building, the tapered model has reduced the drag coefficient by 18% and the set-back model has reduced the same by 13%. hence the tapered model performed best in terms of form modifications. It can be concluded that the corner modification has out performed the form modification on basis of drag coefficient.

REFERENCES

[1] Franke, J., Hirsch, C., Jensen, A.G., Krüs, H.W., Schatzmann, M., Westbury, P.S., Miles, S., Wisse, J. and Wright, N., May.(2004) Recommendations on the use of CFD in predicting pedestrian wind environment. In Cost action C (Vol. 14).

[2] Paul, R. and Dalui, S.K.(2016), Wind effects on 'Z'plan-shaped tall building: a case study. International Journal of Advanced Structural Engineering, 8(3), pp.319-335.

[3] Daemei, A.B., Khotbehsara, E.M., Nobarani, E.M. and Bahrami, P.(2019),Study on wind aerodynamic and flow characteristics of triangular-shaped tall buildings and CFD simulation in order to assess drag coefficient. Ain Shams Engineering Journal.

[4] Alexander, D. K., Jenkins, H. G., & Jones, P. J. (1997, September). A comparison of wind tunnel and CFD methods applied to natural ventilation design. In Proceedings of Building Simulation (Vol. 97, pp. 321-326).

[5] KP, N., & VN, K. (2016). Experimental and Analytical Investigations of Cellular Steel Beams. International Research Journal of Engineering and Technology Volume 3, 3, 1886–1892. https://www.irjet.net/archives/V3/i8/IRJET-V3I8334.pdf

[6] Amin, J.A. and Ahuja, A.K.,(2010). Aerodynamic modifications to the shape of the buildings: a review ofthe state-of-the-art.,

[7] .Bairagi, A.K. and Dalui, S.K.,(2018). Comparison of aerodynamic coefficients of setback tall buildings due to wind load., Asian Journal of Civil Engineering, 19(2), pp.205-221.,

[8] KM, D., & VN, K. (2016). International Journal of Innovative Research in Science and Engineering. Performance Based Design of High Rise Buildings for Occupant Comfort, 2(5), 89–100. http://www.ijirse.com/wp-content/upload/2016/02/1665ijirse.pdf

[9] Bhattacharyya, B. and Dalui, S.K.(2015)., Along and across wind effects on irregular plan shaped tall building. In Advances in Structural Engineering (pp. 1445-1460).New Delhi.,