

# Aerodynamic Modifications against Wind Excitation on Tall Buildings-Shape Optimization

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**Abstract**—The structures that are man-made are bluff- bodies. During the structural analysis of a tall building, its stability under wind forces is of a major concern. Being a bluff body, the aerodynamic study plays a critical role in the determination of the principal response of a high-rise building to wind forces. Tall buildings can be susceptible to excessive motion during wind events that can cause occupant discomfort and reduce the overall appeal of the structure. Furthermore, these excessive motions can create high base loads, which can increase the cost of the structure. Structural engineers generally opt for optimizing the structural system or increasing modal mass to reduce wind-induced motion. This paper presents an overview of a proposed tall building design platform that has the aim of determining the significance of aerodynamic modifications against wind excitation, which include modifications of building's cross-sectional shape and its corner geometry, sculptured building tops, vertical openings through-building.

**Keywords**— *Bluff body aerodynamics, shape effects, Finite Volume Analysis, Drag Coefficients, ANSYS, Computational Fluid Dynamics (CFD), Shape optimization of building, Aerodynamic Modifications, Corner modification, Tapered building, Cross Section (C.S)*

## I. INTRODUCTION

Nowadays the national development depicts the presence of tall high rise building all around the nation as a pride factor and a showcase to the prosperity of the country. Tall buildings, which are usually designed for office or commercial use, are among the most distinguished space definitions in the architectural history of American urbanism in the twentieth century. They are primarily a reaction to the rapid growth of the urban population and the demand by business activities to be as close to each other as possible. Every architects' imaginative reinterpretations of the building type, the inadequacy and high cost of land in urban areas, the need to preserve significant agricultural production, the concept of skyline, cultural significance and prestige, have all contributed to force buildings upward.

Today, it is virtually impossible to imagine a major city without tall buildings. Tall buildings are the most famous landmarks of cities, symbols of power, dominance of human ingenuity over natural world, confidence in technology and a mark of national pride; and besides these, the importance of tall buildings in the contemporary urban development is without doubt ever increasing despite their several undeniable negative effects on the quality of urban life

The tall buildings are designed primarily to serve the needs of the occupancy, and, in addition to the satisfied structural safety, one of the dominant design requirements is to meet the necessary standards for the comfort of the building users and the serviceability. In this context, since wind can create excessive building motion, the dynamic nature of wind is a critical issue, negatively affecting occupancy comfort and serviceability. Moreover, the human response to building motion is a very complicated phenomenon concerning both physiological and psychological features. Furthermore, excessive building motion can, create noise and crack partitions, damage non-structural elements such as curtain walls, cause glasses to break, reduce fatigue life, malfunction of the elevators and equipment, and result in structural damages or even collapse. Different design methods and modifications are possible, ranging from alternative structural systems to the addition of damping systems in order to ensure the functional performance of flexible structures and control the wind induced motion of tall buildings

An extremely important and effective design approach among these methods is aerodynamic modifications in architecture, including, all possible modifications of building's cross-sectional shape and its corner geometry, sculptured building tops, and horizontal and vertical openings through building. By changing the flow pattern around the building, aerodynamic modifications in building shape i.e., an appropriate choice of building form, could moderate wind responses when compared to original building shape.

## II. AERODYNAMIC MODIFICATIONS OF TALL BUILDING

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 deflections and comfort of occupants.

The wind induced motion of a tall building can be controlled either by reducing the wind loads or by reducing the response. A proper selection of building shape and architectural modifications can result in the reduction of motion by altering the flow pattern around the building. A building can be designed with smooth lines and curves so that it, like a plane, is highly aerodynamic, and that the wind will just move smoothly over it, without pushing too much. Therefore, aerodynamic modifications, including modifications of cross-sectional shape of the building, its corner geometry, sculptured building tops, openings through building are also an extremely important and effective design tool to mitigate wind induced motion

### III MODELLING

Finite volume method is considered to be the best tool for analyzing the structures recently many software's uses this method for analyzing and designing. The most popular one is ANSYS (FLUENT) software. The physical aspects of fluid flow are governed by the conservation principles of mass, momentum and energy. Computational fluid dynamics (CFD) is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. The fundamental basis of any CFD problem is the Navier- Stoke's Equation, which define any single phase fluid flow.

The cross-section area of each of the buildings considered were same however, the length and width of the model was varied. The full scale dimensions and coordinate origins for each of the model are shown in Figure 1. The height of the buildings was taken to be 150 m at full scale. The dimensions shown in Figure 1 were chosen to minimize the geometric correction factors and provide the same cross-sectional area for each model. The north arrow, in the center of Figure 1, can be used to identify the wind direction.

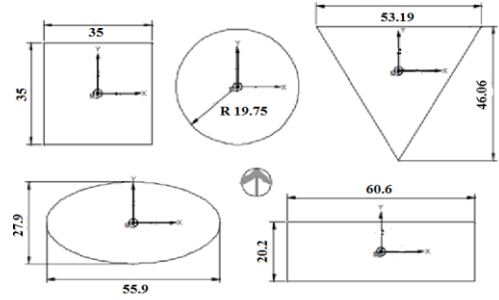


Fig.1. Dimensions of basic building models

The domain constructed around the building model is of rectangular shape. It has 150 m length in the upstream direction and a 250 m in downstream direction. The domain has 150 m width sideways and a height of 300 m from the base of the building model. The wind velocity applied is 165 kmph.

The boundary condition applied for the inlet of the domain is velocity inlet and for outlet is out flow condition. All other four faces of the rectangular domain are assigned a wall condition.

### IV. AERODYNAMIC MODIFICATIONS OF RECTANGULAR SHAPED BUILDING AGAINST WIND EXCITATION

An appropriate choice of building shape and architectural modifications are also extremely important and effective design approaches to reduce wind induced motion by altering the flow pattern around the building. These aerodynamic modifications can be classified into three main groups:

- Modifications to building shape including effect of tapered cross section, setback and sculptured top, and efficient building shapes;
- Modifications to corner geometry;
- Addition of openings.

Since the analysis of basic cross section shapes shows that building with rectangular shape has the highest drag, further analysis is concentrated on the building with rectangular C.S. All the building models with aerodynamic modification considered for further analysis has a height of 150 m. The CFD analysis of modified shapes are conducted at 46.6 m/s (165 kmph).

#### A Building with Chamfered Corner

C.S Dimension – Length is 60.60 m, Breadth is 20.2 m with Corner chamfered at a distance of 5 m from edge at 45 deg angle.

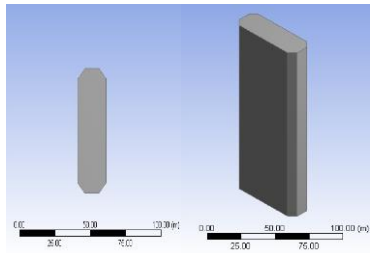


Fig. 2 Plan and isometric view of rectangular model with chamfered corner

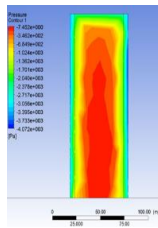


Fig. 3 Pressure Contour front view of rectangular model with chamfered corner

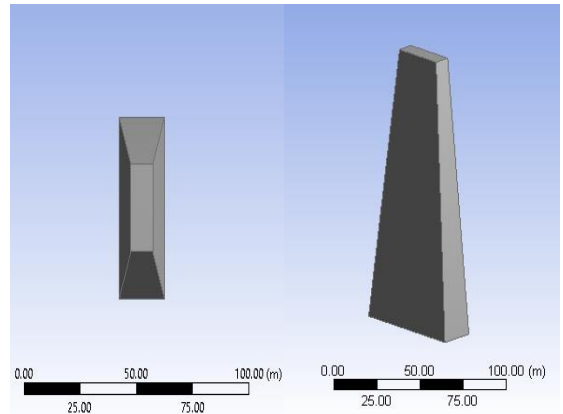


Fig. 6 Plan and isometric view tapered rectangular model

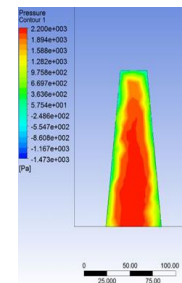


Fig. 7 Pressure Contour front view tapered rectangular model

**B Building With Rounded Corner**

C.S Dimension – Length is 60.60 m, breadth is 20.2 m with corner rounded at a radius of 5 m

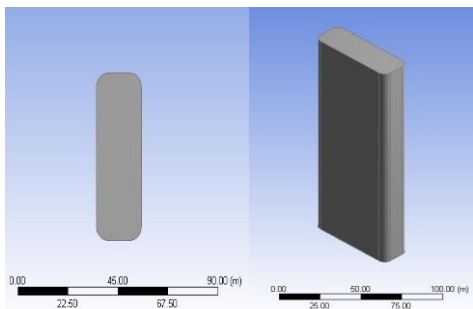


Fig. 4 Plan and isometric view of rectangular model with rounded corner

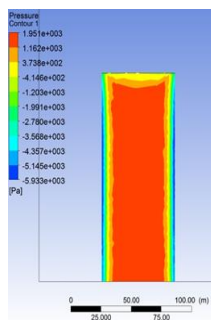


Fig. 5 Pressure Contour front view of model with rounded corner

**C Building with Tapered faces**

C.S Dimension – Length is 60.60 m (at base), breadth is 20.2 m (at base), tapering angle 2 degrees in front and rear faces and 6 degrees on other two faces

**D Building with Stepped Cross section**

C.S Dimension – For Length 60.60 m, breadth is 20.2 m (at base and up to 50 m height), Length is 45.45 m with breadth is 15.15 m (from 50 m to 100 m height) and Length is 30.30 m with breadth is 10.1 m (from 100 m to 150 m height)

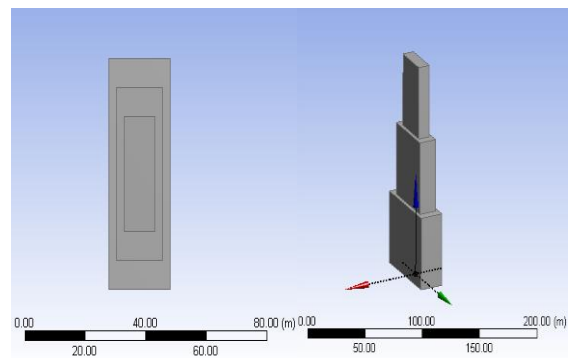


Fig. 8 Plan and isometric view of Stepped rectangular model

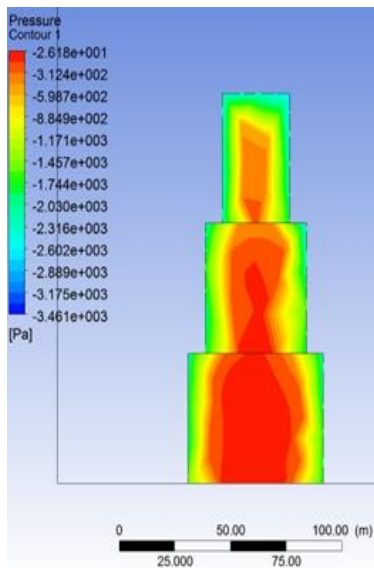


Fig. 9 Pressure Contour front view of Stepped rectangular model

**F Building With Two Steps at Corner**  
 C.S Dimension – Length is 60.60 m, breadth is 20.2 m, and Corner has two steps of 2.5 m × 2.5 m dimensions

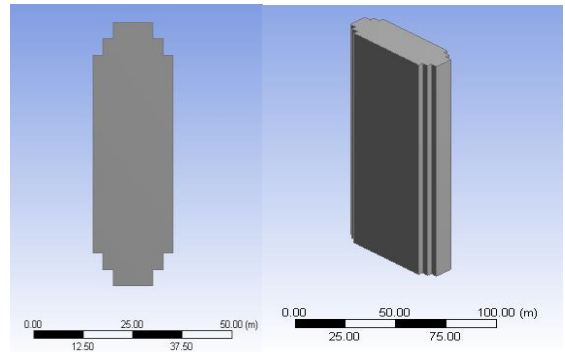


Fig. 12 Plan and isometric view of two steps at corner rectangular model

**E Building With Single Step at Corner**  
 C.S Dimension – Length is 60.60 m, breadth is 20.2 m and has a single step of 2.5 m × 2.5 m on vertical edges

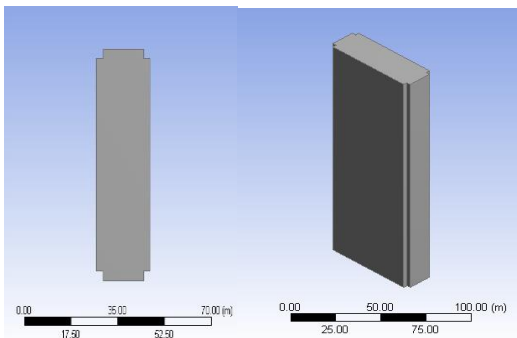


Fig. 10 Plan and isometric view of rectangular model with Single Step at Corner

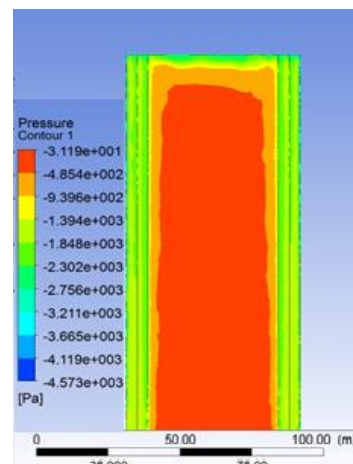


Fig. 13 Pressure Contour front view of rectangular model with two steps at Corner

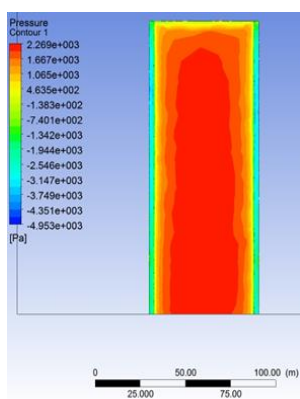


Fig. 11 Pressure Contour front view of rectangular model with Single Step at Corner

**G Building With Opening**

C.S Dimension – Length is 60.60 m, breadth is 20.2 m, opening of dimension 27 m × 27 m at a height of 95 m from base.

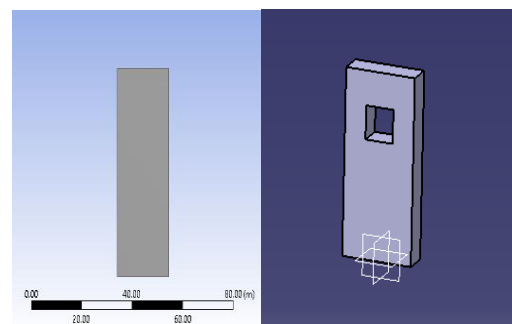


Fig. 14 Plan and isometric view of rectangular model with opening



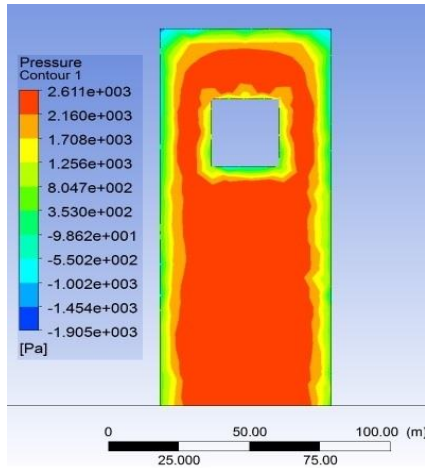


Fig. 15 Pressure Contour front view of model with opening

TABLE 1 Summary of analysis of building models with different

Sl. No.	Aerodynamic Modification done on building	Max. drag Coefficients ( $C_d$ )	Max. Drag Force on building (kN)	Moment about base (kNm).
1	Building with Chamfered Corner	1.38734	16773.58	1850.927
2	Building With Rounded Corner	0.892394	10789.44	595.8162
3	Building With Tapered Faces	1.479649	14766.01	334.1602
4	Building With Stepped Cross Section	1.540090	15295.27	1340.809
5	Building With Single Step At Corner	1.364332	16495.39	1279.759
6	Building With Two Step At Corner	1.613491	19507.81	105.87437
7	Building With Opening at Top	1.88587	21549.76	1421.834

### V CONCLUSIONS

An appropriate choice of building shape can result in a significant reduction of aerodynamic forces by changing the flow pattern around the building. This way of treatment can moderate wind responses when compared to the original building shape.

- From the wind engineer’s point of view, architectural modifications such as setback, tapering and sculptured building tops are very effective design methods of controlling wind excitation and many of the most elegant and notable buildings.
- Architectural modifications to corner geometry, such as chamfered corners, rounded corners, tapered corner can also significantly reduce wind induced response of buildings.

- Addition of openings completely through the building, particularly near the top, is another very useful way of improving the aerodynamic response of that structure against wind.
- From the analysis carried out in the aerodynamic modification of building with rectangular C.S with rounded corners edges have the least drag.

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### REFERENCES

- [1] Ryan Merrick and Girma Bitsuamlak, “Shape Effects On The Wind-Induced Response Of High-Rise Buildings”, Journal of Wind and Engineering, Vol. 6, No. 2, July 2009, pp. 1-18
- [2] Yong chul Kim and Jun Kanda, “Characteristics of aerodynamic forces and pressures on square plan buildings with height variations”, Journal of Wind Engineering and Industrial Aerodynamics. Vol. 98 ,2010, pp. 449–465
- [3] B. Blocken and R. Ramponi, “CFD simulation of cross-ventilation flow for different isolated building configurations: Validation with wind tunnel measurements and analysis of physical and numerical diffusion effects”, Journal of Wind Engineering and Industrial Aerodynamics. , Vols.104–106 , 2012, pp. 408–418
- [4] Y.C. Kim et al, “Wind-induced responses of super-tall buildings with various atypical building shapes”, Journal of Wind Engineering and Industrial Aerodynamics., Vol. 133,2014, pp. 191–199R. Nicole, "The Last Word on Decision Theory," *J. Computer Vision*, submitted for publication. (Pending publication)
- [5] T. van Hooff et al., “CFD analysis of cross-ventilation of a generic isolated building with asymmetric opening positions: Impact of roof angle and opening location”, Journal of Wind Engineering and Industrial Aerodynamics.. Vols. 104–106 (2012), pp. 408–418
- [6] Yong Chul Kim et al., “Wind pressures on tapered and set-back tall buildings”, Journal of Wind Engineering and Industrial Aerodynamics, Vol. 39, 2013, pp. 306-321
- [7] Yukio Tamura et al., “Characteristics of internal pressures and net local roof wind forces on a building exposed to a tornado-like vortex”, Journal of Wind Engineering and Industrial Aerodynamics, Vol. 112, 2013, pp. 52-57
- [8] Anupam Chakrabarti et al., “Effect of interference on Wind loads on Tall buildings”, Journal Of Academia And Industrial Research., Vol. 1(12), May 2013, pp. 758–760
- [9] Young-Moon Kim et al, “Dynamic responses of a tapered tall building to wind loads”, Journal of Wind Engineering and Industrial Aerodynamics, Vol. 90 ,2002 ,pp. 1771–1782.
- [10] Agerneh K. Dagneu et al., “LES evaluation of wind pressures on a standard tall building with and without a neighboring building”, The Fifth International Symposium on Computational Wind Engineering (CWE2010) Chapel Hill, North Carolina, USA May 23-27, 2010
- [11] Browne, M. Suresh Kumar, K. 2005. "Effect of Comer Balconies on Wind-Induced Response of Tall Buildings". The 10th Americas Conference on Wind Engineering. Baton Rouge, Louisiana.
- [12] IS : 875 (Part 3) - 1987, Indian Standard Code of Practice for Design Loads (Other than Earthquake) for Building and Structures, Bureau of Indian Standards, New Delhi
- [13] Matin Alaghmandan1 et al, “The Future Trend of Architectural Form and Structural System in High-Rise Buildings”, Architecture Research, 2014, Vol 4(3),pp.55-62
- [14] Agerneh K. Dagneu et al, “Computational evaluation of wind pressures on tall buildings”, 11th Americas Conference on Wind Engineering San Juan, Puerto Rico, June 22-26, 2009