© 2015 IJEDR | Volume 3, Issue 4 | ISSN: 2321-9939

A Study of Wind Pressure on Tall Buildings and Its Aerodynamic Modifications against Wind Excitation

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***Abstract* - Bluff body aerodynamics plays a critical role in the determination of the principal response of a high-rise building. 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 optimal external shape and structural system for tall buildings subject to aerodynamic loads. The platform is intended to bridge the gap between the traditionally manual conceptual design stage and the more automated detailed design stage in an attempt to define a new generation of innovative tall buildings. The project work deals with the analysis of tall buildings with ANSYS Computational Fluid Dynamics (CFD). The model provided by ANSYS is used to find the behavior of building when subjected to wind load. A comparison is made between the effect of building shape on the wind-induced response of a structure through a comprehensive investigation of the building of different cross section based on the CFD results. Finally, 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, are done.**

***Index Terms* - Tall Building, 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

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. Architects' imaginative reinterpretations of the building type, the inadequacy and high cost of land in urban areas, the desire to prevent the disorganized urban expansion, the need to preserve significant agricultural production, the concept of skyline, influence of 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 equipments, 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, 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 defections 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

II.b Scope of study

Wind is a phenomenon of great complexity because of the many flow situations arising from the interaction of wind with structures. Wind exerts forces and moments on the structure which results in decrease in comfort level of occupants. with the use of finite volume method in optimum design of shape of structures, which range from some relatively simple problems to the problems of increased complexity.

III STRUCTURE MODELLING

III.a Description of Software Used

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.

III.b Model Parameters

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.

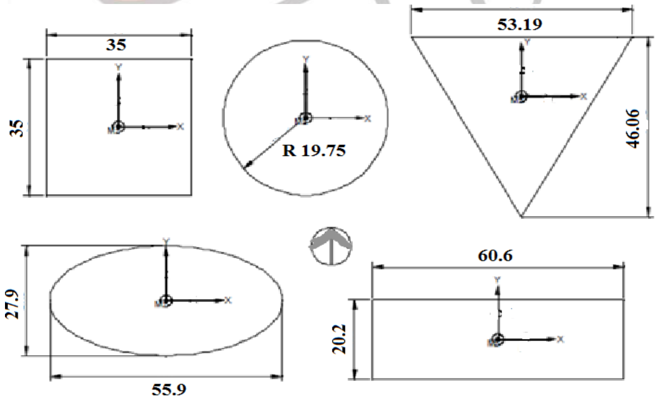

Fig.1. Dimensions of basic building models

III.c Domain and Boundary Conditions

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.

Table1 Summary of simulation model

Sl.No.	DESCRIPTION	DETAILS
1.	Reynolds number	1.9 E+6 – 17.8E+6
2.	Type of solver	Pressure based-SIMPLE scheme
3.	Turbulence model	Standard k-ε
4.	Inlet flow velocity	165 kmph (46.6 m/s)
5.	Mesh	Unstructured tetrahedral meshing
6.	Material properties of fluid domain (air)	Density- 1.225 kg/m^3 Viscosity- 1.7894e-05 kg/m-s

IV RESULT OF THE CFD ANALYSIS ON BASIC BUILDING MODELS

The wind responses for each of the building models were derived and is hoped that the findings will encourage designers to consider wind performance early in the design process. Pressure contour for building models having various cross sections is shown in the Figure 2.

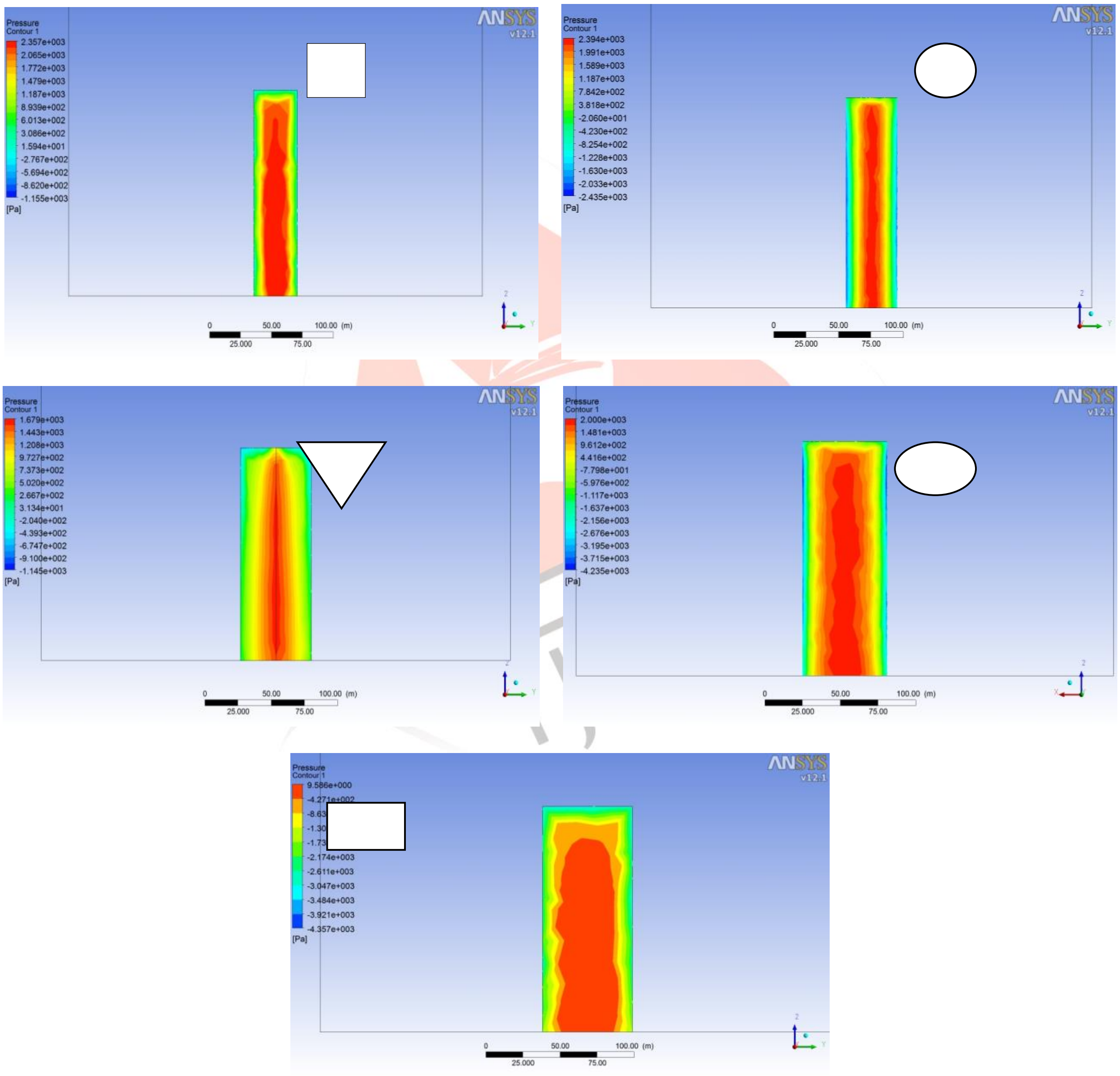

Fig.2. Pressure contours of building models with different C.S

Table 2 shows the maximum drag coefficient, drag force and the moment about z axis of the building at a speed 165 kmph.

Table 2 Results of Base Models

Cross-Sectional shape of building	Max drag Coefficients	Maximum Force (kN)	Moment about z axis, M_z (kNm).
Square	1.3942	9735.577	790.97519
Circular	0.6375	5023.856	127.4201
Triangular	1.1733	12450.867	1188.4518
Elliptical	0.9627	10737.206	1013.0521
Rectangular	1.8886	22834.384	2257.402

The results described above outline the general wind loading characteristics of simplistic building shapes. The data indicate certain shapes that are prone to wind phenomena, such as vortex-shedding, which can generate high dynamic loads and govern the design. Elliptical, triangular and rectangular shaped buildings were identified as being more susceptible to high torsion loading.

V. 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).

V.(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.

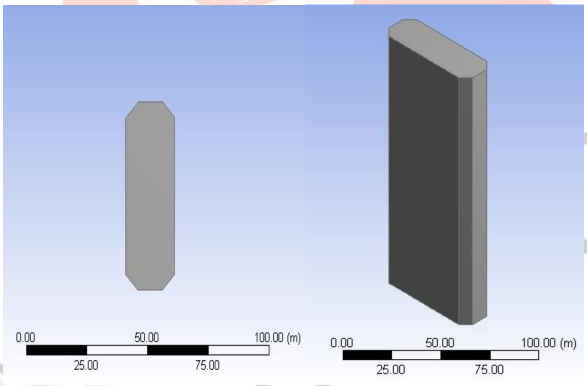

Fig. 3 Plan and isometric view of rectangular model with chamfered corner

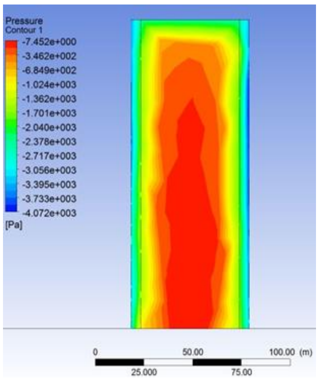

Fig. 4 Pressure Contour front view of rectangular model with chamfered corner

V.(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

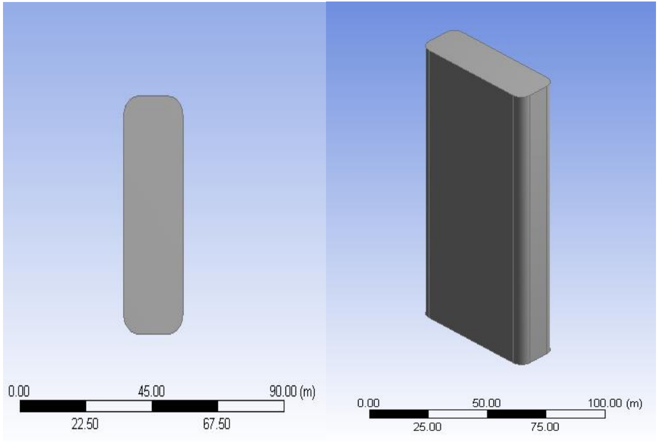

Fig. 5 Plan and isometric view of rectangular model with rounded corner

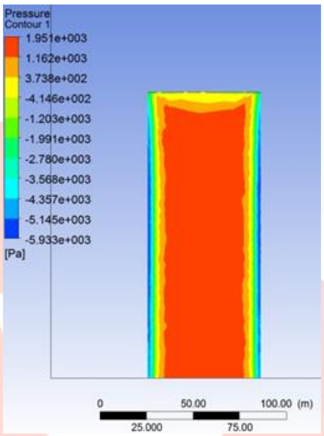

Fig. 6 Pressure Contour front view of rectangular model with rounded corner

V.(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

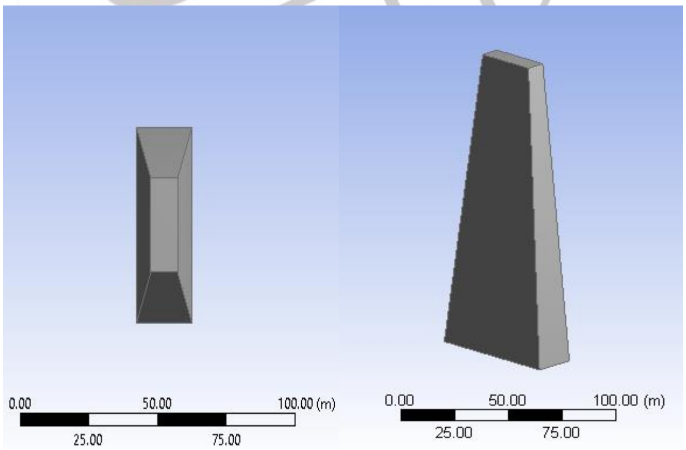

Fig. 7 Plan and isometric view of tapered rectangular model

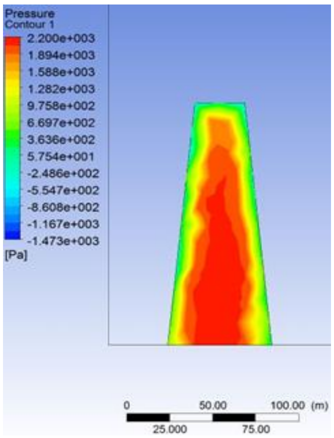

Fig. 8 Pressure Contour front view of tapered rectangular model

V.(d) Building with Stepped Cross section

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

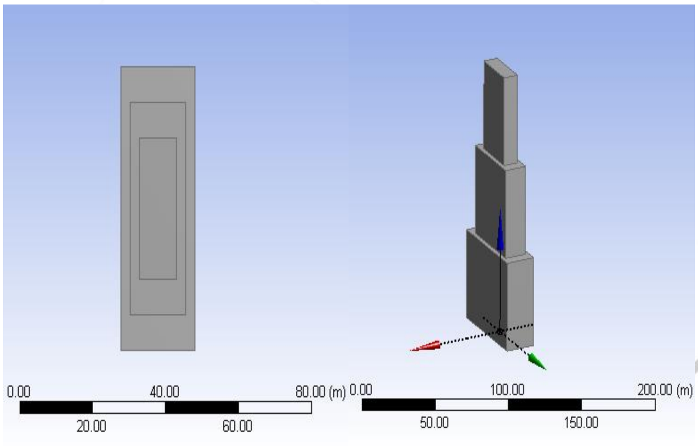

Fig. 9 Plan and isometric view of Stepped rectangular model

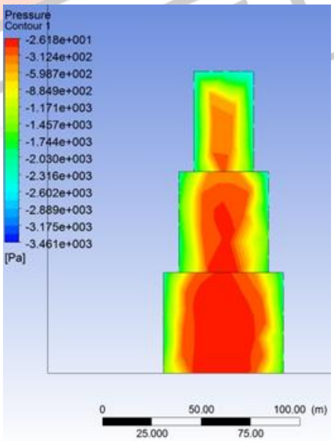

Fig. 10 Pressure Contour front view of Stepped rectangular model

V.(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

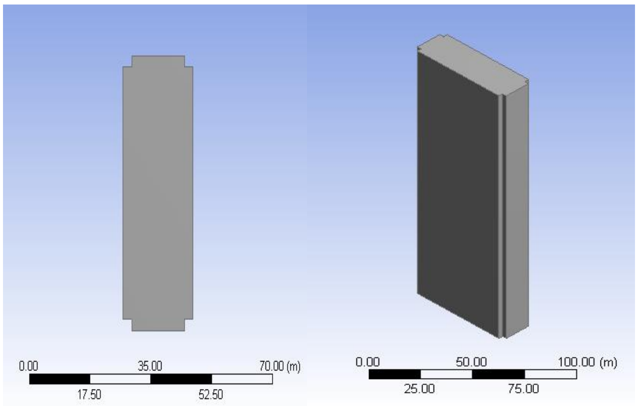

Fig. 11 Plan and isometric view of rectangular model with Single Step at Corner

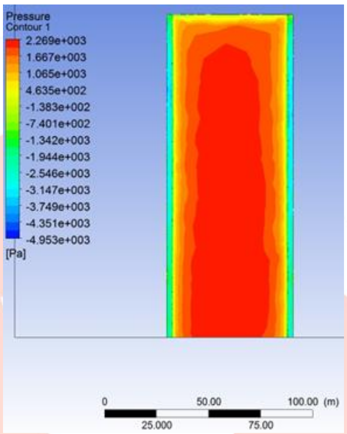

Fig. 12 Pressure Contour front view of rectangular model with Single Step at Corner

V.(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

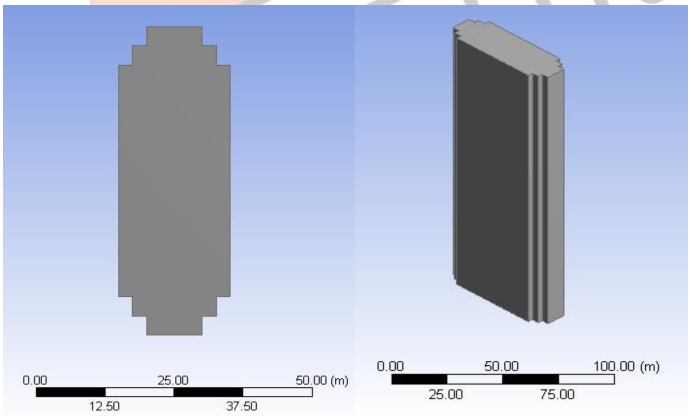

Fig. 13 Plan and isometric view of two steps at corner rectangular model

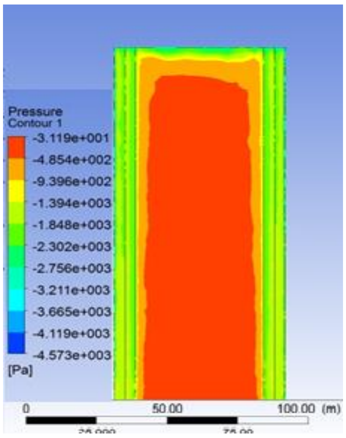

Fig. 14 Pressure Contour front view of rectangular model with two steps at Corner

V.(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.

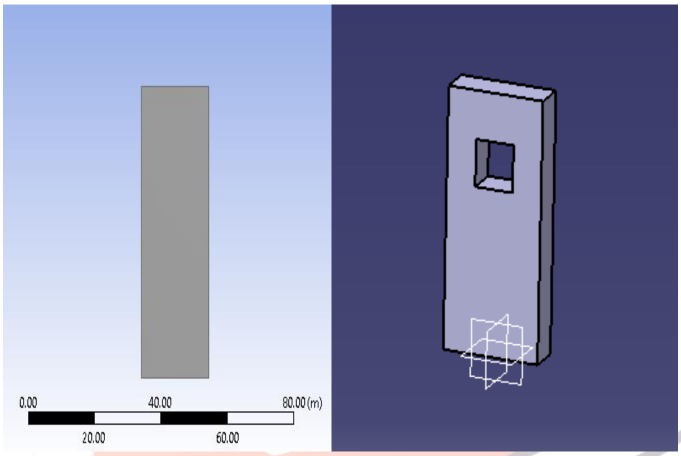

Fig. 15 Plan and isometric view of rectangular model with opening

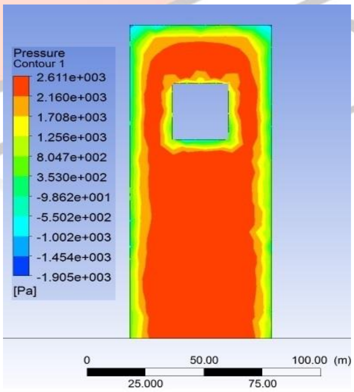

Fig. 16 Pressure Contour front view of rectangular model with opening

Table 3 Summary of analysis of building models with different

Serial. No.	Aerodynamic Modification done on building	Maximum drag Coefficients (C_d)	Maximum Drag Force on building (kN)	Moment about base (kNm).
1	Building with Chamfered Corner	1.3873444	16773.576	1850.9274
2	Building With Rounded Corner	0.89239417	10789.438	595.8162
3	Building With Tapered Faces	1.4796495	14766.007	334.16016
4	Building With Stepped Cross Section	1.5400902	15295.247	1340.8096
5	Building With Single Step At Corner	1.3643321	16495.394	1279.7598
6	Building With Two Step At Corner	1.6134911	19507.806	105.87427
7	Building With Opening at Top	1.88587	21549.764	1421.8341

VI. 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.

- Tall buildings cause accelerated wind at ground level, which may influence the comfort and safety of the pedestrians. The overall massing of the building and its orientation towards the prevailing wind are critical factors that dictate how much the impact will be.
- Because of the enormous variety of the possible shapes in building design and their different interactions with the surrounding structures, it is difficult to develop simple general rules for the preference of shapes as a tool for reducing wind related problems. In this respect, the wind tunnel testing is usually the best way for determining project specific wind loads and building motions.
- 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. The study carried out in this paper will be helpful for finding more efficient use of the techniques in Optimization of tall structures for wind loading.

VII. ACKNOWLEDGEMENT

First of all, I would like to thank Almighty God and my family. I express my sincere thanks and regards to Mr. Jithin P N, Assistant Professor, Dept. of Mechanical Engineering, RSET Kakkanad and Ms. Anna M Thomas, Assistant Professor, Dept. of Civil Engineering, MBITS Nellimattom for thier constant encouragement throughout my work. I would like to extend my heartfelt gratitude to all the staff members, Dept. of Civil Engineering, MBITS Nellimattom for their direct and indirect support during this work. I would also like to thanks my friends for their valuable co-operation and suggestions.

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