Aerodynamic Shape Optimization of a Tall Building

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ABSTRACT

In the realm of structural engineering, the aerodynamic design of tall buildings is crucial for ensuring stability against wind forces. These man-made structures, known as bluff bodies, require careful consideration of lateral loads during design to maintain their integrity and urban functionality. To mitigate adverse wind effects, various aerodynamic modifications are employed, such as altering cross-sectional shapes and corner designs. In a study focused on Kanpur, four distinct design strategies were analyzed, highlighting the significance of aerodynamic adjustments in enhancing the durability and aesthetic of high-rise buildings.

Keyword: *Aerodynamic shape, wind load, Drag coefficient ,Model analysis, Drag Force, Tall structure*

1. INTRODUCTION:

The lateral load on the buildings plays an important role in the design of high structures. The structures response to wind depends on the wind's characteristics. Tall buildings, usually designed for office or commercial use, are among the most distinguished definitions of space in American urbanism's twentieth-century architectural history. According to National Building Code 2005 building having height more than 15m of India is called a high-rise building. Vertical growth of buildings has become an ultimate option available due to the rapid growth of population, the high cost and, for improvement in aesthetic view of city and restriction in horizontal growth due to less space. The Wind can be defined as the large-scale horizontal movement of free air.

In metropolitan cities the creative reinterpretations of the building type by architects, the inadequacy and high cost of land in urban areas, the desire to prevent disorganized urban expansion, the need to maintain significant agricultural production, the idea of skyline, the impact of cultural significance and prestige have all contributed to the fact that buildings may produce excessive construction movement, the dynamics nature of wind is a critical issue, negatively affecting occupancy comfort and serviceability.

Now a days, it is assumed that tall buildings are symbol of power, technology, landmark of metro cities but beside of this if care was not taken before construction of these buildings, it can cause undeniable negative effects on the quality of urban life. 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 the natural world, confidence in technology and a mark of national pride.

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 equipment's, 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 the building shape, i.e. an appropriate choice of building form, could moderate wind responses when compared to original building shape.

1.1 Minor Modifications

corner roundness, corner recession, chamfered corners, fitting of small fins and vented fins to the corners and slotted corners are the example of minor modification The researcher finds that small corner cut, and recession are significantly effective to prevent aero-elastic instability by increasing the aerodynamic damping. For a deep depth rectangular prism, however, this effectiveness by the corner modifications is insignificant. The benefits of corner modification have remained debated, for these modifications to buildings corners, in some cases, are ineffective and even have negative effects according to wind direction. Mentions corner modifications in Taipei 101 building provide 25% reduction in base moment when compared to the original square section. Holmes (2001) finds that chamfers of the order of 10% of the building width reduces both the along wind response by 40% and the across wind response by 30%, when compared to the rectangular cross-sectional shape without any corner modification.

1.2 Major Modification

Modifications such as corner-recession, chamfered corner, helical shape, tapered shape, setback shape are the example of major modification. This modification can be grouped into two types according to its effect on structural and architectural concept. Therefore, the major modification, which considerably affects the architectural and structural design of tall buildings, contains tapering, or setbacks along the height, sculptured building shape, openings, varying the shape of buildings, and twisting of building. Building codes admit a reduction of the wind pressure design loads for circular or elliptical buildings up to 40% of those of rectangular buildings.

2. ANALYSIS:

Since the analysis of basic cross section shapes shows that buildings with rectangular shapes have 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 have a height of 180 m. The CFD analysis of modified shapes are conducted at 39 m/s (144.4 kmph). After the model formation CFD analysis is done by Ansys software and output is noted. In this research work major modification is considered for basically area of Uttar Pradesh where wind speed is 39 m\s so for analysis purpose four model is consider which detail are given below. Fig 1 presents the flow diagram of this study.

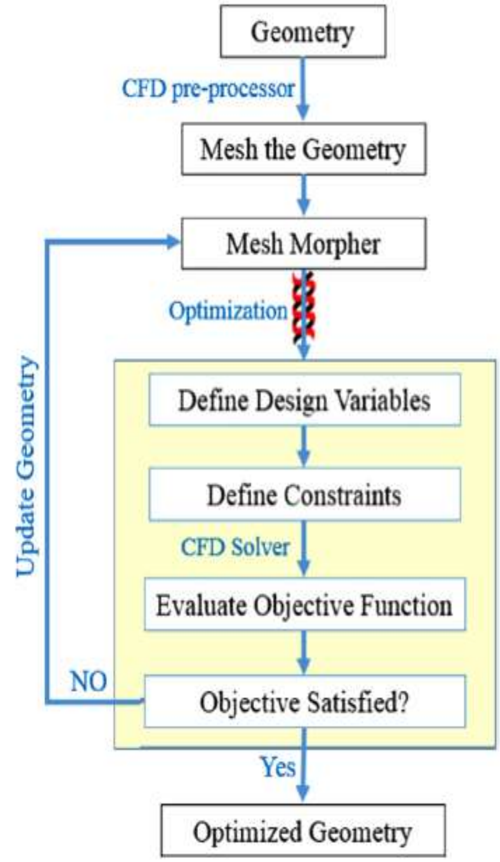

Fig.1 Aerodynamic shape optimization utilizing CFD

Table 1 Summary of simulation model

S.No.	Description	Detail
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	140.4 kmph (39 m/s)
5	Mesh Unstructured	tetrahedral meshing
6	Material properties of fluid domain (air)	Density- 1.225 kg/m3
7	Viscosity-	1.7894e-05 kg/m-s

2.1 Building with Single Step at Corner

C.S Dimension –

Length is = 150 m, width is =20 m with a single step of 2.5 m × 2.5 m on vertical

2.2 Building with Stepped Cross section (Case 2)

C.S Dimension: Length is = 60 m and width is = 20 m (at base and up to 50 m height)

Length is = 45 m and width is =15 m (from 50 m to 100 m height)

Length is = 30 m and width is= 10m (from 100 m to 150 m height)

2.3 Building with Rounded Corner (Case 3)

C.S Dimension: Length is= 60m, width is =20 m, Corner rounded at a radius of 5 m

2.4 Building with Tapered faces (Case 4)

C.S Dimension: Length is = 60 m (at base), width is =20m (at base), Tapering angle 2 degrees in front and rear faces and 6 degrees on other two faces

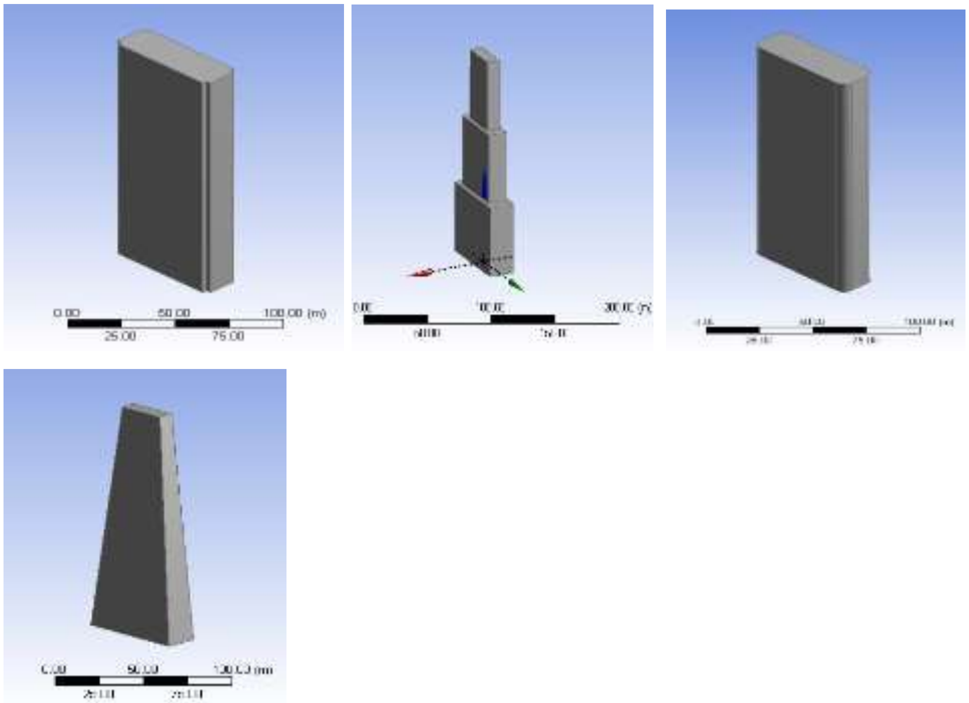

Fig 2 Different building models

Table -1 Element and Node detail of different cases

S.No.	Model Mesh	Number of Elements	Number of Nodes
1	Building With Single Step at Corner (Case1)	8945474	9107692
2	Building With Stepped Cross Section (Case2)	8470921	8865089
3	Building With Rounded Corner (Case 3)	9098433	9163888
4	Building With Tapered Faces (Case4)	8870938	9088336

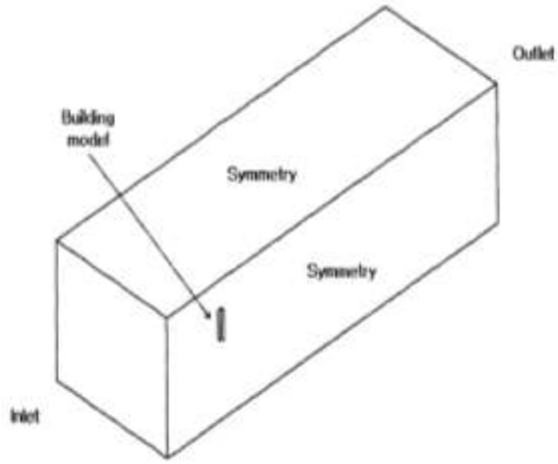

Fig 3. Numerical Domain

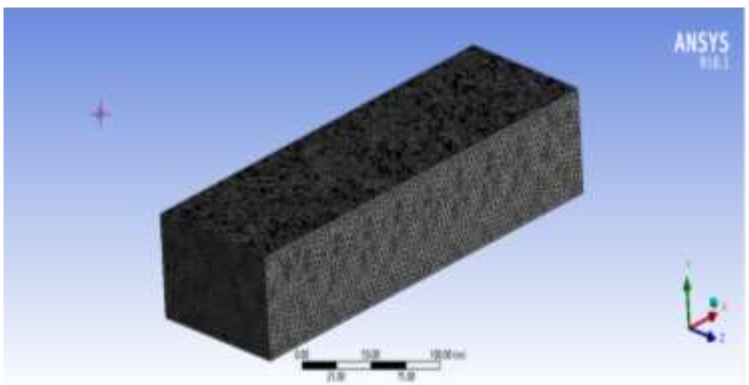

Fig 4. Mess Generation of structure model

3. RESULT

wind force coefficient and wind moment coefficient acting on the wall of each of various models. The reason that wind force coefficient of each model has the mean value of about 0.15 to 0.18 is that a certain force acts on the front face of a building model. As vortices are shed alternatively first from one side and then the other side after the flow develops, the feature that coefficient values fluctuate within certain ranges is shown. Wind force coefficient acting on left and right side of a building model has a mean value of about 0.0. For the force acting on these sides, vortices are shed alternatively to the left and the right side of a model, thereby inducing pressure difference. Like wind force coefficients in the direction of the wind and two sides of a building, wind moment coefficient shows similar patterns.

3.1 Results of change drag coefficient of different model of tall structure.

From the analysis carried out in the aerodynamic modification of building with rectangular C.S with rounded corners edges have the least drag

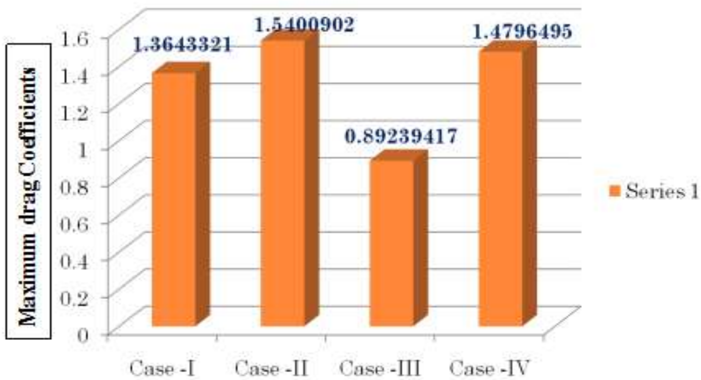

Chart -1 Variation of drag Coefficients at different height.

3.2 Results of change maximum drag Force of different model of tall structure

From the analysis carried out in the aerodynamic modification of building with rectangular C.S with rounded corners edges have the drag force 10789.438 kN which is least.

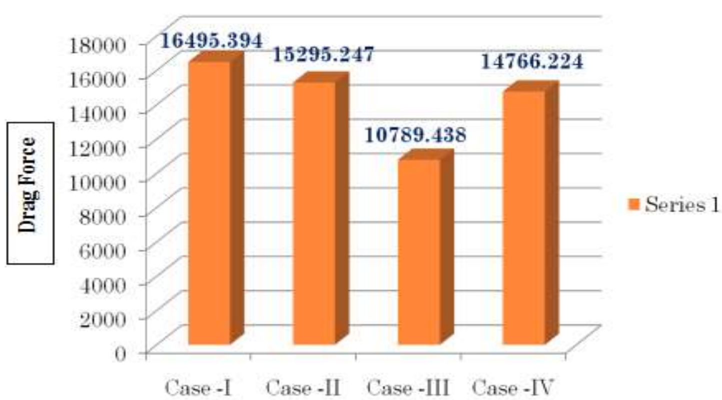

Chart -1 Variation of drag force at different height (kN)

3.3 Results of change in Bending moment of different model of tall structure

From the analysis carried out in the aerodynamic modification of building with rectangular C.S with rounded corners edges have the least moment equall to 1618.41 kN m.

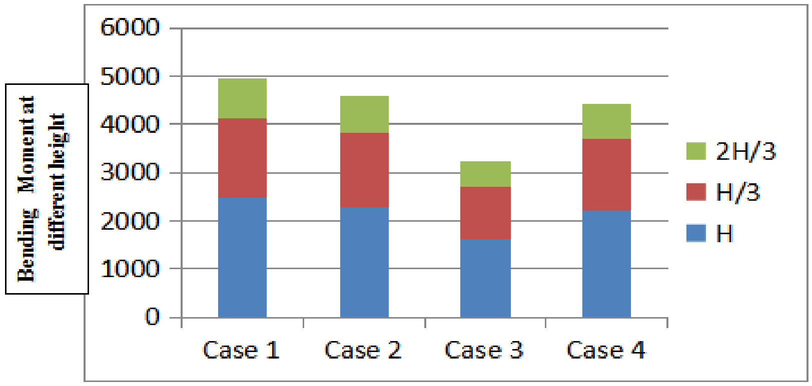

Chart -1 Variation of bending moment at different height (kN-m)

4. CONCLUSIONS

After calculating the factors, it was found that, Case-III (building with tapered faces) all three values are coming minimum such as for case-I Drag coefficient is 0.89239417, drag force is 10789.438 kN and bending moment is 1618.41kN m from the analysis carried out in the aerodynamic modification of building with rectangular C.S with rounded corners edges have the least drag.

1) The effect of increase in length on the frequency is reciprocal in nature as the length increases the value of Tall buildings cause accelerated wind at ground level, which may influence the comfort and safety of the pedestrians.
2) 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.
3) The overall massing of the building and its orientation towards the prevailing wind are critical factors that dictate how much the impact will be.

Architectural modifications to corner geometry, such as chamfered corners, rounded corners, tapered corners can also significantly reduce wind induced response of buildings.

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