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Research paper

Study of Building Aerodynamics for Designing Natural Ventilation System

Anuj Gupta[1]*, Bhavyanidhi Vats[2] , Anwer Ahmed[3] , Sushant Verma[4] , Vipul Kumar Sharma[5]

[1,3,4,5] G. L. Bajaj Institute of Technology & Management, INDIA
[2] Moradabad Institute of Technology, INDIA
**Corresponding author E-mail: gupta1992anuj@yahoo.in*

Abstract

Study of building aerodynamics is an important part of building design because aerodynamic factor helps us to design considering wind velocity. If building has not been designed with this factor, wind may damage external walls of the building. In this study, 2D and 3D models of building in three different shapes has been considered for the simulation. Cylindrical, cuboidal and back stair type building has been considered with steady state, laminar air flow and building walls with no slip condition problem. With the study of air flow in the surrounding of the building, effect of air flow on the ventilation system will be concluded in this paper.

Keywords: Building Aerodynamics; Building Ventilation; Air Flow affecting Ventilation System.

1. Introduction

With the rise in height of the building, importance of the building aerodynamic factor has been increased. With the proper designing of building, we can reduce the impact of winds on the walls which helps in increasing maintenance and life of the outer walls. Building aerodynamic factor also helps in decreasing load on ventilation system and provides natural ventilation. The flow of air has been induced by the pressure gradient across the buildings. Difference in pressure can be generated with two different methods as one by examine external wind flow and other as temperature gradient between indoor and outdoor air [1].
Impact of wind on the external walls of the tall building increases which effects strength of the building and life of the building material. In 1981, Zdrakovich discussed about the aerodynamic treatment with the circular shaped buildings for decreasing impact of winds on the buildings [2] while in 2003, Abalos et al. discussed about the rotation of the aerodynamic shield about an axis according to the direction of the winds for the reduction in the impact of winds [3].
In 2001, Holmes concluded that the crosswinds and torsional increased with the buildings having high rise [4]. In 2009, Tse et al. discussed about the relation between building aerodynamics and cost of the building [5].
In 1988, Melbourne discussed about the chamfering of the corners and its effect on the building performance [6] while Kawai discussed about the corner cut in the design of the building [7]. In 2004, Gu et al. also investigated corner cuts on the building and concluded that peak amplitude of the across-wind force decreases with this modification [8]. In 2006, Suresh et al. discussed about the effect of the double step corner and concluded that across-wind and along-wind forces decreases by 40% and 20% respectively [9]. Tse et al. also compared two different modifications on the corner of the building and concluded that recessed corners are more efficient in comparison with chamfered corners [5].
In 1997, Cooper et al. studied the effect of unsteady wind load on a tapered building and concluded that tapered building shows much lower level of unstable aerodynamic damping [10] while Kim et al. (2002) and You et al. (2007) investigated and compared the effect of wind on tapered and square plan shaped building. They had concluded that wind pressure along the direction of wind flow reduced by 10% - wind pressure along the direction of wind flow reduced by 10% - 30% [11,12]. In 2008, Kim et al. had simulated tapered building with the taper ratio of 5%, 10% and 15% and compared with the cuboidal building structure in a wind tunnel. During his study, he observed reduction in velocity impact on building [13].
In 1987, Mohsen et al. discussed about the effect of building aerodynamics on ventilation system. He had simulated his model using wind tunnel and concluded that ventilation efficiency is inversely proportional to the Reynolds number [14]. In 2002, Jiang et al. had computed a CFD model for the study of effect of building aerodynamics on ventilation system and concluded that difference in pressure coefficient across the building is constant when direction of wind varied with time [15]. In 2003, Allocca et al. concluded that sometimes wind might not be effective for designing ventilation system because it may reduce the effect of buoyancy force [16].

2. Boundary Condition and Computational Model

For understanding air flow impact and study of air flow around a building few assumptions were considered before starting simulation such as:

1. Steady state condition.
2. Air flow is laminar.
3. No slip on building walls.
4. Building walls are plane and smooth, no rough surface.

oundary conditions have been applied for the simulation in 2D and 3D model are same in all building design. ANSYS has been used for the simulation of the models. Wind flow temperature and velocity is considered at 300K and 2m/s respectively.

For the simulation of cuboidal shaped building, we had considered 2D and 3D models of building. 3D model was considered for the study of impact of wind on the building, while 2D model was considered for the study of air flow. SolidWorks was used for the 3D modelling of the building. Figure 1 is representing the 3D model of the building while figure 2 (a, b and c) are representing dimensions of the building in all three views (front, side and top). All dimensions are in feet. 2D model was designed for the study of flow analysis around the building. Figure 3,4 are representing side view model for the analysis of air flow in the front of building. Figure 5 is representing top view of model for the analysis of flow of air in the sides of the building. Direction of air is represented in all figures.

Figure 1: Cuboidal Building

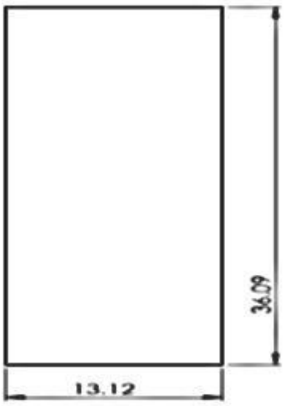

Figure 2 (a): Cuboidal Building Front View

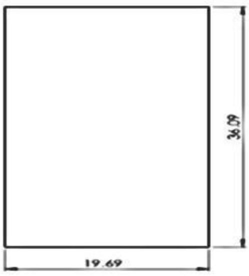

Figure 2 (b): Cuboidal Building Side View

Figure 2 (c): Cuboidal Building Top View

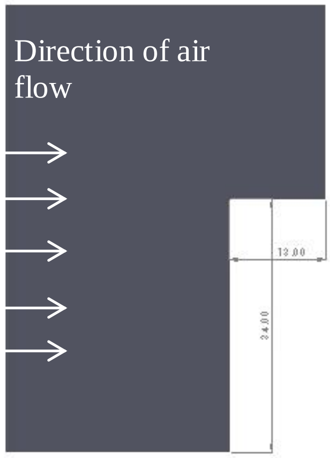

Figure 3: Side View 1

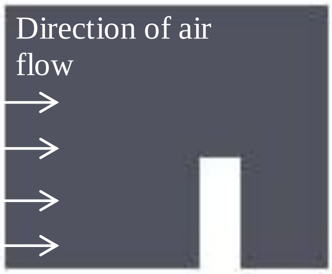

Figure 4: Side View 2

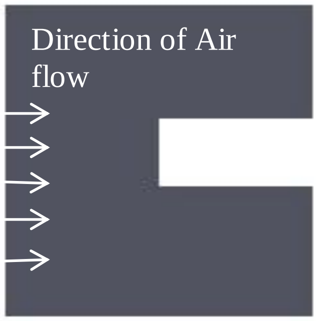

Figure 5: Top View

We had considered 2D model for the study of flow analysis around the building while 3D model was considered for the analysis of pressure applied by the air flow on the walls of the building. SolidWorks was used for the 3D modelling of the building. Figure 6 is representing the 3D model of the building while figure 7, 8 and 9 are representing dimensions of the building in all three views (top, side and front view). All dimensions are in feet. Figure 10 is representing top view of model for the analysis of flow of air in the sides of the building. Direction of air is represented in all figures. Flow analysis for the circular building from the front will be same as for the cuboidal building.

Figure 6: Model for the Cylindrical Building

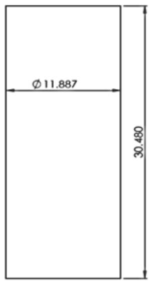

Figure 7: Front View of the Model

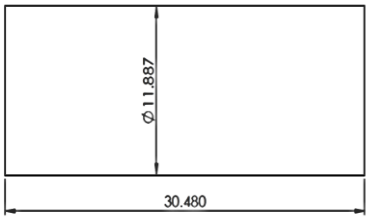

Figure 8: Side View of the Model

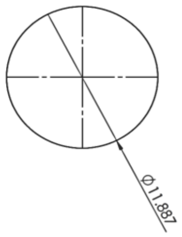

Figure 9: Top View of the Model

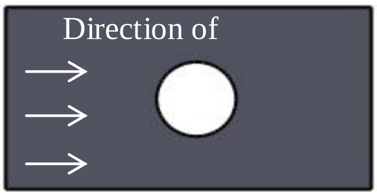

Figure 10: 2D model for air flow analysis

For our study of building design having minimum load on the walls, we had proposed the back stair design of the building. Model is having reduction of 6 ft. on each floor of three storey building.
We had considered 2D model for the study of flow analysis around the building while 3D model was considered for the analysis of pressure applied by the air flow on the walls of the building.
SolidWorks was used for the 3D modelling of the building. Figure 11 is representing the 3D model of the building while figure 12 and 13 are representing dimensions of the building in all three views (top, side and front view). All dimensions are in feet. Figure 14 is representing top view of model for the analysis of flow of air in the sides of the building. Direction of air is represented in all figures. Flow analysis for the back stair building from the side will be same as for the cuboidal building.

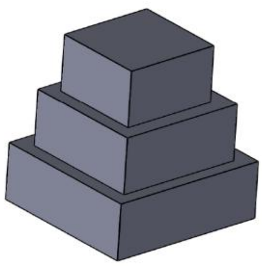

Figure 11: 3D model of the back stair building

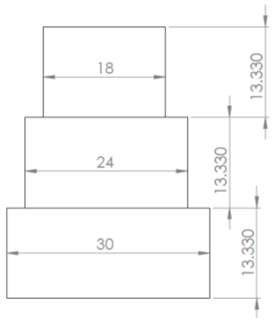

Figure 12: Front View of model

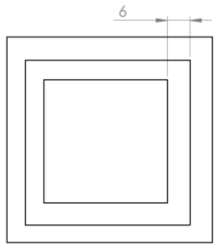

Figure 13: Top View of the model

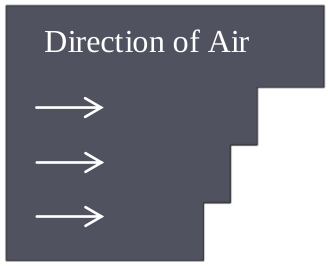

Figure 14: 2D model for air flow analysis

3. Validation and Simulation

In 2013, Borders et al. [17] had studied the effect of wind on the three shapes of buildings i.e. rectangular building, tapered building and back-stair building. He had simulated his model using flow simulation integrated with SolidWorks. He analyzed his models for the steady state conditions under laminar flow of the fluid considering no slip. Following parameters were applied for performing simulation:

1. Tapered building corners were tapered 10%.
2. Rectangular building is having 10° chamfered.
3. In back stair building, 1m2 had been removed every 30m.
4. Wind velocity had been considered at 30 m/s.

Simulation study of cylindrical building for the wind pressure is represented in figure 15, for cylindrical in figure 16 and for back stairs in figure 17. Variation of wind impact pressure with the other studies has been represented in figure 18. Minimum pressure of wind impact has been observed in back stair structure.

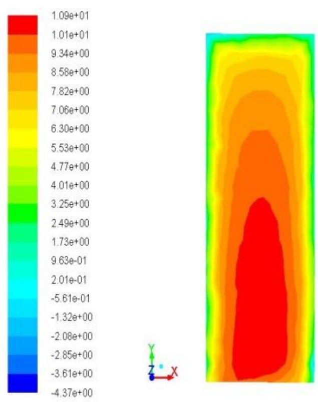

Figure 15: Pressure in front of Cuboidal Building

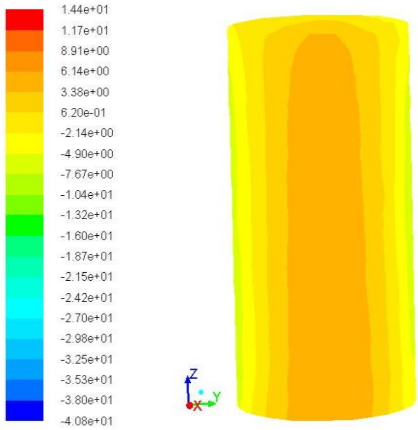

Figure 16: Pressure in front of Cylindrical Building

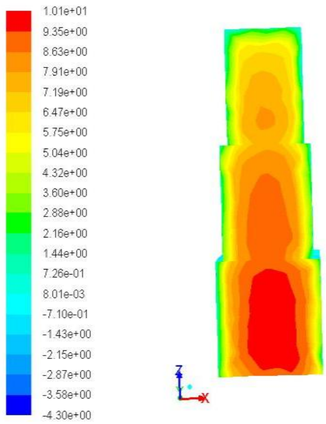

Figure 17: Pressure in front of Back Stair Building

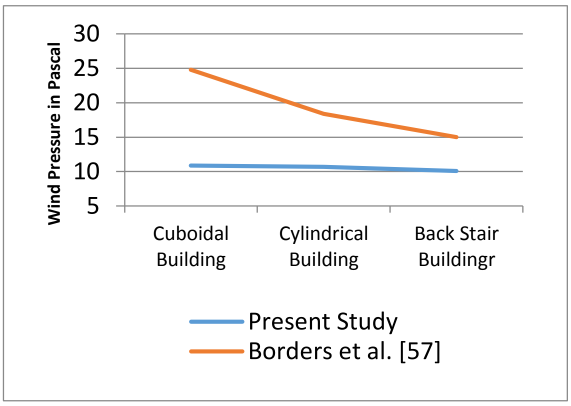

Figure 18: Comparison of wind pressure in different design of building

4. Result and Discussion

Flow analysis around the building has been completed in two parts, one will be for the air flow in front of the building, shown in figure 19 (a, b). In figure 20 (a, b), vortex formation due to edge of the building has been represented. From figure 19 (a), it has been observed that the flow of wind is moving away from the building due to which ventilation system needs to work more i.e. load on ventilation system increased while in figure 19 (b) it has been observed that flow of wind is not so high in back stair in comparison with cuboidal building i.e. load on the ventilation system has been decreased. Figure 20(a) representing the formation of vortex in cuboidal building which resist in the working of natural ventilation in a building. With a small modification in the roof design of model, figure 20 (b), back pressures has been developed which helps in the natural ventilation system. Due to low pressure in back side of building, efficiency of natural ventilation has been increased.

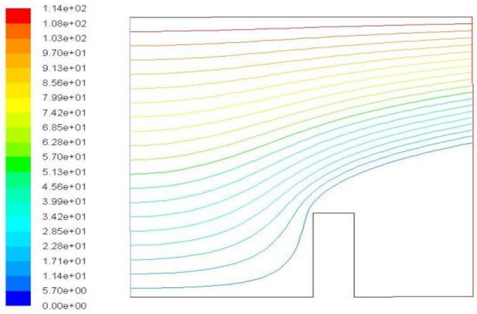

Figure 19 (a): Flow Analysis in Cuboidal building

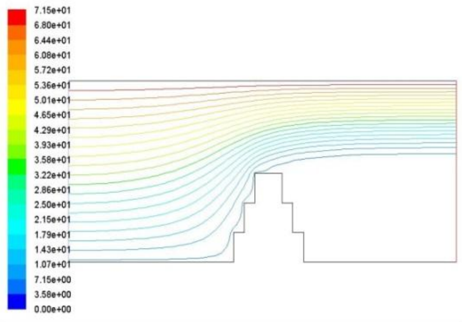

Figure 19 (b): Flow Analysis in back stair building

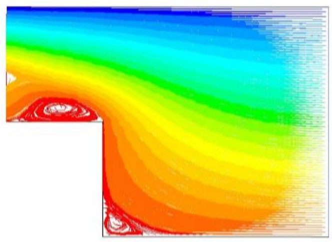

Figure 20 (a): ortex generation Cuboidal building

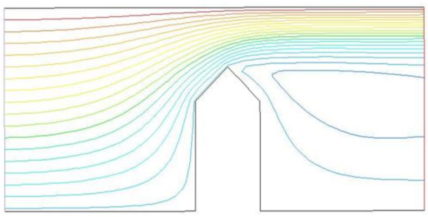

Figure 20 (b): Back pressure in back stair building

Flow analysis on the sides of the building has been shown in figure 21 (a, b). In figure 21 (a), vortex formation has been observed which provides vibration and low stability of building which has been resolved with the modification of the corners of the building shown in figure 21(b).

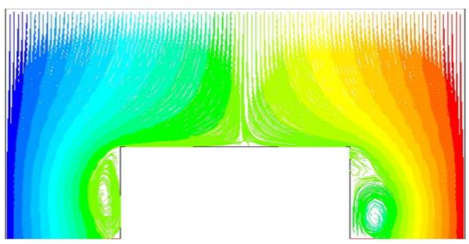

Figure 21 (a): Vortex generation on the sides of building

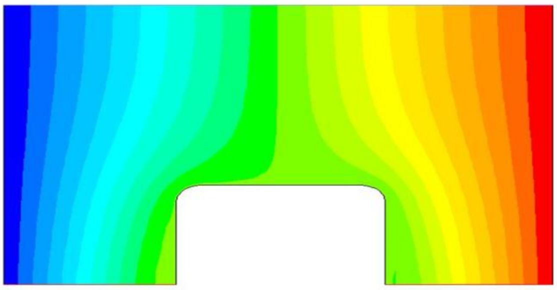

Figure 21 (b): Cuboidal building with rounded corners

5. Conclusion

After performing simulation for the models, we can conclude the following statements:

1. Minimum wind load has been observed in the case of back-stair building.
2. With a small modification in designing roof of the building, back pressure has been generated which helps in the circulation of air for the natural ventilation.
3. With the rounded corners, formation of the vortexes on the sides of the building has been eliminated. It helps in the reduction of causing building vibration due to wind.

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