

DESIGN AND STRUCTURAL ANALYSIS OF A WIND FENCE USED  
FOR PROTECTING MODULAR DATA CENTER FROM  
HIGH SPEED WIND

by

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## Abstract

# Design and Structural Analysis OF A Wind Fence Used For Protecting Modular Data Center From High Speed Wind

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Various data centers built in an open area are occasionally susceptible to different kinds of natural calamities. Wind, either from any of the sources like hurricane, tornado or storm is one of those ecological dangers with high speed flow. These high speed winds can be responsible for downed power lines, trees and collapsing of buildings as well, the wind may adversely impact a data center's structure. Windbreaker or wind fence is basically used to reduce the high speed of the wind resulting in the protection of structures or objects behind it. Some modular data centers which encounter problems of high speed winds may require such kind of barrier for the protection of their structure and to insure proper operation of the system.

The design of a barrier for such particular application comprises of various parameters such as materials used for barrier, barrier dimensions and moreover

the structure of the barrier. Additionally it should also be economical for construction. This paper discusses the design of new barrier for a modular data center application which can reduce wind speed of 44.7 m/s (100 mph) to 9 m/s (20mph) and also to check whether it can withstand such high wind load. The main aim is to design and analyze the barrier for modular data center using different materials which can sustain such high speed winds.

The model of wind fence and the modular data center were created in FloTherm 10.1. The CFD analysis was carried out for two different scenario of wind fence that is Single wall and Split wall. In Single wall configuration, the fence is kept on the ground before the modular data center and in split wall configuration, in which two wind fences, one on the ground and other on the roof before exhaust of datacenter were used. Various parameters such as fence dimensions and porosity were changed to see the effect of wind load on it.

For structural analysis, 3D model of the barrier is designed using PTC Creo Parametric 3.0 and stress analysis performed using ANSYS 16.1. The force from the wind speed is applied as a uniformly distributed load for carrying out structural analysis of the fence. An analysis is then carried out considering all the conditions relevant to the case to obtain optimal design parameters. Stress results obtained through analysis will be compared with yield strength of the material to check for the feasibility of the chosen material. The stress results of cases which consider different perforations of the barrier in the direction of the wind are

compared to obtain optimized design parameters for construction of the windbreaker.

The results from analysis of the barrier which include the stress analysis of the barrier and the amount of wind speed reduction will be used to compare different cases. The von-mises stress values should be checked against the permissible strength limit of the chosen material. Finally, multi-design variable optimization is carried out to find the most suitable design of the barrier for modular data center which can withstand such high wind load.

## Table of Contents

Acknowledgements.....	iii
Abstract.....	iv
List of Illustrations.....	xi
List of Tables .....	xiii
Chapter 1 INTRODUCTION.....	1
1.1    Modular Data Center .....	4
1.1.1    Introduction.....	4
1.1.2    Yahoo’s Chicken coop data center .....	6
Chapter 2 WIND FENCE .....	9
2.1 Effectiveness of windbreak.....	11
2.1.1 Effect of Height.....	11
2.1.2 Effect of density .....	12
2.1.3 Effect of Distance.....	14
2.1.4 Effect of Orientation .....	15
2.1.5 Effect of Length .....	15
Chapter 3 COMPUTATIONAL FLUID DYNAMICS ANALYSIS.....	17
3.1    Introduction.....	17
3.2    Governing Equations .....	17
3.3    Turbulence Modeling.....	19
3.3.1 LVEL Epsilon Model.....	19

3.3.2 K-Epsilon Turbulence Model .....	19
3.4 Mesh and Mesh Sensitivity .....	19
3.5 Parts in Flotherm 10.1 .....	20
3.5.1 Cuboid .....	20
3.5.2 Resistance .....	21
3.5.3 Enclosure .....	21
3.5.4 Source .....	21
3.5.5 Monitor Points .....	22
3.5.6 Region .....	22
3.5.7 Command Center .....	22
Chapter 4 SINGLE WALL CASE .....	24
4.1 Description of the Modular Data Center .....	24
4.2 Description of the Wind Fence .....	25
4.3 CFD Model .....	26
4.3.1 Dimensions of Model .....	26
4.3.2 Model Setup .....	26
4.3.3 Boundary Conditions .....	27
4.3.4 Meshing .....	27
4.4 Mesh Sensitivity Analysis .....	28
4.5 Different Cases .....	29
Chapter 5 CFD RESULTS .....	30



5.1	50% Perforation .....	30
5.1.1	Velocity Profiles .....	30
5.2	60% Perforation .....	32
5.3	70% Perforation .....	33
Chapter 6 FINITE ELEMENT ANALYSIS (SINGLE WALL) .....		35
6.1	Perforated Metal .....	35
6.1.1	Perforation Shape.....	36
6.1.2	Perforation Pattern .....	37
6.2	Model Setup.....	38
6.3	Mesh Sensitivity Analysis .....	40
6.4	Results.....	41
6.4.1	50% Perforated.....	41
6.4.2	60% Peforated.....	43
6.4.3	70% Perforated.....	44
Chapter 7 SPLIT WALL CASE .....		46
Chapter 8 FINITE ELEMENT ANALYSIS (SPLIT WALL) .....		48
8.1	10% Perforated Wall.....	49
8.2	20% Perforated Wall.....	51
8.3	30% Perforated Wall.....	52
Chapter 9 CONCLUSION .....		54
Chapter 10 FUTURE WORK AND SCOPE .....		56

References .....	57
Biographical Information.....	58

## List of Illustrations

Figure 1.1 HP Ecopod Module at eBay Data Center .....	5
Figure 1.2 Yahoo’s Compute Coop Data Center facility.....	8
Figure 2.1 Windbreakers used at airports .....	10
Figure 2.2 Wind speed behind a windbreaker as percentage of incoming speed .	11
Figure 2.3 Difference between solid wall and wall with density.....	14
Figure 4.1 Model of Modular Data Center .....	25
Figure 4.2 Single Wall Configuration.....	26
Figure 4.3 Meshed model .....	28
Figure 4.4 Mesh Sensitivity Analysis .....	28
Figure 5.1 At 0.5 m From MDC .....	30
Figure 5.2 At 2 m from MDC .....	31
Figure 5.3 At 3.5 m from MDC .....	31
Figure 5.4 Graph of X velocity vs Distance of wind fence from MDC.....	33
Figure 6.1 Different shapes of holes with different patterns .....	38
Figure 6.2 PTC Creo Model of wind fence.....	39
Figure 6.3 Stress Results for 50% Perforated .....	41
Figure 6.4 Deformation for 50% Perforated Wall .....	41
Figure 7.1 Split Wall schematic configuration .....	46
Figure 7.2 Graph of Speed Vs Distance of wall from MDC .....	47

Figure 8.1 Model of Upper Wall.....	48
Figure 8.2 Model of Lower Wall .....	49
Figure 8.3 Stress Results of 10% Lower & Upper Wall.....	49
Figure 8.4 Deformation for 10% Lower & Upper Wall .....	50

## List of Tables

Table 1.1 Saffir – Simpson Hurricane Wind Scale .....	3
Table 4.1 Dimensions of the Model.....	26
Table 4.2 Mesh Sensitivity Analysis .....	29
Table 5.1 50% Perforated Wall.....	32
Table 5.2 60% Perforated Wall.....	32
Table 5.3 70% Perforated Wall.....	33
Table 6.1 Mesh Sensitivity Analysis .....	40
Table 6.2 50% Perforated with Steel material .....	42
Table 6.3 50% Perforated with Aluminium material.....	42
Table 6.4 60% Perforated with Steel material .....	43
Table 6.5 60% Perforated with Aluminium material.....	43
Table 6.6 70% Perforated with Steel material .....	44
Table 6.7 70% Perforated with Aluminium material.....	44
Table 8.1 10% Perforated with Steel material .....	50
Table 8.2 10% Perforated with Aluminium material.....	51
Table 8.3 20% Perforated with Steel material .....	51
Table 8.4 20% Perforated with Aluminium material.....	52
Table 8.5 30% Perforated with Steel material .....	52
Table 8.6 30% Perforated with Aluminium material.....	53

## Chapter 1

### INTRODUCTION

Data centers are physical infrastructures used for storage of computer systems, servers, telecommunication systems and other components used for the company's information technology needs. For making sure the proper functioning of all the equipments in the data center, there is proper environmental control is required. Data centers often require backup power supply systems and effective cooling systems such as air conditioning, economizer cooling, since all these IT equipment stored in the data center produces large amount of heat within the data centers. As the whole data center structure is expensive which should be maintained and protected from all those factors that may cause its malfunctioning.

Designing a data center is one of the major tasks for which many aspects are required to be considered. One of the major aspects should be considered are the environmental effects acting externally on data center structures. Earthquakes, Wind effects, Rain effects, Flooding are few of those environmental impacts. Earthquakes have the greatest impact on data center structures. Wind loading generated from any of the sources like hurricane, tornado or typhoon affect the structural integrity of data center. These high speed winds flowing over the structure develops pressure against the exterior cladding. While flowing over the structure wind creates upward force on the roof resulting in the local failure of its cladding, roof or supporting frame structures. Also in windstorms the high speed

winds pick up the objects and carry along with them on to the building structures which damage critically particularly their windows. In case of wind with very high speeds, resulted from hurricane can be a cause for the lateral deformation of the whole structure or in the rare cases it directly blows away the entire structure.

Sir Francis Beaufort designed a Beaufort Scale in 1805 in which wind speeds are classified. In this scale, we can see that the wind speed more than 73 mph (32.63 m/s) is classified as Hurricanes [1]. These hurricanes have classification in Saffir – Simpson wind scale. The Saffir – Simpson Wind scale is 1-5 rating based on hurricane's sustained wind speed. The scale gives the information about the potential property damage according to different categories. The following table shows the Saffir – Simpson Hurricane Table [2].

The following chart given below proves that the wind speed exceeding 74 mph can cause significant amount of damage to the external structures of any kind of building. If these wind are blown over a data center then it would result in great loss either financial and working of that enterprise. The aim of this analysis is to design a windbreaker which can reduce the wind speed from 100 mph (44.7 m/s) to 20 mph (9 m/s) average velocity in the direction normal to the exterior face of Modular Data Center and also to analyse it structurally to withstand such high wind load.

Table 1.1 Saffir – Simpson Hurricane Wind Scale

Category	Sustained Wind Speed	Type of Damage
1	74 mph to 95 mph	Very dangerous winds will produce some damage: Damage primarily to unanchored mobile homes, shrubbery and trees. Some damage to poorly constructed signs. Well-constructed frame homes could have damage to roof, shingles, vinyl siding and gutters.
2	96 mph to 110 mph	Extensive damage caused: Well-constructed frame homes could sustain major roof and siding damage. Considerable damage to mobile homes, poorly constructed piers. Considerable damage to shrubbery and some trees blown down.
3	111 mph to 130 mph	Devastating damage occurs: Structural damage to small residences and minor amount of curtainwall failures. Mobile homes and poorly constructed signs are destroyed. Trees with foliage blown off trees and large trees blown down.
4	131 mph to 155 mph	Catastrophic damage occurs: More extensive curtainwall failures with some complete roof structure failures on small residences. Shrubs, Trees and all signs are blown down. Complete destruction of mobile homes. Extensive damage to doors and windows.
5	155 mph or higher	Catastrophic damage occurs: Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over. All shrubs, trees, signs blown down. Severe and extensive doors and windows damage.



## 1.1 Modular Data Center

### 1.1.1 Introduction

A Modular Data Center is an alternative way to the traditional data center which can be placed anywhere data capacity is needed. It is a portable method of deploying data center capacity. They comprises of purpose engineered modules and components to provide data center capacity with multiple power and cooling options. Modules can be shipped anywhere for adding or integrating in the existing data centers or for new order according to customer's requirement. The use of standardized components making them easier and cheaper for the construction of Modular data centers [3].

Modular data centers come in two types of form factors. The more common type, referred as containerized data centers in which the whole data center equipment is get fitted into standard shipping container which is then transported to a desired location. They typically come outfitted with their own cooling systems. Cisco makes one of these known as Cisco containerized data center.

Another form of Modular data center fits data center system into a facility which consists prefabricated components that are easy and quick to build on site and can be added as capacity needed. For example, HP's version of this type of modular data center, is constructed of sheet metal components that are formed into four data center halls linked by a central operating building. Modular data

centers are designed for rapid deployment to the particular location required by customer. The delivery takes place fully equipped unit which in turn leads to cost saving for its construction compared to traditional data center. The time for its construction also reduced to great extent. Hence, the Modular data center is better alternative compared to traditional data center in every aspect.



Figure 1.1 HP EcoPod Module at eBay Data Center

The HP EcoPod module is the largest single module deployment, claimed by HP. Its capacity is expanded with “ Double-wide” design in which two 40 feet containers are joined together. It can house almost 44 IT racks in two rows and can produce 1.4 megawatts. It has several options for cooling either with the use of outside air or Direct Expansion cooling based on the condition. The cooling system switches between ambient to direct cooling depending on the temperature

of outside air when the outside air is too warm to use. This Modular data center compressed the workload of 10000 square foot data center to 900 square feet data center and it takes just 3 months for its construction.

#### *1.1.2 Yahoo's Chicken coop data center*

Yahoo's chicken coop data centers are mostly similar to the traditional chicken coops. It's impossible to trap hot air in the coop and more draft get created as the roof gets warmer. In this design openings are provided in the elevated floor. The air from below the floor is drawn up through the coop keeping the coop cool. The air movement also removes excess moisture. As, the best way of cooling the computing equipment is ventilating a data center using a full-roof cupola system, Yahoo used the same system. The first design was standard fare having a raised white-space and forced air cooling.

The company gave a different approach for its second design Yahoo Thermal Cooling (YTC). The white-space in YTC is considered the cool zone. Hot air exiting the server rack is captured in an enclosed space and forced up through an intercooler. YTC concept became unique because the server fans move the air. The entire building works as the air handler. the shape was designed in such a way to allow heat to rise via natural convection. For using simplified air-flow path, Yahoo engineers designed louver systems in order to regulate the entry of air at the inlet of the data center. Also to control the flow of air exiting from the cupola equipment and to adjust the temperature of the recirculated air. In summer

there is no free cooling available so they designed variable speed fans, filter assemblies and most important the evaporative Inter-Cooling Modules.

Yahoo implemented three different kinds of cooling modes:-

- Unconditioned outside air cooling

When the outside air is between 70F and 85F enters from side walls of data center through adjustable louvers it is pulled by air-handling units and get filtered. Fans housed in the rack mounted computing and networking devices draw cooling air from inner space through rack mounted equipment and eject hot exhaust air to the interior space. Exhaust air moves up through natural convection and goes out through adjustable louvers in the roof length cupola.

- Outside air tempered by evaporative cooling

When temperature exceed 85 degrees F, Inter-Cooling Modules and air-handling units draws the outside air through side-wall louvers. After cooling the servers, the exhaust air exits building in same way as when unconditioned air enters the data center.

- Mixed outside air cooling

When outside air temperature drops below 70 degrees F, heated exhaust air is mixed with incoming air to maintain an air temperature of 70 degrees F. It depends on how automated the cooling system is. In

winter days when ambient air is too cold, heated exhaust air is redirected to mixing space and recirculated through the inside space.

After using this design it is proved to be very energy efficient. It was found that approximately 36 million gallons of water were saved per year with this design compared to conventional water-cooled chiller plant design having comparable IT loads, an almost 40 percent cut in the electricity usage relative to industry-typical legacy data centers.



Figure 1.2 Yahoo's Compute Coop Data Center facility

## Chapter 2

### WIND FENCE

Wind fence are barriers used to reduce the speed of wind. They redirect the wind in another direction. They usually consists of trees, shrubs, grasses, different kind of fences or other materials. The environmental conditions behind the winbreak known as sheltered zone become most effective as the reduction of speed of wind takes place through windbreak. As wind blows with high speed against a windbreak, pressure builds up on the windward side (the side towards the wind) and most of the air goes up or around the ends of the windbreak.

As long as wind strikes on any structure then the major concerned for mechanical damage (Wind fence types and effects) and loads is the force which is wind power. Wind power is calculated as square of windspeed. So as the wind speed increases wind power increases in terms of its square so it becomes huge in practical. Clearly, even there is a small reduction in the wind speed it is more than enough to reduce the wind power significantly.



Figure 2.1 Windbreakers used at airports

Windbreak (or windfence or wind shelter) slows the wind in one place by deflecting it to another. The best windbreaks create a zone behind the windbreak which will have wind of around a quarter of the speed. A windbreak can reduce windspeeds by over 50% of the incoming windspeed over large areas and over 80% over localized areas. The following figure show the effects of windspeed around the well designed windbreak.

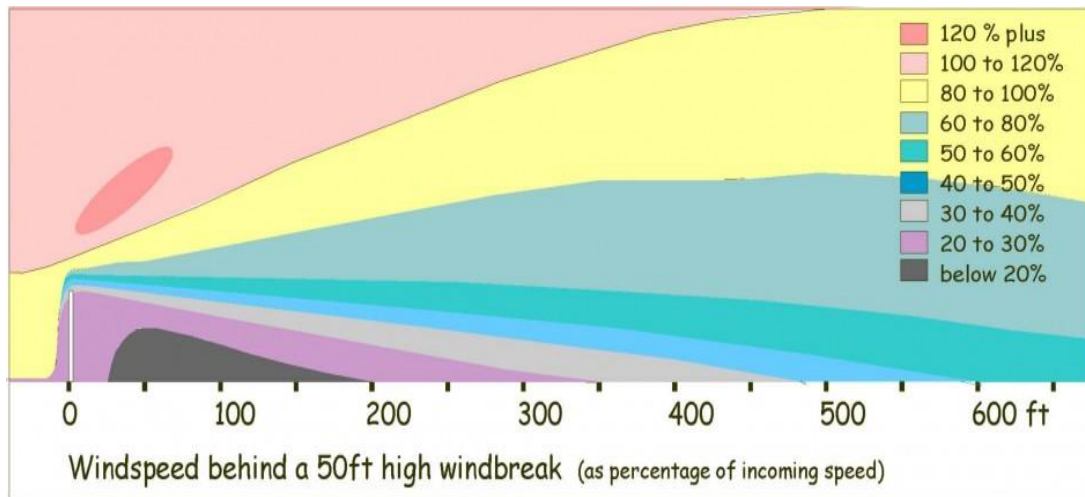


Figure 2.2 Wind speed behind a windbreaker as percentage of incoming speed

## 2.1 Effectiveness of windbreak

The effectiveness of windbreak is based on how it gets designed. There are various parameters while considering the design for windbreak. The parameters includes: Height of the windbreak, distance from the data center, density of the windbreak area, length and orientation of the windbreak. These parameters help in reducing wind speed and changing the climate conditions.

### 2.1.1 Effect of Height

Windbreak height (H) is the most important factor determining the downward area protected by a windbreak. Value of height differs from windbreak to windbreak. As per concerning few applications like farming where there are multiple row windbreak design in such case, the height of the tallest tree-row determines the value of H.



On the windward side of a windbreak, wind speed reductions are measurable upwind for a distance of 2 to 5 times the height of the windbreak. On the side away from the wind, wind speed reductions occur up to  $30H$  downwind of the barrier. Within this protected zone, the structural characteristics of a windbreak, especially density, determine the extent of wind speed reductions. In case of data center, the wind speed should be reduced immediate after passing windbreak and just before the point of entry of air into the data center and exhaust of air out of the data center. So there is no need of protecting up to a large distance downwind. Therefore windbreak height ( $H$ ) is same like the data center height.

#### *2.1.2 Effect of density*

The density of windbreak is the term used for the ratio of solid portion of whole barrier to the total area of the barrier. As wind passes through open portion, more open area more wind will pass through it. If the windbreak is very dense then low pressure develops on the leeward side of the windbreak. This low pressure area behind the windbreak pulls air coming over the windbreak downward, creating turbulence and reducing protection downwind. As density decreases, the amount of air passing through windbreak increase, moderating the low pressure and turbulence, increasing the length of the downwind protected area. As the protected area is larger, there is not much wind speed reductions. By

adjusting windbreak density different wind flow patterns and areas of protection are established.

A windbreak density of 40 to 60 percent provides the greatest downwind area of protection. Windbreaks designed to catch and store snow in a confined area usually have several rows, and densities in the range of 60 to 80 percent. As farmsteads and livestock areas need protection from winter winds, they require windbreaks in multiple rows with high densities. In this case though the protected area is smaller but there is high reduction in the wind speed.

For the data center opening area in the windbreaker plays a vital role. A thorough study was made to determine the optimum design of opening area in the windbreaker so that wind speed will reduce at the inlet and outlet of the data center. Considering a solid wall option as a windbreaker would be not the suitable design, as it will help to reduce the wind speed but there will be lot of turbulence before the inlet and outlet and also there will not be sufficient amount of ambient air at the inlet of data center. So the option of cooling data center with ambient air cannot be used. Hence proper density is required in the windbreaker design.

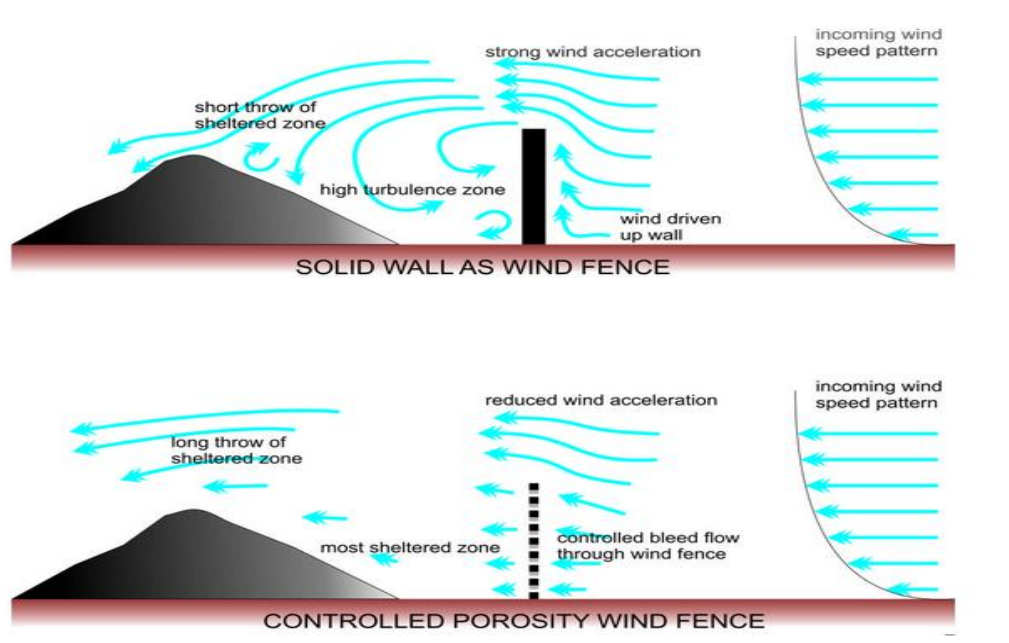


Figure 2.3 Difference between solid wall and wall with density

### 2.1.3 Effect of Distance

The position of the windbreaker from the area to be protected matters a lot for reducing the wind speeds downwind. For considering data center protection, if the windbreaker is placed very close to the data center, it will protect data center from high speeds wind but at the same time it will block the inlet of the ambient air to the data center and also the exhaust of the data center. If windbreak is far away from the data center it will fail to reduce the wind speed before the inlet and outlet of the data center. Hence, it is very important to place the windbreaker at an optimum distance from the data center to get the purpose done.

#### *2.1.4 Effect of Orientation*

The windbreakers are most effective when they are normal to prevailing winds. Each windbreak is unique for its purpose and design, and hence the orientation of each windbreak depends on the design objectives. Farmsteads and feedlots usually need protection from cold winds and blowing snow or dust. Orienting these windbreaks normal to the troublesome winter wind direction provides the most useful protection. Field crops normally need protection from hot, dry summer winds, abrasive, wind-blown soil particles or both.

The orientation of these windbreaks should be perpendicular to prevailing winds during critical growing periods. In order to control soil erosion, windbreaks should be planted to block the prevailing winds during the times of greatest soil exposure-winter and early spring. Although wind may blow predominantly from one direction for a season, it rarely blows exclusively from that direction. As a result, protection is not equal for all areas on the leeward side of a windbreak. If wind changes the direction then it does not blow against the windbreak and hence the area to be protected get decreases. At last the installation of windbreak depends on the site, the wind direction(s), and the design objectives.

#### *2.1.5 Effect of Length*

Despite the fact that the height of a windbreak decides the degree of the protected area downwind, at the same time the length of windbreak also determines the total area getting protection. For the most efficiency the

continuous length of a windbreak ought to surpass the height, no less than 10:1. This ratio diminishes the impact of end-turbulence on the total protected area. The efficiency of windbreak is influenced by its continuity. Gaps in a windbreak become funnels that concentrate wind flow, creating areas on the downwind side of the gap in which wind speeds often exceed open field wind velocities. Effectiveness of windbreak vanishes if there are gaps [4].

## Chapter 3

### COMPUTATIONAL FLUID DYNAMICS ANALYSIS

#### 3.1 Introduction

Computational fluid dynamics (CFD), is a branch of fluid mechanics in which it uses algorithms and numerical solutions to solve and analyze all those problems that involve any fluid flow. The interaction of any kind of flow like liquids and gases with the surfaces defined by boundary conditions is solved by the computers which perform the calculations required for simulations. High speed supercomputers give better results. A scientific model is generated which represents the actual system and then it was solved and analyzed. In this scenario, it analyzed the effect of wind flow across the wind fence and how the that affects the velocity, pressure and different parameters in the system.

CFD provides qualitative prediction of fluid flows with the help of mathematical model, numerical methods and software tools. Analysis made from CFD helps engineer to perform any work for improving or designing new or already existing device [5].

#### 3.2 Governing Equations

The numerical solution for most of the problems that involve fluid flow or problem related to flow are solved by set of three differential equations. These equations are combining known as Navier-Stokes equations. In these equations it

include “Conservation of Energy”, “Conservation of Mass” and “ Conservation of Momentum”.

Now, for this scenario wind fence was analysed for wind flow reduction, hence temperature is constant and only varying parameter was air flow. Hence only conservation of mass and conservation of momentum were taken into consideration for solving the problem.

In general form

The Conservation of mass:-

$$\frac{\partial(\rho)}{\partial t} + \nabla \cdot (\rho u) = 0$$

The Conservation of momentum:-

$$\frac{\partial(\rho u)}{\partial t} + (\rho u \cdot \nabla)u = \nabla \cdot (\mu \nabla u) - \nabla p + \rho f$$

These equations get solved in the solution region. In solution region, solutions are obtained by considering all the boundary conditions which are applied to that region. Temperature, pressure, viscosity or any environmental conditions are involved as those boundary conditions. The solution region also plays role while solving solutions whether its open, closed or symmetric in nature.

The governing equations are getting solved using some common techniques which involve Finite Element Method, Finite Difference Method and Finite Volume Method. Each of these technique use different methodologies for solving.

### 3.3 Turbulence Modeling

When the flow of fluid experiences any chaotic or irregular motion while flowing through stream then that flow is said to be turbulent flow. Unlike laminar flow the velocity of flow change at every point in terms of magnitude and direction. The Reynolds no is deciding factor whether flow is laminar or turbulent. If Reynolds no is high then the flow is turbulent and if its low then the flow is laminar. There are two different turbulent models available in FloTherm 10.1 :- LVEL turbulence model and K-Epsilon turbulence model.

#### *3.3.1 LVEL Epsilon Model*

The LVEL turbulence model requires only few terms to determine the effective viscosity. They are nearest wall distance (L), the local velocity (VEL) and the laminar viscosity. In this model, Poisson's equation is solved initially to calculate the maximum length scale and local distance to nearest wall.

#### *3.3.2 K-Epsilon Turbulence Model*

The K-Epsilon turbulence model solves the governing equations along with another two additional equations, namely, the kinetic energy of turbulence (k) and the dissipation rate of kinetic energy turbulence ( $\epsilon$ ). It is also known as the two equation model and is used widely in turbulent flow modeling.

### 3.4 Mesh and Mesh Sensitivity

Meshing is helpful to cover a geometry with the minimum number of elements that required in the solution region to cover geometry. Grid constraints



were used to show minimum and maximum number of elements throughout the geometry.

Meshing is an important feature of any CFD software, since if the model created is not properly meshed, the results of the simulation would be inaccurate. The mesh needs to be fine in critical areas and can be coarse in areas of less importance. Keeping the mesh fine in critical areas would give the most accurate results. Mesh sensitivity analysis can determine when the solution has reached grid independence. Grid independence is the ultimate point where, there is no more effect in solution on the addition of large number of elements. FloTHERM 10.1 uses a Cartesian grid system and the values of any variable are calculated at the center of each grid cell. While meshing the model created in FloTHERM 10.1 there is an option of keeping the grid fine, medium or coarse. Also, localizing a grid is another option to improve the mesh.

### 3.5 Parts in Flotherm 10.1

#### *3.5.1 Cuboid*

It is the most basic part in FloTHERM 10.1. It can be used to represent many objects in the system. It is a solid block and can be used to represent any external structure like here it was used to create modular data center, a solid wall, etc. It also has the option to be collapsed to represent a plate.

### *3.5.2 Resistance*

The resistance part is used to define region which acts as a barrier to flow of fluid. It usually represents a porous media. The void volume fraction can be defined from the resistance library depending on the requirement. In this scenario the resistance is used to represent a porous wind fence. Different values of void volume fraction are given to the resistance to simulate a wind fence with varying porosities. Also it can be used for modeling filters, vents for different applications.

### *3.5.3 Enclosure*

The enclosure is a hollow part which was used to define the outer boundaries of the system. It is cubical in shape and each side of the cuboid can have independent properties. The thickness can be defined to an enclosure or it can be kept as thin. It can be used for modeling racks, servers etc.

### *3.5.4 Source*

The source is used to represent the objects that require power to be defined. It is used to simulate a wind source, with a fixed velocity assigned to it. The direction of the wind source can be defined as needed. The source area can be made equal to the area of the enclosure, such that all the wind source velocity is channeled through the enclosure, thus the whole enclosure is acting as a wind tunnel.

#### *3.5.5 Monitor Points*

Monitor points can be used to determine the various parameters at crucial points in the solution domain. They usually monitor temperature, pressure at those crucial points within the system. In this scenario monitor points were used to measure pressure at the portion close to the inlet and exhaust of the modular data center.

#### *3.5.6 Region*

Region is mainly used for two purposes. The first one to create a refined mesh in a particular area where it needs. A region can be created in a particular area where a finer mesh is required and the mesh density can be improved in that particular region using the Localize feature. Another use of the region is that it can be used in post processing. The values of different parameters like, velocity, pressure, speed, temperature can be determined within a particular region.

#### *3.5.7 Command Center*

The command center in FloTHERM 10.1 can be used to solve different scenarios at the same time which enable us to see the effects in the change of certain selected variables. It enables to vary multiple parameters and see their individual or combined effect on the total system. Parametric and mesh sensitivity analysis can be performed using the command center.

Basically, the procedure that is followed while using the command center is that, a base case is loaded as the project. Then in the command center, the

parameters that are to be varied, called as the Input Variables are selected. The results that are required, for example, pressure, temperature, velocity, speed, etc. can be selected in the Output Variables. These can be viewed in the Scenario Table generated along with the input variables as well. There is also a provision where we can monitor the solution and check for convergence.

As its already mentioned that the work has been done for two different scenario.

1. Single Wall Case
2. Split Wall Case (Previous Results of CFD)

## Chapter 4

### SINGLE WALL CASE

The model created was chicken coop inspired modular data center and the wind fence is located at a certain distance in front of the MDC. The external structure of the MDC is modelled as the study is concerned with the wind loading on the external structure itself. The model was created using FloTHERM 10.1 parts.

#### 4.1 Description of the Modular Data Center

The model of a modular data center is similar to chicken coop and also resembles the Yahoo's Chicken Coop Data Center. It has two sections, the lower section which is the IT pod, which consists of all the IT equipment, filtration units, fans, etc. It also consists of the inlets for the ambient air to enter the data center, which is used for cooling purposes. The top section consists of the chicken coop or chimney, which acts as the exhaust for the hot air that rises from the hot aisle within the modular data center.

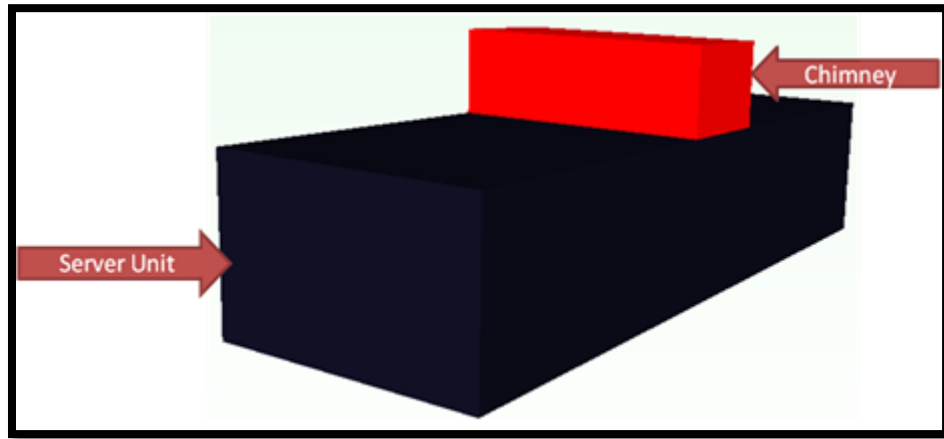


Figure 4.1 Model of Modular Data Center

#### 4.2 Description of the Wind Fence

The wind fence used in this model is of a single wall type. The wall is placed on the ground in front of the modular data center. The height of the wind fence is chosen equal to the height of the MDC. The wind fence is modelled using the resistance part in FloTHERM 10.1. This allows the wind fence to be modelled as a porous body with varying resistances. The initial case chosen was with 10% void volume fraction.

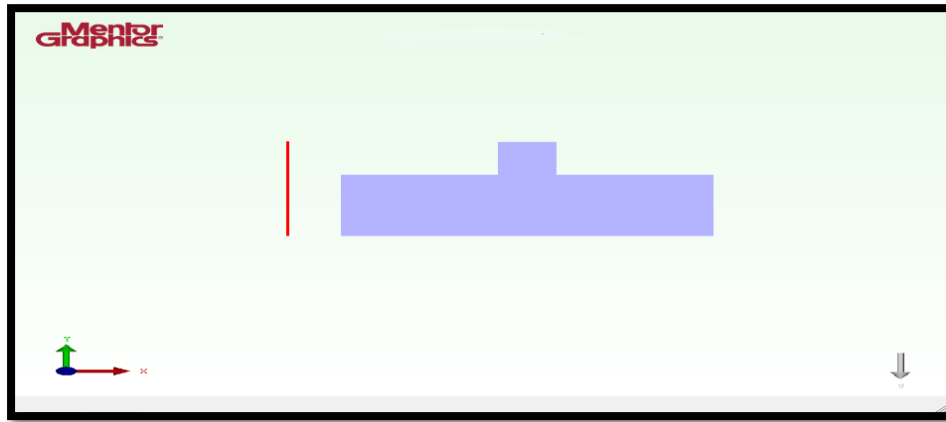


Figure 4.2 Single Wall Configuration

### 4.3 CFD Model

#### 4.3.1 Dimensions of Model

Table 4.1 Dimensions of the Model

	Length (m)	Width (m)	Height (m)
Lower portion of MDC	11.16	6.3	3.74
Upper portion of MDC	2.2	6.3	2.0
Single Wall	0.006	6.3	5.74

#### 4.3.2 Model Setup

The model setup used for all the cases was as follows:

- Model Was Bi-Symmetric. Only half model is investigated.
- Type of Solution was set to Flow Only
- Gravity was set to Normal, acting in  $-Y$  direction as  $9.8\text{m/s}^2$ .
- The flow type was set to Turbulent and Turbulence Model used was the LVEL K-Epsilon Model

- Wind Velocity was set to 44.7 m/s originating from Source direction of wind was in positive X direction.

Note: The Turbulent flow model was selected as the fluid velocity was very high (44.7 m/s) and also the Reynolds Number calculated was very high. The K-epsilon model is chosen as there are large empty volumes within the enclosure and the representation of turbulence was necessary within the enclosure. Since this model solves the two turbulence equations in addition to the governing equations, it proves to be the best model to use for this particular case.

#### *4.3.3 Boundary Conditions*

The boundary conditions selected for the model were, Y-low face of the solution domain has no slip condition. The Z-low face has the symmetric boundary condition. Because of the symmetry it saved the computational time by a large amount, since the numbers of elements were reduced by half the amount.

#### *4.3.4 Meshing*

The mesh created was very fine in the critical locations and coarse in locations which do not affect the flow characteristics. In the regions where there was large amount of change in pressure and turbulence, the mesh was finer, while the regions within the MDC which does not affect the flow, the mesh was coarse.

The total mesh size was about 5.8 million cells and the maximum aspect ratio was 4.9. Since the model is symmetrical, half model was meshed.



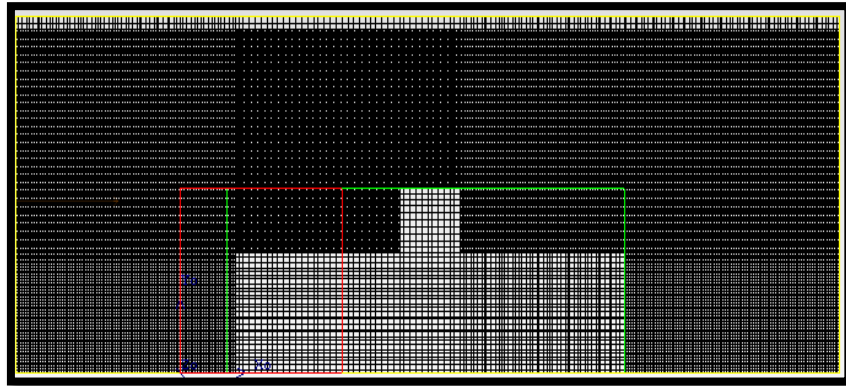


Figure 4.3 Meshed model

#### 4.4 Mesh Sensitivity Analysis

Mesh sensitivity analysis is carried out to get the solution accurate. Mesh sensitivity analysis was done in order to understand the relationship between the input and output variables of the model. In the mesh sensitivity analysis, the input variable was the number elements and its effect on the output variable like speed was studied.

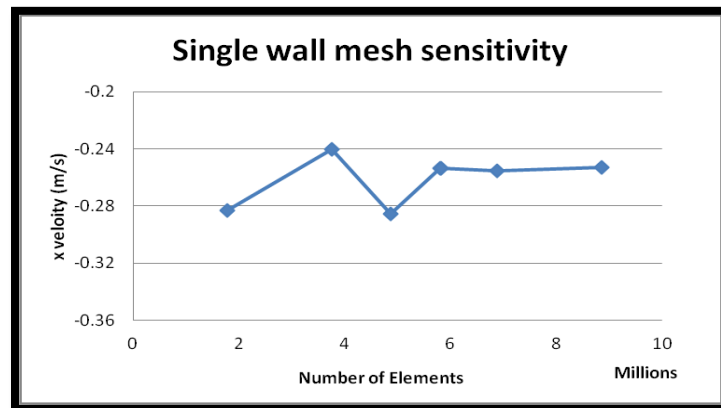


Figure 4.4 Mesh Sensitivity Analysis

The following table shows the Mesh Sensitivity Analysis

Table 4.2 Mesh Sensitivity Analysis

No of Elements	X Velocity (m/s)
1769591	-0.283104
3744773	-0.240303
4869653	-0.285783
6871044	-0.253894
8862350	-0.253909
5804972	-0.255607

Mesh Sensitivity was achieved at 5.8 million elements with the aspect ratio of 4.9.

#### 4.5 Different Cases

The two main parameters that were considered for the analysis were distance of the wind fence from the MDC and perforation of the wind fence. The initial case considered when the fence was at 2 m from the MDC. The distance was then varied in the steps of 0.5 m. A total of six cases were considered, at distances of 0.5, 1, 1.5, 2.5, 3 and 3.5 meters from the MDC. Perforations was varied from 10% - 80%.

## Chapter 5

### CFD RESULTS

The following results were obtained by varying the distance of the windbreaker from the MDC and the perforations in the windbreaker. The results were monitored at a region which is 0.3 m before the MDC.

Assumption: The maximum wind speed that is acceptable at a distance of 0.3 m from the MDC is 20 mph (9 m/s).

With the above variable parameters that are distance from MDC and perforation ratio, the acceptable values got were:

#### 5.1 50% Perforation

##### *5.1.1 Velocity Profiles*

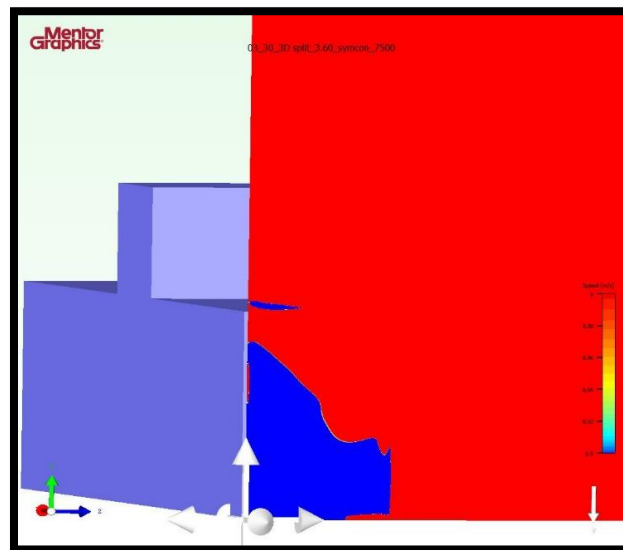


Figure 5.1 At 0.5 m From MDC

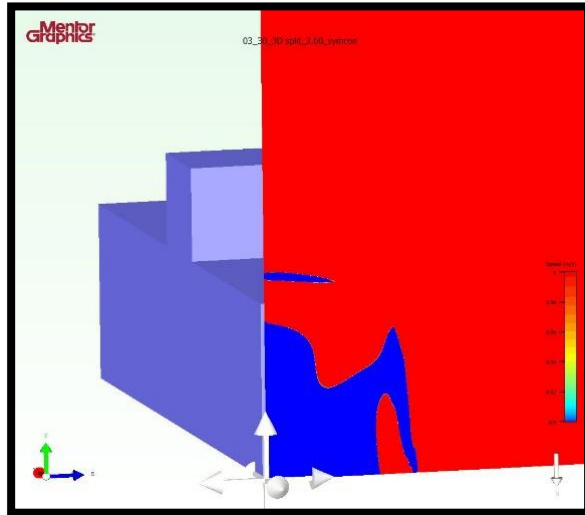


Figure 5.2 At 2 m from MDC

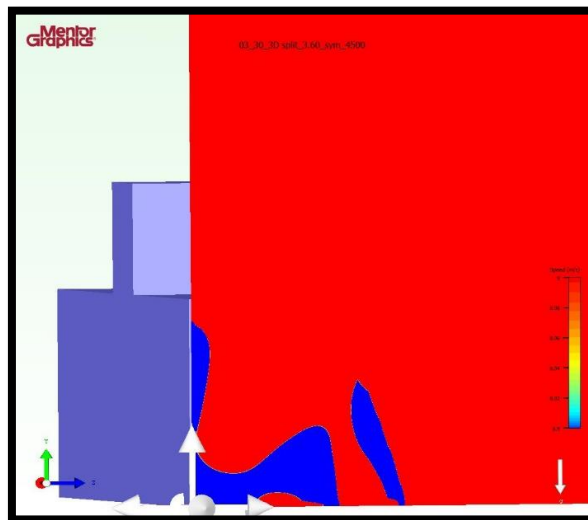


Figure 5.3 At 3.5 m from MDC

Table 5.1 50% Perforated Wall

Cases	-3	-2	-1	0	1	2	3
Distance from MDC (m)	0.5	1.0	1.5	2	2.5	3.0	3.5
Mean Speed (m/s)	3.86	3.7	3.57	3.49	3.23	2.51	2.38
Mean Pressure (Pa)	608.05	911.58	1224.08	1468.10	1599.07	1711.05	1818.49

## 5.2 60% Perforation

Table 5.2 60% Perforated Wall

Cases	-3	-2	-1	0	1	2	3
Distance from MDC (m)	0.5	1.0	1.5	2	2.5	3.0	3.5
Mean Speed (m/s)	4.27	4.35	4.20	4.02	3.86	3.09	3.00
Mean Pressure (Pa)	553.53	679.52	815.97	932.75	1029.86	1112.03	1187.23

### 5.3 70% Perforation

Table 5.3 70% Perforated Wall

Cases`	-3	-2	-1	0	1	2	3
Distance from MDC (m)	0.5	1.0	1.5	2	2.5	3.0	3.5
Mean Speed (m/s)	4.28	4.42	4.40	4.32	4.24	3.55	3.56
Mean Pressure (Pa)	335.40	390.68	457.91	525.88	585.90	652.63	702.43

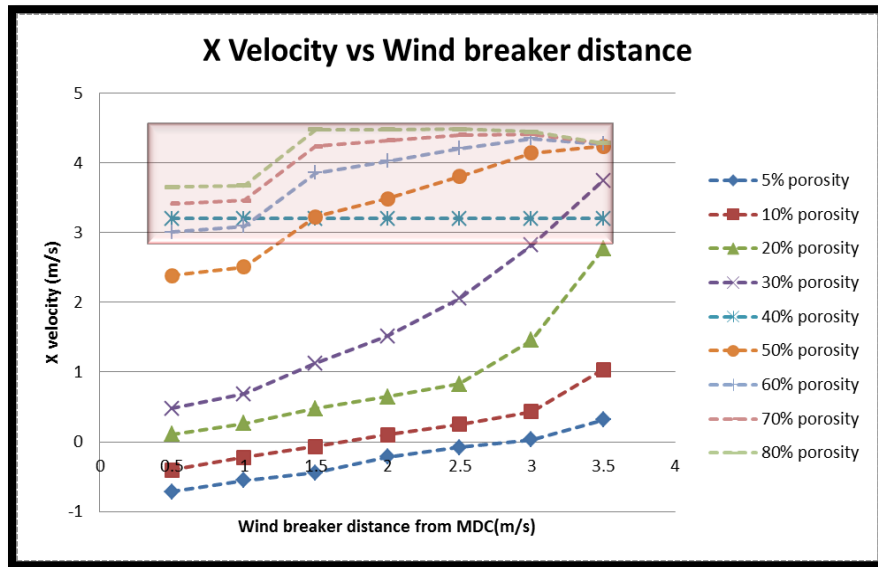


Figure 5.4 Graph of X velocity vs Distance of wind fence from MDC

From the CFD analysis plot, it proved that the wind fence was able to reduce wind speed at following positions:-

- At 50%; 1.5m, 2m, 2.5m and 3m
- At 60%; 1m, 1.5m, 2m and 2.5m
- At 70%; 1.5m, 2m and 2.5m

CFD analysis proved that the wind fence was able to reduce the wind speed but structurally it should be strong enough to withstand such high wind load.

## Chapter 6

### FINITE ELEMENT ANALYSIS (SINGLE WALL)

Structural Analysis is the main part in the design of any equipment. It helps to prove that functionally as well as strength wise the material chosen for the equipment is best. On the other hand if the equipment functions perfectly but is not able to withstand the loading then it will fail continuously and thus it would increase in the cost ultimately. Hence structural analysis plays a vital role in the design of any device.

Design of any device or equipment is a crucial part in the analysis. For this case the wind fence design was the crucial part. Regular fence design with the poles was selected for analysis. Fence structure means solid, perforated also matters for its analysis. In this case of wind fence a new approach was given to use perforated metal as a fence instead of porous material. For design of perforated metal sheet there were few parameters which has to be considered.

#### 6.1 Perforated Metal

Perforated metal is one of the alternative used instead of using porous material. In the porous material there are chances of clogging of different particles or contaminants in the pores of the material which gradually reduce the working efficiency of the material. In perforated metal sheets the holes are created in the sheets only using different shapes and patterns with the help of standard dies and different tools for customized designs. The design of perforated sheet has two



major parameters to be considered. The first one is perforation shape and perforation pattern.

#### *6.1.1 Perforation Shape*

The types of hole shapes available in perforated products is limited only by the technological ability to machine the cutting dies into a specific configuration that can not only create the shape, but withstand the stresses of the punching process. The most commonly used and most affordable hole shapes are:

- Round Holes.

A round hole is very easy and most economical shape to generate, as its very simple of machining a round piece that results in low manufacturing costs. Round hole patterns are used in a variety of applications which includes air-conditioning and heating systems, decorative finishes for architectural installations.

- Square Holes.

Square holes can provide a large open area while they also provide a strong barrier that can be used to resist impact loads, prevent entry of wind into protected areas. Increased wear on equipment occurs during the square hole perforation process as there is increase in the stresses near the corners of the square shape. For this reason, the creation of square hole patterns increases the cost of production over that of round holes.

- Slot Holes

Slot holes consist of long rectangles with a half-circle or square ends. Slots can be installed parallel to either the width or the length of the sheet depending on user preference and needs of the application.

#### *6.1.2 Perforation Pattern*

The standard pattern types used for perforating metal are straight line and staggered, which fit the majority of perforated metal uses.

- Straight Line.

Straight-line perforated metal layouts consist of repeating rows that contain an identical number of holes in each row and follow the same alignment down the sheet as it is pulled through the punch. Straight patterns are designed by specifying both the distance between holes and the distance between successive rows of holes.

- Staggered Layouts.

Staggered layouts are specified based on the angle between centers of successive lines of holes. For instance, one of the most common patterns is a 60° staggered pattern, which means that after one row of holes is punched, the die moves over and punches the next row in such a manner that the line drawn from the center of a shape on

the previous line to the center of an adjacent shape on the new line forms a  $60^\circ$  angle from the previous row [6].

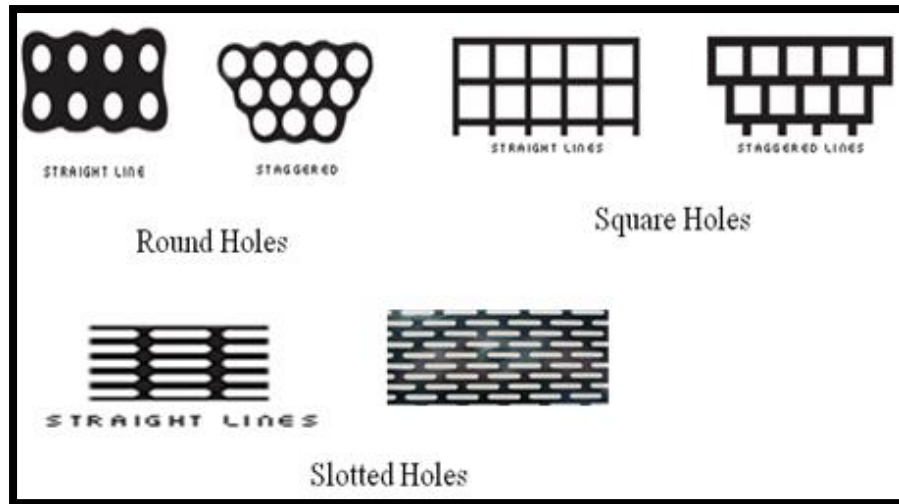


Figure 6.1 Different shapes of holes with different patterns

## 6.2 Model Setup

- Model of the wind fence was created using cad software in PTC Creo Parametric 3.0
- Meshing of the model was carried out in ANSYS 16.1 and structural analysis too.
- Pressure values for carrying out the analysis were taken from the CFD results and it applied on the model. Pressure values were in Pascal (Pa).
- Though the model was not that complicated still the mesh sensitivity had been carried out. Through mesh sensitivity analysis mesh size was achieved about 20 mm and the structure was very fine.

- Analysis was carried out considering major two parameters:
  - Perforation Ratio of the wind fence which was varied from 50% - 70% as these were the proven results of the CFD analysis.
  - Using different materials which are currently used by the industries for manufacturing the perforated sheets. The materials include Stainless Steel and Aluminium with different grades of each. Following grades of SS and Al were used for the analysis of the wind fence.

For SS – AK 304, AK316, AK321

For Al – 2024 T3, 2024 T4, 7075 T6

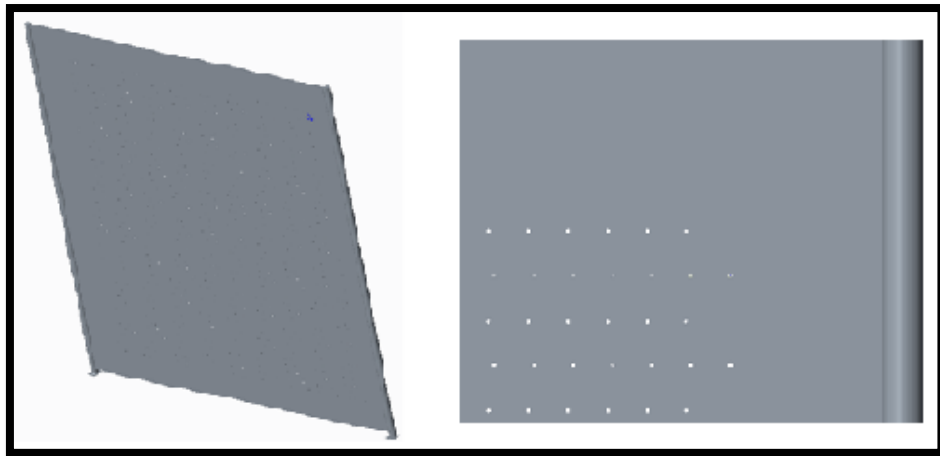


Figure 6.2 PTC Creo Model of wind fence

### 6.3 Mesh Sensitivity Analysis

In order to get good and accurate results of stress analysis, mesh sensitivity of the model was carried out. For mesh analysis the model was analyzed for different kinds of mesh like coarse, medium and fine mesh. Input variable was selected as the size of the element and accordingly its effect on the model was examined in terms of stress values. The mesh size, when the difference between the consecutive stress values was less than 5% was the acceptable mesh size. The following table shows the mesh sensitivity analysis.

Table 6.1 Mesh Sensitivity Analysis

Mesh Element Size ( MM )	Elements	Equivalent Stress (Pa)
50	1.95E+06	1.0269E+09
40	1.98E+06	1.0224E+09
30	2.05E+06	1.0209E+09
20	2.1E+06	1.0209E+09
10	2.4E+06	1.0208E+09

From the output of the above table that is equivalent stress values, at the mesh sizes of 20mm and 10mm there was not much difference in the stress values. Hence the 20mm mesh size with fine mesh structure was selected for analysis of all the models.

## 6.4 Results

### 6.4.1 50% Perforated

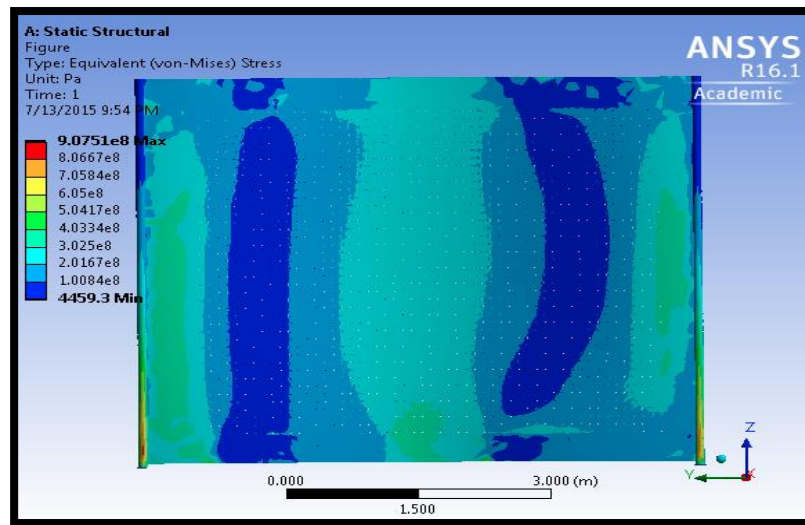


Figure 6.3 Stress Results for 50% Perforated

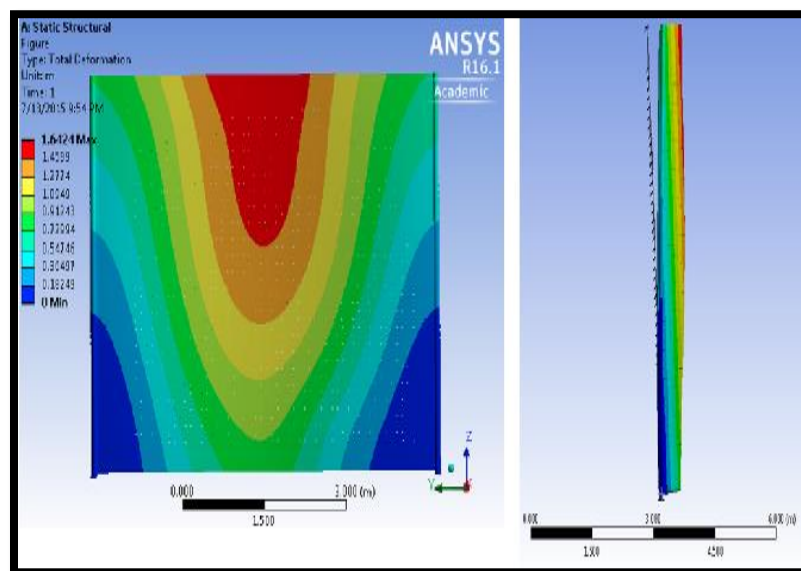


Figure 6.4 Deformation for 50% Perforated Wall

Table 6.2 50% Perforated with Steel material

Parameters	Units	Material		
		Steel		
Grades		AK 304	AK 316	AK 321
Density	Kg/m <sup>3</sup>	8030	7990	9010
Young's Modulus	GPa	193	193	193
Poisson's Ratio		0.24	0.24	0.24
Tensile Yield Strength	MPa	290	290	276
Ultimate Tensile Strength	MPa	621	579	621
Pressure	Pa	1468.10	1468.10	1468.10
Results				
Equivalent Stress	MPa	907.51	870.30	924.26
Deformation	M	1.64	1.20	1.87

Table 6.3 50% Perforated with Aluminium material

Parameters	Units	Material		
		Aluminium		
Grades		2024 T3	2024 T4	7075 T6
Density	Kg/m <sup>3</sup>	2780	2780	2810
Young's Modulus	GPa	73.1	73.1	71.1
Poisson's Ratio		0.33	0.33	0.33
Tensile Yield Strength	MPa	427	324	503
Ultimate Tensile Strength	MPa	475	469	572
Pressure	Pa	1468.10	1468.10	1468.10
Results				
Equivalent Stress	MPa	982.20	964.30	910.18
Deformation	M	2.16	1.67	1.95

#### 6.4.2 60% Peforated

Table 6.4 60% Perforated with Steel material

Parameters	Units	Material		
		Steel		
Grades		AK 304	AK 316	AK 321
Density	Kg/m <sup>3</sup>	8030	7990	9010
Young's Modulus	GPa	193	193	193
Poisson's Ratio		0.24	0.24	0.24
Tensile Yield Strength	MPa	290	290	276
Ultimate Tensile Strength	MPa	621	579	621
Pressure	Pa	932.30	932.30	932.30
Results				
Equivalent Stress	MPa	580.61	530.42	597.32
Deformation	M	1.58	1.12	1.87

Table 6.5 60% Perforated with Aluminium material

Parameters	Units	Material		
		Aluminium		
Grades		2024 T3	2024 T4	7075 T6
Density	Kg/m <sup>3</sup>	2780	2780	2810
Young's Modulus	GPa	73.1	73.1	71.1
Poisson's Ratio		0.33	0.33	0.33
Tensile Yield Strength	MPa	427	324	503
Ultimate Tensile Strength	MPa	475	469	572
Pressure	Pa	932.30	932.30	932.30
Results				
Equivalent Stress	MPa	531.18	529.26	545.20
Deformation	M	2.93	2.43	2.62



### 6.4.3 70% Perforated

Table 6.6 70% Perforated with Steel material

Parameters	Units	Material		
		Steel		
Grades		AK 304	AK 316	AK 321
Density	Kg/m <sup>3</sup>	8030	7990	9010
Young's Modulus	GPa	193	193	193
Poisson's Ratio		0.24	0.24	0.24
Tensile Yield Strength	MPa	290	290	276
Ultimate Tensile Strength	MPa	621	579	621
Pressure	Pa	525.88	525.88	525.88
Results				
Equivalent Stress	MPa	241.13	215.36	286.24
Deformation	M	0.67	0.35	0.87

Table 6.7 70% Perforated with Aluminium material

Parameters	Units	Material		
		Aluminium		
Grades		2024 T3	2024 T4	7075 T6
Density	Kg/m <sup>3</sup>	2780	2780	2810
Young's Modulus	GPa	73.1	73.1	71.1
Poisson's Ratio		0.33	0.33	0.33
Tensile Yield Strength	MPa	427	324	503
Ultimate Tensile Strength	MPa	475	469	572
Pressure	Pa	525.88	525.88	525.88
Results				
Equivalent Stress	MPa	305.43	302.28	312.76
Deformation	M	1.41	1.36	1.84

From the structural analysis it proved that the wind fence with 70% perforation and located at the distance of 2m from the MDC is the optimized design for single wall case. The material which can be served as the best material for that case is Steel AK 304.

## Chapter 7

### SPLIT WALL CASE

The another approach for solving this problem is given by using split wall instead of single wall to reduce the wind speed. In case of split wall there were two different walls were used. The lower wall was placed on the ground just in front of the inlet dampers of the MDC and the upper wall was placed in front of the exhaust dampers of the MDC. The CFD analysis was done for this case previously but structural analysis was yet to carried out. Hence taking into consideration the previous results of the split wall case the stress results were calculated.

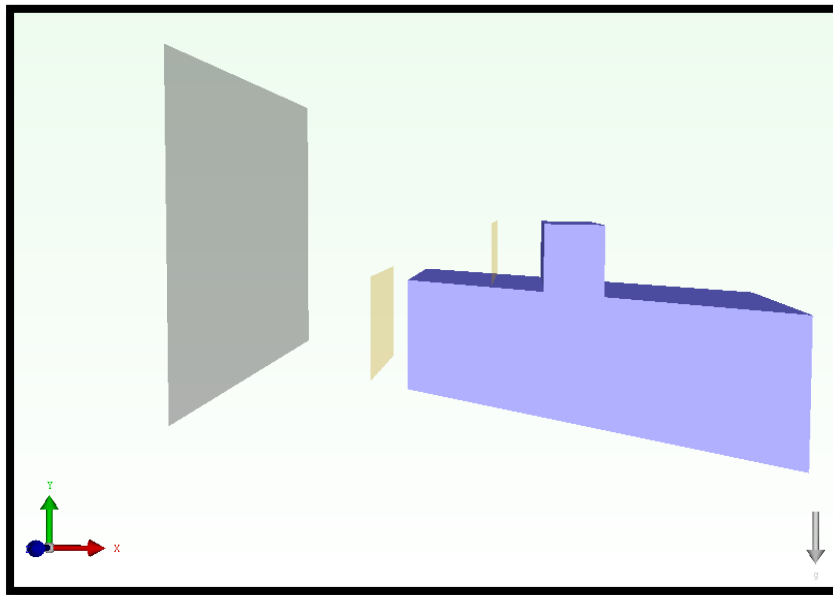


Figure 7.1 Split Wall schematic configuration

From previous results, the following graph shows the acceptable locations of the wind fence where it was able to reduce the wind speed from 44.7 m/s to 9 m/s and along with the different perforation ratios.

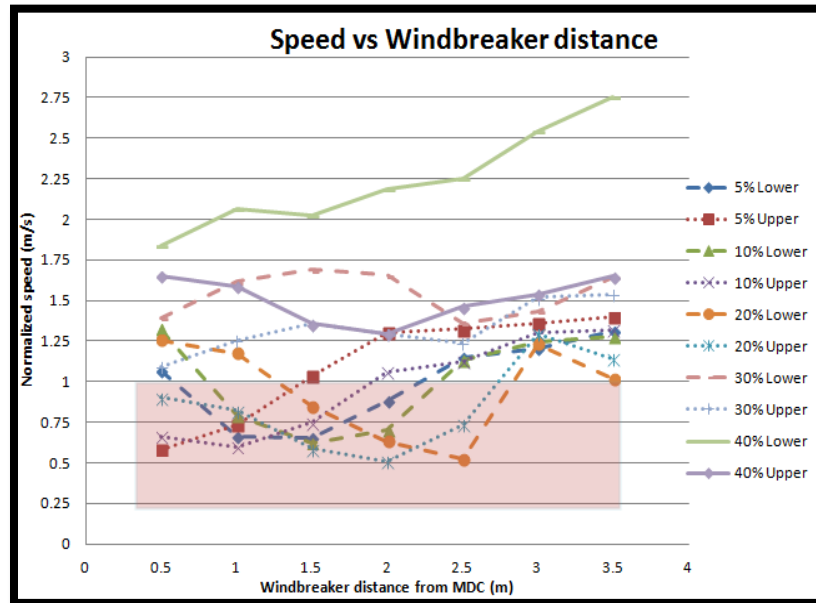


Figure 7.2 Graph of Speed Vs Distance of wall from MDC

From the CFD analysis plot, it proved that the wind fence was able to reduce wind speed at following positions:-

- At 10%; 1m and 1.5m.
- At 20%; 1.5m, 2m and 2.5m
- At 30%; 2m, 2.5m and 3.5m.

CFD analysis proved that the wind fence was able to reduce the wind speed but structurally it should be strong enough to withstand such high wind load [7].

## Chapter 8

### FINITE ELEMENT ANALYSIS (SPLIT WALL)

For FEA analysis of the split wall case there were two different models created in PTC CREO 3.0 for lower wall and for upper wall. Both the models were analyzed for the same perforation ratio and same material used as standard.

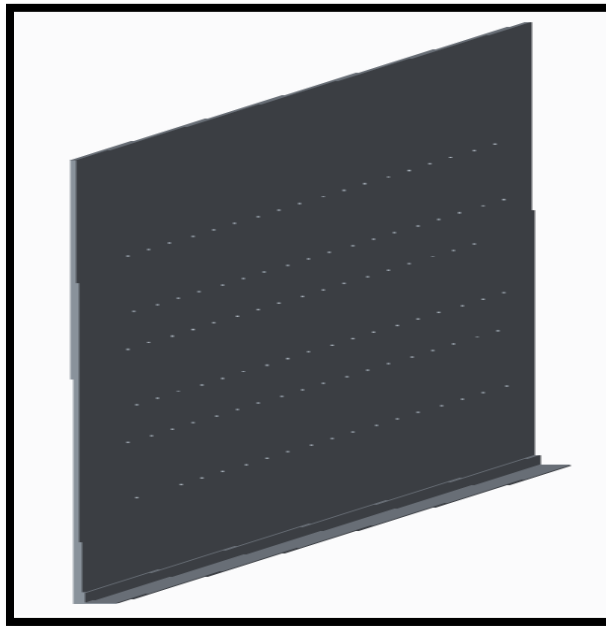


Figure 8.1 Model of Upper Wall

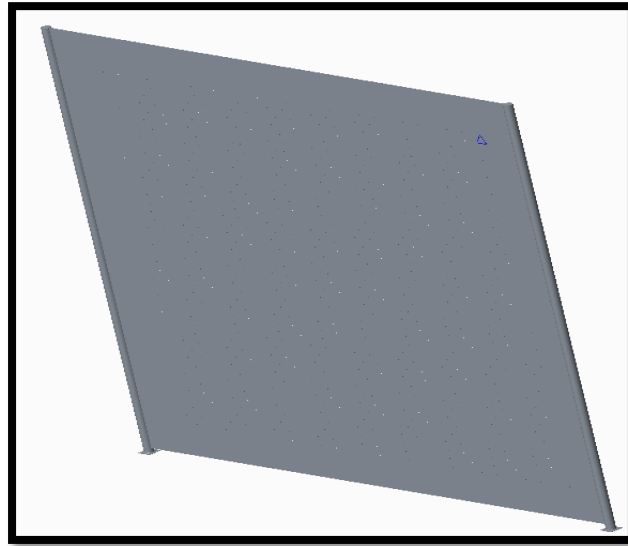


Figure 8.2 Model of Lower Wall

### 8.1 10% Perforated Wall

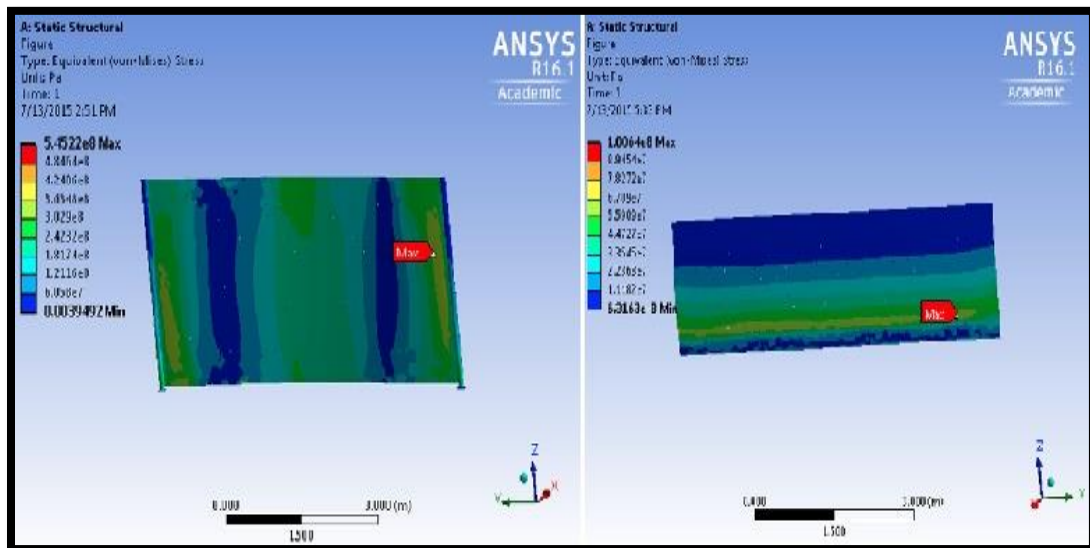


Figure 8.3 Stress Results of 10% Lower & Upper Wall

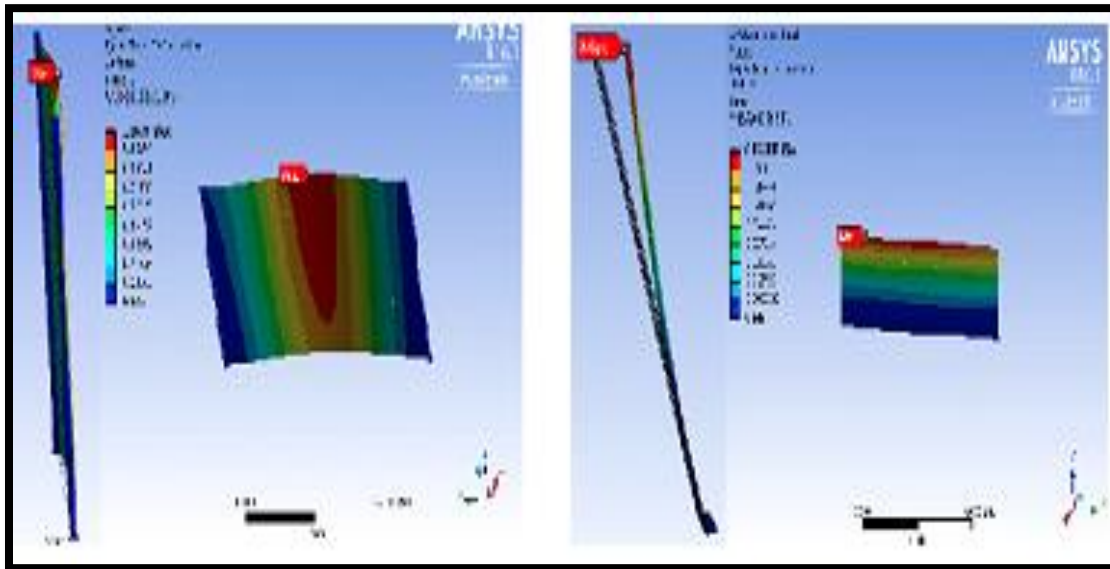


Figure 8.4 Deformation for 10% Lower & Upper Wall

Table 8.1 10% Perforated with Steel material

Parameters		Units	Material		
			Steel		
Grades			AK 304	AK 316	AK 321
Density		Kg/m <sup>3</sup>	8030	7990	9010
Young's Modulus		GPa	193	193	193
Poisson's Ratio			0.24	0.24	0.24
Tensile Yield Strength		MPa	290	290	276
Ultimate Tensile Strength		MPa	621	579	621
Pressure (Upper)		Pa	831	831	831
Pressure (Lower)		Pa	1130	1130	1130
Results ++					
Upper Wall	Equivalent Stress	MPa	100.64	99.28	106.36
	Deformation	M	0.062	0.058	0.085
Lower Wall	Equivalent Stress	MPa	545.22	542.30	548.14
	Deformation	M	1.06	0.94	1.54

Table 8.2 10% Perforated with Aluminium material

Parameters		Units	Material		
			Aluminium		
Grades			2024 T3	2024 T4	7075 T6
Density		Kg/m <sup>3</sup>	2780	2780	2810
Young's Modulus		GPa	73.1	73.1	71.1
Poisson's Ratio			0.33	0.33	0.33
Tensile Yield Strength		MPa	427	324	503
Ultimate Tensile Strength		MPa	475	469	572
Pressure (Upper)		Pa	831	831	831
Pressure (Lower)		Pa	1130	1130	1130
Results					
Upper Wall	Equivalent Stress	MPa	97.92	96.59	99.24
	Deformation	M	0.196	0.124	0.265
Lower Wall	Equivalent Stress	MPa	774.19	770.58	786.41
	Deformation	M	2.91	2.74	3.24

## 8.2 20% Perforated Wall

Table 8.3 20% Perforated with Steel material

Parameters		Units	Material		
			Steel		
Grades			AK 304	AK 316	AK 321
Density		Kg/m <sup>3</sup>	8030	7990	9010
Young's Modulus		GPa	193	193	193
Poisson's Ratio			0.24	0.24	0.24
Tensile Yield Strength		MPa	290	290	276
Ultimate Tensile Strength		MPa	621	579	621
Pressure (Upper)		Pa	592	592	592
Pressure (Lower)		Pa	132	132	132
Results					
Upper Wall	Equivalent Stress	MPa	60.25	58.82	64.48
	Deformation	M	0.055	0.041	0.084
Lower Wall	Equivalent Stress	MPa	289.54	286.41	290.57
	Deformation	M	0.121	0.087	0.23



Table 8.4 20% Perforated with Aluminium material

Parameters		Units	Material		
			Aluminium		
Grades			2024 T3	2024 T4	7075 T6
Density		Kg/m <sup>3</sup>	2780	2780	2810
Young's Modulus		GPa	73.1	73.1	71.1
Poisson's Ratio			0.33	0.33	0.33
Tensile Yield Strength		MPa	427	324	503
Ultimate Tensile Strength		MPa	475	469	572
Pressure (Upper)		Pa	592	592	592
Pressure (Lower)		Pa	132	132	132
Results					
Upper Wall	Equivalent Stress	MPa	60.64	58.48	65.25
	Deformation	M	0.139	0.128	0.148
Lower Wall	Equivalent Stress	MPa	314.77	311.51	322.14
	Deformation	M	0.354	0.326	0.453

## 8.3 30% Perforated Wall

Table 8.5 30% Perforated with Steel material

Parameters		Units	Material		
			Steel		
Grades			AK 304	AK 316	AK 321
Density		Kg/m <sup>3</sup>	8030	7990	9010
Young's Modulus		GPa	193	193	193
Poisson's Ratio			0.24	0.24	0.24
Tensile Yield Strength		MPa	290	290	276
Ultimate Tensile Strength		MPa	621	579	621
Pressure (Upper)		Pa	422	422	422
Pressure (Lower)		Pa	91	91	91
Results					
Upper Wall	Equivalent Stress	MPa	42.95	42.25	41.86
	Deformation	M	0.039	0.040	0.038
Lower Wall	Equivalent Stress	MPa	225.81	223.42	223.61
	Deformation	M	0.097	0.0094	0.098

Table 8.6 30% Perforated with Aluminium material

Parameters		Units	Material		
			Aluminium		
Grades			2024 T3	2024 T4	7075 T6
Density		Kg/m <sup>3</sup>	2780	2780	2810
Young's Modulus		GPa	73.1	73.1	71.1
Poisson's Ratio			0.33	0.33	0.33
Tensile Yield Strength		MPa	427	324	503
Ultimate Tensile Strength		MPa	475	469	572
Pressure (Upper)		Pa	422	422	422
Pressure (Lower)		Pa	91	91	91
Results					
Upper Wall	Equivalent Stress	MPa	43.22	42.15	45.24
	Deformation	M	0.099	0.097	0.098
Lower Wall	Equivalent Stress	MPa	217	216.52	220.58
	Deformation	M	0.24	0.25	0.27

From the structural analysis it proved that the wind fence with 30% perforation and located at the distance of 3.5m from the MDC at lower and upper portion is the optimized design for split wall case. The material which can be served as the best material for that case is Aluminium 2024 T3.

## Chapter 9

### CONCLUSION

Following conclusions can be drawn from the analysis :

- Steady state analysis was conducted and the air flow across the wind fence was analyzed.
- Static structural analysis was carried out to check the strength of the wind fence and to check for the material whether it can withstand such high wind load.
- Significant reduction in the speed of the wind below the desired value was achieved due to the presence of the wind fence in front of the MDC.
- Optimum configuration found as :-
  - For Single Wall when its 70% perforated and located at the distance of 2m from the MDC structure was the best design. The material selected was Steel AK 304. The reason for that is with 70% perforation less material will be in use and hence reducing the weight and choosing steel because placing on ground would require more strength and as steel is stronger than aluminium irrelevant of the cost factor.

- For Split Wall when its 30% perforated and located at the distance of 3.5m from the MDC structure was the best design. The material selected was Aluminium 2024 T3. The reason for that is as there were two different walls used to reduce the speed of the wind hence it should have such opening area which can satisfy the need of reduction of the speed and 30% perforation would reduce in the material cost too. For choosing aluminium over steel because for same strength aluminium is lighter than steel and also it is cheaper than steel.

## Chapter 10

### FUTURE WORK AND SCOPE

- Transient analysis can be carried out for an in depth study of the flow fields around the MDC.
- In case of structural analysis
  - Analyze the wind fence using different perforation patterns available in the market and also analyze using different shape of holes.
  - Analyze the wind fence by changing its design in different ways and also changing the different materials that are used for the wind fence construction.

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### Biographical Information

Nikhil Dilip Baviskar was born in Jalgaon, India. He received his Bachelor's degree in Mechanical Engineering from Pune University, India in 2012. He completed his Master of Science degree in Mechanical Engineering at the University of Texas at Arlington in August 2015.

His primary research areas include Computational Fluid Dynamics, Design and Structural Analysis. He has worked on the CFD analysis of the flow past a Modular Data Centers. He has also worked on the structural analysis for the different components that are undergoing very high impact loading. The project he has worked on was designing a windbreaker to reduce high speed wind loading on modular data centers and structural analysis of the windbreaker.

He joined the EMNSPC research team under Dr. Dereje Agonafer in August, 2014.