TENSILE MEMBRANE STRUCTURE AS A FILLING STATION ROOF IN BANGLADESH, A PRACTICAL PROJECT, METHODOLOGY AND DESIGN PROCESS

[1]Latifa Sultana

Abstract--*Tensile Membrane Structure may be an innovative alternate solution for Filling Station Roof in Bangladesh. Most of the filling station in Bangladesh are constructed developing low land adjacent to the highway and most of the roofs are constructed by R.C.C. Roofs height are generally more than 5.5 meter. In Bangladesh these height are not conventional for other typical building. So shuttering materials specially props for this height are not available. There is happened many accident during construction of this roof for heavy selfweight of R.C.C and lacking of proper shuttering and improper soil improvement.Tensile Membrane Structure is a very light weight structure. So foundation costing is very much economical than other conventional structure. No shuttering materials are required. Chances of accident during construction are reduced. So it is safe for construction. This light weight structure allows to freely innovating exciting solutions for the buildings which may attract general people including customer and make a better business opportunity. So Tensile Membrane Structure may be the best solutions for this type of project in Bangladesh.*

Keywords-- *Form Finding, Light weight structure, tensile membrane structure, Warp & weft of membrane, 5th construction material.*

I INTRODUCTION

Tensile Membrane Structure is a light weight structure and is architecture of new generation as well as possibility to supplement traditional architectural solutions. Tensioned membrane material is considered to be the fifth construction element after metal, stone, glass and concrete. Tensile membrane structure is advanced structure using polymer textile to be roof material. This light weight material allows architects and engineers to freely innovate exciting experimental solutions for their building's solutions. There are many reasons that convince to use 5th materials of construction refer as tensile membrane structure.

Some of them are as follows

i. Light weight material
ii. Free forms
iii. Economical
iv. Rapid for construction
v. Recycling (eco-friendly)

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vi. Wide range of applications from large scale building to urban design until small cover walk way

Figure 1: Tensile Membrane Structure

1.1 Filling Station

A filling station is a facility that sells fuel and engine lubricants for vehicles. The most common fuels sold are gasoline and diesel fuel. Fuel dispensers are used to pump petrol/gasoline, diesel, compressed natural gas, or other types of fuel into the tanks within vehicles and calculate the financial cost of the fuel transferred to the vehicle. Generally filling stations are covered by an open roof. Most of the filling stations are constructed by R.C.C developing low land in Bangladesh.

Figure 2: Conventional filling station roof in Bangladesh

1.2 Construction of Filling Station Roof and Context of Bangladesh

Most of filling station in Bangladesh are constructed at low land adjacent to the Highway.Lands are developed by filling sand and most of the roofs are constructed by R.C.C. Roofs height are generally more than 5.5 meter. In Bangladesh these height are not conventional for other typical building. So shuttering materials specially props for this height are not available. There is happened many accident during construction of this roof for heavy selfweight of R.C.C and lacking of proper shuttering and improper soil improvement.

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Figure 3: Accident during construction of a filling station at Bahadurpur in Ashuganj upazila of Brahmanbaria on Monday noon (Aug 28, 2017).

1.3 Demand of Tensile Membrane Structure for the Filling Station

Tensile Membrane Structure is a light weight structure. Compare with conventional R.C.C filling station roof the weight of tensile membrane structure is very low may be 7%-10% of R.C.C structure. So foundation costing is very much economical than other conventional structure. No shuttering materials are required for construction. Chances of accident during construction are reduced. So it is safe for construction.

In all respect tensile membrane structure is economical for this type of project. Moreover the construction process is very fast and less hassled. Finally this light weight structure allows to freely innovating exciting solutions for the buildings which may attract general people including customer and make a better business opportunity. So Tensile Membrane Structure may be the best solutions especially for this type of project in Bangladesh. Hence proposed Tensile Membrane Structure of the filling station is a landmark.

Figure 4: Side View of the Proposed Filling Station by Tensile Membrane Structure

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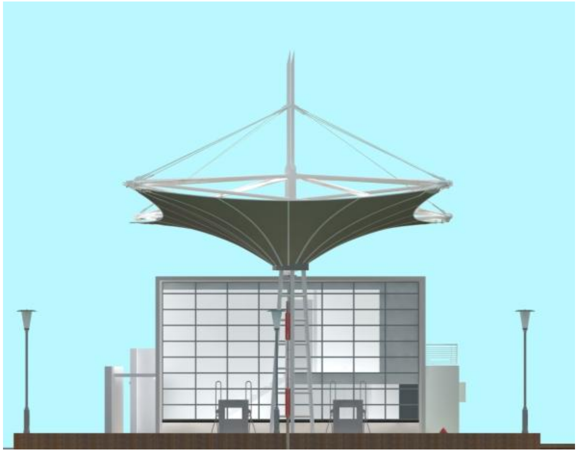

Figure 5: Front View of the Proposed Filling by Tensile Membrane Structure

II PROJECT BRIEF

The proposed tensile membrane canopy shade structure consists of connected fabric panels with structural members supporting them at different locations. The fabric shape could be idealized into a conical shape funnel.

The canopy consists of 3 conical funnel. In the width direction of the shade dimension of each funnel is equal whereas in the long direction of the shade two funnels are equal and other one is little bit shorter.

Each of two equal funnels is rested on 5 equal sizes of CHS which are supported from foundation in the ground. Other funnel

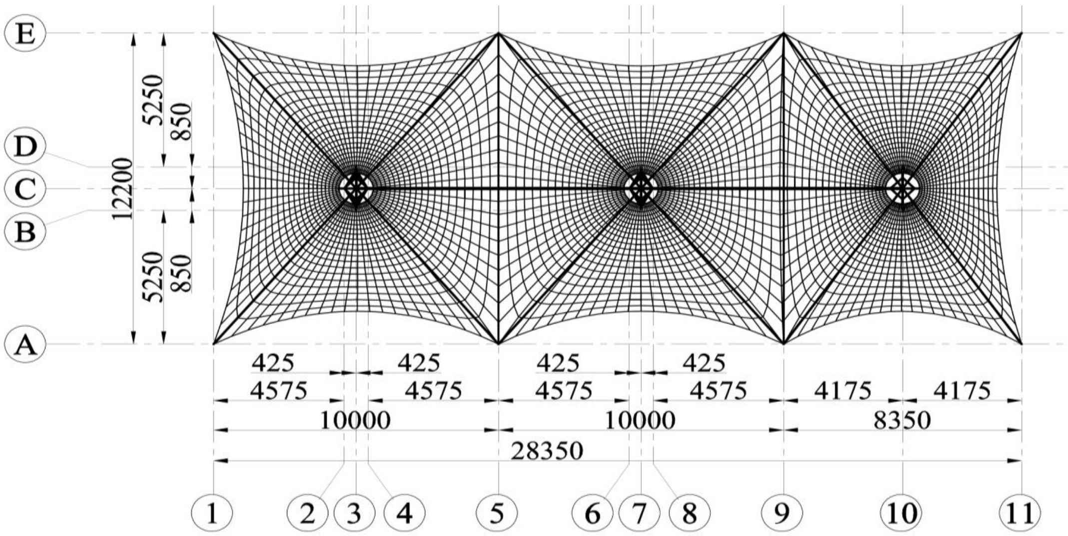

Figure 6: Fabric Layout Plan of the Proposed Filling Station by Tensile Membrane Structure

is rested on a larger size of CHS supported on the roof of utility building.

The steel structure of each funnel comprise of 4 nos. of angular frame diagonally by CHS. One end of each frame is connected with cable and other end is connected with steel mast.

Steel masts are braced by CHS in the long direction of the shade.

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The base of column mast is bolted to the precast holding down bolt to RCC pedestal column.

Some of steel frames are bolted connections and some are welded connections.

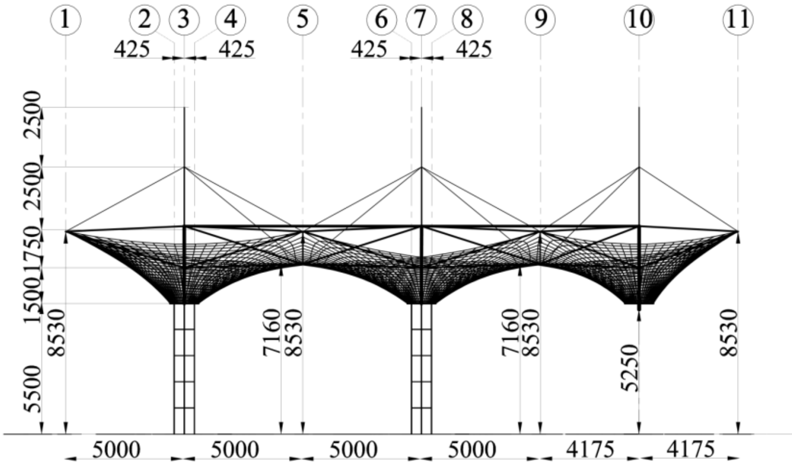

Figure 7: Side View of of the Proposed Filling Station by Tensile Membrane Structure

III METHODOLOGY FOR ANALYSIS & DESIGN

The Fabric Canopy shade structure consists of connected fabric panels with structural members supporting them at different locations. The fabric shape could be idealized into a conical shape funnel.

The analysis of the tensioned membrane structure is done in two stages. Firstly is to do the form finding of the membrane or fabric. Then by using the forces from the static analysis of the prestressed membrane and applied to the steel structure and do a design check of the steel structure.

Following reference documents, unit, code & standard and software are used.

Reference documents: for wind load

Bangladesh National Building Code-BNBC-2006, EURO CODE, IS-875 Part-3

Unit: The S.I system

Code & Standard: BS 6399 : Part 1 : 1996 – Code of practice for dead and imposed loads, BS 6399 : Part 3 : 1988 – Code of practice for imposed roof loads, BS 5950-1 : 2000 – Code of practice for design – Rolled and welded sections.

Software: ixCube4-10, STAADPro.V8i, Etabs, Autocad, 3d Max .

Materials are used as specified as follows

All Circular Hollow Section CHS members to CHS section conforming BS EN 10210 S275

All plates to BS EN 10025 S275 or equivalent.

The corner plate is using S355 material.

Anchor Bolts – Gr. 8.8

Connecting Bolt - Gr. 8.8

Border cable use PE coated galvanized steel wire rope

Safety cable is galvanized steel wire rope dry type.

PVC fabric FERRARI PRECONTRAINT 1202-S / or Equivalent

Tensile Strength (Warp): 560 daN/5cm

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Tensile Strength (Weft): 560 daN/5cm

3.1 Membrane/Fabric analysis

The task of determining appropriate forms of the membrane based on the given outline is using the software ixCube 4-10.

The ixCube 4-10 form finding method is based on the method of force density algorithm. After the equilibrium shape is formed, the form is then applied with external load, ie imposed load, wind load and etc. and static analysis of the fabric is then carried out.

The fabric analysis is performed using the software ixCube 4-10. It is a non-linear program to perform the fabric analysis. In the fabric analysis, wind pressures (as per the calculation) is applied on the pre-stressed fabric. The software performs several iterations unless the results converge. The results of the fabric analysis are fabric stresses, cable tension force and reaction forces at the fabric support.

3.2 Structural System

The proposed fabric canopy shade structure consists of connected fabric panels with structural members supporting them at different locations. The fabric shape could be idealized into a conical shape funnel.

The canopy consists of 3 conical funnel connected by cable along the short direction of the shade. Structural system of these 3 conical funnel are developed from 3 rectangular areas whose dimensions are 10MX12.2M, 10MX12.2M & 8.35MX12.2M. The steel structure of each funnel comprise of 4 nos. of angular frame diagonally by CHS. One end of each frame is connected with cable and other end is integrated with steel mast.

Each of two equal funnels is rested on 5 equal sizes of CHS which are supported from foundation in the ground. Other funnel is rested on a larger size of CHS supported on the roof of utility building.

Due to architectural limitation & requirement column masts are framed in tapered pattern and for lateral stability it is considered larger in the short direction of the shade at ground. Upper part of the masts are formed a square pattern. The stability of the structure is dependent on ties and bracing.

So column masts are braced laterally at different level. Steel masts above the rings are farther braced by CHS in the long direction of the shade.

The base of column mast is bolted to the precast holding down bolt to RCC pedestal column.

Due to limitation and constrain for site access, the steel structure is designed such that it will be able to be lifted by a small tonnage crane eg. 30 tons and so most of the connections are decided bolted connection. Some of steel frames are welded connections.

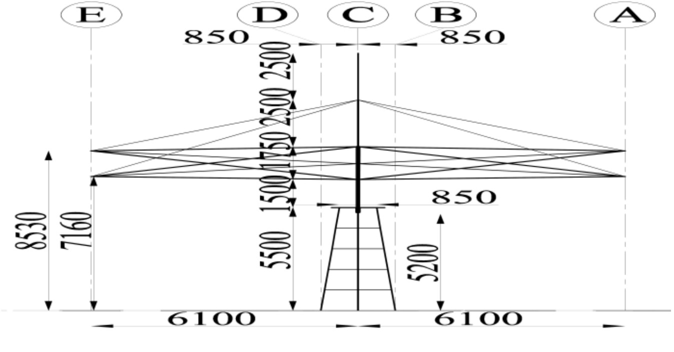

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Figure 8: Front View of Structural System

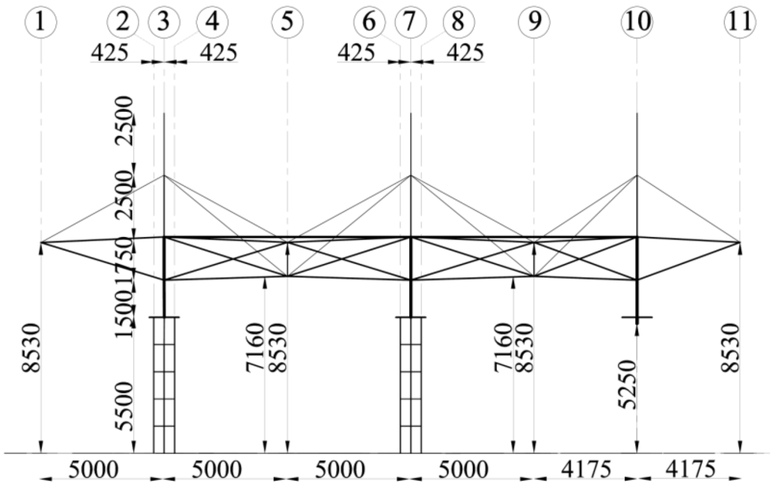

Figure 9: Side View of Structural System

3.3 Loading Assumption

The fabric roof and steel structure is subjected to the following loading:

a) Dead Load like Self weight of steel truss, column, bracing etc.

b) Prestress force in the membrane

c) Imposed live load on membrane roof

d) Wind load in different condition

Table 1: Basic Load Case

1. Prestress (P Factor) and Selfweight	DL
2. LL Uniform	LL
3. Wind From Left Side	W(+X)
4. Wind From Right Side	W(-X)
5. Wind From Front Side	W(+Y)
6. Wind From Back Side	W(-Y)
7. Wind Uniform Uplift	Wu

3.4 Structural Model using ixCube 4-10 and Steel Analysis & Design

ixCube 4-10 is specially developed software for Tensile Membrane Structure industry. On the ixCube 4-10 software there are many landmark Tensile Membrane Structure around the world.

First of all an appropriate forms of the membrane using form finding option is developed based on the given outline.

The ixCube 4-10 form finding method is based on the method of force density algorithm. It is a non-linear program to perform the fabric analysis. After the equilibrium shape is formed, external load, ie imposed live

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load, wind load etc are applied on the pre-stressed fabric. A static analysis of the fabric is then carried out. The software performs several iterations unless the results converge. The results of the fabric analysis are fabric stresses, cable tension force and reaction forces at the fabric support.

This Membrane model is analyzed for member forces and reactions for different load combinations. Member design is performed using BS: 5950

3.5 Design Model

The steel structure has been modeled as a 3 dimensional frame model along the center line of the steel section. The ends of frame member are connected by nodes. The entire steel member in this case uses all Circular Hollow Section CHS.

All column mast and column bracing are assumed to be Beam type, Linear behavior & Stiff deformable deformability.

All beams are assumed to be Truss type, Linear behavior & Stiff deformable deformability.

All Cables are assumed to be cable type, non Linear behavior and deformable

3.6 Design of Steel Members

The design of the member size complied to BS5950 where the ultimate strength is used and the relevant load factor is applied to the imposed loading. For deciding the correct pipe size for every member, compression will be the deciding factor and the compression capacity depends on the slenderness ratio (l/r) and the tension capacity only depends on the sectional area.

The final member sizes for individual member are determined from the worst force and moment from the ultimate load combination.

The software is able to check the sizes assigned based on the output from the worst load combination. The model view is attached for reference.

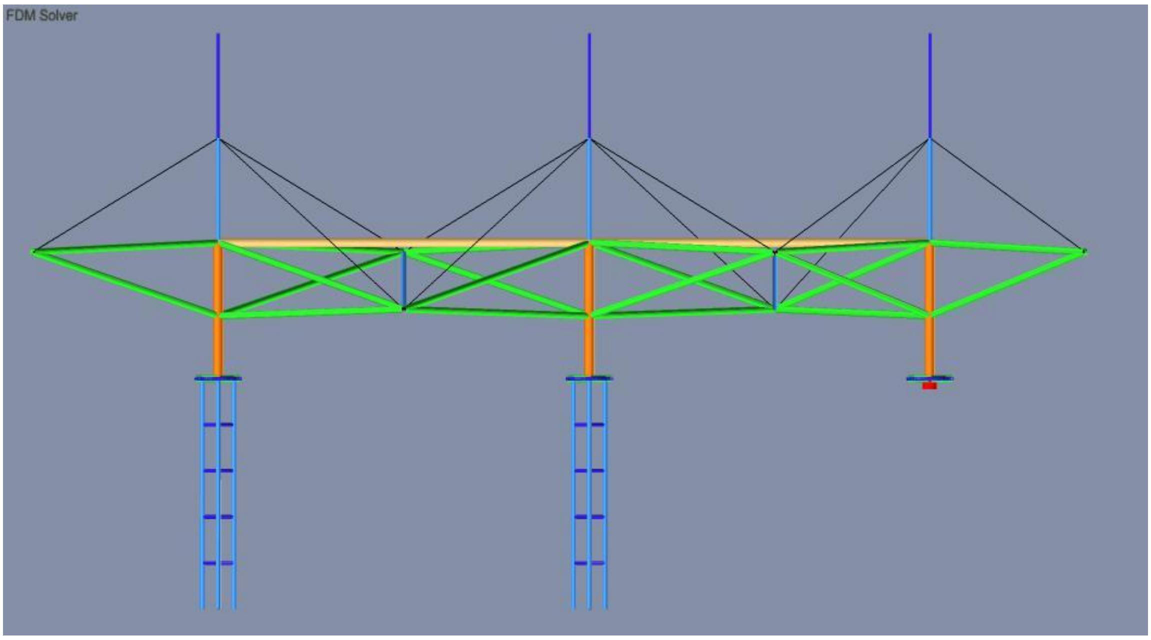

Figure 10: Model Side view (Only Structural Member)

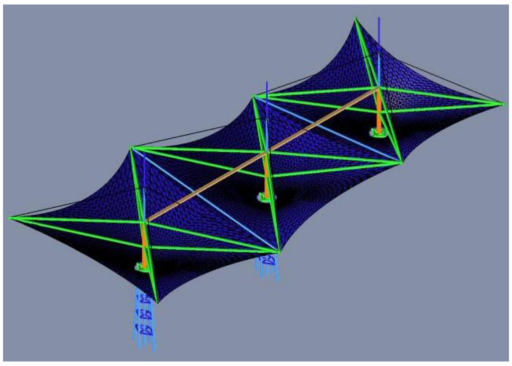

Figure 11: Model Isometric view with Membrane

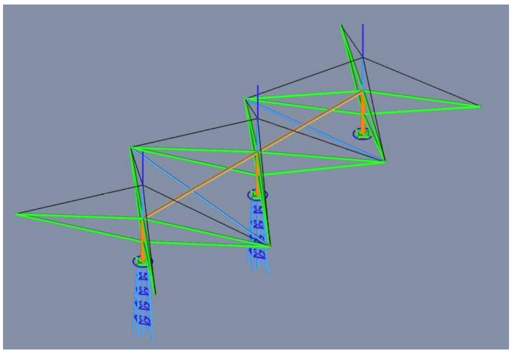

Figure 12: Model Isometric view (Only Structural Member)

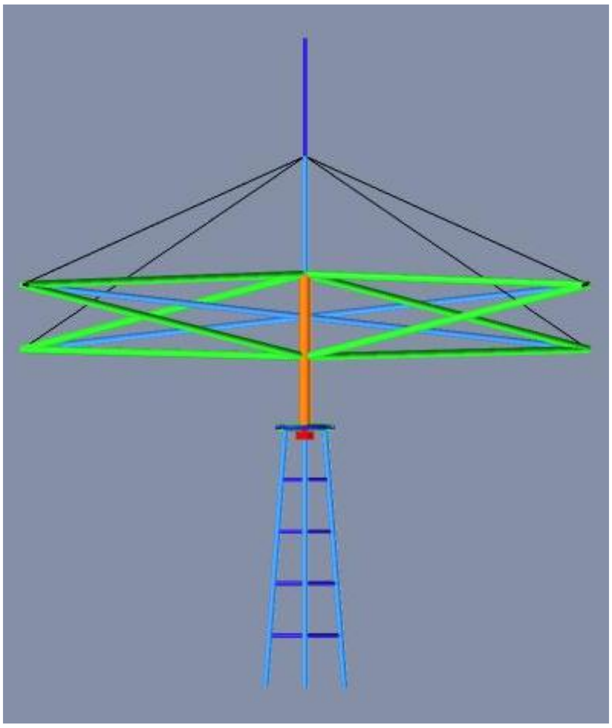

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Figure 13: Model Front view (Only Structural Member)

3.7 Plate Connection to CHS using STAADPro.V8I

For the tensile structure, there is a lot of connection with plate welded to Circular Hollow Section (CHS) for fixing of fabric, for bolting of bracing member, cable connection etc. To check the influences of forces to these plate and main member is quite complex, so a finite element model (FEM) is done using STAADPro.V8i for some typical connection to verify the von mises stresses or equivalent stress is not to exceed the yield stress of main member and plates.

The von mises stress shall not exceed 90% of the material yield stress. We have used S275 materials. Therefore the connection stresses shall not exceed 0.9x275 N/mm2 = 247.5 N/mm2

Extract 6 finite element model done at 6 connections as shown and attached for information.

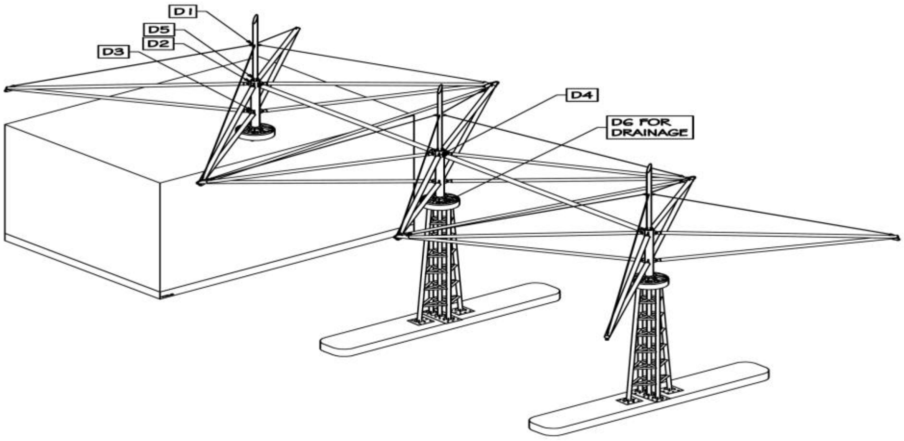

Figure 14: Key plan for connection design

Plate Connection to CHS at D2

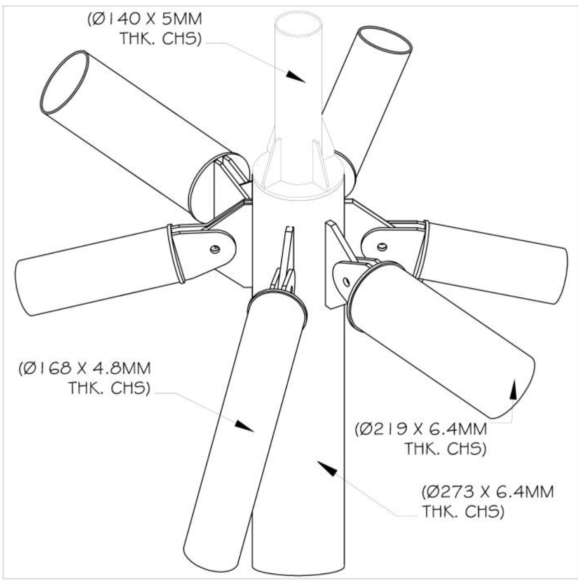

Figure 15: Information on the joint

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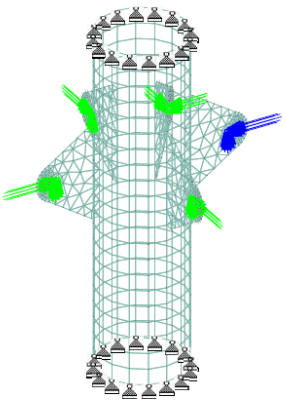

Figure 16: FEM with force @ bolt hole **Figure 17:** 3D rendered view

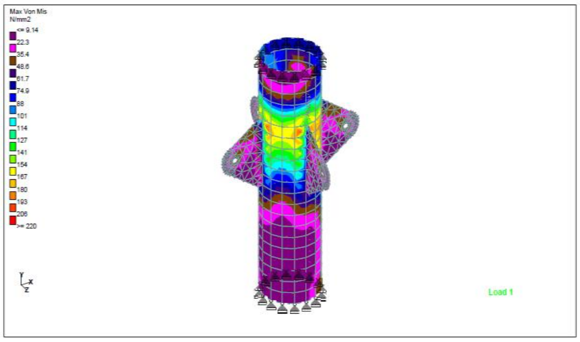

Figure 18: Max von mises output

Plate connection to CHS at D3

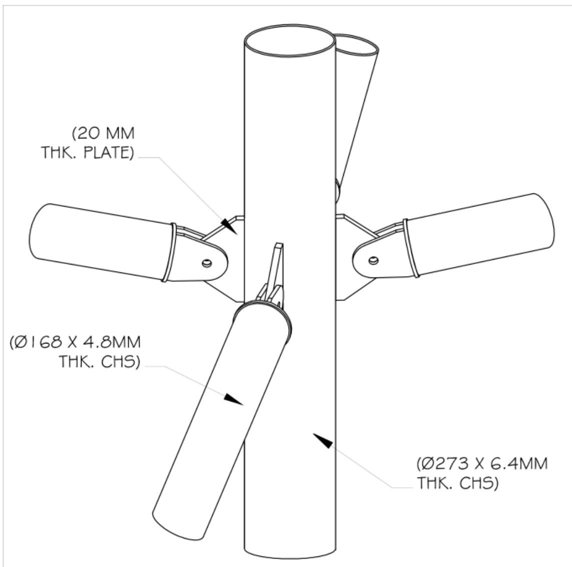

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Figure 19: Information on the joint

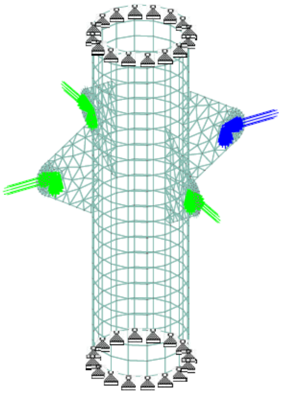

Figure 20: FEM with force @ bolt hole **Figure 21:** 3D rendered vie

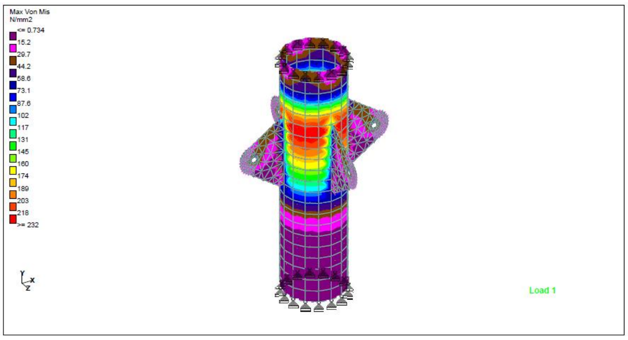

Figure 22: Max von mises output

Plate Connection to CHS at D4

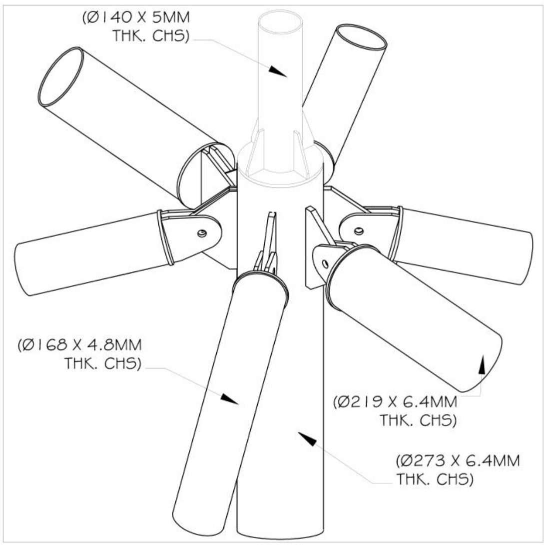

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Figure 23: Information on the joint

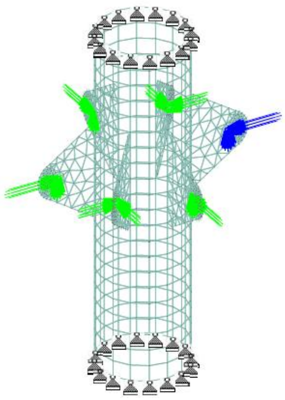

Figure 24: FEM with force @ bolt hole **Figure 25:** 3D rendered view

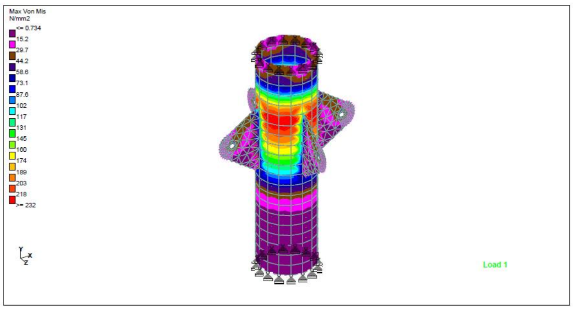

Figure 26: Max von misses output

Plate Connection to CHS at drainage (D6)

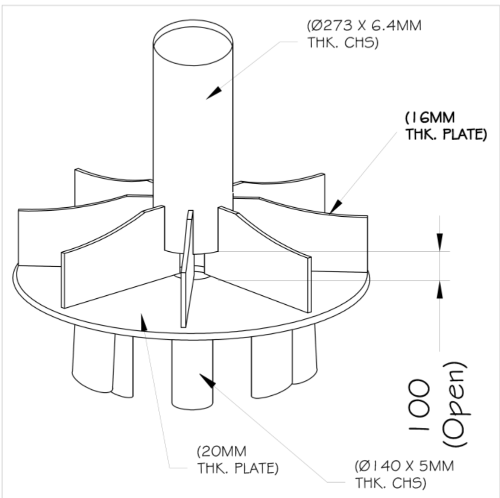

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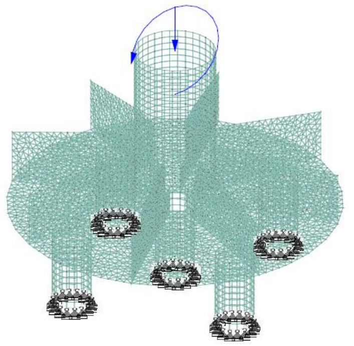
Fig 27: Information on the joint



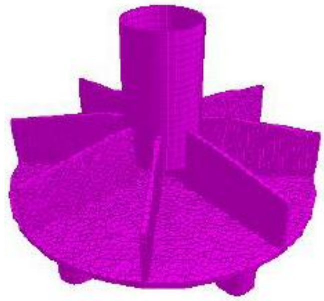


Figure 29: 3D rendered view

Figure 28: FEM with force @ Column

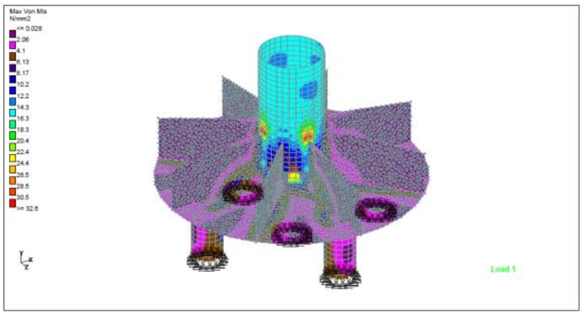


Figure 30: Max von mises output

Summary of Connection Details

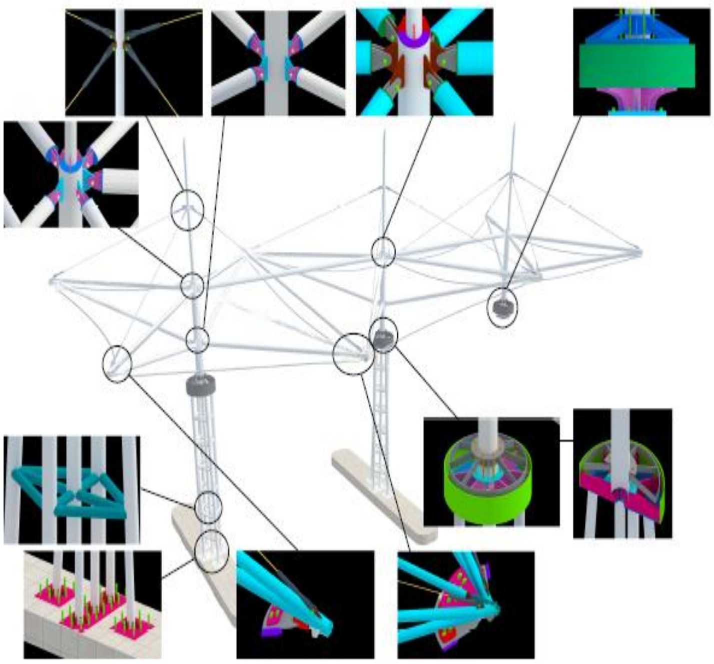


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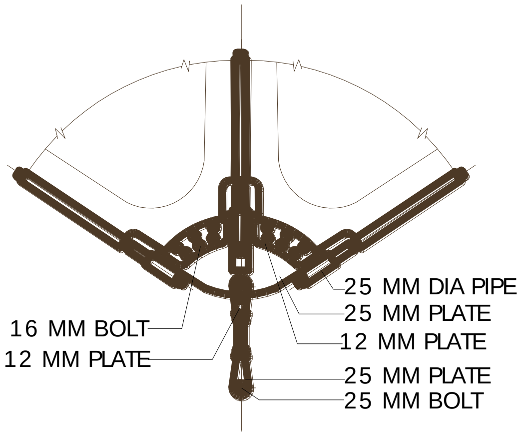
Figure 31: Summary of connection details

3.8 Corner Plate

There are two types of corner plates used in the project. One type of corner plates is used at extreme end of membrane end. And



other types are used in the intermediate end of membrane where two funnels are connected. Corner plates are used connecting membrane with steel beam and cable

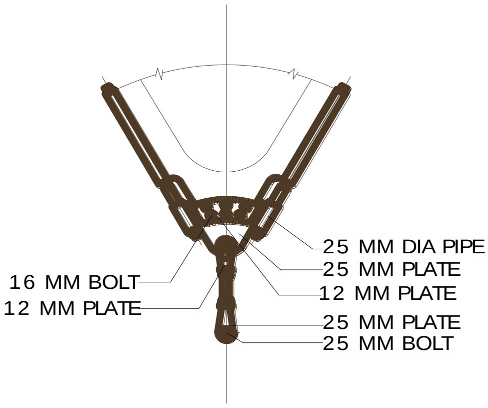
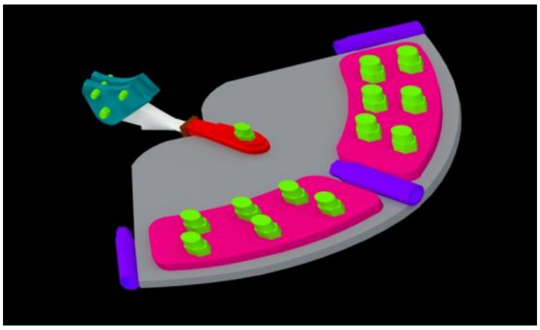


Figure 32: Details of corner plate



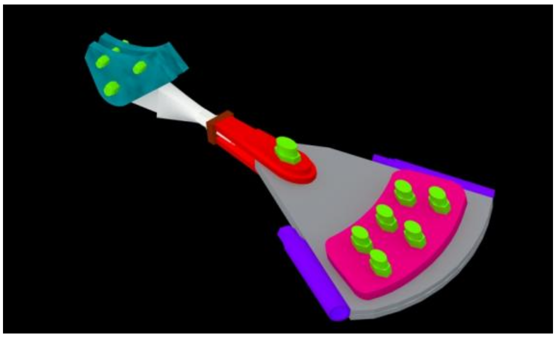


Figure 33: 3D of corner plate

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IV RAIN WATER DRAINAGE

Rain water in the funnel will fall in the ring of funnel. Column mast of the funnel is detailed such a way so that water cannot be obstructed by that column mast. A 100 mm opening is detailed between column mast and base plate of ring. A 130 mm diameter of hole is provided in the ring base plate so that water can passes through the hole.

Middle column mast of below the ring is connected with the plate vertically downward and attached to the ground base. A 130 mm diameter PVC pipe is then connected to the lower part of the vertical column mast in the ground so that water comes through the vertical column can be drained out to the central drain pit of the project.

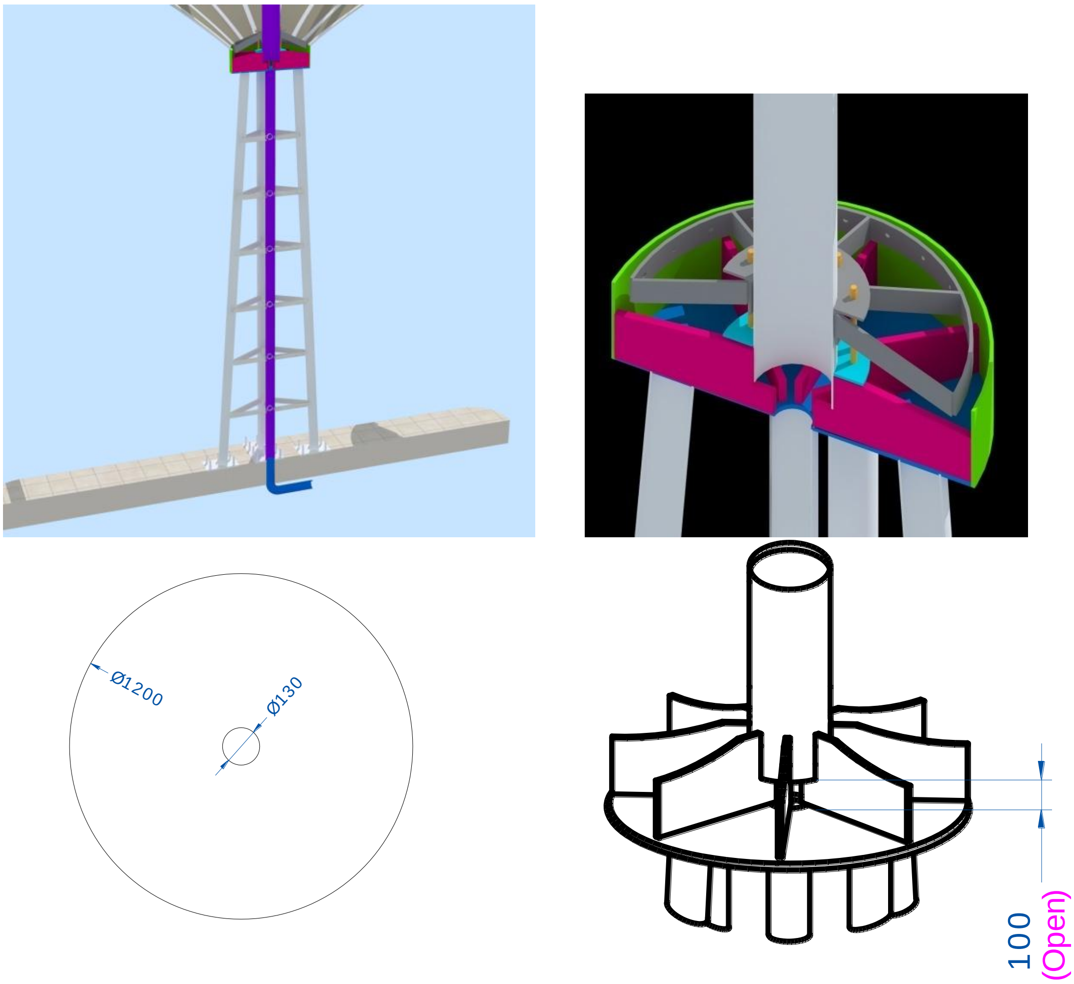

Figure 34: Drainage Detail

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V Membrane Analysis Details

Membrane Stress output from ixCube 4-10

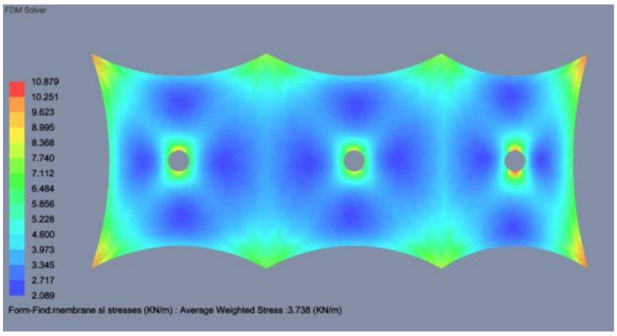

Figure 35: Form-Find Warp stress-SI

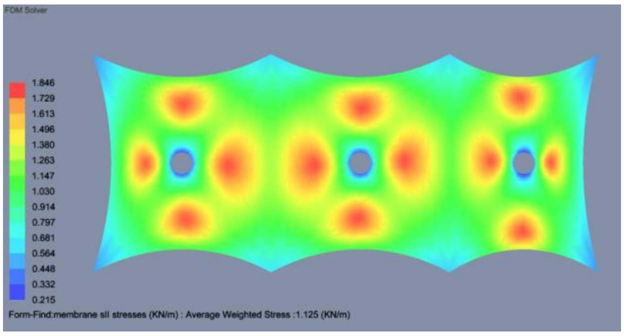

Figure 36: Form-Find Warp stress-SII

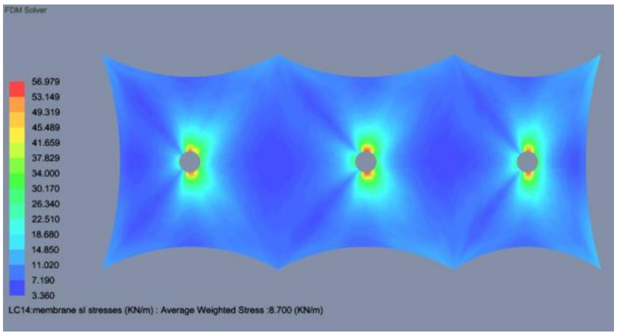

Figure 37: LC14 (DL+LL+W(+X)):Warp stress-SI

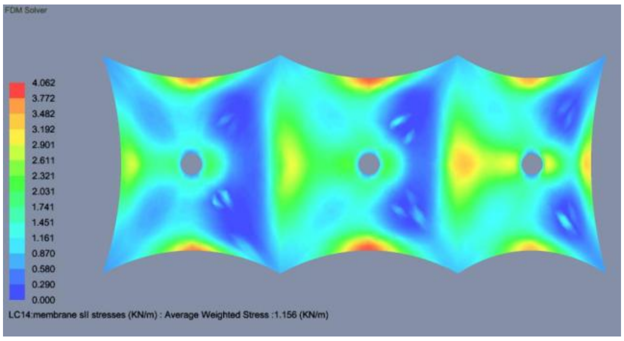

Figure 38: LC14 (DL+LL+W(+X)):Weft stress-SII

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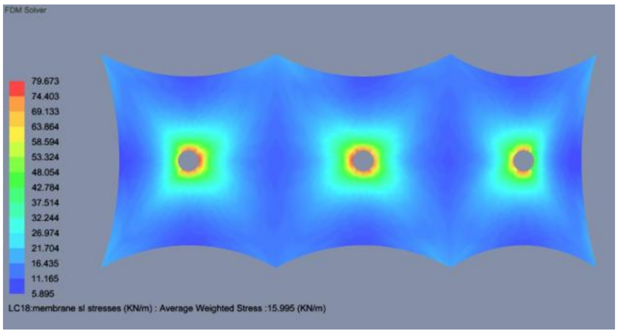

Figure 39: LC18(DL+LL+Wu):Warp Stress-SI

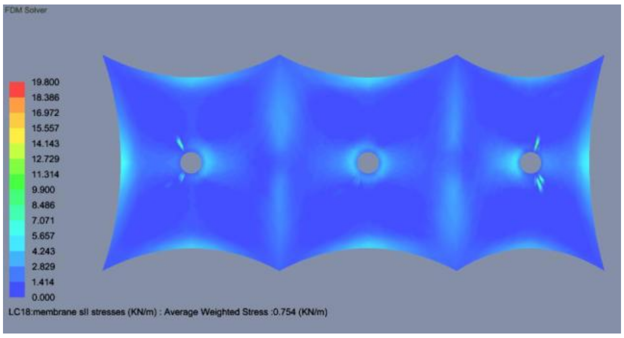

Figure 40: LC18(DL+LL+Wu):Weft Stress-SII

5.1 Fabric Stress & Selection of Fabric

Average maximum stress in the fabric for service load combinations

a) In warp direction = 18 KN/m

b) In weft direction = 11 KN/m

Tensile Strength of the fabric - PVC FERRARI PRECONTRAINT 1202 -S / Or Equivalent

a) In warp direction = 560 daN/5cm

= 112 KN/m

b) In weft direction = 560 daN/5cm

= 112 KN/m

Factor of Safety for the fabric stresses

a) In warp direction = 112 / 18

= 6.22 > 4, Hence acceptable

a) In weft direction = 112 / 11

= 10.18 > 4, Hence acceptable

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Hence, proposed fabric is **SAFE**

VI DISCUSSION

Tensile membrane structure is advanced structure where the exterior shell is a fabric material over a frame works. Flexibility characteristics of this structure provide virtually unlimited designs of distinctive elegant forms**.** Finding the proper shape of the structure 'prestress' is applied under a unique process named 'form finding'. Fabric is maintained in tension in all directions to provide stability. Improper stress ratio in fabric may be caused 'ponding' and 'wrinkle'. Fabricating the fabric structure 'patterning' is the other important part of the design.

From the above discussion we can say that tensile membrane structure is the structure with combination of fabric & frame. To design a tensile membrane structure it should be felt that 'it's basically steel, fabric & cables' then the design to be developed under the consideration of 'form finding', structural response to loads, 'patterning', choosing the right fabric, and picking the right component.

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