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Tensile Roof Structure

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Abstract: *Membrane Structures are highly popular in architectural design now a days. There is trend of using membrane structures. It satisfies both attractive architect's design as well as structural design. The preliminary type of structure most commonly used by man was Tents. As the name suggests, Tension fabric structures utilize fabric in complete tension, as a primary building material. Every part of structure is loaded only in tension with no requirement to resist bending or compression. Soap film model is the classic example of Tensile Structures. Assembly of tensile membrane structures creates a unique structural system, indeterminate in its behavior and nonlinear in its deflection patterns. Tensile structures are gaining popularity due to their light weight, structural efficiency, serviceability, aesthetic appearance, installation and dismantling feasibility, climate regulation effects and less maintenance expenditures. Due to its light weight and stretch property, they can be used on places such as stadiums, large parking etc. Computer aids like Form Finder, Dlubal RFEM and AutoCAD is used for modeling and analysis.*

Keywords: Tensile membrane Structures, Material, Form-Finding, Analysis, Dlubal RFEM

I. INTRODUCTION

Tensile membrane structures forms a part of a unique technology which gives designers, architects and engineers the ability to experiment with form (Shape) and create exciting structures. These structures do not only visually exciting, but are environmentally good and economically competitive as well. Since the materials are lightweight, they are very efficient in long span applications and are frequently constructed with considerable savings in the foundation and supporting structure costs. As an additional benefit, they do additional than just transmit forces to the ground. They provide the basic architectural form and provide much of the building cover.

Conventional structures depend on internal rigidity (stiffness) to attain stability and to carry loads. Fabric structures constructed of elements that have small or no bending or shear stiffness (cables and membranes) must depend on their form and internal tensile forces to carry loads. These structures are complicated to design as they have a tendency to be highly non-linear behavior; also their shape is not known when design starts. Tensioned fabric increases its capacity to carry load as it deform. They can maintain high ratio of applied load to self –weight, as compared to steel and concrete structure for same span.

Architectural fabrics typically consist of woven glass fibre yarns with a polytetrafluoroethylene (PTFE) coating or woven polyester yarns with a polyvinyl chloride (PVC) coating. They have negligible bending and compression stiffnesses. Hence fabric structures are designed with sufficient curvature to enable environmental loads to be resisted as tensile forces in the plane of the fabric. This contrasts with conventional roofs in which loads are typically resisted by arch action or by stiffness in bending. The shape of the fabric canopy is vital to its ability to resist all applied loads in tension. To resist both uplift and down-forces (typically due to wind and snow respectively) the surface of the canopy must be double-curved and prestressed. Typically conic or saddle shapes are used to achieve this, taking advantage of their inherent double-curvature.

II. FABRIC MATERIAL

The most important and defining component of a fabric structure is the fabric material itself. Structural fabric can be broken down into yarns, which in turn are made of fibers. The membrane is made up of yarns that are in turn made up of fibers. These fibers, which are generally made of nylon, polyester, Polyethylene, glass and compose the structural component of the membrane. There are a variety of ways to join fibers to create yarn and a number of ways to weave yarn into fabric. The fibers can either be bunched in a parallel fashion or twisted together shown in figure 1.

The woven yarns provide tensile strength, whilst the coating stabilises and protects the weave and provides waterproofing, shear stiffness , improve its weather protection and dirt-resistance, more durable.These top coatings have a large influence on the performance and appearance of the fabric, because they not only provide the fabric with some of its UV resistance, but they also vastly improve its self-cleaning characteristics. There are several types of coating like Polyvinylchloride (PVC) , PTFE (Teflon) ,PVF ,PVDF ,Silicone ,Polyethylene and ETFE Foils (figure 2).

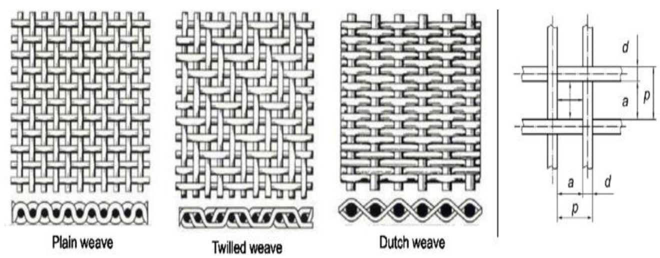

Figure 1: Fiber patterns

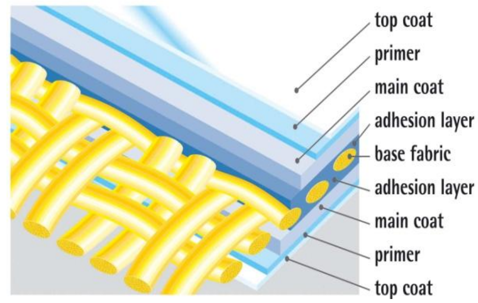

Figure 2: Component of fabric

Table 1: Advantages & Disadvantage of tensile structure

Advantages of tensile structure		Disadvantages of tensile structure
1)	Light weight and flexible	Cannot take heavy weather condition
2)	Economical	Creep
3)	Fire Resistance	No rigidity
4)	Translucency	Less thermal value
5)	Tensile Strength	Loss of tension is dangerous for stability
6)	Simple and fast installation	Skills require is more as compare to conventional building
7)	Workability	
8)	Ultraviolet radiation protection	
9)	Saving energy	
10)	High strength to weight ratio	
11)	Less impact on site	

III. ANALYSIS

Determination of the minimal surface shape (form finding) and large displacement behaviour under load requires nonlinear finite element analysis. In this work, software used are AutoCAD, Dlubal RFEM5, RWIND 2. RFEM is structural analysis software that uses the finite element approach. RFEM software is useful for modelling , analysis and designing of tensile roof structure. To study the concept of geometry of fabric (form Finding), Initial load distribution and Deformation of the fabric membrane, simple analysis of membrane structure Cone is performed in Dlubal RFEM5.

There are currently no Indian standard, British or European codes for the design of fabric structures, although the European collaborative group TensiNet is aiming to produce a draft design guide in the near future that will collate current good practice and recommendations. The US standard ASCE/SEI 55-10 "Tensile Membrane Structures" [Am10] is primarily a valuable code for design and construction practice. A detailed commentary is also an inherent part of the document. It includes all tensile membrane structures which exceed a defined size, temporary and permanent, but it explicitly excludes air-supported and air-inflated structures. The standard does not limit the application to any membrane material, i. e. it applies for all fabrics and foils as well. Membrane physical properties shall be determined in accordance with ASTM D4851.

The proposed tensile structure is located in kevadia. The structure is made up of mild steel tubular sections. The structure provides roof to the walk way area using tensile fabric membranes and steel. Rectangular cone dimension 4 x 4.5 m and 3m clear height and 5m is total height and 1mm thickness of fabric material.

- Design fabric material as per ASCE 55-10 and loading as per ASCE 7.
- Fabric type is PTFE and The elastic constants provided are Ex = 634 kN/m, Ey = 213 kN/m, Vxy = 0.29 and Vyx = 0.87.

- The material for steel section selected is Steel IS 513 D | IS 800:2007.
- Design steel member according to IS 800:2007.
- IS 1161: 1998 Hollow steel section for structural use.

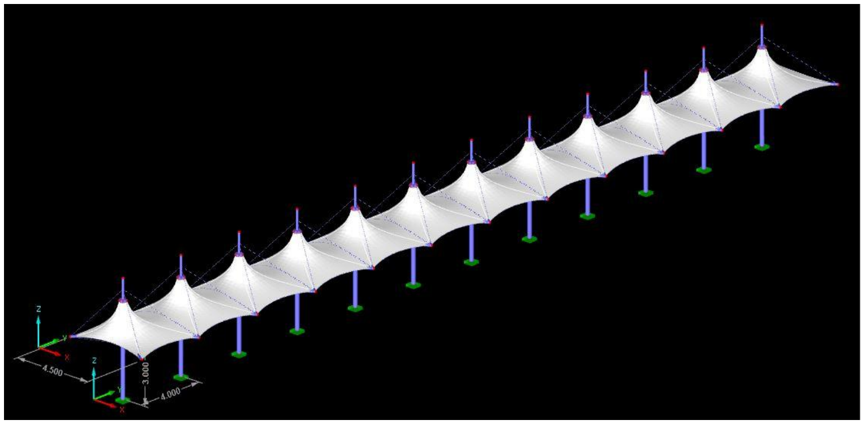

Figure 3: Walkway modal

IV. LOAD ASSUMPTIONS AND COMBINATIONS (AS PER ASCE 7-2010)

- **Units:** All units are specified in SI system for solving equations. Forces are in Kilo Newton and moments in KN-m.
- **Sign Conventions:** Positive signs indicate compression and negative signs indicate tension.
- **Prestress:** Models Initial Force of 2 KN/m is applied to observe the variation in Form as well as strains.
- **Dead Weight:** The dead weight is assumed including all the fittings. Absorption of liquid is not possible, so any addition in the dead load due to water ingress is not possible.
- **Imposed Loads:** An exception is noted for “awnings and canopies of fabric construction supported by a lightweight rigid skeleton structure” for which the minimum live load is 0.24 kN/ /m2.

4.1 Wind Loads

For kevadia basic wind speed is 39 m/s
Exposure category= C
Kd = wind directionality factor=0.85
Kzt = topographic factor=1
G = gust-effect factor=0.85
Consider wind direction 0 degree and 90 degree

4.2 Load Combinations

- self weight + prestress
- self weight + prestress + live
- self weight + prestress + wind 0 degree
- self weight + prestress + wind 90 degree
- self weight + prestress + live + wind 0 degree
- self weight + prestress + live + wind 90 degree

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V. RESULT

Global Deformation according to ASCE 7-2010

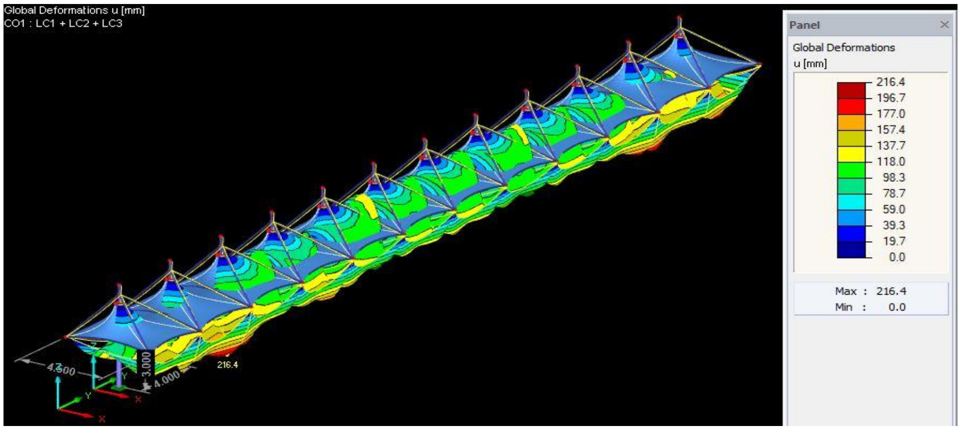

Figure 4: Global deformation for load combination

Basic Internal forces in fabric

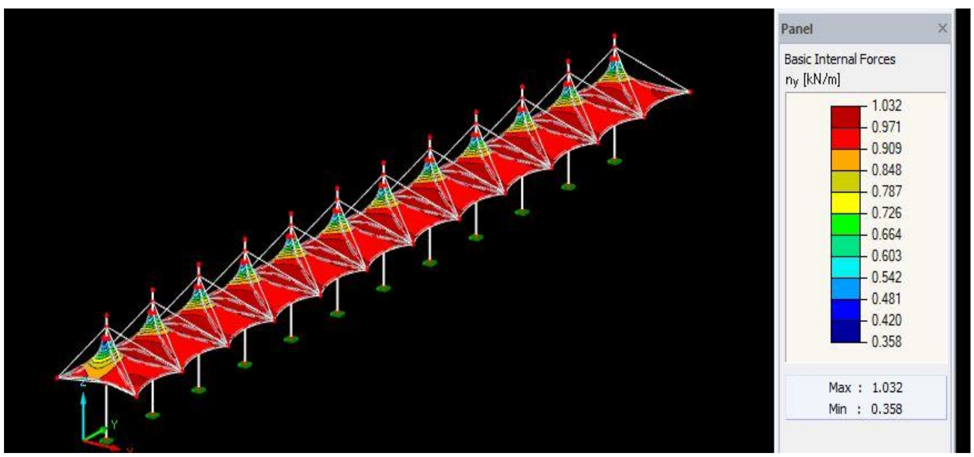

Figure 5: Basic Internal forces in fabric in weft direction

Steel take-off

RF-STEEL IS - [KEVADIA WALK WAY]

4.1 Parts List by Member

Part No.	A Cross-Section Description	B Number of Members	C Length [m]	D Total Length [m]	E Surface Area [m²]	F Volume [m³]	G Unit Weight [kg/m]	H Weight [kg]	I Total Weight [kg]
1	1 - RO 152.4x5.4 | IS 1161-1998	12	2.50	30.00	14.36	0.07	19.58	48.94	587.29
2	1 - RO 152.4x5.4 | IS 1161-1998	12	0.50	6.00	2.87	0.01	19.58	9.79	117.46
3	2 - RO 101.6x4.8 | IS 1161-1998	24	0.50	12.00	3.83	0.02	11.46	5.73	137.50
4	2 - RO 101.6x4.8 | IS 1161-1998	24	2.50	60.00	19.15	0.09	11.46	28.65	687.52
5	1 - RO 152.4x5.4 | IS 1161-1998	12	1.50	18.00	8.62	0.04	19.58	29.36	352.37
6	2 - RO 101.6x4.8 | IS 1161-1998	24	3.61	86.53	27.62	0.13	11.46	41.32	991.56
7	3 - Round 10	24	4.00	96.00	3.02	0.01	0.62	2.47	59.19
8	3 - Round 10	24	3.20	76.84	2.41	0.01	0.62	1.97	47.37
9	3 - Round 10	24	4.12	98.95	3.11	0.01	0.62	2.54	61.01
10	3 - Round 10	24	2.55	61.19	1.92	0.00	0.62	1.57	37.72
11	3 - Round 10	24	3.64	87.36	2.74	0.01	0.62	2.24	53.86
12	2 - RO 101.6x4.8 | IS 1161-1998	48	0.24	11.31	3.61	0.02	11.46	2.70	129.60
13	2 - RO 101.6x4.8 | IS 1161-1998	48	0.15	7.20	2.30	0.01	11.46	1.72	82.50
14	2 - RO 101.6x4.8 | IS 1161-1998	6	4.00	24.00	7.66	0.04	11.46	45.83	275.01
15	3 - Round 10	13	4.50	58.50	1.84	0.00	0.62	2.77	36.07
Sum		343		733.88	105.07	0.47			3656.04

Figure 6: Steel take-off

Design ratio

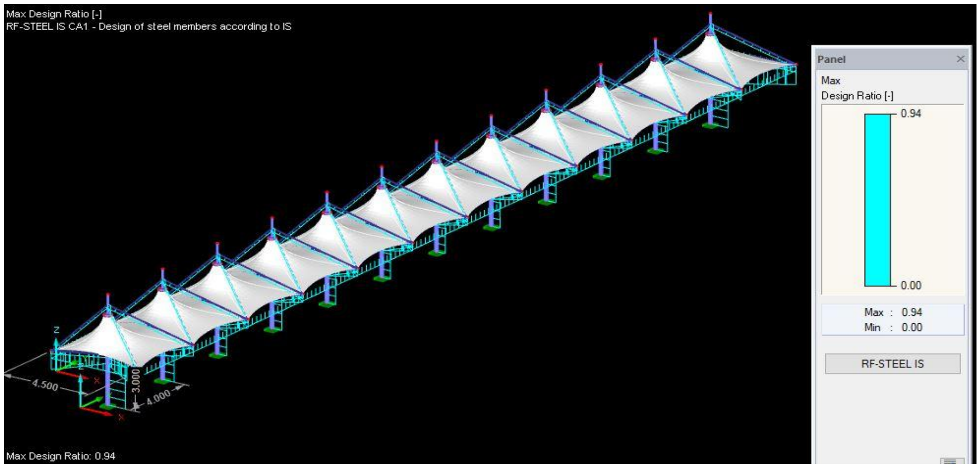

Figure 7: Design ratio

VI. CONCLUSION

1. The use of Tensile Fabric Structures increases gradually. Current fabric structure design practice is to use high factors of safety (between 5 and 10). Such high factors are necessary as the non-linear, time-dependent behaviour of architectural fabrics is poorly modelled, typically being represented by assumed values of Young's modulus and Poisson's ratio.
2. In the tensile structure, fabric form depends on the boundary conditions.
3. The structural action of tensile structures depends on curvature rather than span, hence their efficiency for large-span structures.
4. Allow for higher energy savings, a consideration that is becoming ever more important to the green building industry.
5. List of material manufacturers and coaters, fabricators and software can be found on the TensiNet Association website.

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