The Behavior of Tensile Fabric Membrane 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. Due to its light weight, earthquake force is neglected, whereas wind load is critical for the structure. Fabric resists tension and has no compression or bearing. 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. A general introduction is presented on material properties, membrane types and design process. A part of dissertation is to the behavior of fabric membrane such as stress-strain distribution and application of wind load on membrane. The study aims to reach the conclusion that, does it is advisable to use fabric membrane as a roof for any residential building.*

Key Words: **Fabric, Form-Finding, Membrane, Strain, Stress**

[1]. 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.

The dissertation work aims, to study the concept and behavior behind the design, analysis and construction of tensile fabric membrane structure. Study is to carry out more research on fabric membrane in order to develop understanding about fabric properties, its innovative design, construction work and future scope. Objective of the study is to observe the variation in the analysis results between two fabric membrane materials, with same structure design. As there no such IS code provision, analysis will be based on previous studies and results respectively. On the basis of design and analysis, it is objective to state wither fabric membrane structure is suitable as a roof for residential building or small houses or Not?

Figure 1: *Conceptual design of fabric structure*

1.1 Why Tensile Shape Like This

Large flat pieces of fabric are very poor on resisting loads. Imagine four person each pulling the strings attached through a tennis ball Fig 2, A fifth person pushing down on the ball can deflect it easily, same as flat tent roof. Again, Try lifting two opposite strings up and lowering the other two. Fig 3, The ball will be now locked in space. Applying this principle to fabric membrane and we achieve 'anticlastic' double curvature surface. It sounds impressive but actually it is simply resulting from one of the three fabric shapes; the hyper, the cone and the barrel Fig 4.

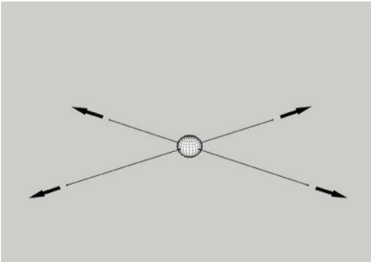

Figure 2: *Stretched ball free to move up & down*

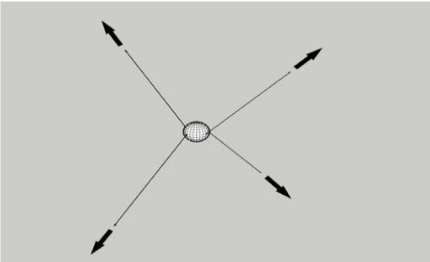

Figure 3: *Stretched ball locked in space*

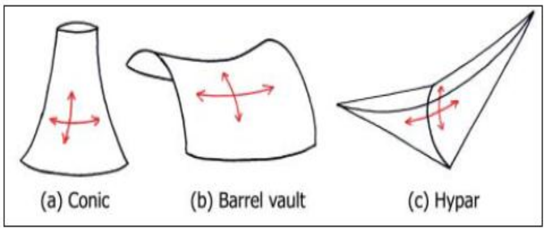

Figure 3: *Three basic fabric shapes*

1.2 Limitations of fabric membrane structure

The use of fabric membrane structure is under limit, due to lake of knowledge regarding its behavior, strength, application and design process. First of all, there is no Indian Standard code (IS) available for design of fabric structure. Hence, design depends on past research and experience.

However, data found also has few drawbacks. The researcher may find that the experimental information does not relate specially to their own research paper. It is difficult to find highly related pieces of research that provide experimental strength. It would be useless for a researcher to reference a study that does not especially relate to the topic of the paper. Furthermore, the information may be complex, depending on the content of the topic or the type of the source. Thus, researchers have to use much time in analyzing this information, adding greater costs to the research process.

1.3 Future scope

Advancements in the technology of membrane structures are continually taking place, even though there are still some problems which need to be addressed. It is hoped that methods will be developed to make membranes structures more enduring architecturally. It is true that as technology increases the quality of the materials will also increase. In order to improve safety, innovative work and design, it is important that techniques are to be developed; more relevant researches should be carried out.

Again, Standard codes should be published respective to their country. For us, Indian Standard code should be published presenting all aspects of design for fabric membrane structure.

1.4 Material used for coating

The two most commonly used materials are:

1.4.1 PVC coated polyester fabric

PVC stands for Polyvinyl Chloride and is applied on the fabric as a paste. It improves the thermal properties of the yarn, provide enhanced surface aspects and helps in cleaning. For fire resistance a secondary coat of plasticizes are applied such as phtalates, phosphates or esters. PVC can be used for imparting color and light stability. The PVC coat is implanted with stabilizing molecules to achieve thermal, oxidation and UV protection.

1.4.2 PTFE coated glass fabrics

PTFE stands for Poly tetra fluoro ethylene. It is the most common and widely used coating material as very few coating materials can provide such a multipurpose and outstanding properties. All this is possible due to chain arrangement of the tetrafluoroethylene monomers. It is one of the best thermal insulators as it can resist high thermal temperatures and has a comparatively low thermal conductivity coefficient. It is Highly resistive against abrasion and corrosive substances such as hydrochloric acid or sulphuric acid.

1.4.3 Silicone coated glass fabrics

Silicone coating is obtain by cross linking of silicone macro-molecules. The chain of silicone is applied on the yarn to provide the protective coating. The advantage of using silicone is that the chain of molecules can be combined with different chemicals to gain the coating with the specific property as required by the structure. For example silicone based substrate are combined with glass to form a covalent hydrophobic film coating.

1.3.4 ETFE foils

ETFE stands for Ethylene Tetra Fluoro-Ethylene. It is a copolymer of ethylene and tetra Fluoro-Ethylene which has very high melting point ranging in between 250°C to 270°C. The foils have a transparency advantage as opposed to other materials. It allows transmitting about 90% of the incident light. Other advantage is to distribute the stress. ETFE foils have a bilinear elastic isotropic distribution behavior of stress.

[2]. DESIGN PROCESS

The methodology includes the way work is carried out. First, the process of design is explained, which comes in three main steps. As follows:

2.1 Form-Finding

Form finding can be defined in the following ways: "Form finding is the iterative process through which a designer arrives at the best possible shape that the membrane can adopt under the applied initial force or pre-stress". The process of form finding basically depends on the boundary conditions and initial force which decide the shape of the structure.

2.2 Static and Dynamic equilibrium

For designing structures it essential to consider different load combinations taking into account the magnitude and direction. The curvature which may obtain by form finding is taken and analysis is done to check the permissible deflections.

The dynamic analysis evaluates the relation between the fluctuating load applied and the structural geometry. As wind is the critical factor, the main objective is to perform dynamic analysis is to check the stability of membrane under wind load cases.

2.3 Patterning

It is the process by which the pre-stressed 3D membrane (the form found structure) is transferred into a 2D pattern for the structure. At this stage the generated shape has pre-stress applied and the cutting pattern therefore has to be smaller than the final shape, as illustrated below.

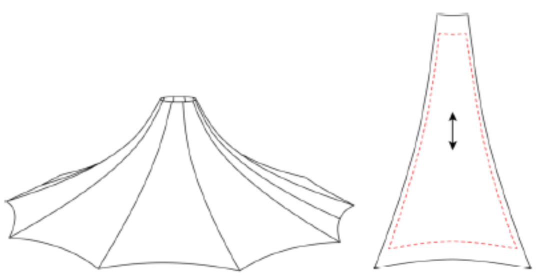

Figure 4: *Patterning and pre-stressing principles. The black lines are illustrating the pre-stressed shape, and the dashed line is representing the cutting pattern (the arrow is showing the warp direction).*

[4] STRUCTURAL MODELLING AND ANALYSIS

In this work, software used are AutoCAD, Dlubal RFEM5, Form Finder and Mpanel. To study the concept of geometry of fabric (form Finding), Initial load distribution and Deformation of the fabric membrane, simple analysis of membrane structure Hyper and Cone is performed in Dlubal RFEM5, with two different type of fabric membranes with different properties (named as PTFE Type A & Type B). In both models Initial Force of 1 KN/m & 2 KN/m is applied to observe the variation in Form as well as strains. Again the boundary conditions of membrane as Fixed and Free are considered to observe variation in results.

MODEL -1: A Hyper of dimension 10 m x 10 m x 3 m is considered, in which Initial Force of 1 KN/m & 2 KN/m is applied and analyzed.

MODEL -2: A Rectangular Cone of 10 m x 10 m x 3 m is considered, in which boundary conditions as Fixed & Free is considered and analyzed.

Table 1: Materials parameters for fabric membrane

Properties		Units	Values	
Fabric Type			PTFE Type A	PTFE Type B
Thickness		mm	10	10
Density		g/cm^2	1.75	1.75
Modulus of elasticity (Ex & Ey)				
	Warp Direction	KN/m^2	420	500
	Weft Direction	KN/m^2	210	300
Tensile Strength (Ex & Ey)				
	Warp	KN/m^2	>40	>40
	Weft	KN/m^2	>40	>40
Shear Modulus G		KN/m^2	20	20
Poisson's Ratio			0.3	0.3

4.1 Results for Hyper

For both the models, after analysis global deformation and strain distribution is observed.

4.1.1 Global Deformation

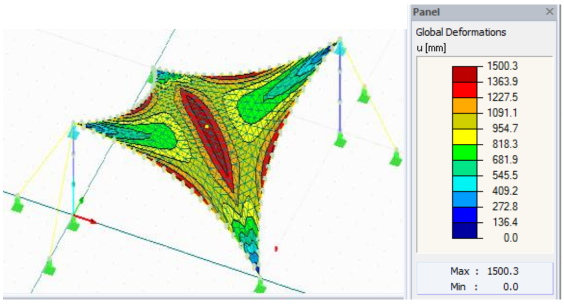

Figure 5: *Global Deformation (u in mm) when Initial Force of 1 KN/m is applied, for both PTFE type A & B, it is same.*

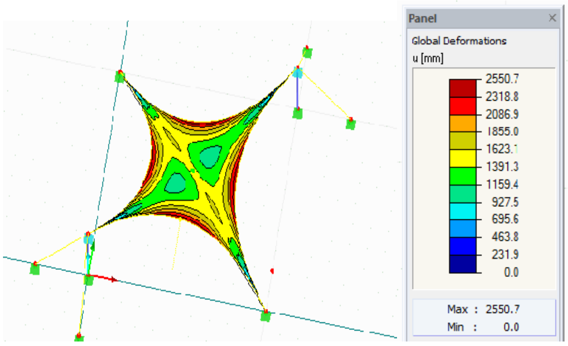

Figure 6: *Global Deformation (u in mm) when Initial Force of 2 KN/m is applied, for both PTFE type A & B, it is same.*

4.1.2 Strain Distribution in X-Direction (Ex)

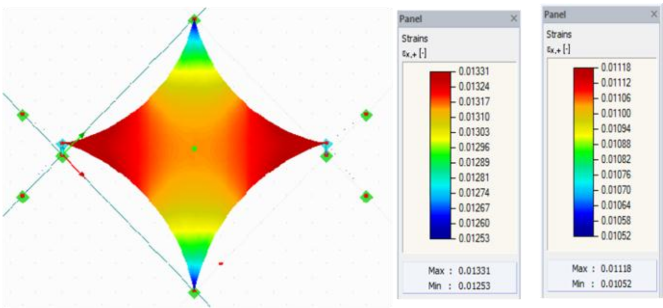

Figure 7: *Strain Ex (Initial Force 1 KN/m) in PTFE Type A & Type B fabric respectively.*

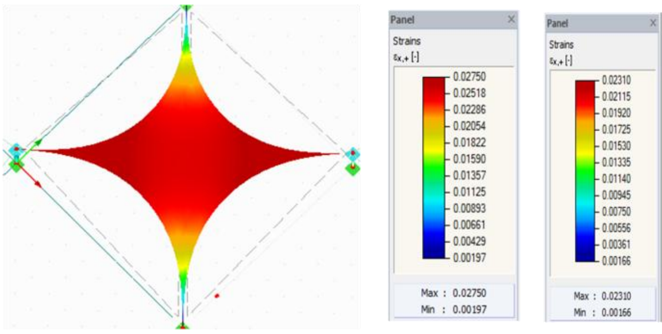

Figure 8: *Strain Ex (Initial Force 2 KN/m) in PTFE Type A & Type B fabric respectively.*

4.1.3 Strain Distribution in Y-Direction (Ey)

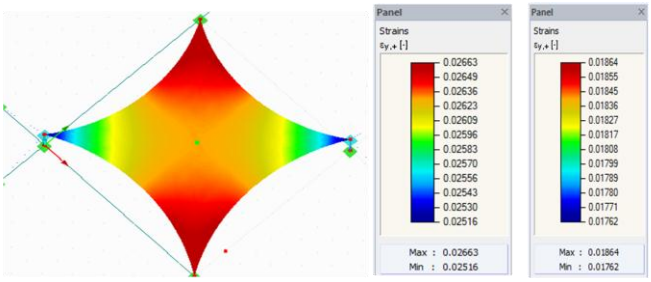

Figure 9: *Strain Ey (Initial Force 1 KN/m) in PTFE Type A & Type B fabric respectively.*

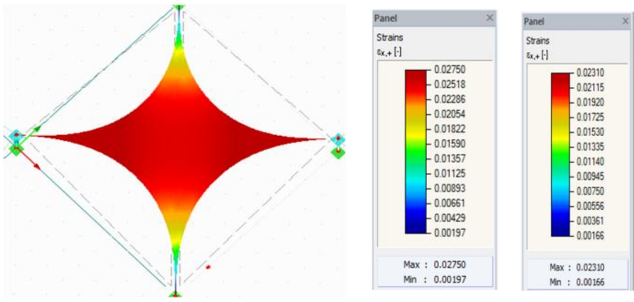

Figure 10: *Strain Ey (Initial Force 2 KN/m) in PTFE Type A & Type B fabric respectively.*

Here, in strain distribution diagrams, strain is distributed in same pattern, only value changes.

4.2 Results for Cone

4.2.1 Global Deformation

Here, in the case of conic structure, we will observe the effect of boundary condition, as fixed and free.

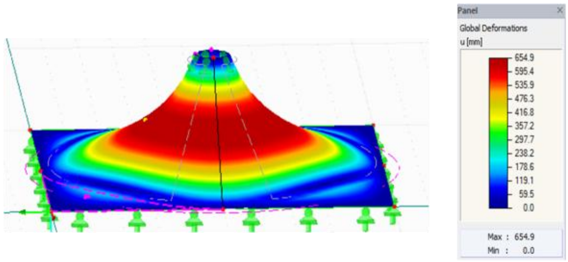

Figure 11: *Global Deformation (u in mm) for fixed boundary condition, for both PTFE type A & B, it is same.*

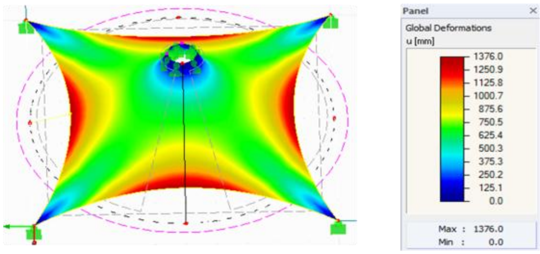

Figure 12: *Global Deformation (u in mm) for free boundary condition, for both PTFE type A & B, it is same.*

[5] WIND LOAD ANALYSIS

As it is known from previous studies that, wind load is critical for fabric membrane structure rather than EQ force. So, application of wind load is studied here. For this, conical structure with base and top diameter of 10m and 1m respectively, with over all height of 7m is modeled.

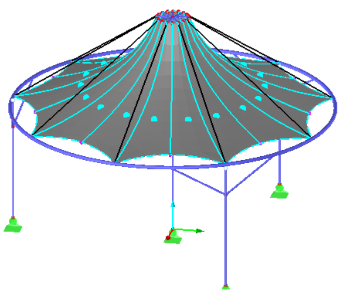

Figure 13: *Model for wind load analysis.*

For Wind load on fabric membrane, we first have to consider the direction of action as well as pressure and suction on membrane. Since, there no IS code provision for wind pressure and suction, we should know the governing Co-efficient (Cpe), which was given under European Design Guide for Tensile Surface Structures- Appendix A 1.2

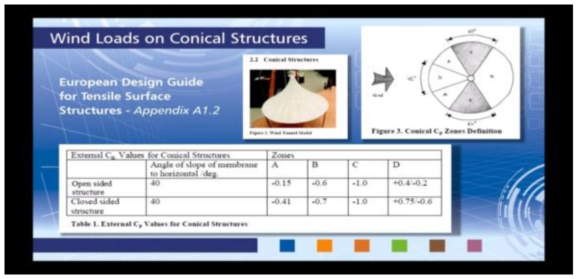

Figure 14: *European Design Guide for Tensile Surface Structures- Appendix A 1.2*

Considering above Cpe value, wind pressure and wind suction values are calculated as per IS: 875 Part-3. Further in the analysis, simple steel frame for membrane support is designed as per IS: 800.

Table 2: Calculated Wind Load as per IS: 875 Part-3

Zone	A	B	C	D	
Cp value	-0.41	-0.7	-1.0	+0.75	-0.6
WL (KN/m^2)	-0.37	-0.65	-0.92	+0.69	-0.55

Here, the load cases for analysis considered are Dead Load (LC1), Wind Pressure (LC2) and Wind Suction (LC3).

According to IS: 800, the Dlubal RFEM takes load combination automatically as;

a) LC1
b) LC1 + LC2
c) LC1 + LC3

After wind load analysis, conceptual steel frame structure to support fabric membrane is designed, according to IS: 800. The material for steel section selected is **Steel IS 513 D | IS 800:2007**.

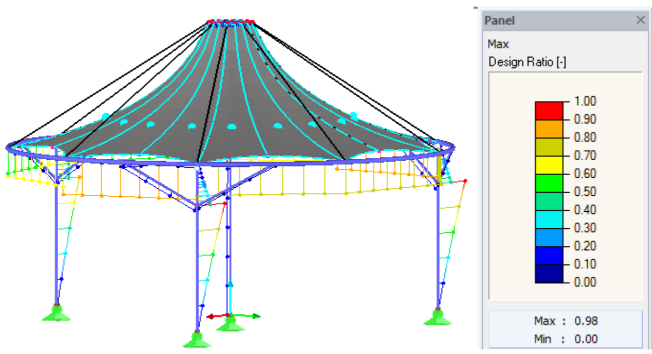

Figure 15: *Designed Steel Frame*

[6] CONCLUSIONS

It can be observed from the previous papers and articles that, fabric membrane structure has benefits, such as large scale and simple construction, durable and life safety as well as sun light and heat controlling capability.

In the analysis of hyper structure, It is observed that, The Form (Shape) of membrane depends on pre-stress or initial force, but not on type or property of fabric. As 1 KN/m & 2 KN/m initial force is applied, there comes a change in form of membrane. Also, strains Ex & Ey decreases as Modulus of Elasticity EX & EY increases.

New IS design code for wind analysis for membrane structure can be developed, as future scope.

In the conic structure, fabric form depends on the boundary conditions.

After analysis, steel members can be summarized as mentioned in **Table 3**.

Table 5.2 Part List by Member

Part No.	Cross-Section Description	Number of Members	Length [m]	Total Length [m]	Surface Area [m²]	Volume [m³]	Unit Weight [kg/m]	Weight [kg]	Total Weight [t]
1	Round 6	9	3.42	30.78+	0.58	0.00	0.22	0.76	0.007
2	RO 219.1x5.6 | IS 3601-2006	9	3.49	31.42	21.62	0.12	29.49	102.92	0.926
4	RO 26.9x1.8 | IS 3601-2006	9	0.35	3.14	0.27	0.00	1.11	0.39	0.004
5	RO 114.3x3.2 | IS 3601-2006	1	7.00	7.00	2.51	0.01	8.77	61.37	0.061
6	RO 60.3x2.6 | IS 3601-2006	9	0.50	4.50	0.85	0.00	3.70	1.85	0.017
7	RO 114.3x3.2 | IS 3601-2006	3	4.00	12.00	3.31	0.01	8.77	35.07	0.105
8	RO 168.3x4 | IS 3601-2006	6	2.00	12.02	6.36	0.02	16.21	32.48	0.195
Sum		46		100.86	36.50	0.17			1.315

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