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Fabrication and Analysis of Tensegrity Based Prism structure

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Abstract - *The objective of this review paper is to understand the basic concept & principal on which tensegrity system is working. A module based on T-Prizm configuration is fabricated using common available materials like UPVC Pipe and Nylon rope, it's a CLASS-I tensegrity model. Tensegrity play an important role in technological advancement of mankind in many fields ranging from Engineering to Biology. Tensegrity consist of both compression member & tensile members.*

Key Words: **Tensegrity, cable, strut, compression, model, tension, elements, u-pvc, nylon.**

1. INTRODUCTION

Tensegrity story is beginning with the question who discover what and when. in 1996 the different views of Buckminster Fuller, David George Emmerich and Kenneth Snelson were thoroughly debated and finally Mr. Buckminster fuller credited to Mr. Snelson for discovering the tensegrity principal. A tensegrity structure, also known as "tensional integrity" The overall goal of tensegrity research is the design of large, irregular systems with an eventual pathway to industrial application.

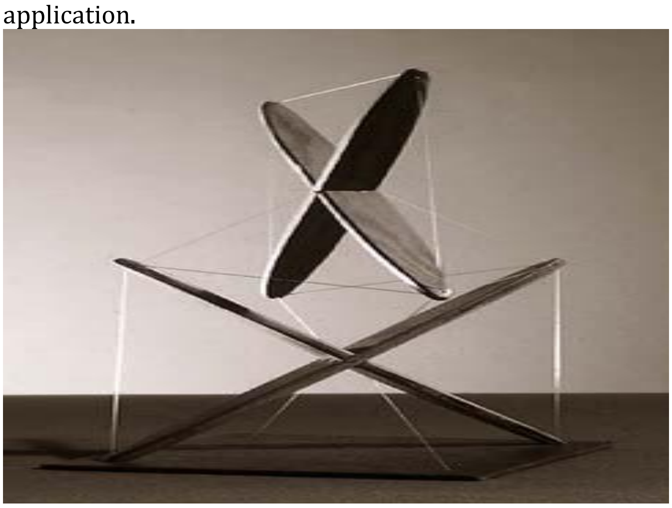

Figure 1. SNELSON'S WoodX-Column1948 [1]

1.1 TENSEGRITY?

Tensegrity system are a class of truss structures but it's behavior is different from truss, composed of cable and strut. All connection is pin-jointed and there for cannot transfer any moments, resulting in axial resistance only. Tensegrity system differ from ordinary truss structure in that members are either compression resisting Struts, or tension resisting cables, but cannot be both. The major defining factor for tensegrity system is that the strut are not allow to connect to each other at any point in the structure. They may only be connected via cables, creating the effect that struts are being suspended in space. The main characteristic of this structure is internal self-equilibrium under the condition that the no external forces act on tensegrity structure. The structure is formed by isolated strut components to sustain the compression forces and continuous pre-stressed cable lines to resist the tensional forces.

Figure 2. Kurilpa tensegrity bridge in Brisbane Australia built in 2009 [1]

1.2 CLASSIFICATION OF TENSEGRITY STRUCTURE

Tensegrity structures are classified in two types.

1. Class-I Structures
2. Class-II Structures

No pair of Compression members touches each other is known as Class-I Tensegrity structures. If compressive members are touch each other at joints, then it is known as Class-II Tensegrity structures. A tensegrity structure is a pre-stress able truss like system involving string element capable of transmitting load in one direction only.

1.3 TENSEGRITY SYSTEMS

Tensegrity Structures are classified as Geodesic & Pre-stressed structures. Tensegrity structures are categories into Three main types: Tensegrity Prism, Diamond Tensegrity & Zig-Zag Tensegrity. Simple X-shaped wooden struts suspended in air by starched nylon cables. The X-module build by Snelson had given birth to tensegrity Concept shown in Fig.1 [1]

Tensegrity Prism: -

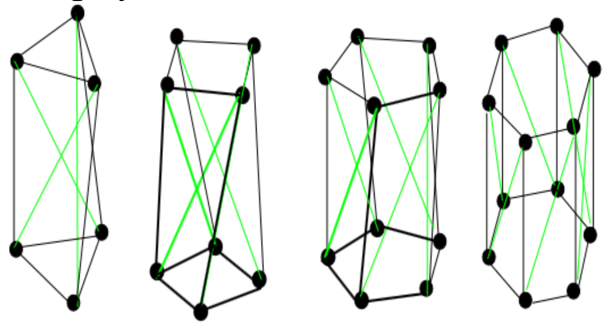

Figure 3. Class-I tensegrity 3D prism [2]

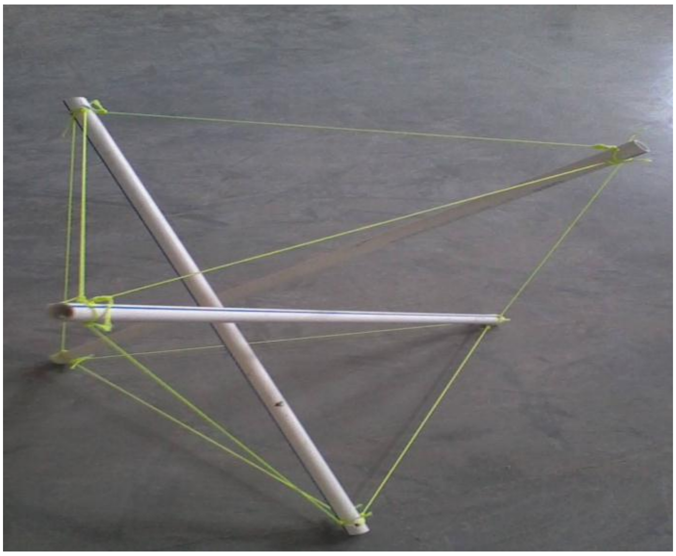

Figure 4. Tensegrity 3-strut model

2. CHARACTERISTICS OF TENSEGRITY

1. Tensegrity structures have a higher load bearing capacity with similar Weight.
2. In tensegrity Structure, Rigid element (struts) in compression Zone but they are discontinuous, hence they do not undergo buckling easily & no torque is generated. [3]
3. Flexible element (cables) are in Tension Zone but they are continuous.
4. Class-II tensegrity topologies where some bars touch each other are advantageous in special case. [2]
5. Force are distributed upon impact; they can fall or bump into things at moderate speed. In additional, their compliance ensures that they do minimum damages to objects they contact. [5]
6. The tensegrity structures are commonly modelled with Frictionless joints, & the self-weight of cable and struts is neglected.
7. It depends on the structure assembly and material used.
8. Tensegrity structure work synergic ally.

3. ADVANTAGES OF TENSEGRITY STRUCTURES

1. Construction of tensegrity structures using tensegrity concepts make it very resilient and very economic.
2. Tensegrity structure are mass efficient, light weight. [5]
3. No one of the member's experience bending moment & are design for axil loads.
4. There is no critical point of weakness because load is distributed in whole structure.
5. Tensegrity structures can be packed into compact forms very easily. [5]

4. APPLICATIONS

Generally, the tensegrity structures lie in their quality of resilience and their economic and efficient use of materials. They make effective possible use in different fields for example

1. Civil Engineering
2. Mechanical engineering
3. Research Activities
4. Architecture
5. Biological

5. MATERIAL CHARACTERIZATION

Tensegrity structure generally consist of soft members as a cables & hard member as a strut. In this study, UPVC pipes as a strut & NYLONE rope as a cable.

Table - 1 Property of UPVC Pipe as per ASTMD D-1785

Parameters	Values
Nominal Size	20.00
Average outer Diameter	26.67
Minimum Wall Thickness	02.87
Specific gravity	1.2 - 1.4
Hardness	110 – 120

5.1 STIFFNESS TEST (IS-14787:2000)

- The specimen shall be a piece of pipe of *150*±3mm length.
- Diameter of Pipe = 26.67mm
- Thickness of Pipe = 2mm
- Deflection speed shall be 5 ± 1 mm/1min.
- Condition the specimen for at least 4 hours in air at 27 ± 2°C.

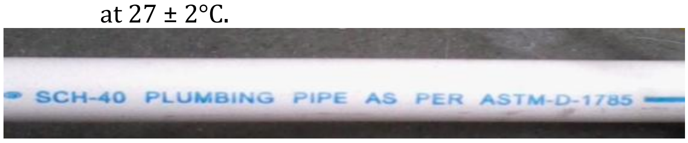

Figure 5. UPVC Pipe SCH-40

$$\text{Pipe Stiffness (PS)} = \frac{F}{\Delta Y}$$

F = Force (kN), Δ Y = Vertical Deflection (m)

Figure 6. Parallel Plate Loading test (stiffness test)

Table - 2 Pipe stiffness results

s.no.	Specimens	Pipe stiffness (Kn/m)
1	Sample – 1	740
2	Sample – 1	633.34
3	Sample – 1	740

Table – 3 Property of NYLON rope

Parameters	Values
Diameter	3mm
Section	3*20
Elongation	40%
Breaking load found	1.7 kN
Melting point	215 to 260 °C

5.2 TENSILE TEST OF NYLON ROPE (as per IS6590:1972)

The normally available wire 3mm in diameter issued for reticulated network were made of NYLON wires. 3*20 consisted wires consist 3 strands with 20 wire in each strand. The net sectional area found as 7.069 X 10^-6 m^2. The wires were tested in a UTM at 200KN as shown in figure.

Figure 7. Sample of 450mm in length with splice

Figure 8. Breaking load test in UTM

Three samples of rope with splice were tested and the young's modulus of the standard wire was found to be **0.542*10^6 kN\m^2**. The average failure load was found to be **1.7 kN.**

6. METHODOLOGY ADOPTED

The design of tensegrities is divided into three distinct steps:

1. Form-finding,
2. Structural stability
3. Load analysis

Form-Finding is an essential problem in the design of tensegrity systems, since the Fulfilment of stability requirements depends on both the shape and geometry. The solution requires simultaneously solving the geometry and self-stress. Thus, any form-finding method would be either based on geometry or mechanics, but both aspects still need to be taken into account that two main methods are available, namely form-controlled and force controlled. The first aspect of the form-finding problem is determining the arrangement and connectivity of the system, such that it is capable of structural stability.

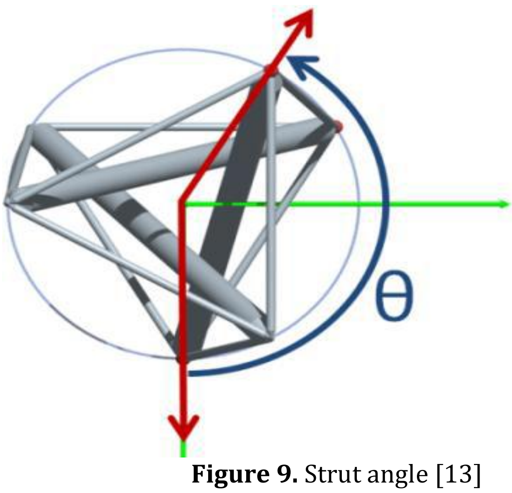

Figure 9. Strut angle [13]

6.1 STRUT ANGLE FROM THE CENTER OF T-PRISM

Strut angle = {(N+2)/4N} 360°
N is number of strut (N=3)
Strut angle = {(3+2)/12} 360°
= 150°

6.2 SIDE ANGLE OF CABLE

Side angle ={(N-2)/4N} 360°
N is number of strut (N=3)
Side angle = {(3-2)/12} 360°
Side angle = 30°

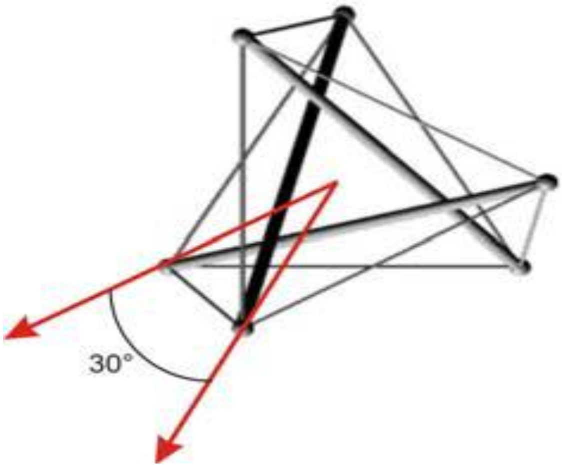

Figure 10. side angle [3]

7. FABRICATION AND TESTING OF TENSEGRITY MODULE

Figure shows the perspective view and the top view of T-Prism module, fabricated as part of present investigation. T-Prism structure module, based on both strut mode and cable mode of deployment, were fabricated in the workshop of the Civil Engineering Department, IES IPS Academy. UPVC & NYLON rope(3X20) is referred by us. Total Length of the Strut is 0.630m. The length of Diagonal cable was 0.450m & that of Top and bottom cable was 0.30m. at the both ends of UPVC pipe 10mm hole was drilled which is 15mm apart from end.

Figure 11. 10mm hole at the ends of UPVC Pipe

7.1 KNOT

A knot is a method of fastening or securing linear such as rope by tying or interweaving.
We are using **Two Half Hitches type of knot.** At each end of the pipe 3 cables were jointed with the help of Knot as shown in figure

Figure 12. Two Half Hitches knot

Table – 4 Dimensions of Tensegrity model

Parameters	value
Length of Top cable	0.30m
Length of bottom cable	0.30m
Length of diagonal cable	0.45m
Length of u-pvc pipe	0.63m
Total height of model	0.52 m
Side angle	30°
Strut angle	150°

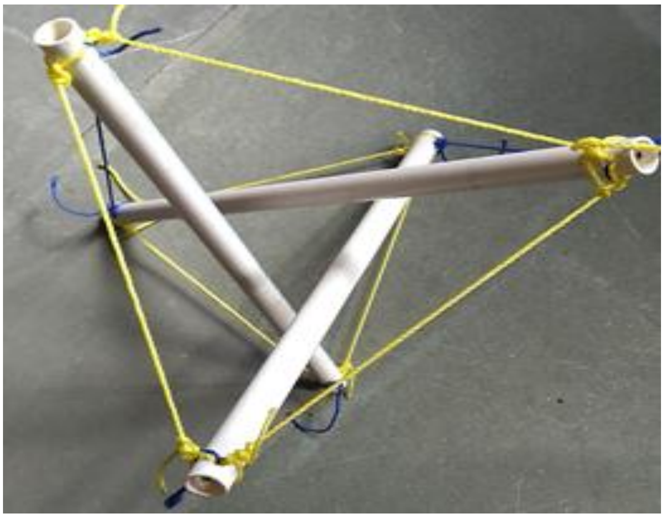

Figure 13. TOP VIVEW

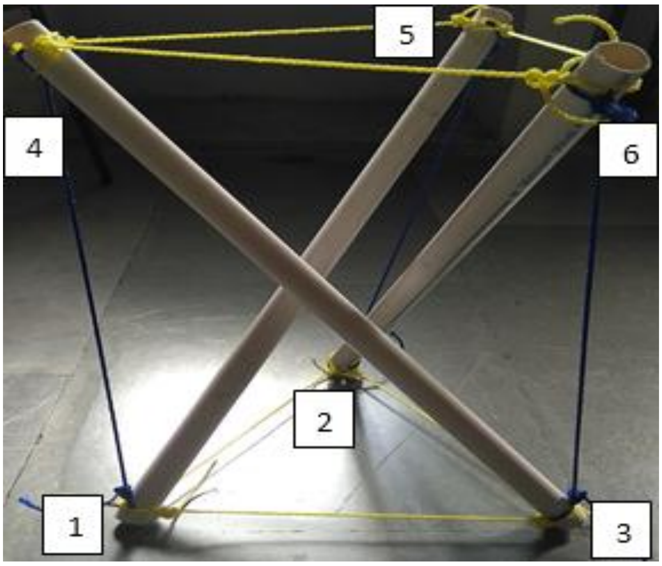

Figure 14. Six joints in T-Prism.

Table-5 Joints & link connection

Joints	Links
1	1-2, 1-3, 1-4
2	2-3, 2-1, 2-5
3	3-1, 3-2, 3-6
4	4-5, 4-6, 4-1
5	5-6, 5-4, 5-2
6	6-4, 6-5, 6-3

8. OUTCOM AND CONCLUSION

Analysis of the structures will be done with the help of compression test. This analysis will helpful for us to know about the vertical displacement in structure. Knowledge of load and displacement would aid in information about the most probable points of failure. Although being load carrying structures, tensegrity structures rarely fail due to member failure. There is great potential of the combination of upvc and tensegrity in the construction industry. It can be used in multiple purposes, such as warehouse, and other medium industries. The fabricated tensegrity structure aims to provide an alternative environment friendly construction for steel. Not only is the structure light in weight compared to conventional steel, it is ecofriendly and cheaper. very small amount of material is required for fabrication of tensegrity prism. The structure developed will be more flexible, economic, easy to fabricate and light in weight. stability of the structure might be affected by short length of nodal joints. The joints get rotation which made the deployment difficult. the loading capacity of the structure maybe obtained along with the mode of failure.

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