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RESEARCH ARTICLE

DESIGN OF TENSEGRITY TOWER

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ABSTRACT

Tensegrity is a portmanteau of tensional integrity. It refers to the integrity of structures as being based in a synergy between balanced tension and compression components. Tensegrity structures are built of struts and cables. The struts can resist compressive force and the cables cannot. Most cable–strut configurations which one might conceive are not in equilibrium, and if actually constructed will collapse to a different shape. Only cable–strut configurations in a stable equilibrium will be called tensegrity structures. If well designed, the application of forces to a tensegrity structure will deform it into a slightly different shape in a way that supports the applied forces. Tensegrity structures are very special cases of trusses, where members are assigned special functions. Some members are always in tension and others are always in compression. A tensegrity structure's struts cannot be attached to each other through joints that impart torques. The end of a strut can be attached to cables or ball jointed to other struts.

INTRODUCTION

'Tensegrity' is a pattern that results when 'push' and 'pull' have a win-win relationship with each other. Pull is continuous where as push is discontinuous. The continuous pull is balanced by the discontinuous push, producing the integrity of tension and compression. These fundamental phenomena do not oppose, but rather complement each other. Tensegrity is the name for a synergy between a co-existing pairs of fundamental physical laws of push and pull, or compression and tension, or repulsion and attraction.

These structures have certain advantages over others like:

- **Tension stabilizes**

A compressive member loses stiffness as it is loaded, whereas tensile member gains stiffness as it is loaded. Stiffness is lost in two ways in a compressive member. In the absence of any bending moments in the axially loaded members, the forces act exactly through the mass center, the material spreads, increasing the diameter of the center cross section; whereas the tensile member reduces its cross-section under load. In the presence of bending moments due to offsets in the line of force application and the center of mass, the bar becomes softer due to the bending motion. For most materials, the tensile strength of a longitudinal member is larger than its buckling strength. Hence, a large stiffness-to-mass ratio can be achieved by increasing the use of tensile members.

- **Tensegrity Structures are easily tunable**

The same deployment technique can also make small adjustments for fine tuning of the loaded structures, or adjustment of a damaged structure. Structures that are designed to allow tuning will be an important feature of next generation mechanical structures, including civil engineering structures.

- **Tensegrity Structures Facilitate High Precision Control**

Structures that can be more precisely modeled can be more precisely controlled. Hence, tensegrity structures might open the door to quantum leaps in the precision of controlled structures. The architecture (geometry) dictates the mathematical properties and, hence, these mathematical results easily scale from the Nano-scale to the mega scale, from applications in microsurgery to antennas, to aircraft wings, and to robotic manipulators. Its main advantage though, is its deployability. Because the compressive members of tensegrity structures are either disjoint or connected with ball joints, large displacement, deployability, and stowage in a compact volume

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will be immediate virtues of tensegrity structures. This feature offers operational and portability advantages. A portable bridge or a power transmission tower made as a tensegrity structure could be manufactured in the factory, stowed on a truck or helicopter in a small volume, transported to the construction site, and deployed using only winches for erection through cable tension. Erectable temporary shelters could be manufactured, transported, and deployed in a similar manner.

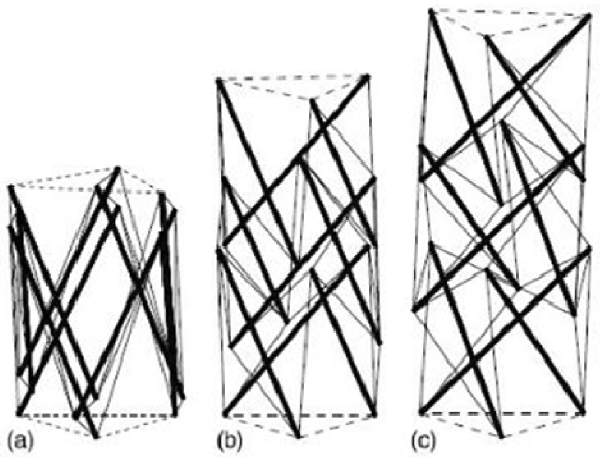

Figure 1. Folding of tensegrity structure

MATERIALS

Material used are jute rope and nylon rope as cables (Tension member) and Bamboo as struts (Compression member).

Material Testing

The Bamboo struts were tested for compression in the UTM as shown. Bamboo specimens of 18cm (L/R<10) were tested and the average compressive strength from several tests came out to be 41.5 KN.

Figure 2. Bamboo strut in UTM

The ropes were tested for tensile strength by tying it to a spring balance and suspending weights from the other end as shown. In this we have tested for two types of ropes:

- Jute rope
- Nylon rope

For jute rope:

Table 1. Jute rope testing

No of Plates	*Weight of 1 Plate(kg)*	*Total weight(kg)*
12	2.84	34.08

For nylon rope:

Table 2. Nylon rope testing

No of Plates	*Weight of 1 Plate(kg)*	*Total weight(kg)*
36	2.84	102.24
5	1.42	7.1
5	0.142	0.71
		110.05

Construction

Simplex Structure

- Constructed using nylon rope and bamboo.
- It is all about three struts up in the air.
- First exhibited by the Latvian artist Karl Ioganson in Moscow in 1920-21.
- Also known as T-Prism structure.

Figure 3. Simplex structure with chair as dead load

Hurdles during Construction

- A single cable is used in the construction without any cut or joint and for each strut there are three cables enter and leaving it, ultimately congestion takes place and structure becomes tough to handle.

- Tensioning of cable is another tough and very time consuming job.
- Length of cable between consecutive struts keep on changing, so its hard to analyse structure.
- Sometimes angle between horizontal cable and angular struts also changes.

G+1 Tensegrity Structure

Amendments for G+1 Tensegrity structure

- To avoid congestion, joints at the ends of struts will be provided.
- Each joint will comprise of – circular metal plate, bolt and hook screw.
- In this assembly joint to joint connection will be made and no cable will pass through (from inside) struts.
- Jute cable will be used as it is difficult to tie knots in nylon cable.

Construction of Joints

- Each joint will comprise of – circular metal plate, bolt and hook screw.
- Firstly we cut a long hollow metal pipe into 12 equal pieces. The diameter of the pipe should be such that it covers the face of bamboo diametrically.
- Then a hook is welded on to the hollow pipe with the help of a washer enclosing the face of the pipe.
- Then these joints are painted so they are ready to be used.

Figure 4. G+1 Tensegrity Tower

Transmission Tower Prototype

Tower properties	
Height of tower	: 12.33 m
Materials used in construction	: Bamboo & Jute
Place of construction	: Near college vicinity (Guna, Madhya Pradesh)
Terrain category (as per IS 875-3)	: Category 2
Total members	: 30
Number of Compression members (Struts)	: 9
Number of Tension members (cables)	: 21
Diameter of cable	: 4 mm
External diameter of Struts	: 40 mm
Internal diameter of struts	: 20 mm
Height of ground storey	: 5.2 m
Height of 1st storey	: 4.33 m
Height of 2nd storey	: 2.6 m

Wind load is applied on both the windward and leeward faces and its intensity is calculated by Indian Standard code for "Wind loads on buildings and Structures (IS: 875-3)"

Table 2. Intensity of load at different heights

Intensity (kN/m^2)	*Height (m)*
1.07299	3
1.07299	6
1.07299	9
1.11600	12
1.13800	13
1.18299	15

Outcome and Conclusion

The structures were subjected to be analyzed in staad.pro. This analysis was done to know about the stress distribution in the members. Knowledge about stress distribution 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 bamboo and tensegrity in the construction industry. The fabricated structure aims to provide an alternative environment friendly construction for a steel poultry shed. It can serve multiple purposes, such as workshop for a cottage industry, warehouse, and other medium industries. Not only is the structure light compared to conventional steel, it is at the same time several times cheaper and ecofriendly. Such structures can pave way for sustainable industrialization of the rural sector in India and other developing nations. Structure fabricated will also be material efficient as very small amount of material is required for their fabrication. The structure developed will be more flexible, easy to fabricate, economic, and lighter than that used previously. Due to the short length of nodal joints, their stability might be affected i.e. they may be prone to rotation which made the deployment difficult. Bamboo of the lightest type available should be used so as to keep the dead load on structure small. It is recommended to perform a destructive testing also, so that the loading capacity of the structure maybe obtained along with the mode of failure. For fine tuning of the structure after the erection has been done, it is recommended to use turnbuckle on each kind of cable so that adjustments can be distributed over whole body of the structure and are not just confined to upper layer.

Future Scope

Field of Tensegrity structures has a great scope of both research and real time usage. The structures that we constructed could further be worked on and can be subjected to various tests like the shake table test and testing in wind tunnel. There are many other structures like sheds and bridges that can be constructed using concept of tensegrity. Also these structures can be made more sustainable and echo-friendly.

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