

Basic Study of Tensegrity Module Used For Pedestrian Bridge

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ABSTRACT: The tensegrity framework consists of both compression members (struts) and tensile members (tendons) in a particular geometric shape in the state of equilibrium by generation of stresses by the structure itself. Tensegrity system development is important for the development and advancement of mankind. Tensegrity structures are light in weight therefore very efficient and deployable. As compared to their self weight they can sustain a large amount of loading if designed properly. Now and further these structures are used in biology, architecture and latest robotics. However, design as well as the arrangement of struts and cable to achieve equilibria is quite complex and challenging.

KEYWORDS: Tensegrity, Pedestrian Bridge, tensegrity modules.

I. INTRODUCTION

Tensegrity is a combination of tensional integrity. It means that these physical laws of tension and compression balances each other rather than opposing, tension is continuous and compression is discontinuous. Tensegrity structures are built of hollow struts and tendons generally made up of steel, titanium, Mylar, Kevlar, etc. The struts are meant to resist compressive force while the cables are designed for resisting tension. The models which do not have a specific stable configuration which shall keep the structure in equilibrium will collapse and get deformed 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.

For something new to this world for a change the use of tensegrity structures for heavy loading is necessary. Concrete is the second thing after water that is consumed by humans which is uneconomical as compared to tensegrity structures.

- **Principle of Tensegrity :**

- '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.

- Some examples of tensegrity in daily life:

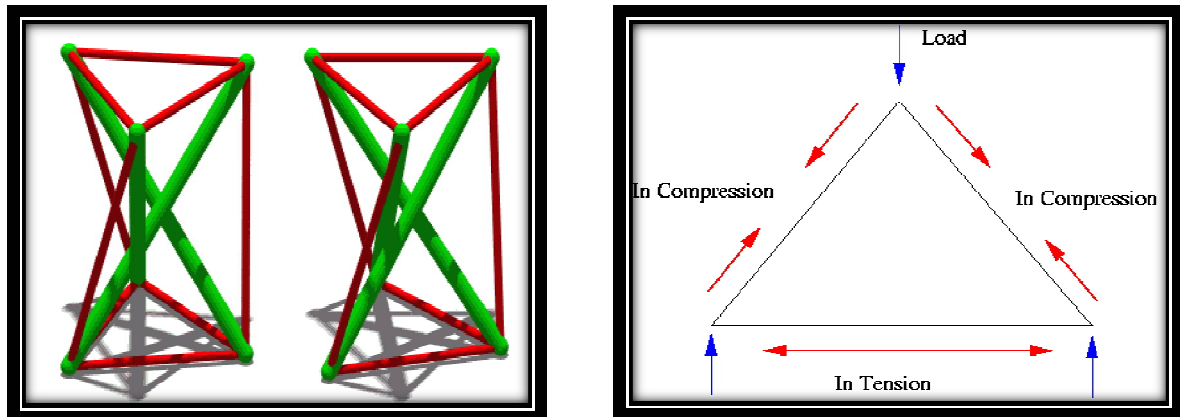
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If one pushes a ping-pong ball on a smooth table with the point of a sharp pencil, the ball would always roll away from the direction of the push, first rolling one way then the other. Push is divergent. On the other hand, if a string be attached to the ping pong ball with tape, then pulling it leads to convergence. So Pull is convergent.

- Another example from common experience occurs when pulling a trailer with a car. When driving uphill, one is pulling against gravity, and a trailer will converge toward the same course behind the car. If the trailer begins to sway, increasing pull by increasing acceleration can dampen the swaying motion. Driving downhill, however, the trailer may begin to push, and the trailer will begin to sway from side to side. Two tensegrity are easily recognizable in the systems of the human body. The muscular-skeletal system is a tensegrity of muscles and bones, the muscles provide continuous pull, the bones discontinuous push. This forms the basis for all human physical mobility. The central nervous system can also be seen as using the analogy of tensegrity where motor neurons and sensor neurons, complement the other in balance.



(Figure.1. Models and behaviour of the module on the application of load, on a single node or at a joint)

- **The Advantages of Tensegrity:**

A large amount of literature on the geometry, art form, and architectural appeal of tensegrity structures exists, but there is little on the dynamics and mechanics of these structures. Form finding results for simple symmetric structures appear and show an array of stable tensegrity units is connected to yield a large stable system, which can be deployable. Several reasons are given below why tensegrity structures should receive new attention from mathematicians and engineers.

- (a) **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.

- (b) **Tensegrity Structures are efficient:**

The geometry of material layout is critical to strength at all scales, from nano-scale biological systems to mega-scale civil structures. Traditionally, humans have conceived and built structures in rectilinear fashion. Civil structures tend to be made with orthogonal beams, plates, and columns. Material is needed only in the

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essential load paths, not the orthogonal paths of traditional manmade structures. Tensegrity structures use longitudinal members arranged in very unusual (and non orthogonal) patterns to achieve strength with small mass. Another way in which tensegrity systems become mass efficient is with self-similar constructions replacing one tensegrity member by yet another tensegrity structure.

(c) Tensegrity Structures are deployable:

Materials of high strength tend to have a very limited displacement capability. Such piezoelectric materials are capable of only a small displacement and “smart” structures using sensors and actuators have only a small displacement capability. Because the compressive members of tensegrity structures are either disjoint or connected with ball joints, large displacement, deployability, and stowage in a compact volume 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.

(d) 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.

(e) Tensegrity Structures Facilitate High Precision Control:

Structures that can be more precisely modelled 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 megascale, from applications in microsurgery to antennas, to aircraft wings, and to robotic manipulators [8].

(f) Tensegrity structures provide a promising paradigm for integrating structure and control design [7].

• Some Disadvantages

- Tensegrity arrangements suffer the problem of bar congestion. As some designs become larger (thus, the arc length of a strut decreases), the struts start running into each other [3]. See figure 2.
- The same author stated, after experimental research, “relatively high deflections and low material efficiency, as compared with conventional, geometrically rigid structures” [3].
- The fabrication complexity is also a barrier for developing the floating compression structures. Spherical and domical structures are complex, which can lead to problems in production. [1]
- In order to support critical loads, the pre-stress forces should be high enough, which could be difficult in larger-size constructions [6].
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- The fabrication complexity is also a barrier for developing the floating compression structures. Spherical and domical structures are complex, which can lead to problems in production.
- In order to support critical loads, the pre-stress forces should be high enough, which could be difficult in larger-size constructions. If the structure becomes too large it faces a problem of bar congestion (i.e. the struts start running into or touching each other).
- They show relatively high deflections and low material efficiency as compared to with Conventional continuous structures.

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- Fabrication complexity is a major barrier in developing floating compression structures.



(Figure 2. Complexity in construction for large tensegrity structures)

- **Characteristics of tensegrities:**

- They have a higher load-bearing capacity with similar weight.
- They are light weight in comparison to other structures with similar resistance.
- They don't need to be anchored or have to lean any surface as they don't depend on their weight or gravity. They are stabilized in any position by equilibrium of compressive forces in struts with tensional forces in prestressed cables. Prestrain in the cables can be transformed into prestress only if the structure is statically indeterminate.
- They are enantiomorphic i.e. exist as right and left-handed mirror pairs.
- Elementary tensegrity modules can be used (such as masts, grids, ropes, rings etc.) to make more complex tensegrity structures.
- Higher the pre-stress, stiffer the structure would be, i.e. its load bearing capacity increases with the increasing prestress. The degree of tension of the pre-stressed components is directly proportional to the amount of space they occupy.
- In a tensegrity structure the compressive members are short and discontinuous, hence they do not undergo buckling easily and no torque is generated in them.
- The resilience depends on the structure assembly and material used.
- They work synergically i.e. their behaviour cannot be predicted by considering the behaviour of any of their components separately.
- They are sensitive to vibrations under dynamic loading. Slight change in load causes the stress to redistribute in the whole structure within no time and thus, they have the ability to respond as a whole.
- Kenner introduced a term 'Elastic Multiplication' for the tensegrity structures. It is a property of tensegrity structure which depends on the distance between two struts. If two struts are separated by a certain distance the elongation of tendons (tensile members) attached to them is much less compared to this distance.
- The deformation response of entire tensegrity structure to load is non-linear as its stiffness increases rapidly with increasing load, like at a suspension bridge.
- The tensegrities are commonly modeled with frictionless joints, and the self-weight of cables and struts is neglected.

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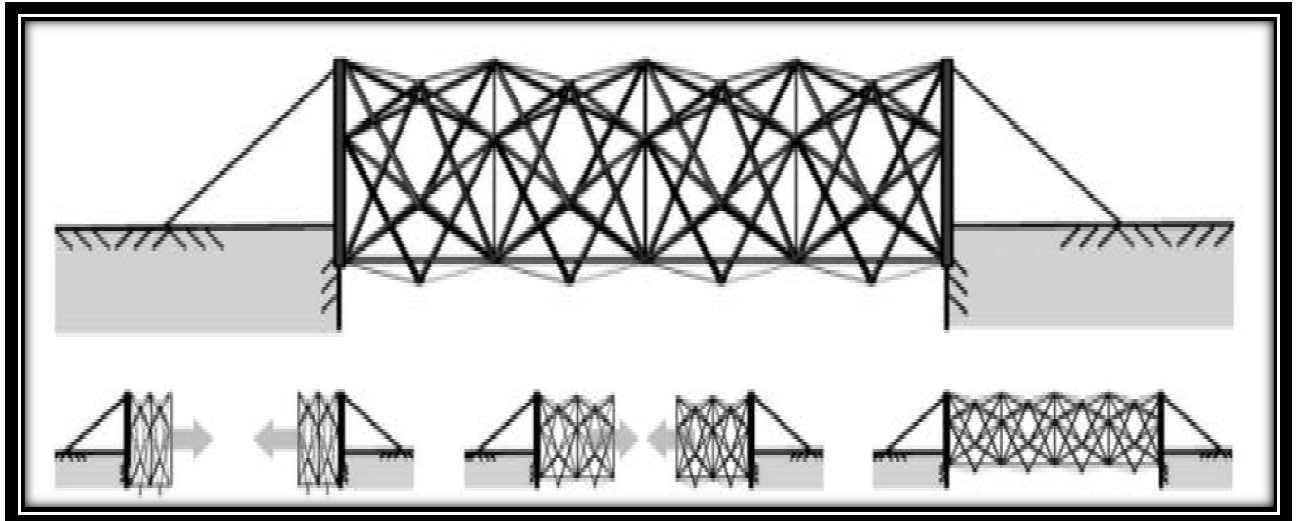


Figure 3(a).A tensegrity pedestrian bridge made by connecting number of modules to each other.

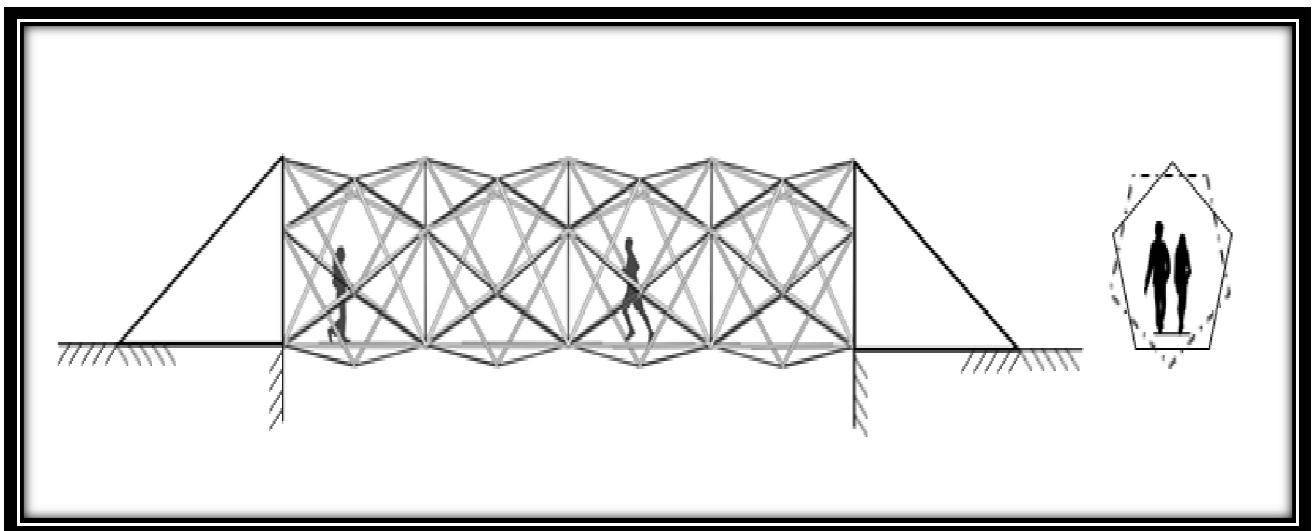


Figure 3(b): The tensegrity pedestrian bridge

The structure is a pedestrian bridge to be built in the French speaking part of Switzerland. The bridge spans 20 m over a river. A distance of 3 m from the ground is considered. The structural system of the bridge is composed of four identical tensegrity modules. Symmetry about midspan is obtained by mirroring two modules. The structure of the bridge is designed with a minimum internal space for walking. The walking area is a rectangular internal free space with a height of 2.5 m and a width of 1.3 m. These dimensions are chosen to have enough room for two persons crossing the bridge simultaneously. Pedestrians cross the bridge walking on a steel deck supported on the bottom nodes at both ends of each module.

II. MODELLING

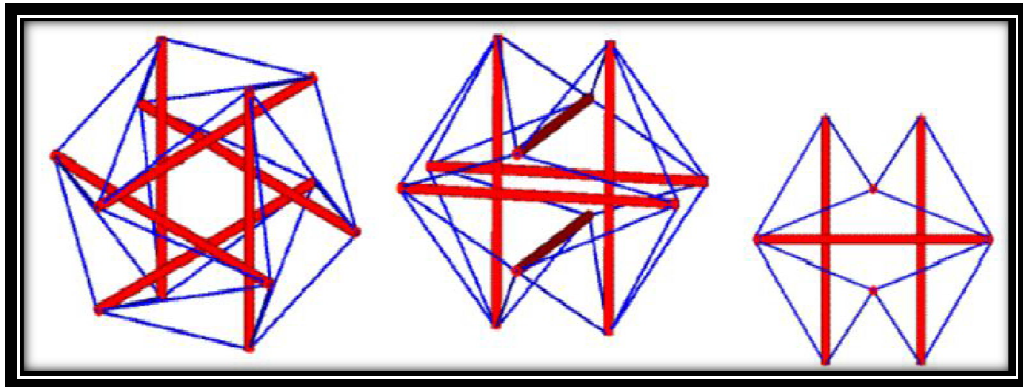


Figure 5. picture of icosahedron module.

The icosahedron polyhedron has 30 edges and 20 faces. A tensegrity can be formed as an icosahedron polyhedron by using 6 struts and 24 tensile vectors. Icosahedrons are symmetrical and tensegrity structures in this shape present parallel struts. Symmetry is an exceptional property for tensegrity. Tensegrity in shape of icosahedrons are classified as “diamond” type due to the shape resembling a diamond created by the ties surrounding the struts. The icosahedron-tensegrity has unique characteristics. Figure illustrating Icosahedrons and give a global image of the shape of this tensegrity structure. Tensegrities in Icosahedral shape is used in different field. One example can be seen in figure where it is used as basis to replicate a feed. The model is build using a sequence of interconnecting icosahedral tensegrities with compression struts of different lengths. The icosahedron has been identified as the basic structure of carbon 60, viruses, cells, and other elements in biology.

III. CONCLUSION

After doing the case study of the tensegrity structures we came to know that the structures are quite economical, efficient, deployable and durable. The structures provide high stability and hence safe for structural use. They are very durable and any repair works can be done without dismantling the whole structure. The use of tensegrity structure should be done for bridges which are designed to carry light loads such as pedestrian bridges, etc. Tensegrity structure design is a challenging task due to geometrical complexity and closely coupled behaviour. The most efficient model is the pentagon ring and the least efficient is hexagon.

A useful extension of the tensegrity grid design guideline includes the ratio of rigidity between cables and struts as well as material properties. Increasing this ratio decreases vertical displacement until reaching a limit that varies with material properties. Tensegrity structures are efficient when properly designed. Further work involves construction and testing a prototype of the pentagon tensegrity bridge. Further work involves construction and testing a prototype of the pentagon tensegrity model.

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