A

Seminar report

On

TENSEGRITY STRUCTURES AND THEIR APPLICATION TO ARCHITECTURE

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Of Civil

SUBMITTED TO: **SUBMITTED BY:**

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Preface

I have made this report file on the topic **TENSEGRITY STRUCTURES AND THEIR APPLICATION TO ARCHITECTURE ;** I have tried my best to elucidate all the relevant detail to the topic to be included in the report. While in the beginning I have tried to give a general view about this topic.

My efforts and wholehearted co-corporation of each and everyone has ended on a successful note. I express my sincere gratitude to …………..who assisting me throughout the preparation of this topic. I thank him for providing me the reinforcement, confidence and most importantly the track for the topic whenever I needed it.

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INTRODUCTION

Tensegrity structures are 3-D trusses where members are assigned specific functions. Some members remain in tension while others are always in compression. Usually for compressive members, solid sections or bars are used; and string or cable type elements can be used as the tensile members.

Most bar–string configurations will not be in equilibrium. Hence, if constructed they will collapse to a different shape. Only bar–string configurations which are pre-stressed and 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.

The word "Tensegrity" is a contraction of the phrase "tensional integrity". It can be traced back to Buckminster Fuller who first coined the phrase in his 1962 patent application. The construction of the first true Tensegrity structure is however attributed to the artist Kenneth Snelson who created his X- piece sculpture in 1948.

In his patent, Snelson describes Tensegrity as a "….class of structures possessing, what may be termed discontinuous compression, continuous tension characteristics." This discontinuity was also recognized by Buckminster Fuller in his patent description, when he stated that "….the structure will have the aspect of continuous tension throughout and the compression will be subjugated so that the compression elements will become small islands in a sea of tension."

Another important aspect is the stability. A Tensegrity system is established when a set of discontinuous compression components interact with a set of continuous tensile components to define a stable volume in space."

A more mechanical description is given by Hanaor who describes Tensegrity structures as "internally pre-stressed, free standing pin-jointed networks, in which the cables or tendons are tensioned against a system of bars or struts." This description introduces the fact that the system is pre-stressed and pin-jointed. This implies that there are only axial forces present in the system and there is no torque.

The general definition of a tensegrity structure is stated as:

"The geometry of a material system is in a stable equilibrium if all particles in the material system return to this geometry, as time goes to infinity, starting from any initial position arbitrarily close to this geometry".

The bars are rigid bodies and the strings are one-dimensional elastic bodies. Hence, a material system is in equilibrium if the nodal points of the bars in the system are in equilibrium.

To summarise, the above descriptions cover most of the aspects of the Tensegrity concept which are listed as follows:

1. **Pin-jointed bar frameworks:** Tensegrity structures belong to the structural group of pin-jointed three-dimensional trusses.
2. **Pure compressive/tensile members:** Tensegrity structures contain only pure compression and tension members. And tension elements used are cables which can sustain only tension.
3. **Localisation of compression:** In classic Tensegrity structures the compressive elements are discontinuous. They seem to be floating in a continuous network of tension elements.
4. **Pre-stressed structures:** A state of pre-stress or self-stress is required for the stability of the structure since it stabilizes internal mechanisms.

CONCEPT OF TENSEGRITY STRUCTURES

Tensegrity structures are structures based on the combination of a few simple but subtle and deep design patterns:

1. Loading members only in pure compression or pure tension, meaning the structure will only fail if the cables yield or the rods buckle.
2. Preload or tensional pre-stress, which allows cables to be rigid in tension.
3. Mechanical stability, which allows the members to remain in tension/compression as stress on the structure increases.

Because of these patterns, no structural member experiences a bending moment. This can produce exceptionally rigid structures for their mass and for the cross section of the components.

A conceptual building block of tensegrity is seen in the 1951 Skylon tower which follows the typical tensegrity structure concept. But there are variations such as the Needle Tower which involve more than three cables meeting at the end of a rod. These cables define the position of the end of the rod which is considered as a well-defined point in space and the other additional cables are simply attached to this well-defined point.

Eleanor Hartley points out visual transparency as an important aesthetic quality of these structures. Korkmaz put forward that the concept of tensegrity is suitable for adaptive architecture due to its lightweight characteristics.

GENERAL CHARACTERISTICS

System:

In relation to the theory of systems, tensegrity structures have components (two kinds, in compression and in tension), relational structures (between the different components), total structure (associating relational structure with characteristics of components) and form (projected on to a three-dimensioned referenced system).

Stable Self-Equilibrated State:

It is said to be stable because the system can re-establish its equilibrium after a disturbance and it is self-equilibrated because it doesn't need any other external condition. It is independent of external forces (even gravity) or anchorages due to its self-stress initial state.

Components:

The components used for a tensegrity structure can be struts, cables, membranes, an air volume, an assembly of elementary components, etc.

Compressed or Tensioned Components:

Instead of using compression and tensile components, the key is that the whole component has to be compressed or tensioned depending on the class of tensegrity structure.

Continuous Tension and Discontinuous Compression:

The compressed components must be disconnected, and the tensioned components should be connected to create an "ocean" of continuous tension with discontinuous compression floating in it.

Boundary Surface of Tensegrity Structures

This is a crucial point since it differentiates between the two type of structures: the conventional structures, where compression is the basis of the load support, and the tensegrities, where this role is played by the tension. In order to avoid controversial systems, such as the torus, with different "insides" and "outsides", tensegrity system is generalised as that in which all its compressed components lie inside the system and the points at the ends of these compressed components do not belong to the boundary (or envelope). Thus, in a tensegrity system, the boundary surface has tension lines only.

BENEFITS OF TENSEGRITY

Tensegrity as a structural system offers many advantages over conventional structural systems. The benefits offered are elaborated as follows:

Tension Stabilizes the Structure

A compressive member loses stiffness as it is loaded, whereas a 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 centre. The material spreads which increases the diameter of the central cross section; whereas tensile members reduce its cross-section under load. In the presence of bending moments since the line of application of force is away from the centre 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 (sand, masonry, and unreinforced concrete are exceptions to this rule). Hence, a large stiffness-to-mass ratio can be achieved by increasing the use of tensile members.

Tensegrity Structures are Efficient

Efficiency of a structure increases with the minimal mass design for a given set of stiffness properties. Tensegrity structures use longitudinal members arranged in a very unusual pattern to achieve maximum strength with small mass.

Tensegrity Structures are Deployable

Since the compressive members of Tensegrity structures are either disjoint or connected with ball joints, large displacement, deployability and stowage in a compact volume is possible in 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. Deployable structures can save transport costs by reducing the mass required, or by eliminating the requirement of humans for assembly.

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 Can Be More Reliably Modelled

All members of a Tensegrity structure are axially loaded. Perhaps the most promising scientific feature of Tensegrity structures is that while the structure as a whole bends with external static loads, none of the individual members of the Tensegrity structure experience bending moments. Generally, members that experience deformation in two or three dimensions are much harder to model than members that experience deformation in only one dimension. Hence, increased use of tensile members is expected to yield more efficient structures.

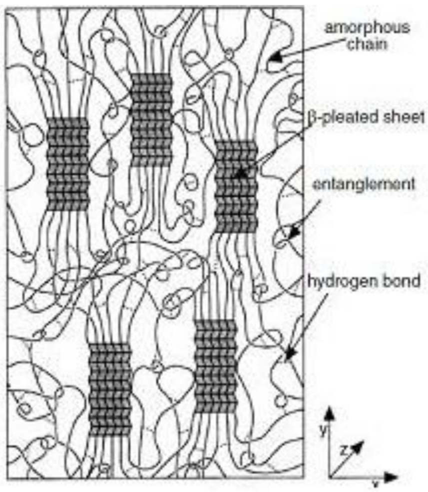
Tensegrity Structures can Perform Multiple Fuctions

A given tensile or compressive member of a Tensegrity structure can serve multiple functions. It can simultaneously be a load-carrying member of the structure, a sensor (measuring tension or length), an actuator (such as nickel-titanium wire), a thermal insulator, or an electrical conductor. Therefore by proper choice of materials and geometry the electrical, thermal, and mechanical energy in a material or structure can be controlled.

Tensegrity Structures are Motivated from Biology

The representation of a spider fibre show that the hard β- pleated sheets are discontinuous and the tension members (amino acid matrix) form a continuous network. Hence, the nano-structure of the spider fibre is a Tensegrity structure.

Nature's endorsement of Tensegrity structures in the form of spider fibre is the strongest natural fibre. Similarly if Tensegrity is nature's preferred building architecture, then the same incredible efficiency possessed by natural systems can be transferred to manmade systems too.



Molecular Structure of Spider Silk

MECHANICAL BEHAVIOUR OF TENSEGRITY STRUCTURES

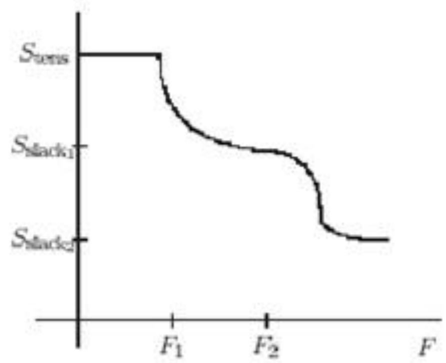
Stiffness of a Tensegrity structure is influenced by many parameters. However, the pretension applied to the Tensegrity is considered to be the most critical. Pretension is a method of increasing the load-bearing capacity of a structure through the use of strings that are stretched to a desired tension. This allows the structure to support greater loads without as much deflection as compared to a structure without any pretension.

For a Tensegrity structure, the role of pretension is monumental. Increasing the pretension allows for greater bending loads to be carried by the structure. In other words, the slackening of a string will occur for a larger external load if pretension is employed.

Tensegrity Structures in Bending

The bending stiffness profiles of Tensegrity structures have stiffness level S_{tens} when all strings are in tension, S_{slack1} when one string is slack, and then other levels as other strings go slack or as strong forces push the structure into radically different shapes.

More complicated Tensegrity geometries will possibly yield many stiffness levels. This inference arises from the possibility that multiple strings can become slack depending on the directions and magnitudes of the loading environment.



Gedanken stiffness profile

The specific profile is heavily influenced by the geometry of the Tensegrity structure as well as of the stiffness of the strings, K_{string}, and bars, K_{bar}.
The ratio called rigidity ratio, K

$$K = \frac{K_{string}}{K_{bar}}$$

is a parameter.

Tensegrity Structures in Compression

For compressive loads, the relationships between stiffness, pretension, and applied load do not always obey the simple principles which apply to bending. In fact, qualitatively different stiffness profiles are observed in compression loading studies of different Tensegrity structures, which cannot be generalized.

Change of Shape with Small Control Energy

Tensegrity structures, even very complicated ones, can be actuated by placing pulleys at the nodes (ends of bars) and running the end of each string through a pulley. Thus, it can be thought of as two pulleys being associated with each string and the rotation of the pulleys can be used to shorten or loosen the string. Thus, in Tensegrity structures, shape changes (moving nodes changes the shape) can be achieved with little change in the potential energy of the system.

STRUCTURAL APPLICATIONS OF TENSEGRITY

General

Kenneth Snelson, made an observation concerning the practical application of Tensegrity structures in relation to the load handling capacity of Tensegrity structures, and thus their limited practical relevance. There have been few actual implementations of the Tensegrity principle in engineering applications, which is mainly ascribed to the lack of knowledge concerning actual construction methods rather than any deficiencies in the Tensegrity concept. Tensegrity structures are certainly relevant in various areas of engineering as emphasised by the benefits mentioned in the preceding sections.

Proposals for Towers

Tensegrity towers can have the following applications:

Lightning conductors:

As it is not required to have these elements in a completely static situation and they tolerate certain small movements, they could serve perfectly for this application.

Communications:

In situations where the margin of displacements is not very strict, Tensegrity towers can be employed to support antennas, receptors, radio transmitters, mobile telephone transmitters, etc.

Wind parks:

The lightness of these Tensegrity towers could minimize the visual impact of these energetic installations.

Aesthetic elements:

Fig 8.1 Rostock tower

Tensegrity structures can enhance the visual landscape of an area. The Tower of Rostock illustrates this aspect.

Roof Structures

An important example of Tensegrity being employed in roof structures is the stadia at La Plata (Argentina), based on a prize winning concept developed by architect Roberto Ferreira. The design adapts the patented Tenstar Tensegrity roof concept to the twin peak contour and the plan configuration, and consequently, it is more similar to a cable-dome structure than to a conventional roof structure. The first studies for the design of Tensegrity grids were carried out by Snelson, but its applications were limited. For the past few years, the main focus has been in the development of double-layer Tensegrity grids and foldable Tensegrity systems. This kind of grid has its most feasible possibilities in the field of walls, roofs and covering structures.

Fig 8.2 U.S. Pavilion for Expo '67 by fuller in 1967

Outer Space Structures

Since the beginning of the "Tensegrity era", one of the most recurring applications found for the floating-compression has been its speculated use in moon-colonies. In 1961, Buckminster Fuller revealed his new inventions: potential prototypes of satellite and moon-structures conceived as tensional integrity which are foldable, extremely light, omni-triangulated, pre-stressed, etc. i.e., "spherical nets in which local islands of compression act only as local sprit-stiffeners". It is not very surprising to arrive at these conclusions, since one of the particular characteristics of Tensegrity structures is that they don't depend on gravity, so they are stable in any position.

Recently, a very well defined project has been carried out from another approach. In this case, tensile integrity structures were not the starting point, but a resource to achieve another objective: the establishment of a self-sustainable society in the moon. This project sought the improvement of new structural concepts that experience completely different external loads (1/6 of Earth's gravity, meteorite impacts, moonquakes, etc.), different risks (like pressure containment, radiation, etc) and different environmental conditions (atmosphere, light, wind, dehydration, etc).

Smart Structures

Most Civil Engineering structures are static. A more challenging functionality for Civil Engineering structures is active adaptation to changing requirements, such as load modifications, temperature variations, support settlements and possible damage occurrence.

The concept of active structures involves structures that include both static and active structural elements. Adaptive structures are defined as structures whose performance is controlled by a system composed of sensors, actuators and a computer that provides the ability to learn and improve response to changing environments.

Since Tensegrities can be equipped with active control systems, they have the potential to adapt to their environments.

Bridges

Advancements in the design of double grid systems has resulted in an expected interest in application of Tensegrity to bridge construction. A recent achievement in this regard is the Kurilpa Bridge in Brisbane, Australia. It is the world's largest Tensegrity bridge, which was opened on the 4th of October 2009.

The Kurilpa Bridge is a multiple-mast, cable-stay structure based on principles of Tensegrity producing a synergy between balanced tension and compression components to create a light structure that is incredibly strong. The bridge is 470m long with a main span of 120m and features two large viewing and relaxation platforms, two rest areas, and a continuous all-weather canopy for the entire length of the bridge. A canopy is supported by a secondary Tensegrity structure. It is estimated that 550 tons of structural steel including 6.8 km of spiral strand cable are incorporated into the bridge.

Fig 8.3 Kurilpa Bridge, Brisbane, Australia

CONCLUSION

The analysis of tensegrity structures reveals the concept that lightweight is a real measure of structural effectiveness. A new architecture with new qualities is predicted which is revolutionary, elastic, light, expandable, active, mobile and dynamic which are the most important features of tensegrity structures. Tensegrity could be one of the structural systems of the future.

Recent developments show that tensegrity could be applied to Architecture and Engineering. Studies show the feasibility of tensegrity as a lightweight structure to cover large spans, bridge shorter distances or support light infrastructures. Of course, a much more detailed structural investigation would be necessary, but at least the pre-supposed idea of tensegrity as an inapplicable system should been disproved.

Investigations on foldable tensegrity structures are under process. As a result of which they could be used for disaster relief in areas devastated by earthquakes, hurricanes, floods and so on, by installing deployable systems in the form of temporal dwellings, bridges, field hospitals, etc. But further research must be carried out to develop these and many other such potential applications.

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