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TENSEGRITY STRUCTURES

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Abstract : The qualities of the tensegrity structures, which make the technology attractive for human use, are their resilience and ability to use material in a very economical way. Thus, the construction of the structures using tensegrity principle will make them highly resilient and reasonably economical at the same time. Though a lot of research has focused on the theoretical aspect such as form finding, only a few practical works have been done on how to use these structures. The main aim of this work is to prove that it is possible to find some applications for such an atypical kind of structure, despite its flexibility and relatively high deflections.

***Index Terms* – Tensegrity structures, Flexibility, High deflections.**

I. INTRODUCTION

The term Tensegrity was shaped by the American architect, engineer, and philosopher Richard Buckminster Fuller (1895 - 1983).The word "Tensegrity" is a contraction of the phrase "tension integrity". Tensegrity is referring to the integrity of structures as being based in an interaction between balanced tension and compression components. Tensegrity structures are built of struts and cables. The struts can resist compressive force and the cables cannot. Tensegrity structures are 3-D trusses where some members are always in tension while others are 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. 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.

II. PRINCIPLES OF TENSEGRITY :

'Tensegrity' is a pattern that results when 'push' and 'pull' have a win-win relationship with each other. Pull is continuous whereas push is discontinuous. The continuous pull is balanced by the discontinuous push, producing the integrity of tension and compression. Tensegrity is the name for a interaction between a co-existing pairs of fundamental physical laws of push and pull, or compression and tension, or repulsion and attraction.

A more common example of a tensegrity is in a child's balloon. When examined as a system, the rubber skin of the balloon can be seen as continuously pulling (against the air inside) while the individual molecules of air are discontinuously pushing against the inside of the balloon keeping it inflated. All external forces striking the external surface are immediately and continuously distributed over the entire system, hence the balloon is quite strong despite its thin material. Thus, a tensegrity is a balanced system composed of two elements, a continuous pull balanced by discontinuous push. When these two forces are in balance, it results in a stabilized system.

III. DEFINITIONS OF TENSEGRITY

To show the evolution of the analysis of these systems, different definitions will be explored in a chronological order.

In the article called Tensegrity, Buckminster Fuller (1961) explained "The compression elements become small islands in a sea of tension". Some years later, he wrote in Synergeticsan extended explanation: "Tensegrity describes a structural-relationship principle in which structural shape is guaranteed by the finitely closed, comprehensively continuous, tensional behaviours of the system and not by the discontinuous and exclusively local compressional member behaviours." (1975b, 700.011)

Kenneth Snelson explained "Tensegrity describes a closed structural system composed of a set of three or more elongate compression struts within a network of tension tendons, the combined parts mutually supportive in such a way that the struts do not touch one another but press outwardly against nodal points in the tension network to form a firm, triangulated, prestressed, tension and compression unit." (Snelson, 2004)

Anthony Pugh gave the following characterisation of tensegrity, “A tensegrity system is established when a set of discontinuous compressive components interacts with a set of continuous tensile components to define a stable volume in space.” (1976, p.3)

Bin-Bing Wang (1998) identifying other important characteristics: tensegrity structures are self-supporting and rigidified by self-stressing. The wider definition given by Wang and Li (1998, 2003) is the following: “Tensegrity systems are free-standing pin-jointed cable networks in which a connected system of cables is stressed against a disconnected system of struts and extensively, any free-standing pin-jointed cable networks composed of building units that satisfy aforesaid definition.” (pp. 93)

Ariel Hanaor described tensegrity structures as “internally prestressed, free-standing pin-jointed networks, in which the cables or tendons are tensioned against a system of bars or struts”.

Finally, René Motro(2003) tried to distinguish two different concepts. He makes the distinction between the “patent based” and the “extended” definition.

“Patent based definition: Tensegrity systems are spatial reticulate systems in a state of self-stress. All their elements have a straight middle fibre and are of equivalent size. Tensioned elements have no rigidity in compression and constitute a continuous set. Compressed elements constitute a discontinuous set. Each node receives one and only one compressed element.”

“Extended definition: Tensegrity system is a system in a stable self-equilibrated state comprising a discontinuous set of compressed components inside a continuum of tensioned components.”

IV. General characteristics

1. Stable self-equilibrated state: Stable because the system can re-establish its equilibrium after a disturbance, and 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. It is stable even in orbit.
2. Components: in contrast to the term “element”, it can be a strut, a cable, a membrane, an air volume, an assembly of elementary components, etc.
3. Compressed or tensioned components: instead of compression and tensile components, because the key is that the whole component must be compressed or tensioned depending on its class.
4. Continuous tension and discontinuous compression: because the compressed components must be disconnected, and the tensioned components are creating an “ocean” of continuous tension.
5. Inside: Motro defines a system as one of tensegrity when all its compressed components are inside the system, and a compressed element is inside when the points between its ends do not belong to the boundary (or envelope). Thus, in a tensegrity system, the action lines lying on the boundary surface are tension lines. See in following figures.

fig:1 false tensegrity
the compressed square assembly of three struts, belongs to the boundary

fig:2 pure tensegrity
the boundary has no compressed component.

Table 1 Morning Traffic Analysis

Type of Vehicles	Number of Vehicles
Car	790
2-Wheeler	1745
3-Wheeler	265
Bus	42
Cycle	53
Other	17

Table 2 Evening Traffic Analysis

Type of Vehicles	Number of Vehicles
Car	1180
2-Wheeler	2644
3-Wheeler	471
Bus	35
Cycle	92
Other	7

Table 3 Total Traffic Analysis

Type of Vehicles	Number of Vehicles
Car	1969
2-Wheeler	4389
3-Wheeler	736
Bus	77
Cycle	145
Other	24

V. THE CREATION OF SIMPLEST CONFIGURATION

Due to complexity of tensegrity structure, it is better to explain the generation of the easiest tensegrity structures. The most primitive case of stressed structures is the kite. This antique toy is simply based on two crossed sticks with a tensioned string around it, joining the four extremes defined by them. This is basically a two-dimensional structure, which can't be considered tensegrity because the two rods in compression are touching each other in the middle of the kite.

The Snelson achieved his first tensegrity sculpture from kite-like modules out of plywood. Moreover, his patent employed X-shaped modules to generate several masts of continuous tension-discontinuous compression and to explain the generation of the simplest tensegrity structure: the "Simplex", "Elementary Equilibrium" or "Three- Struts T-Prism" (fig. 3).

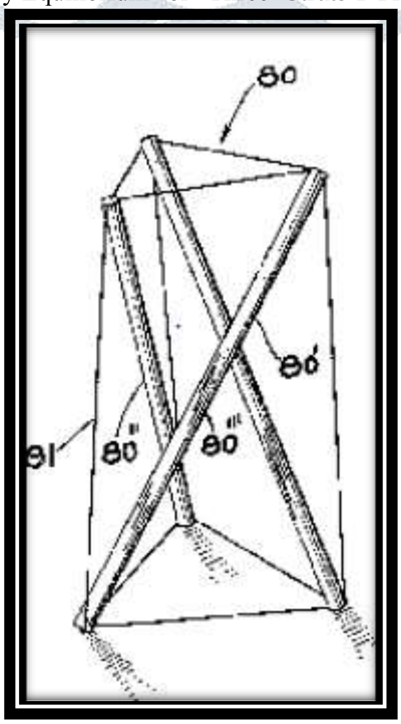

fig:3 False Tensegrity

"Generation of the Simplex", by Snelson.

As per Snelson's description, how to create "Elementary Equilibrium", is shown in figure 4 graphically. Beginning with a kite-like module (fig. 4.11.a), when we fix two of its corners to the ground, we can remove the string between them (fig. 4.11.b). As pointed out above, in order to consider this configuration as tensegrity, it is necessary to separate the two struts, which are in contact at their middle point. So, we push the other two corners as in fig. 4.11.c, and fix this situation by attaching two tendons to the ground (fig. 4.11.d). Finally, we add the third pole between these two points and tie its ends to the corners of the kite lying on the ground.

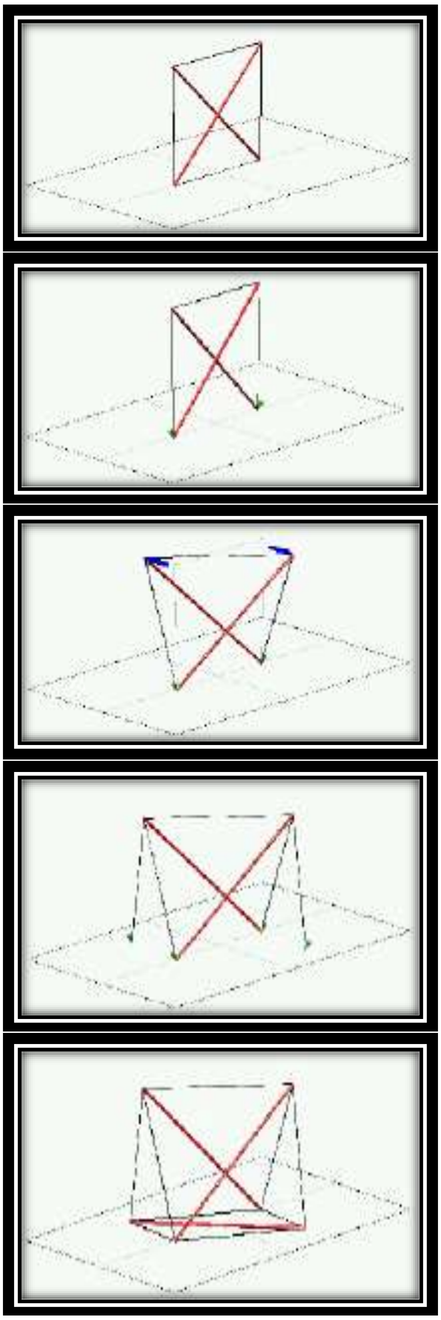

fig:8 derivation of the simplex

5.1 Features

The precise and detailed configuration of the "floated compression" structures, make it possible to accept the assumption that they have very special characteristics.

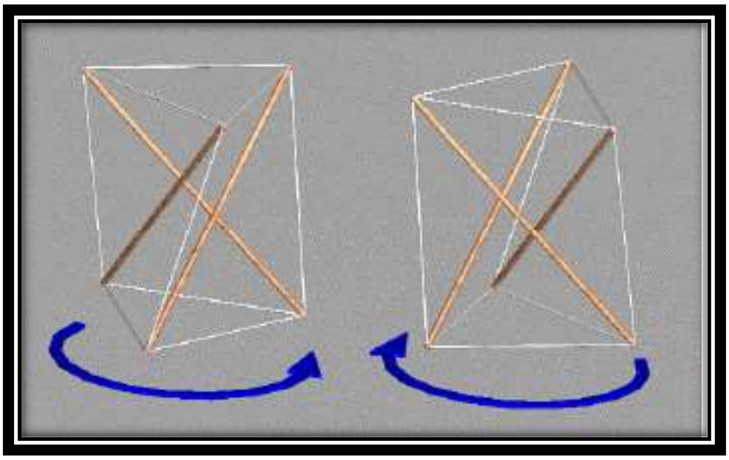

fig:5 right-handed and left-handed simplex (dextrorse & sinistrorse)

- They are very lightweight in comparison to other structures with similar resistance, or if preferred, they have a high resistance in comparison to other structures with similar weight. In contrast, Wang (2003) states that this characteristic is not inherent, as for example tensegrity grids are heavier than conventional structural grids.
- They don't depend on gravity due to their self-stability, so they don't need to be anchored or leaned on any surface. The systems are stable in any position.
- Most tensegrity systems are existed as right and left-handed mirror pairs, "dextrorse" and "sinistrorse" respectively, see figure 5.
- If the self-stressing is higher in a tensegrity system, its load-bearing capacity is higher too.
- They have the property of synergy where the behaviour of the whole systems is not predicted by the behaviour of any of their components taken separately.
- The flexibility or stiffness of the structure depends on the materials employed, and by their method of assembly. They can be very flexible or very rigid and quite strong.
- They are very sensitive to vibrations under dynamic loads.
- The response to the loads is non-linear.
- Some tensegrities, under axial load, experience a rotation around this axe. The direction of this rotation depends on the handedness of the system.

VI. Merits and demerits of tensegrity structures

6.1 Merits of Tensegrity Structures

- The multidirectional tension network encloses fortuitous stresses where they take place, so there are no points of local weakness.
- Due to the ability to respond, it is possible to use materials in a very economical way, offering a maximum amount of strength for a given amount of building material. In Vesna's and Fuller´s words, tensegrity demonstrates etherealization, or the capability of doing more with less. Perhaps, 'ethereal' is more adequate than 'ephemeral'.
- They don't suffer any kind of torque or torsion, and buckling is very rare due to the short length of their components in compression.
- Tensional forces naturally transmit themselves over the shortest distance between two points, so the members of a tensegrity structure are precisely positioned to best withstand stress.
- Tensegrity structures are deployable and efficient.

fig:6 complexity in construction for large tensegrity structures

6.2 Demerits of Tensegrity Structures

- Tensegrity arrangements need to solve the problem of bar congestion. As some designs become larger, the struts start running into each other.
- Tensegrity arrangement suffer he problem of bar congestion as some designs become larger, the struts start running into each other (See figure 6).
- The same author stated, after experimental research, "relatively high deflections and low material efficiency, as compared with conventional, geometrically rigid structures".
- 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.
- The inadequate design tools have been a limitation until now. There was a lack of design and analysis techniques for these structures.
- Proposed shell analysis as the best way, although this is a bit distant from structural reality. In spite of this evidence, Pugh (1976) estimated, incorrectly, that as the connections between struts and tendons are pinned joints, the design and calculation of these figures was relatively simple.

VII. Conclusion

Needless to say, few things can be achieved without more investigation, but tensegrity could be one of the structural systems of the future.an important step was reached by finding several examples of tensegrity prototypes that could be applied to Architecture and Engineering. His own proposals could serve as an illustration to 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 presupposed idea of tensegrity as an inapplicable system has been disproved.

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