Modular Transformable Cable-Strut Structure

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Abstract

Self-tensioned structures composed of cables and struts usually involve simple connections at the nodes that allow for easy cable detachment. These structures are therefore potentially deployable, since, once a single or a system of cables are detached or loosened, the structure can loose its stiffness or collapse; respectively when the cables are back in place, the structure acquires stiffness and rigidity. This paper presents a new concept of a modular self-tensioned structure that is composed of sets of struts forming a triangular shape, and two disjointed struts held in place by a cables. By changing strut sizes and cable lengths the structure can change form to respond to various functional needs and contextual requirements. The configuration of the basic module, variations of the module, and methods of creating larger structures by attaching modules to each other, are described in this paper. An application of the proposed self-tensioned structure to be erected at the port of Patras in Greece, during Patras' tenure as the 2006 Cultural Capital of Europe, and which responds to set requirements and to a specific urban environment, is presented.

1 Introduction

"Structures autotendant" or "autondue," translated as "self-tensioned structures," is the term used by their inventor, George Emmerich [1996], to define a class of structures that can be described coherently as internally prestressed cable networks. The term 'tensegrity' coined by Buckminster Fuller [1975], who also came up with the same invention at about the same time, refers to the same structures but places emphasis on the continuity of the tension elements of the structure. In their most common configuration, these structures are composed of tendons (straight cables) and struts (a strut is prestessed in compression) and are prestressed pin-jointed structures that do not require any external anchorage [Hanaor 1973].

In most existing configurations of self-tensioned structures the network of struts is disjointed, so that each strut is connected to several cables but to no other strut. A technological characteristic of self-tensioned structures is that they usually involve bar to cable connections at the nodes, which are typically simpler than the bar to bar connections, and allow for easy cable detachment. These structures are therefore potentially deployable, since, once a single or a system of cables are detached or loosened, the structure can loose its stiffness or collapse; respectively when the cables are back in place, the structure acquires stiffness and rigidity.

Most existing configurations of self-tensioned structures occur from the assembly of identical self-supported units of simple geometry which are attached to each other by following given patterns and rules. Depending on the connection pattern, two basic configurations of self tensioned structures can be generated: configurations with disjointed struts throughout the entire network [Hanaor 1976], and configurations containing both bar to bar and bar to cable connections [Motro 1992]. In this paper an application of the general concept of self-tensioned structures is presented. The geometry of the proposed structure deviates from both the geometry of existing configurations of typical tensioned units and from structures that occur from the assembly of such units. The configuration of this new structure is described in the following section.

2 Geometric configuration and morphological variations

The form and shape of the proposed new structure is subject to an orderly and hierarchical organization of parts. The structure presents a bi-axial symmetry and consists of two counter symmetrical triangles, the sides of which are struts rigidly attached to each other. The two triangles are placed at a slanted position with regard to their planes of symmetry and a long strut that also lies at the plane of the triangles' symmetry passes through their centers of gravity and extends on both sides of the structure's center. The vertices of the two triangles are attached to the ends of the long strut with cables. Similarly, the vertices of the triangle are connected to each other with crossing cables, completing in this manner a closed network of cables that holds in place all rigid members 'Fig. 1'. The two nodes of the crossing cables are connected to each other with a strut lying on an axis perpendicular to the axis of the long strut.

As shown in Fig.2, several morphological variations of this typical module have been developed. In each configuration, the dimensions of the members may vary affecting both the overall geometry of the structure and the level of pre-stress that has to be applied to each set of cables. Identical modules can be connected to each other in a linear mode to form larger structures.

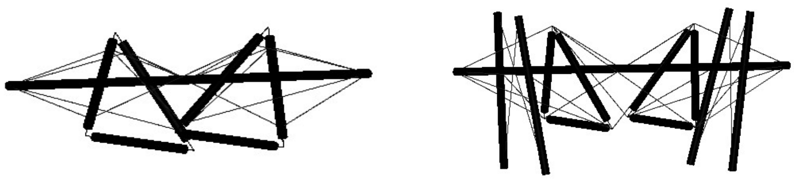

Figure 1. Basic module and variation.

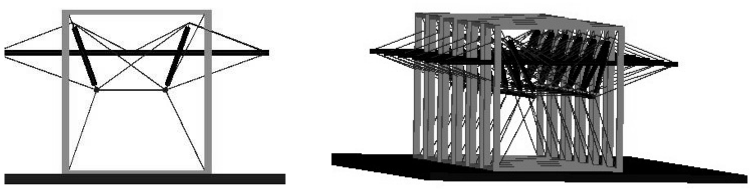

Figure 2. Structure that occurs from the repetitive use of the basic module.

Easy assembly and disassembly of the structure is one of its main features. Several methods for the assembly, erection and prestressing of the proposed module are considered. Depending on the size of the structure and proportions of its parts, the structure can be either entirely assembled on site or partially pre-assembled before transportation. The triangles that consist of struts can be collapsible, as well as the long strut which can be retractable or composed of three members bolted or screwed to each other. All struts at their ends will include a simple mechanism that will allow for minor length extension which will be used to apply pretension to the cables after assembly.

3 Full scale application of the typical module: Conceptual approach

During the planning of the cultural activities, that will take place in Patras, Greece, designated as the "2006 Cultural Capital of Europe," a proposal has been submitted for the design and construction of transformable structures/ installations which are expected to change Patras to an urban site of architectural innovation and experimentation. One of the proposed structures that has been approved for construction is a landmark structure based on an application of the pre-tensioned module described in the previous section; its location and features are described below.

The landmark structure will be placed on the mole at the Patras port, which is central to the most lively section of the city that combines, commercial, administrative, entertainment, leisure and other public activities, and is visible from various view points on the major circulation arteries. The main body of the structure, as seen in Fig. 3, 4 & 5, is an adaptation of the basic module discussed in the previous section. In this application, three tensioned membranes are added to the structure: One central piece of diamond shape that has its two vertices attached to the upper vertices of the slanted triangles and the other two at the nodes of the intersecting diagonal cables that connect the two triangles. Another two symmetrically placed membrane members, also of diamond shape, with one of their axis shifted away from the center of the diamond, that have their two ends connected at the lower vertices of the triangle, one in the mid point of the long strut and the other at the end point of the strut. The resulting structure, with the addition of the symmetrically placed fabric membranes, bears strong figural references to recognizable images in cities with a seafront (seagulls, sailing boats). The struts of the structure that seem to fly in the cables network intensify this image.

The placement of the structure, with its main axis in a vertical direction with regard to the axis of the mole, accentuates perspective and pulls the eye of the observer to the unlimited sea and sky horizon. The structure, which embodies an innovative structural and technological concept that is inherently and uniquely linked with its formal expression, with the added imagery that that the fabric members and the flying bars, that seem to fight gravity create, and with its placement on a focal seafront location, is expected to draw a subtle metaphor to the unlimited potential the integration of arts and science can offer; an expression the structure itself tries to capture.

Figure 3: Self-tensioned structure to be erected at the port of Patras in Greece, during Patras tenure as the 2006 Cultural Capital of Europe.

The proposed structure is thus opting to become a new landmark of the city that will symbolize its significant role as the host of the 2006 Cultural Capital of Europe. At a practical level, the space underneath the structure can be used for mounting information on cultural events and activities on a daily basis.

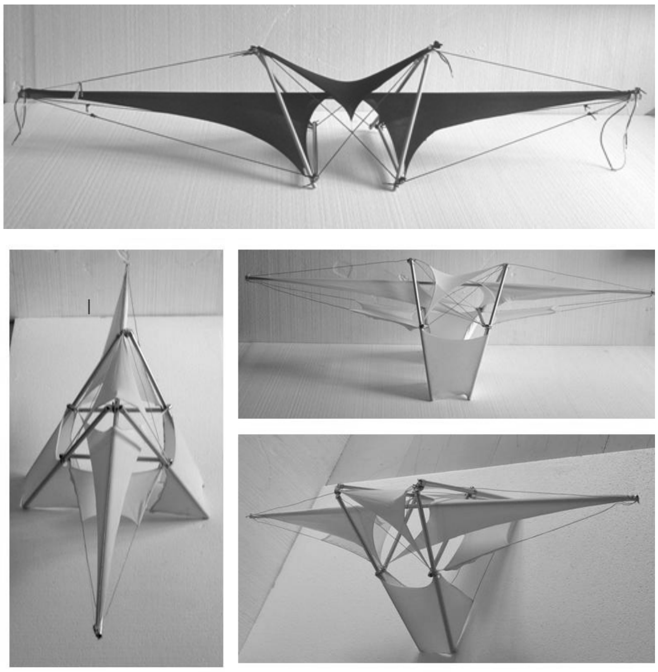

Figure 4. Study models of the proposed structure

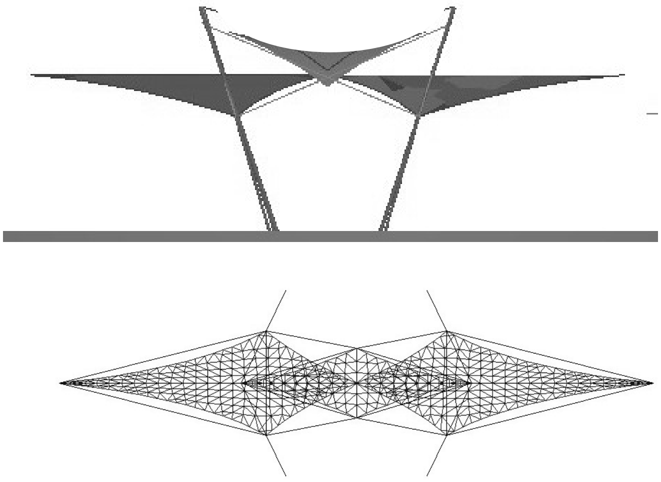

Figure 5. Views of the structure in its final configuration

4 Technical considerations and challenges

For the structure at the mole, as mentioned, an adaptation of the basic unit has been proposed. The main bar is placed parallel to the ground level and the two sides of the triangles have been extended to reach the ground. They are thus forming ‘A’ shaped frame supports that are directly attached to the ground.

In the configuration that has been adapted to fit the dimensions and setback requirements of the current location at the mole, the beam on the symmetry plane of the structure is 24 m long and at a distance of about 6 feet from the ground. The A shaped supports are also placed at a distance of 6 m from each other at their bases. The nodes of the crossing cables are connected with a horizontal beam, the ends of which lie on an axis vertical to the axis of the main beam and at 1, 4 m away from their plain of symmetry. As for construction materials, tubular steel members will be used for all struts, and flexible steel cables for the tendons. For the membrane members a translucent fabric has been selected.

A major challenge in this project was the design of the structure to withstand the strong winds that prevail in the area. The structure has been designed for wind velocity in the range of 30 m/sec. For the analysis of the frame, consisting of the two triangular members, the horizontal tubular bar and the cables, wind loads are considered concentrated at the nodes and non linear displacements have been calculated with the use of stiffness method. Except for the support points, which are considered as articulations, all other nodes have 6 degrees of freedom. For the analysis of the entire structure, including the pretension applied to cables, and the dynamic analysis of the tensioned membrane, the commercially available software FORTEN has been utilized. The steel frame is dimensioned according to EUROCODE 3 and member dimensions are determined as follows: a tubular section of exterior dimension Φ323, 9 mm with thickness 8,8 mm has been used for the long strut, and cables of circular section with diameter 10 mm.

As for the assembly and erection of the structure, several approaches and methods are considered. The collapsible triangular components will be assembled after their on site transportation, while the long strut will be constructed out of three parts, where the two end-parts will be of smaller radius that the central part. Due to the large size of the structure, alternative methods for membrane attachment, tensioning, and cable pre-tensioning, need to be considered and evaluated. The authors will further collaborate with the construction engineers in developing the most efficient method not only for the assembly and prestressing of the structure but also for identifying the most efficient reverse process, that is the disassembly and re-erection of the structure at another location.

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