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A study of a tensegrity structure for a footbridge

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Abstract. It is known that tensegrity systems are made of isolated bars subjected only to compression, connected by stretched cables. The use of these structures comes with advantages such as making large openings and low consumption of materials. This paper analyses the problems related to the building and calculation of a 36-meter-long pedestrian bridge. The structure of the bridge is made up of a double arch of compressed bars and tensioned cables, which supports the path by means of cables. The structure has a number of kinematics degrees of freedom and is statically indeterminate in the same time, which means that it can be pretensioned. Pretensioning introduces compression efforts in the bars and tension efforts in the cables, which fixes the kinematic degrees of freedom and confers rigidity to the system, thus resulting a structure which can support the external loads. The paper deals with aspects of structural analysis and static calculation of the structure subjected to loads.

1. Introduction

These structures were discovered in 1920 by Karl Ioganson and had different names until 1962 when Richard Buckminster Fuller called them "Tensile-integrity Structures" [1].

Due to the fact that these structures were in fact some mechanisms, they tended to attract engineers who gave them different uses, such as domes, towers, roofs for stadiums, temporary structures, exhibition pavilions and even aerospace structures [2].

Furthermore, in the field of bridges, many engineers and architects have conceived an impressive number of tensegrity bridges as follows: Kurilpa Bridge, Footbridge Proposal by Tor Vergata University, Footbridge Proposals by Wilkinson Eyre, Splash Bridge Proposal by Cullum, Bankside Bridge Proposal, Deployable Bridge Thesis Proposal, Bamboo Footbridge Proposal, Tube Bridge Proposal, Simplex Module Footbridge Proposal [3].

The first bridge of its kind is called Kurilpa Bridge and it was built in Brisbane, Australia on October 4, 2009. This bridge has a total length of 470m and a main opening of 120m; it weighs 540 tons and used about 6.8 km of cables [4].

While Kurilpa Bridge is integrally a tensegrity bridge, the other ones are artistic structural objects or theoretical proposals.

Even if the finite element method is successfully used in classical structures, the design of tensegrity structures is still a huge challenge for the designer from a structural and visual point of view [5]. Finding a form for a bridge structure is the most important step in the study; this is indicated also in literature [6]. Compared to the computerized modelling of tensegrity structures, the physical modelling of the model represents a second significant research step.

The structures analysed in this paper complied with the construction rules of tensegrity systems, therefore they are made from isolated bars subjected to compression only [7, 8], which are connected



by stretched cables. By their mode of construction these systems are infinitesimal mechanisms with one or more degrees of kinematic freedom, they get geometrical deformability by tensioning the cables.

Since the rigid bars are not interconnected, the nodes are simplified. Rigidization of the structure by pretensioning leads to a small number of elements compared to the classical structures.

The structure is statically analysed, self-stress efforts are established and the stabilization effect of the pretension is emphasized.

2. The implementation methodology

2.1. Hypotheses

To facilitate the calculation, we apply a set of assumptions [9] like truss girder:

- the bars are straight and the bar axes are concurrent in nodes;
- external forces apply only to the nodes;
- the bars are perfectly articulated at the nodes.

Therefore the use of these assumptions, the systems' bars will have be subjected only to axial tension or compression efforts, and the resulting position of the deformed structure will be given only by the change in the bars' length.

2.2. Description of the pedestrian bridge structure

The main structural element is a double tensegrity arch, which has stretched bars on the outer side, and compressed bars, on the inside (figure 1). Figure 2 shows the transversal bars that keep the two arches in vertical position and, at the same time, give a lateral stiffness to the structure. Figure 3 shows the cross section of the pedestrian bridge at the middle of the opening, and a headroom inside a bridge, for pedestrians, with $h_g = 3.55\text{m}$ and $b_g = 4\text{m}$.

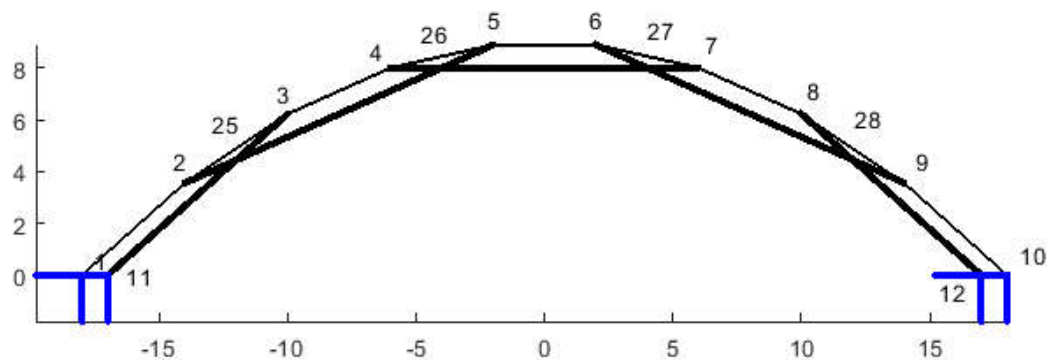


Figure 1. Side view of the pedestrian bridge.

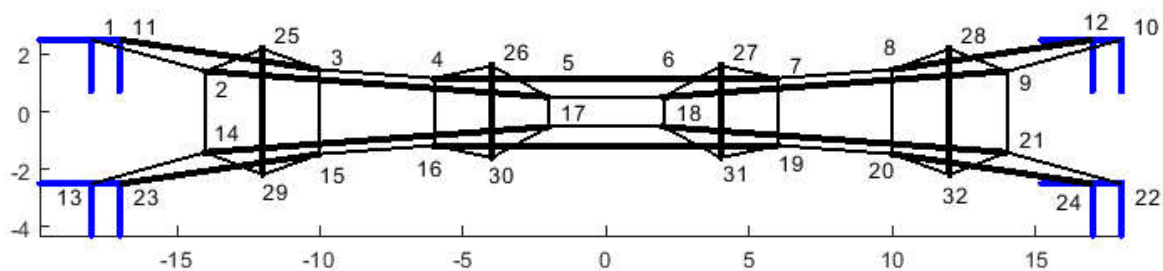


Figure 2. Plan view of the pedestrian bridge.

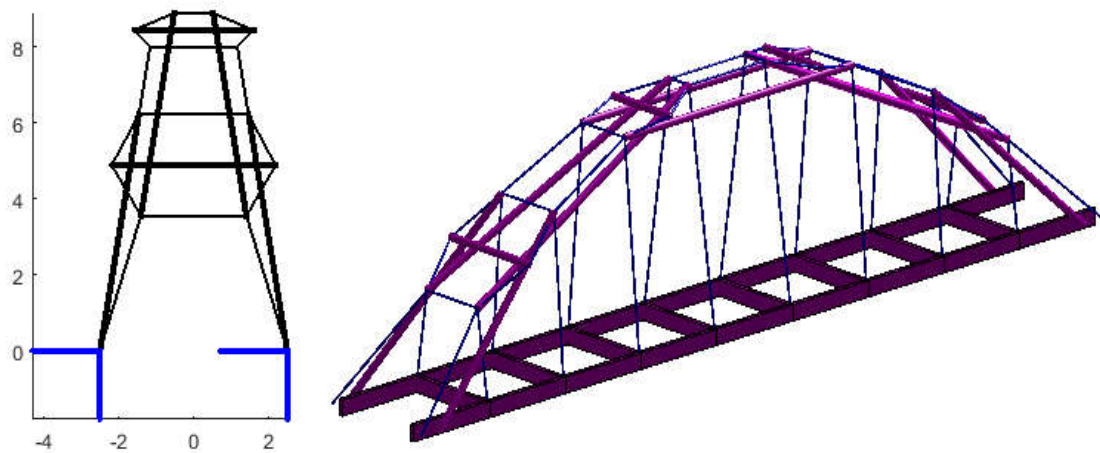


Figure 3. Cross section and 3D view of the pedestrian bridge.

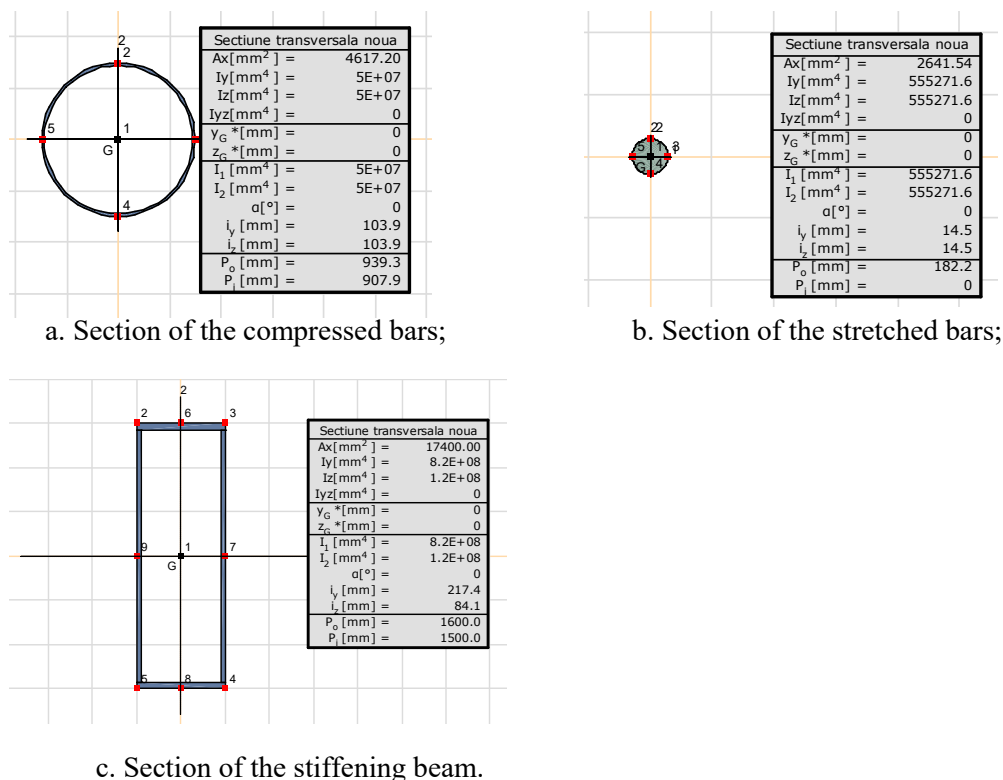


Figure 4. Characteristics of the structural elements.

The structure of the deck is suspended from the main structure by round steel bars. The nodes that secure the path suspension are located at 4 m horizontally. The solidarization of the two arches is accomplished by tensegrity polygons consisting of deviated arch cables, transverse cables and

transversal bars. Figure 4 presents the sections used for making the spring bars and the stiffening beams for the deck.

The double arch is a truss system with the following features:

- no. bars $b = 54$;
- no. supports $r = 24$;
- no. nodes $n = 32$;
- no. of degrees of freedom $m = 19$;
- degrees of static indeterminacy $s = 1$.

The structure being statically undetermined, it can be pretensioned; cable pretensioning fixes the displacements of the $m = 19$ dofs, and ensures the rigidity of the structure.

2.3. Static analysis results

The structure was studied for two load cases:

1. dead load of 5.0 kN/m^2 and live load of 5.0 kN/m^2 on the whole span (P+Q);
2. dead load of 5.0 kN/m^2 and live load of 5.0 kN/m^2 on half of the span (P+Q on $L/2$).

The analysis of the structure shows that the arch alone is too flexible, especially in the case of the live load on half of the span, but the stiffening beam limits the deformations. The capable bending moment for the beam is $M_c = 822 \text{ kN}$, the steel cable can support $N_{cap} = 792 \text{ kN}$, the longest bar has a length of 13.13 m can take $N_{cap} = 600 \text{ kN}$.

Table 1. Static calculation results.

	P+ Q		P+ Q on L/2	
	N	N/N _{cap}	N	N/N _{cap}
$N_{\text{cable max}}$	426.639	0.538	319.979	0.404
$N_{\text{bars max}}$	474.954	0.792	356.215	0.594
	M	M/M _{cap}	M	M/M _{cap}
M_{max}	44.578	0.054	227.848	0.277
$W_{\text{max}} (\text{m})$	0.034		0.057	

Table 1 presents the results of the axial efforts in the bars and cables, the moment of the beam and the maximum vertical displacement of the stiffening beam, the effort recorded in the two load assumptions, and the ratio between the effective and the capable effort.

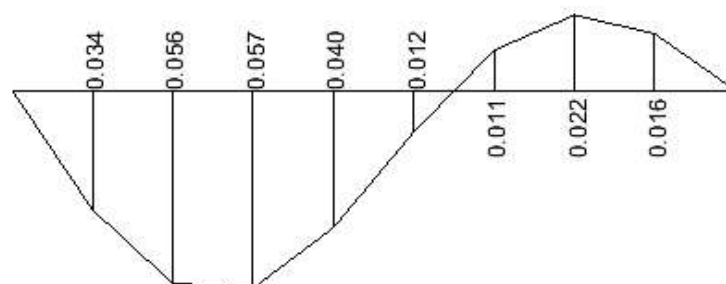


Figure 5. Vertical displacements in the rigidity stiffening beam of loads $(p + u \frac{1}{2})$.

A short analysis of the report indicates that the structure has a significant reserve of load-bearing capacity. For the calculation of efforts and deformations, the pedestrian bridge was loaded with

prestressing efforts, permanent loads from the weight of the deck and of the structure, and the loads of pedestrians which were applied in two load cases: load on the half span and load over the entire span.

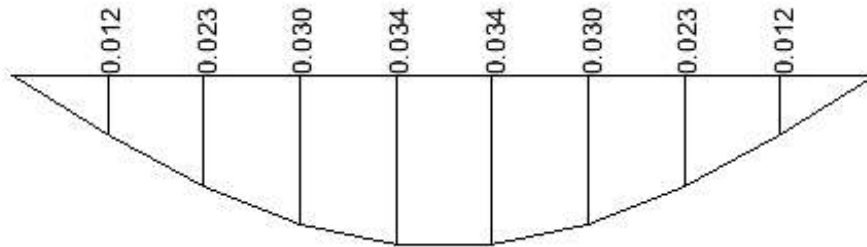


Figure 6. Vertical displacements in the stiffening beam of loads $(p + u)$.

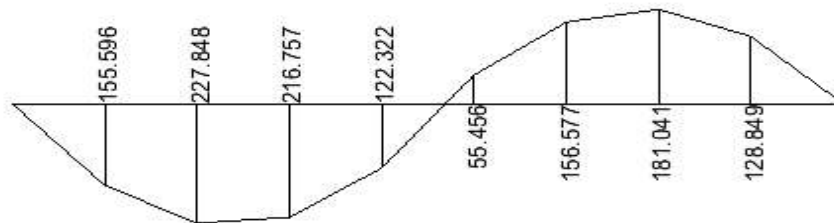


Figure 7. Bending moments in the stiffening beam from loads $(p + u/2)$.

Figures 5, 6, 7 and 8 present the values of the vertical displacements and the bending moment diagrams in the stiffening beam corresponding to the load cases. It is obvious that when the beam is loaded at half the span, we will have vertical and positive displacements (which can be neglected), but in the moment diagram, there is a negative moment with significant values.

The computations were solved by a SCILAB software of the authors. This software has program modules for the kinematic and geometric nonlinear analysis of truss systems. Also a special module was created to introduce the effect of the stiffening beams.

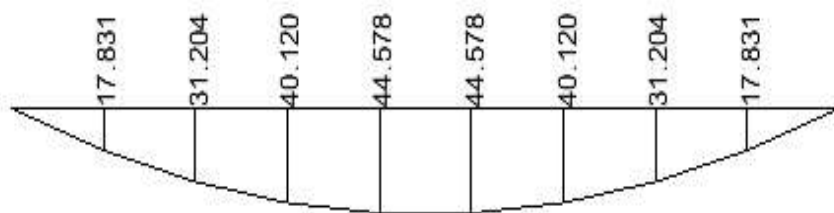


Figure 8. Bending moments in the stiffness beam of loads $(p + u)$

3. Conclusions

Tensegrity footbridges are lightweight and efficient structures with high strength to weight ratio compared with traditional ones. Using only a small number of compressed elements working in isolation one from another by a net of cable elements subjected to tension, less material and respectively less weight of material are used for supporting a given load. The stiffness of the structure is given by the effect of prestressing of the elements. The main disadvantages of tensegrity bridges consist in large deformations and vibrations. Tensegrity systems can withstand heavy loads, but their flexibility makes them to deflect considerably even under small loads. The stability, stiffness and load carrying capacity of the tensegrity structure studied in this paper were increased by using the supplemental stiffening effect of the longitudinal beams which support the deck.

As future research directions, we intend to study aspects like structure behaviour under static and dynamic loads in exploitation. We currently work to obtain a structure model to assess its behaviour by measurements.

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