ANALYSIS OF THE USE OF TENSEGRITY AS DISPLAY POSTUMENTS IN MUSEUMS

Przemysław PALACZ[1], *Izabela MAJOR*[2]

[1] Czestochowa University of Technology, Faculty of Civil Engineering, Akademicka 3 Street,
42-200 Czestochowa, Poland
[2] Czestochowa University of Technology, Faculty of Civil Engineering, Akademicka 3 Street,
42-200 Czestochowa, Poland

przemyslaw.palacz@pcz.pl, izabela.major@pcz.pl

DOI: 10.35181/tces-2022-0012

Abstract. *Tensegrity structures, due to their high stiffness and lightness, have been interesting for designers and architects for decades. The key stage of each design is the selection of the optimal structural system, the task of which is to ensure the load-bearing capacity and meet the visual expectations of modern museums and traditional exhibitions. The article analyzes the use of the tensegrity structure as display pedestals in museums due to its stability and load-bearing capacity. Numerical calculations of the analyzed structural systems of museum pedestals were performed using the finite element method in RFEM. After the analysis, it can be concluded that a properly selected tensegrity structure for the construction of a museum pedestal is an interesting solution worth considering when designing.*

Keywords

Tensegrity structure, museum pedestal, steel structure, infinitesimal mechanism.

1. Introduction

Exhibition pedestals in museums fulfill the role not only of displaying the items on display, but also of an appropriate interior arrangement. Tensegrity structures are the subject of reflection among scientists and engineers from such disciplines as architecture, civil engineering, aviation, biology and robotics, which results in more and more interesting projects using this concept [1]. The tensegrity system is a spatial structure consisting of ropes and struts. The stability of the structure is ensured by the integrity between the compressed struts and the stretched ropes. Due to the presence of many tensile cables in the structure, it provides a high strength-to-weight ratio while maintaining high stiffness [2].

The word *tensegrity* comes from a combination of words *tensile* and *integrity*. The definition of a tensegrity system is: "*A tensegrity is a system in stable self-equilibrated state comprising a discontinuous set of compressed components inside a continuum of tensioned components"*. There are many methods of selecting the geometry of the tensegrity structure, but they are looking for more and more effective ones. Tensegrity is a spatial lattice in which the infinitesimal mechanism is balanced by a self-equivalent system of forces [3]. The tensegrity model is an articulated structure consisting of compression elements located in a network of tension members. Steel is characterized by high tensile strength, so it is worth using these features in structures. An example of the simplest tensegrity structure is shown in Fig. 1.

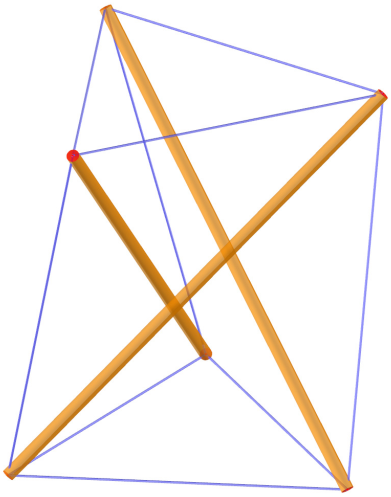

Fig. 1: Model of the simplest tensegrity structure based on a triangle, where the compressed struts are orange bars and the stretched ropes are blue bars. The top base of the triangle is rotated 150° about the bottom base.

Tensegrity structures, due to their unique advantages of self-balance and lightness, have been popular among engineers for many years. The use of the tensegrity structure can be found in many projects, eg in the article [4] the construction of a four-legged robot with tensegrity legs was proposed. The authors experimentally tested the tensegrity structure in the robot protorype and showed that the tetrapod has a high load capacity and good adaptation to the terrain. However, in the article [5] the authors presented a prototype of a modular system of a light steel and glass floor with a tensegrity load-bearing frame, where they demonstrated the effectiveness of the structure used. In turn, in articles [6-15], the authors presented an analysis of the use of tensegrity in various engineering projects. The analysis showed that such systems are characterized not only by lower mass, but also by lower stresses in individual bars, and the computational examples show the effectiveness of using such solutions in engineering structures. This article analyzes the use of tensegrity technology in museum pedestals, which are used not only to present exhibits, but also to attract attention through an effective-looking structure.

2. Computational Models of the Pedestal Structure Adopted for Analysis

Two construction systems of the pedestal were adopted for the analysis, one with an equilateral triangular base inscribed in a circle with a diameter of 1.4 m, and the other with a square base inscribed in a circle with a diameter of 1.4 m. The height of the pedestal in both cases was assumed to be 1.6 m. In addition, diagonal braces were modeled between the lower and upper bars to increase the stiffness of the pedestal structure. In a square-based model, the load capacity is provided by one bar between the V-shaped compression bars rotated 90 degrees relative to the top member. On the other hand, in the model with a triangular base, the load capacity is also ensured by one central bar between the Y-shaped bars. The calculation models are shown in Fig. 2. On the other hand, the geometry of the adopted calculation models is shown in Fig. 3 and 4.

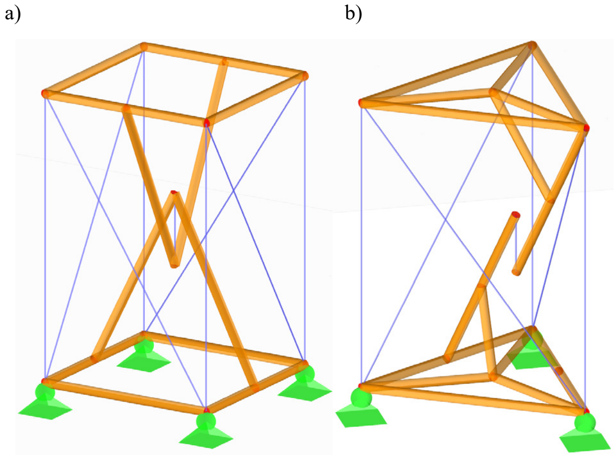

Fig. 2: Computational models in the Dlubal RFEM program: a) Model with a square base; Model with a triangular base.

The model of the display pedestal was modeled in Dlubal RFEM, assuming steel grade S235 and modulus of elasticity 210 GPa for all structure elements. In order to compare the displacements of the upper nodes of the pedestal, a nodal load with a total force of 4 kN was adopted, which corresponds to a weight of approx. 400 kg.

A square tube was assumed for the compressed bars (struts), while the tension members were assumed to be a steel full bar, and the supports were assumed to be articulated.

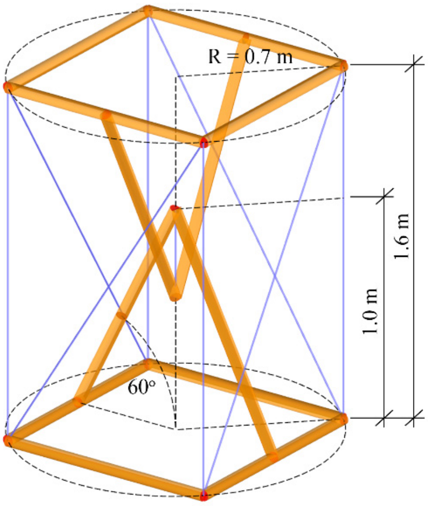

Fig. 3: Geometric model of the model with a square base.

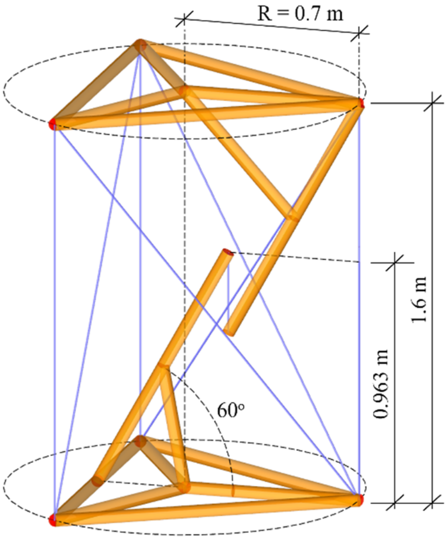

Fig. 4: Geometric model of the model with a triangular base.

In the next stage, calculations with the finite element method were performed and the optimization of individual elements of the structure was performed due to the fulfillment of the ultimate limit state conditions based on Eurocode 3 [16]. The resistance of the members in compression, taking into account the buckling, was calculated on the basis of the formula:

$$N_{b,Rd} = \frac{\chi \cdot A \cdot f_y}{\gamma_{M1}}$$

where χ is the reduction factor for the relevant buckling mode, A is the cross-sectional area of the member in compression in (mm^2), f_y is a yield strength in (N·mm^{-2}), γ_{M1} partial factor for resistance of members to instability assessed by member checks, which is equal to 1. When determining the buckling factor, the bar fixing factor was adopted $\mu = 1$, because the tensegrity rods are mounted articulated. On the other hand, the load capacity of the tensile elements was calculated on the basis of the formula:

$$N_{pl,Rd} = \frac{A \cdot f_y}{\gamma_{M0}}$$

where A is the cross-sectional area of a bar in tension in (mm^2), f_y is a yield strength in (N·mm^{-2}), γ_{M0} is a partial factor for resistance of cross-sections, which is equal to 1. The bending resistance of the bars was calculated from the formula:

$$M_{c,Rd} = \frac{W_{pl} \cdot f_y}{\gamma_{M0}}$$

where W_{pl} is an indicator of the bending strength in (mm^3), f_y is a yield strength in (N·mm^{-2}), γ_{M0} is a partial factor for resistance of cross-sections, which is equal to 1. One type of bars was assumed in both types of structures analyzed.

3. Results and Discussion

On the basis of the performed calculations, optimization of cross-sections in bars was carried out. As a result of the FEM analysis, optimization of the structure elements was performed by selecting the smallest possible cross-sections meeting ultimate limit state conditions. Table 1 shows the maximum forces occurring in individual elements, the selected cross-section, the ultimate limit state, vertical displacement of the upper nodes and the total weight of the pedestal structure.

By analyzing the results presented in Table 1, it can be seen how important the appropriately adopted structural arrangement of the pedestal is.

Tab.1: Results of numerical calculations of the analyzed pedestal structures.

Rod	*Cross section*	Model with a square base		Model with a triangular base	
		Force [kN]/ Bending moment [kNm]	*ULS [%]*	*Force [kN]/ Bending moment [kNm]*	*ULS [%]*
Bearing rod	∅8	5.73/0.00	48	5.65/0.00	47
External bars	∅8	0.00/0.00	0	0.00/0.00	0
Diagonal bars	∅8	0.00/0.00	0	0.00/0.00	0
Compression bars bearing	SP 40x3.0	– 2.40/0.00	5	– 4.97/1.50	107
Base bars	SP 40x3.0	0.00/0.74	37	0.00/1.47	108
Vertical displacement of the upper nodes		5.1 mm		51.6 mm	
Total mass		48.16 kg		55.29 kg	

* the sign "-" means compression of the bar.

In the analyzed structures, one type of compression / bending rod made of a 40x3 mm square tube and one type of tendons made of a rod with a diameter of 8 mm were assumed, so that you can compare the load capacity and weight of the structure with the adopted load-bearing system. When analyzing the results of forces and displacements, it can be noticed that it is important to properly select the structural system, because when comparing both models, the model with a square-shaped base is much more effective due to the displacement and use of the cross-section capacity. The maximum displacement of the upper node in the square shape was 5.1 mm, while in the triangular base it was 51.6 mm and RFEM showed instability of such a system. Such a displacement with such a small structure significantly exceeds the permissible values and cannot occur in such structures. When analyzing the conditions of the ultimate limit state, also in the square-based model, the values indicate that the selected bars are sufficient, while in the second case the load capacity was exceeded, so the cross-section would have to be increased, thanks to which the structure would no longer give the impression of lightness, which is important when choosing a structure visually. The use of unusual design solutions has always aroused the interest of people and attracted their eyes. The use of the tensegrity structure in the construction of platforms for museum exhibits is an interesting solution that can attract the attention of visitors to the exhibition.

4. Conclusion

The article presents the structure of a tensegrity as an interesting solution in structural mechanics in the design of a pedestal for museum exhibits. The uniqueness of such a structure is determined by the self-tensioning state and infinitesimal mechanisms that stiffen it. Due to the axial forces in individual elements of the system, some of them can be replaced with light ties, which makes the structure light and effective. It is worth noting, however, that in the tensegrity construction there is a risk of failure of the entire system as a result of damage or breakage of one of the elements, and this may damage the entire pedestal. The article presents an analysis of the results of calculations using the finite element method, performing the design of tensegrity structure bars with regard to the ultimate limit state according to Eurocode 3, while comparing the results for two different models. As a result of the analysis carried out on the basis of modeled, loaded and dimensioned models of pedestals, it can be concluded that a properly selected tensegrity structure for the construction of a pedestal is an interesting solution that is worth being interested in when designing.

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About Authors

Przemysław PALACZ was born in Czestochowa, Poland. He received his M.Sc. in 2018 from Czestochowa University of Technology. His research interests include modern material-construction solutions, numerical modelling (FEM) and analysis of mechanical wave propagation phenomena using measurement techniques.

Izabela MAJOR was born in Nowy Sącz, Poland. She received her M.Sc. in 1999 and PhD in 2005 from Czestochowa University of Technology. She received docent from Žilina University in 2014. The propagation of waves in elastic structures made of compressible and incompressible materials described with elastic potential dependent on the invariants of the deformation tensor, studies of nonlinear elastic waves of weak and strong discontinuities in hyperelastic materials including their numerical modelling, based on modern computer methods are the areas of her scientific and research work.