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PROTOTYPE OF AN ACTIVE TENSEGRITY UNIT

Tensegrity structures and hybrid tensegric structures can be defined as spatial systems, which consist only from set of compressed members and set of tensioned members and they can be used to developing systems with a possibility of an active control. Structures with an active control or active structures are equipped with sensors and actuators and they are subjected to continuous monitoring. A test facility with an active tensegrity unit and some basic experimental tests which were carried out are presented in the paper. Results obtained from the experimental tests are compared with the FEM created in ANSYS.

1. Introduction

The word or term tensegrity was created by Richard Buckminster Fuller and it is a contraction of tensional integrity. R.B. Fuller described tensegrity as islands of compression in a sea of tension. Thus, tensegrity structures can be defined as spatial systems, which consist only from discontinuous set of compressed members (struts) that are placed inside a continuous set of tensioned members (spiral strands or ropes). According to some researchers more efficient tensegrity structures can be built if compressed components are allowed to join. These systems can also be described as hybrid tensegric structures [1].

The origin of tensegrities is associated with the production of sculptures, but they are gradually being used in the creation of load-carrying structures. Additionally, tensegrity structures can be also used for the systems with a possibility of an active control. Structures with an active control or active structures are equipped with sensors and actuators and they are subjected to continuous monitoring [2]. Sensors record data about external loads and about structural response (axial forces and deflection). Action members (usually telescopic struts) allow an adjustment of the geometry and thus the level of prestressing forces in cables.

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Active control of structures helps to satisfy all design criteria (especially serviceability limit states criteria), for example in the case of a temporary increase of external loads.

The research of active structures or structures with the possibility of an active control is a necessary step for the development of intelligent systems [2].

2. Prototype of active tensegrity structure

Presented active tensegrity unit as well as whole test facility was developed at the Institute of Structural Engineering of the Faculty of Civil Engineering in Košice. Its production was performed in cooperation with INOVA Praha Ltd. This active tensegrity unit was developed and manufactured in order to test the possibility of active control of tensegrity systems through an action element.

The chosen tensegrity unit consists of a strut that is centered in the rectangular base and stiffened by crossed cables. This unit is also known as a tensegric unit cell of type I [1], or like a crystal pyramid [3] and it is suitable for the generation of line structures or plate structures with a straight or curved central line.

The theoretical dimensions of the active tensegrity unit are 2 x 2 m and the theoretical height is 0,76 m. The unit consists of thirteen members (5 compressed member and 8 cables) as is presented in Tab. 1. A hydraulic cylinder forms the central strut or an active member.

Table 1. Members of the active tensegrity unit and their properties

Member	**Cross-section**	***A* [mm^2]**	**Material**	***E* [MPa]**
Compressed members	∅ 51 / 3,2 mm	475,90	steel S 235	160 000
Upper and bottom cables	∅ 6 mm	21,80	steel cable 1+6	210 000
Central or active member	–	475,90	–	210 000

The whole test facility consists of the following parts (Fig. 1 and 2):

- self-supporting frame,
- tensegrity unit with an action member (AP),
- hydraulic load cylinder (ZV) and hydraulic power unit,
- dynamometers in the bottom and upper cables,
- tensionmeters in the compressed members,
- control electronics and control software.

Fig. 1. The active tensegrity unit suspended on the self-supporting frame

a) b) c)

Fig. 2. Some parts of the test facility: a) action member (AP), b) hydraulic power unit, and control electronics, c) hydraulic load cylinder (ZV)

3. Basic tests of the active tensegrity unit

To this time several simple tests were carried out on the prototype of the active tensegrity structure. It is a test BS 01, which simulates the increase of the prestressing in the cables as a result of a movement of the action member and test BS 02, which simulates the increase of the external load at a constant value of the initial prestressing in the cables.

Test results of BS 01

During the test BS 01 the changes at the level of the prestressing forces in the cables were monitored. External loads respectively force in the hydraulic load cylinder during the test was equal to zero. The test was controlled by a definition of the value of an axial force in the AP. The test duration was 140,15 s. Measured test results are presented in Fig. 3 and 4.

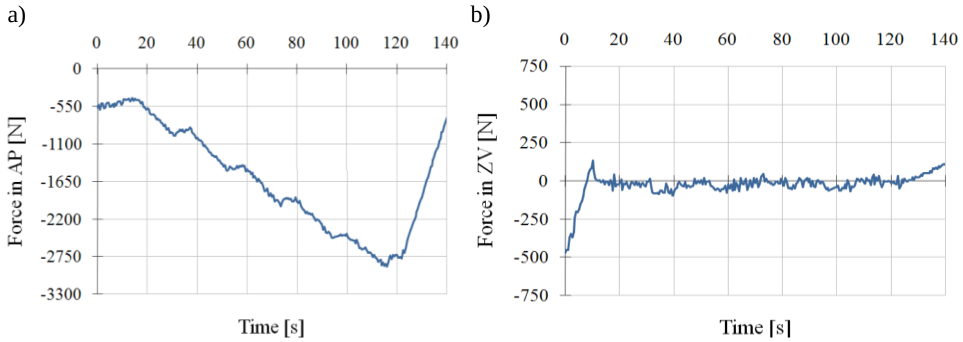

Fig. 3. BS 01 – change of the axial forces in the action member AP (a) and in the loading member ZV (b)

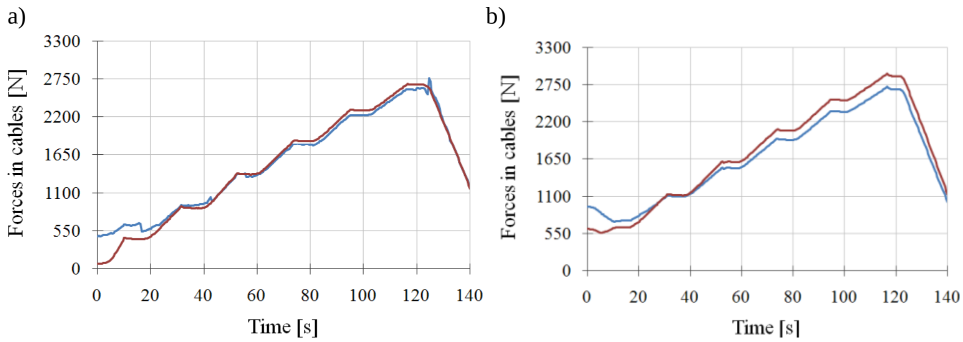

Fig. 4. BS 01 – change of the axial forces in the bottom cables (a) and top cables (b)

Test results of BS 02

Also in the test BS 02 the changes at the level of the prestressing forces in the cables were monitored. The test was controlled by a definition of the initial value of an axial force in the action member (in other words, by a definition of the initial prestressing in the cables) and by the definition of the external load respectively force in the hydraulic load cylinder. The test duration was 140,45 s. Measured test results are presented in Fig. 5 and 6.

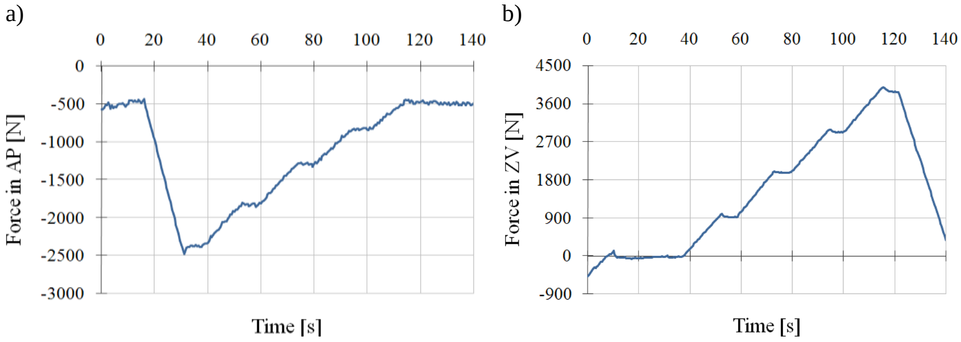

Fig. 5. BS 02 – change of the axial forces in the action member AP (a) and in the loading member ZV (b)

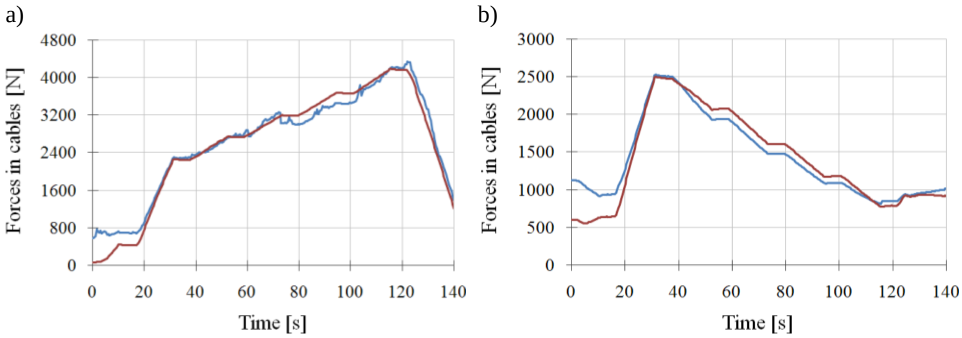

Fig. 6. BS 02 – change of the axial forces in the bottom cables (a) and top cables (b)

4. Numerical analysis

A finite element model of the active tensegrity unit was created in the ANSYS software as is shown in Fig. 7. The following types of finite elements were used [4]:

- LINK10 tension-only spar (e1) for the top and bottom cables,
- LINK10 compression-only spar (e2) for the compressed members,
- LINK11 linear actuator (e3) for the active member (AP).

The geometrically nonlinear calculation takes into account the impact of large displacements. Real constants and material properties are shown in Tab. 1. The finite element model of the active tensegrity unit is supported at the nodes 1, 3, 4 (in the Y axis direction) and node 5 (in the X, Y and Z axes direction).

Comparison of results

In Figure 8 and 9 are compared and verified the experimentally measured results obtained from the test BS 01 with those obtained by the finite element method analysis of the active tensegrity unit model in ANSYS software.

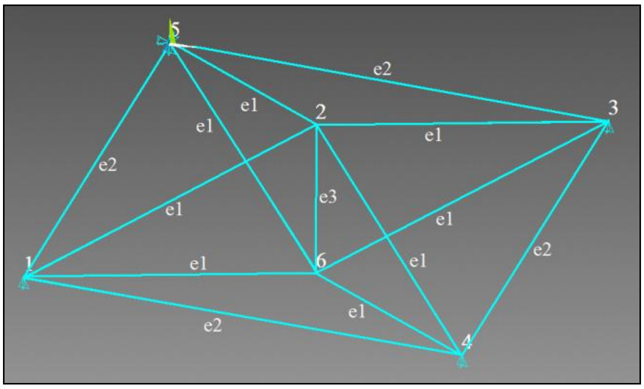

Fig. 7. A finite element model of the active tensegrity unit

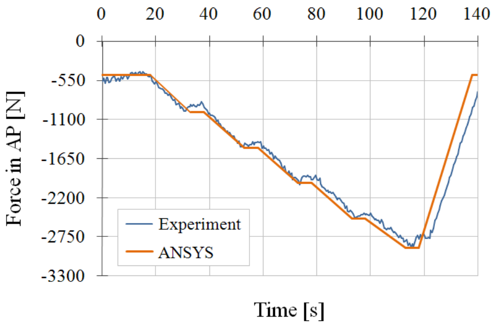

Fig. 8. BS 01 – change of the axial forces in the action member AP

a) b)

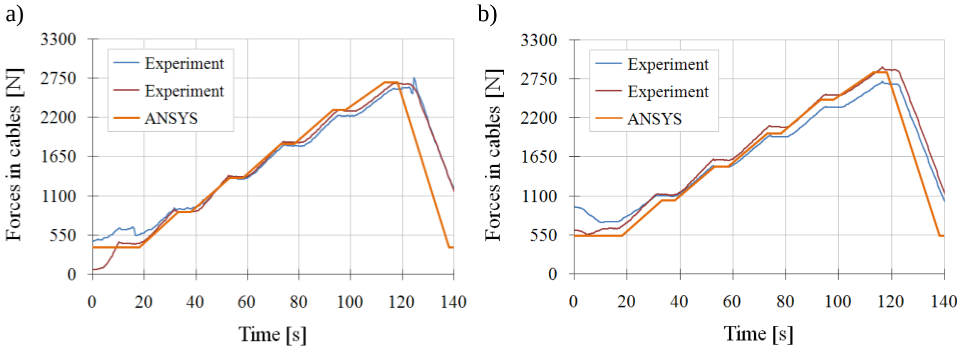

Fig. 9. BS 01 – change of the axial forces in the bottom cables (a) and top cables (b)

In Figure 10 and 11 are compared and verified the experimentally measured results obtained from the test BS 02 with those obtained by the finite element method analysis of the active tensegrity unit model in ANSYS software.

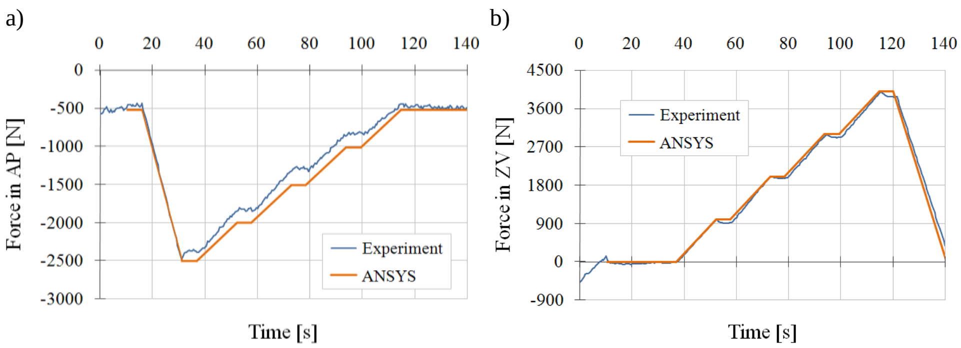

Fig. 10. BS 02 – change of the axial forces in the action member AP (a) and in the loading member ZV (b)

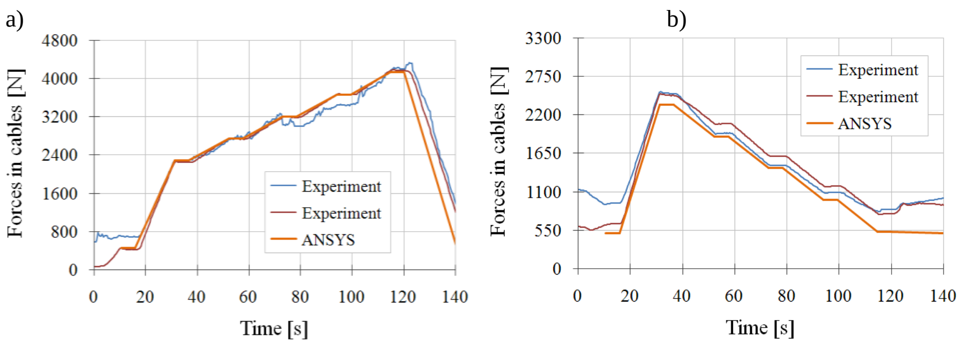

Fig. 11. BS 02 – change of the axial forces in the bottom cables (a) and top cables (b)

5. Conclusions

The experiments BS 01 and BS 02 are only basic tests, which are aimed to prove the functionality of the prototype of the active tensegrity unit as well as the functionality of the whole test set.

In the future experimental program more exacting tests will be developed. Tests will have a longer duration and they will also include various control instructions through which it will be possible to modify the shape of the tensegrity unit and the level of the prestressing forces in the cables. Control instructions enable the fulfillment of all design criteria at any time of an exploitation of the structure tested. Using the cables made of synthetic materials will be also considered and the time dependent behavior will be investigated.

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