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Experimental and Theoretical Analysis of Cable dome

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Micro Abstract
The paper deals with analysis of newly developed adaptive cable dome which has the ability to change stiffness configuration to adapt its behavior to current loading conditions. Adaptive cable dome was developed and created on the Faculty of Civil Engineering Technical University of Kosice. In the article are presented results of experimental and theoretical analyses which are compared. Tests are aimed to verifying ability of cable dome to adapt its state of stress to changing load cases.

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Introduction

Pre-stressed cable structures like tensegrity structures or cable domes are composed of tensioned cables and compressed struts. Their implementation is very promising in projects that require active systems. Namely cable domes which are proposed by D. Geiger [2] to covering large span. Cable domes were intensively studied since first appearing in the nineties and their forms have been extended from the Geiger and Levy forms to other new forms that include the Kiewitt form, the hybrid forms and the birds' nest form [3], [8]. Cable domes are sensitive to asymmetric loads and changes of pre-stress. Cable dome equipped with sensors and active members (actuators) provide shape-control potential to adapt own geometry and pre-stress to changing loads [5] , [6]. In the paper is presented an adaptive cable dome, with the ability to alter its geometrical form and stress properties.

1 Adaptive cable dome model

The elementary shape of the cable dome in the Levy form with a circular base with diameter 3,0 m. Cable dome consist of 42 tension members (cables) and 7 compression mem-bers (struts). A central compressed strut is designed as an actuator used to modify the geometry and pre-stress of the system. The analyzed cable dome consist of ridge cables, diagonal cables, hoop cables, vertical struts and one top middle active member. The basic geometry of the cable dome's model is shown in Figure 1.

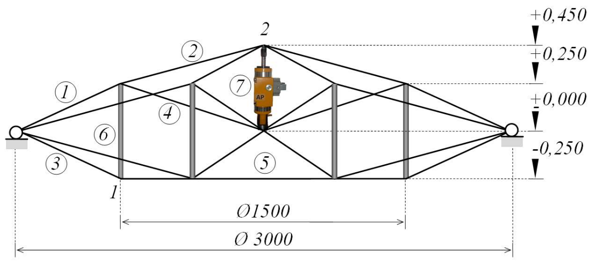

Figure 1. Section view of cable dome in Levy form with geometry with described basic members: (1) and (2) rigid cables, (3) and (4) diagonal cables, (5) hoop cables, (6) vertical struts and (7) active member.

Compressed struts of the cable dome are created from circular hollow sections of 30x5 mm and are made from steel S235 with Young's modulus of elasticity 210 MPa. The length of the struts is 500 mm.For tensile cables were used strand ropes with construction 7 strands with 7 wires per strand with a nominal diameter of 6,0 mm were used. Cables were made from stainless austenitic steel 1.4401. The cross-sectional area of the cables is 15,14 mm^2 and Young's modulus of elasticity is 120 MPa. A central compressed strut is actuator which used to modify the geometry and pre-stress of the system. The theoretical length of actuator is 450 mm with self-weight of actuator 16 kg and increased on the bottom point by 55 kg from connecting cylinder.

2 Form-finding processes

Before analysis of adaptive cable dome is necessary find optimal state between geometry and pre-stress of the cables. For this task was used dynamic relaxation method [7]. The dynamic relaxation method is an attractive approach for static analyses of cable and membrane structures because both form-finding and structural analysis can be carried. In the method is motion of the structure over time used to achieve the equilibrium state.

3 Numerical analysis

To study of behaviour of the adaptive cable dome was used finite element method. Be-cause that to solve cable dome is large geometrically nonlinear problem for solution in finite element method was used Newton-Raphson procedure. The nonlinear analyses were conducted by the ΔFEM software developed by the authors [4] and the ANSYS Classic finite-element software package [1].

3.1 Finite element analysis

For the analyses of the adaptive cable dome were used two-node spatial elements with three degrees of freedom at each node in the software ANSYS marked as LINK 10 and LINK 11. The LINK 10 element was used to model the tension cables and compressed struts and the LINK 11 linear actuator was used to model the action member (Figure 2). LINK 11 is tension-compression element with three degrees of freedom at each node: translations in the nodal x, y, and z, directions. The element is defined by two nodes, a viscous damping C (force * time/length), stiffness K (force/length), and mass m (force * time2/length). The element initial length $L_\frown$ and orientation are determined from the node locations.

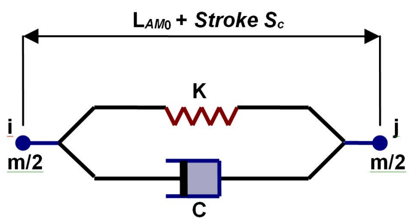

Figure 2. LINK 11 element

3.2 Obtained results

This section gives a comparison of experimental and numerical results obtained from tests of the adaptive cable dome. The comparison of experimentally obtained forces over time with theoretically obtained forces by ANSYS and ΔFEM software are shown in Figure 3.

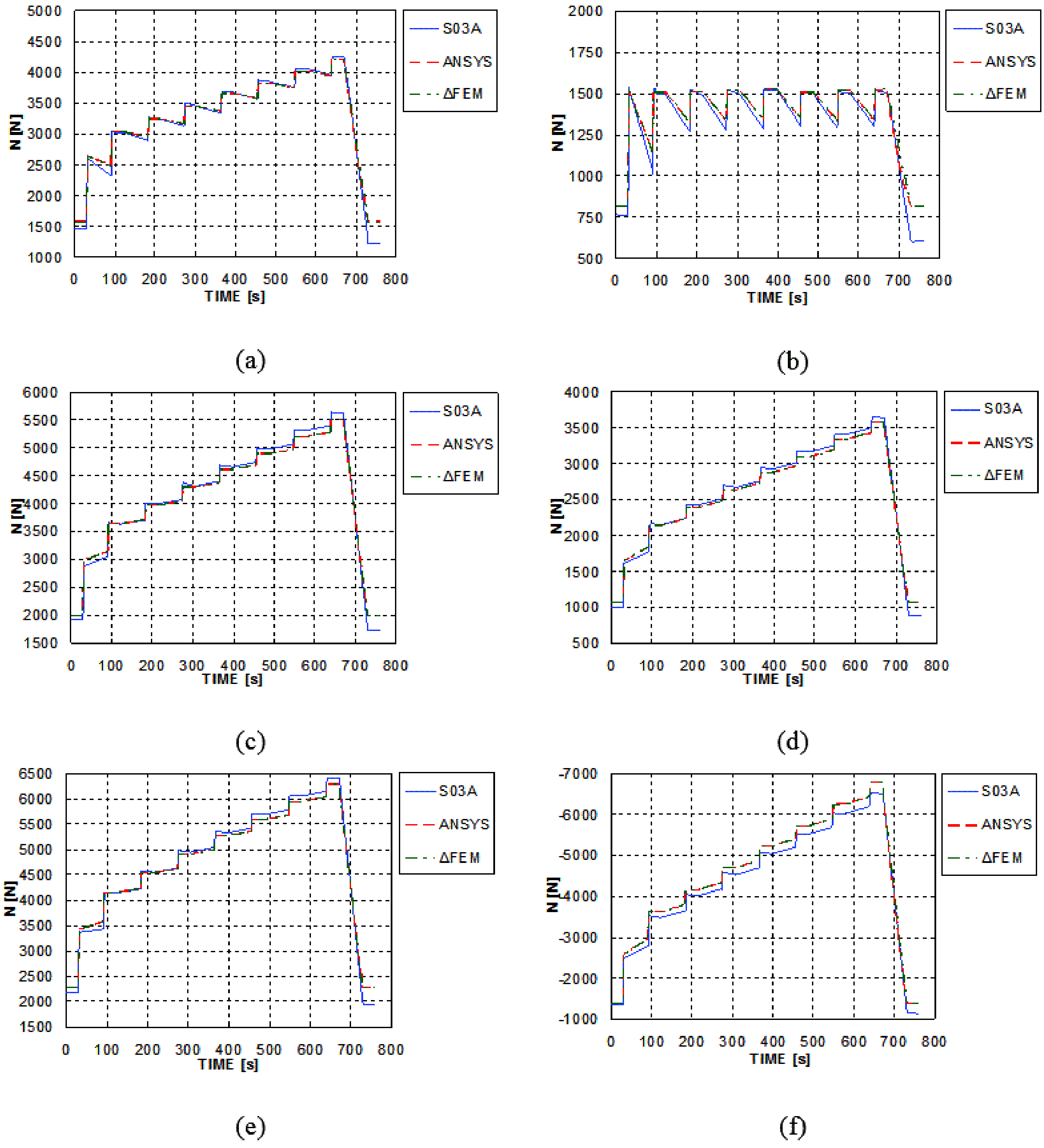

Figure 3. Comparison of theoretically obtained by ΔFEM and ANSYS software with experimentally obtained courses of internal forces in the cables and action member: (a) ridge cables (1), (b) ridge cables (2), (c) diagonal cables (3), (d) diagonal cables (4), (e) cable hoop (5) and (f) action member.

Conclusion

Theoretically results from the nonlinear finite-element analysis in software ANSYS and ΔFEM compared by the test which was measured on the test equipment of the cable dome demonstrated that the behaviour of the adaptive cable dome can, generally be closely predicted theoretically. Results confirmed a physical relevance and mathematical correctness of the applied theoretical approaches and can be used to other analysis of the cable domes with more action members.

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References

[1] I. Ansys. *Release documentation of Ansys 11.0.* Southpointe, 275 Technology Drive, Canonsburg, 2005.

[2] D. Geiger, A. Stefaniuk, and D. Chen. *The design and construction of two cable domes for the Korean Olympics.* Proc., IASS Int. Symp. on Shells, Membranes and Space Frames, Vol. 2, Osaka, Japan, 265-272, 1986.

[3] M. Levy. *Georgia dome and beyond achieving lightweight-longspan structures.* Proc., IASS-ASCE Int. Symp., ASCE, 560-562, 1994.

[4] M. Mojdis. *Analysis of adaptive cable domes.* PhD. thesis, Technical University of Kosice, Kosice, Slovakia, 2011.

[5] K. Shea, E. Fest, and I. Smith. Developing intelligent tensegrity structures with stochastic search. *Advanced Engineering Informatics*, Vol. 16(1):p. 21–40, 1999.

[6] W. Sobek, P. Teuffel, A. Weilandt, and C. Lemaitre. Adaptive and lightweight. In *Proc., The Int. Conf. on Adaptable Building Structures, Eindhoven*, pages 234–245, Eindhoven, 2006.

[7] B. Topping and P. Ivanyi. *Computer aided design of cable membrane structures.* Saxe-Coburg Publications, Kippen, Stirlingshire, Scotland, 2007.

[8] X. Yuan, L. Chen, and S. Dong. Prestress design of cable domes with new forms. *International Journal of Solids and Structures*, Vol. 44(9):p. 2773–2782, 2007.