CZASOPISMO INŻYNIERII LĄDOWEJ, ŚRODOWISKA I ARCHITEKTURY
JOURNAL OF CIVIL ENGINEERING, ENVIRONMENT AND ARCHITECTURE
JCEEA, t. XXXV, z. 65 (1/18), styczeń-marzec 2018, s. 5-12, DOI:10.7862/rb.2018.1

Peter CAUNER[1]
Stanislav KMEŤ[2]

ANALYSIS OF CABLE DOME UNDER VARIOUS INITIAL CONDITIONS

The paper focuses on the numerical analysis of Levy cable dome under two various initial conditions. Experimental device of cable dome is equipped with 7×7 wire ropes with diameter ϕ 6 mm. Nevertheless, it is completely changed for 1×19 wire ropes single strand with diameter ϕ 4 mm. The interchange could lead to creation of more adaptive structure for further static and dynamic analyses. Furthermore, it is essential to stress out that force gauges will improve accordingly.

Keywords: cable dome, active member, stiffness, tensegrity

1. Introduction

Cable domes have been employed as lightweight, large span roofs. Cable domes belong to hybrid tensegrity systems to a class of free-standing pint-jointed structures where stability is provided by the self-stressed state in tensioned and compressed elements [1, 3]. The cable-strut structural system is statically and kinematically indeterminate. The initial pre-stress is a key factor for determining the shape and load carrying capacity. The stiffness of cable domes is determined by their states of prestress [1, 4, 5].

2. Model of cable dome

Laboratory of Excellent Research in Technical University of Košice is equipped with experimental device of Levy cable dome. The Levy cable dome is on Figure 1. Model of the cable dome consists of 7 compression members and 42 tension members. Nevertheless, one of the 7 struts is designed as an hydraulic actuator (active member – AM). Cable dome is created above circular plan with diameter 3,000 mm and it is fixed in 6 nodes. Geometry of the cable dome with individual sets of members is on Figure 2. Regarding the model of Levy cable

[1] Corresponding author: Peter Cauner, Technical University of Košice, Faculty of Civil Engineering, Institute of Structural Engineering, Vysokoškolská 4, Košice, 04200, Slovakia, peter.cauner@tuke.sk
[2] Stanislav Kmeť, stanislav.kmet@tuke.sk

dome, vertical struts are Set 6, active member is Set 7, diagonal cables are Set 3 and Set 4, ridge cables are Set 1 and Set 2 and hoop cables are Set 5. Load cylinder (LC), force gauges (FG) and construction details (CD) are on the Figure 1 [2, 3].

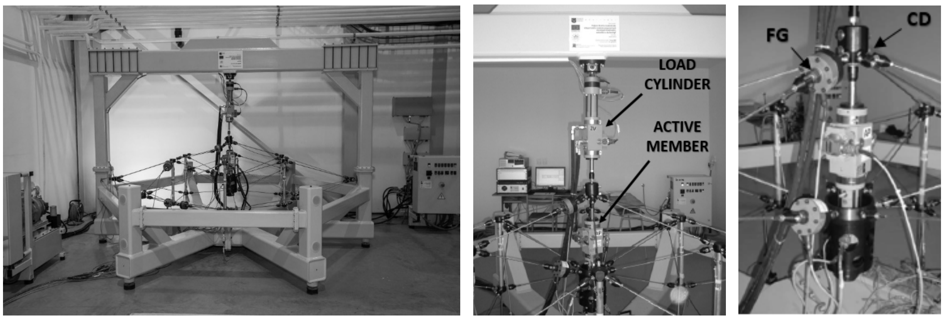

Fig. 1. Experimental device of Levy cable dome

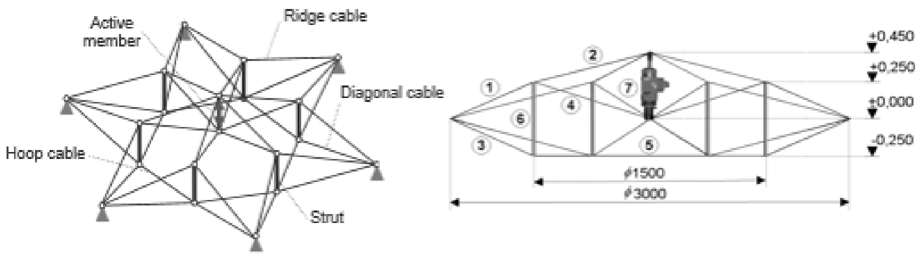

Fig. 2. Geometry of Levy cable dome

3. Analysis

The analysis was carried out with 7x7 wire ropes with diameter ϕ 6 mm and 1×19 wire ropes single strand with diameter ϕ 4 mm. The stiffness of cable domes is conditioned by their states of prestress.

3.1. Dynamic relaxation method

The cable domes belong to a class of truss structures that cannot attain a stable equilibrium configuration without introducing prestress to some members. The stable equilibrium state is achieved by form-finding. Whereas, the efficient method for achieve stable equilibrium state is dynamic relaxation method [2, 6]. At any time t the residual force R_{ix}^{t} in the x coordinate R_{ix}^{t} direction at node i, as the difference between external and internal forces in the corresponding direction, is expressed as:

$$R_{ix}^{t} = M_{ix}\dot{v}_{ix}^{t} + C_{ix}v_{ix}^{t} \tag{1}$$

where: M_{ix} – fictitious mass at node i in the x direction,

C_{ix} – viscous damping factor for node i in the x direction,

v_{ix}^{t} – velocity at time t in the x direction at node i,

$\dot{v}_{ix}^{t}$ – acceleration at time t in the x direction at node i.

Due to damping, nodal velocities and acceleration decay to zero as the solution is approached. The static equilibrium is thus attained and residual forces come to zero [3].

3.2. Initial pre-stress of the Levy cable dome

Equilibrium state is determined by geometry of the structure and value of prestress of its members. However, form-finding was carried out by dynamic relaxation method in order to achieve stable equilibrium state.

Table 1. Element properties

Element	Cross-section	E	Material	Tensile strength	Breaking load
Cable	ϕ 6 mm	120 GPa	7x(1+6)	1 770 MPa	24.72 kN
Cable	ϕ 4 mm	130 GPa	1x19	1 770 MPa	14.88 kN
Strut	ϕ 30/5 mm	210 GPa	S235	-	-

Table 2. Initial pre-stress

ϕ 6 mm		ϕ 4 mm	
Element	**Initial prestress [N]**	**Member**	**Initial prestress [N]**
Set 1	1 572.7	Set 1	1 579.9
Set 2	811.2	Set 2	816.5
Set 3	1 989.8	Set 3	1 993.5
Set 4	1 064.6	Set 4	1 067.8
Set 5	2 269.4	Set 5	2 273.6
Set 6	-989.6	Set 6	-992.3
Set 7	-1 378.8	Set 7	-1 386.0

Nevertheless, initial force 5 kN was applied to diagonal cables Set 3. Initial geometry has been approached after 4 approximations. The maximum nodal displacement (in cables ϕ 6 mm) is $-1.6\cdot10^{-3}$ mm and $-1.2\cdot10^{-3}$ mm (in cables ϕ 4 mm). Element properties and initial pre-stress forces are shown in the Table 1 and Table 2.

3.3. Static analysis with symmetric load

Numerical model contains symmetrical vertical load which is applied on the structure with various initial conditions. First model consists of cables with diameter ϕ 6 mm a next model contains cables with diameter ϕ 4 mm. Load is applied on the top of every vertical strut where cables and struts are connected. This symmetrical load is applied on the both cable domes. In the Figure 3 and Figure 4 are compared internal forces in every Set. Conversely maximum of nodal displacements of both structures are shown in the Figure 5. Nevertheless, maximal nodal displacement is in the bottom point of active member i.e. in the middle of span of Levy cable dome. The difference between internal forces is minimal although value of difference of nodal displacements is nearly 1.2 mm. Stiffness of structure with cables ϕ 4 `mm is lower, moreover, added mass of construction details and force gauges is lower as well. Based on these conditions interchanges of cables could lead to creation of better prototype of Levy cable dome for further dynamic analyses and optimization process.

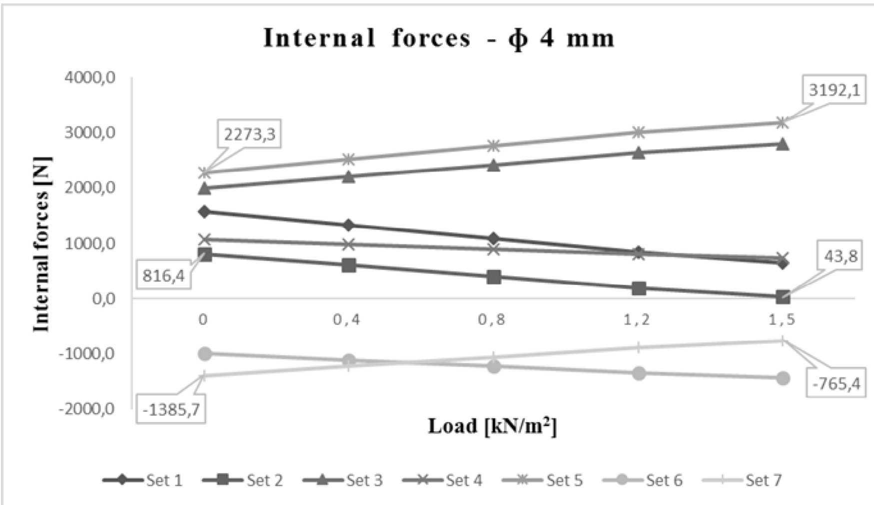

Fig. 3. Internal forces – ϕ 4 mm

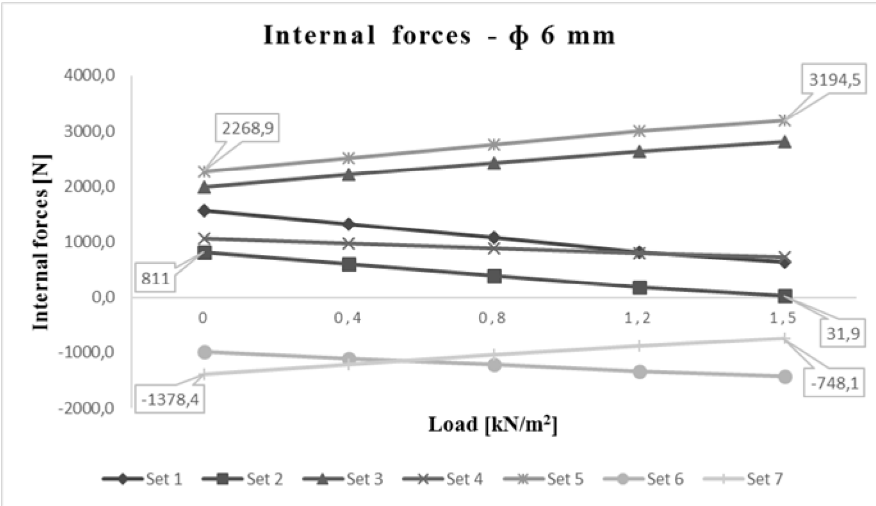

Fig. 4. Internal forces – ϕ 6 mm

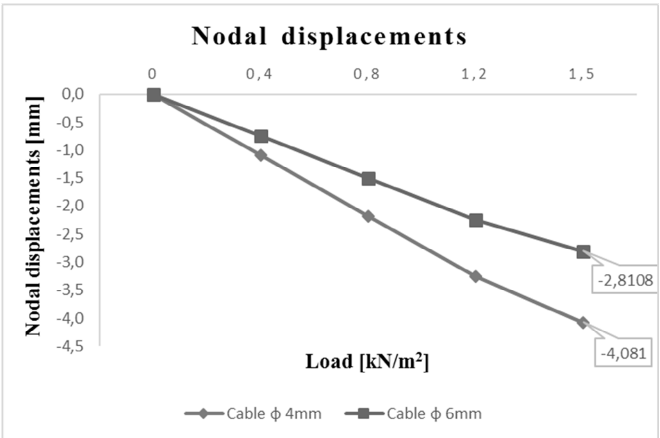

Fig. 5. Nodal displacements

Load capacity of cables is on the Figure 6 and Figure 7. Naturally, cables with diameter ϕ 4 mm are more efficient than cables with diameter ϕ 6 mm. The value of maximum load capacity is 21.5% when 1.5 kN/m^2 of vertical symmetric load is applied.

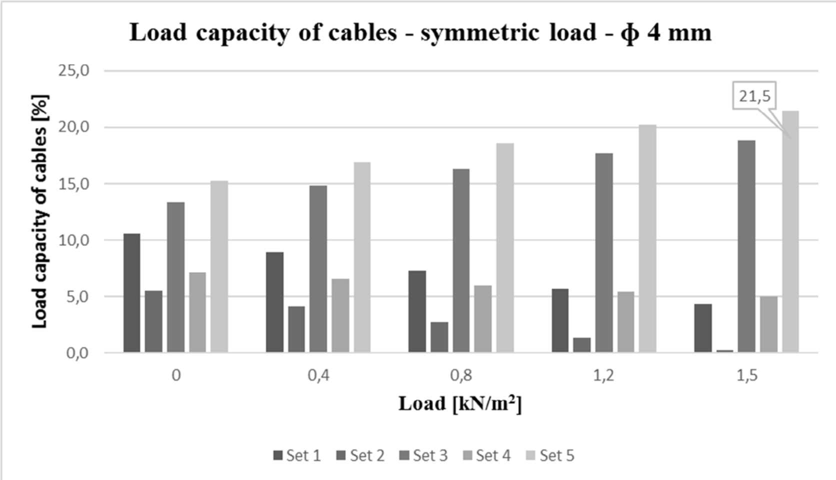

Fig. 6. Load capacity of cables – ϕ 4 mm

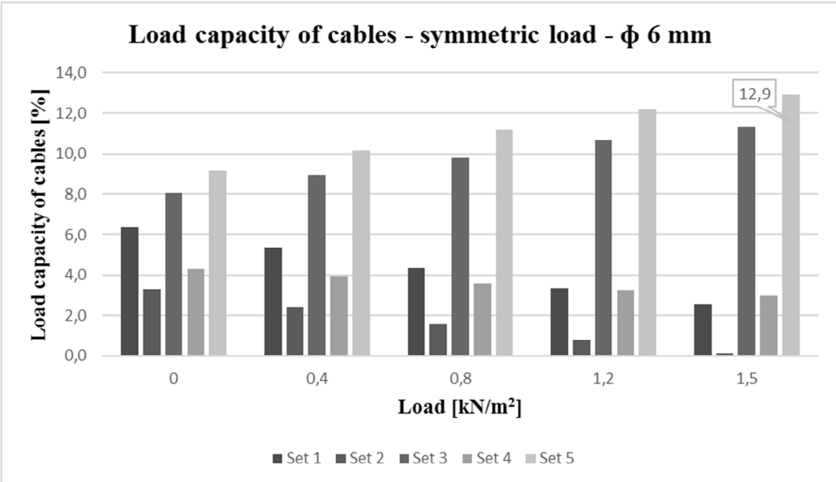

Fig. 7. Load capacity of cables – ϕ 6 mm

3.4. Active cable dome

Next analysis provides some other view on analysis of Levy cable dome focused on load capacity of cables. Adaptive cable dome is equipped with active member. Active member has ability to prolong its length about 100 mm. Levy cable dome was loaded by load cylinder. Load cylinder generate force to active member. Maximal force generated by load cylinder is 7 kN. Set 5 is most important group of cables which includes the maximal tensioned forces in the Levy cable dome. Load capacity of Set 5 cables with diameter ϕ 4mm is on the

Figure 8. Main axis contains force in load cylinder. Force in active member is on the Figure 9. Chain-dotted columns represent situation beyond limits. Force in load cylinder and active member cannot extend 7 kN (black chain-dotted) and axial forces in tensioned members cannot be lower than 0 kN (red chain-dotted - forces lower than 0 kN in group of cables Set 2). The value of load capacity of cables extended 41% in this type of analysis.

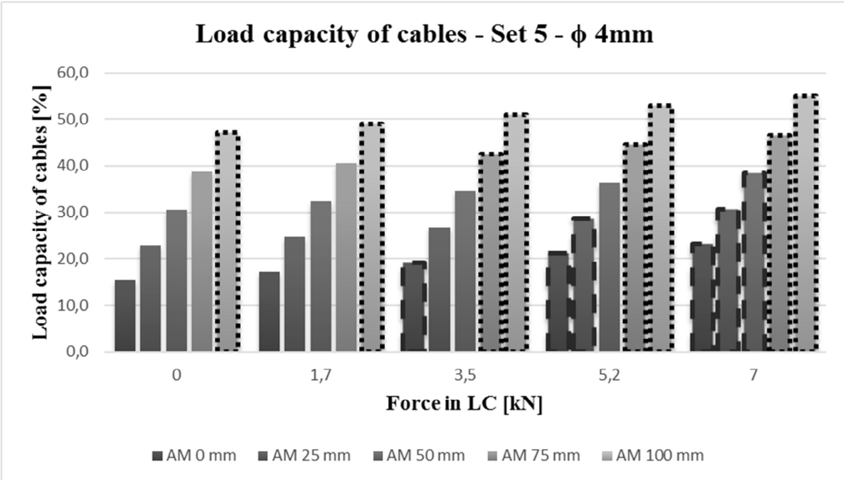

Fig. 8. Load capacity of cables – Set 5

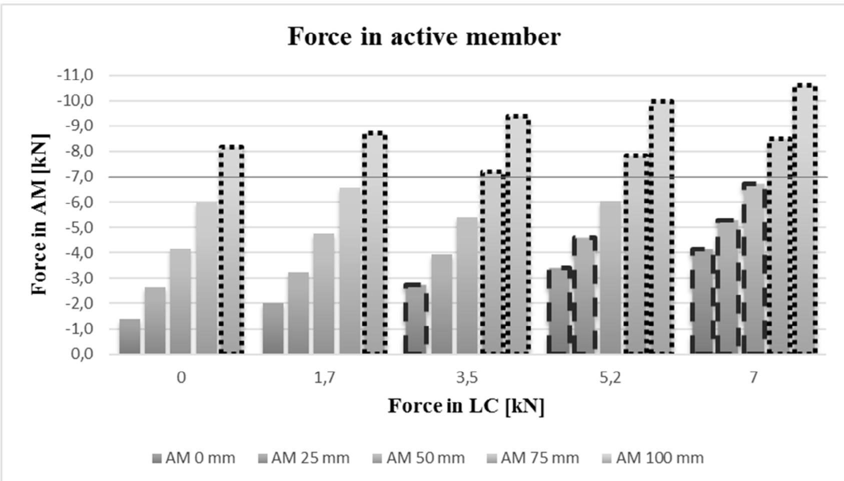

Fig. 9. Force in active member – ϕ 4 mm

4. Conclusion

Above is presented analysis of Levy cable dome under various initial conditions. Results lead to creation of better conditions for further static and dynamic analysis of cable dome. Cables with diameter ϕ 4 mm are more suitable than ϕ 6 mm. Given the above, load capacity of cables extended 41%. Added mass of construction details and associated force gauges is lower. It provides the improvement of dynamic properties of structure. Analyses were carried out by software Ansys – LS DYNA.

Acknowledgements: *The paper is carried out within the project No. 1/0302/16, partially founded by the Science Grant Agency of the Ministry of Education of Slovak Republic and the Slovak Academy of Sciences. Paper is the result of the Project implementation: University Science Park TECHNICOM for Innovation Applications Supported by Knowledge Technology, ITMS: 26220220182, supported by the Research & Development Operational Programme funded by the ERDF.*

References

[1] Yuan, X. F., Chen, L. M., Dong, S. L.: Prestress design of cable domes with new forms. In: International Journal of Solids and Structures. Vol. 44, 2007, no. 9, p. 2773–2782.

[2] Mojdis, M: Analysis of adaptive cable domes. PhD thesis, Technical University of Kosice, 2011, Slovakia (in Slovak).

[3] Kmet, S., Mojdis, M. Time-dependent analysis of cable domes using a modified dynamic relaxation method and creep theory, Computers & Structures, Volume 125, September 2013, Pages 11–22, ISSN 0045-7949.

[4] Kmet, S., Platko, P., Mojdis, M. Analysis of Adaptive Light-Weight Structures, Procedia Engineering, Volume 40, 2012, Pages 199–204, ISSN 1877-7058.

[5] Motro, R. 2003.Tensegrity: Structural system of future. Published in Great Britain and the United States by Kogan Page Science, an imprint of Kogan Page Limited. ISBN 1-903996-37-6.

[6] Ohsaki, M, Kanno, Y.: Form-finding of cable domes with specified stresses by using nonlinear programming, Kyoto University, Sakyo, Kyoto 606-8501, Japan. http://www.se-lab.archi.kyoto-u.ac.jp/ohsaki/pdf/c0302.pdf.

Przesłano do redakcji: 24.09.2017 r.
Przyjęto do druku: 31.03.2018 r.