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CABLE TRUSS ANALYSES FOR PRESTRESSED SUSPENSION BRIDGE

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Abstract: *At the present moment a suspension bridge is the most suitable type for very long-span bridges. Increased deformability is one of the basic disadvantages of suspension bridges. Usage of prestressed suspension bridge with cable truss is a method of fixing the problem of increased deformability. A prestressed suspension bridge with cable truss with the cross web and span of 200 m was considered as an object of investigations. It was shown, that usage of cable truss for prestressed suspension bridge allows reducing the vertical displacements up to 16% in comparison with the single cable. Applying of structure with four stabilization cables instead of structure with two stabilization cables allow to reduce difference of displacements in transverse direction by 24%.*
Key words: long span bridge, physical model, kinematic displacements.

1. INTRODUCTION

At the present moment a suspension bridge is the most suitable type for very long-span bridges [1]. So long spans can be achieved because main load carrying cables are subjected to tension and distribution of normal stresses are close to uniform [2].
Increased deformability is one of the basic disadvantages of suspension bridges [3]. Increased deformability is conditioned by appearance of elastic and non-straining (kinematic) displacements. The elastic displacements are caused by large tensile inner forces. Kinematic displacements are caused by initial parabolic shape change, resulting from non-symmetrical or local loads [4]. Serviceability limit state is dominating for suspension cable structures.
The problem of increased kinematic displacements can be solved by increasing the relation of dead weight to imposed load, which is achieved by adding of cantledge [5]. But this method causes the increase of material consumption.
Usage of prestressed cable truss is another method of fixing the problem of shape change under the action of unsymmetrical load [6 – 9]. Usage of prestressed cable truss allows the development of bridges without stiffness girder, but overall bridge rigidity will be ensured by prestressing of stabilization cable [10]. The deck can be made of light composite materials.
Smaller displacements can be achieved if we replace a single cable with a cable truss with a cross web, in case of non-symmetrical load (Fig.1) [11].

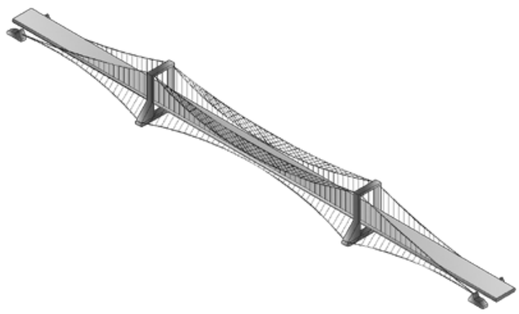

Fig. 1. Prestressed suspension bridge with cable truss load carrying structure

The other problem of suspension bridges is non-uniform displacements, in the case when the load is applied to the half of suspension bridge in transversal direction. The problem can be fixed by the rational placement of stabilization cables [12].
A prestressed suspension bridge with span

of 200 m was considered as an object of investigations.

The aim of this study is to develop rational structure of cable truss for prestressed suspension bridge when load is applied to half of span and to compare it with the single cable. Achieved results should be checked on the physical models. Rational placement of stabilization cables also should be obtained.

2. APPROACH TO THE SOLUTION OF THE PROBLEM

2.1. Design model

The prestressed suspension bridge with span of 200 m was chosen as an object of investigations. Bridge pylon height is equal to 21 m. Bridge has two lines in each direction and two pedestrian lines. Bridge main load caring structure is made from cable trusses. Deck is connected to cables by suspensions and is made from pultrusion composite trussed beam with step 5 m, pultrusion composite beams with height 300 cm and step 1 m and composite pultrusion plank with height 40 mm [13-15]. The bridge is characterized with reduced dead weight of the deck in comparison with existing structures [16]. It was assumed that deck do not have stiffness in longitudinal direction. The bridge is loaded by the load model LM:1 (according to Eurocode 1) [17].

Design scheme of investigation object is shown on the Fig. 2.

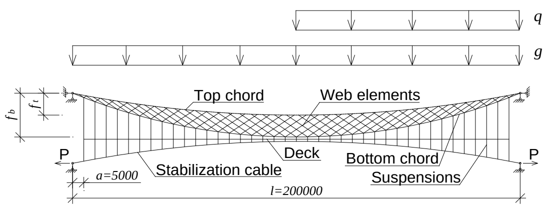

Fig.2. Design scheme of cable truss. q – imposed load; g – dead load; f_b – bottom chord camber, f_t – top chord camber.

The structural material is pretensioned steel rope [18, 19] with modulus of elasticity 167000 MPa and rope grade 1960 MPa. The dead load, applied to the structure is 51.1kN/m, imposed load is 82.2 kN/m. The load is applied to the deck.

2.2. Design method

The vertical displacement under the action of load applied to half of span was considered as criteria of rationality of cable truss structure. Rational structure of cable truss is defined by rational relation of top and bottom chord cambers, rational slope of web elements, rational number of web elements inclined to the center of cable truss, rational distribution of material consumption among bottom cord, top chord and web elements.

The slope of each web element is expressed by the distance from the pylon to the connection of web element with the top chord. The distance from the pylon to the connection of web element with the top chord for any web element can be expressed by dependency depending on the distance from the pylon to the connection of the same element with bottom chord (Fig. 3).

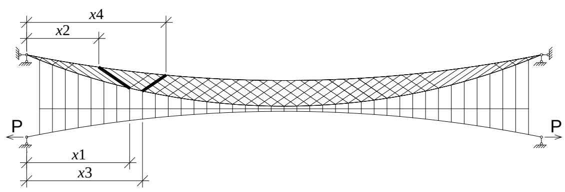

Fig. 3. Position of web elements. x_2 and x_4 – distance from the pylon to the connection of web element and top cord; x_1 and x_3 – distance from the pylon to the connection of web element and bottom cord

Rational characteristics of cable truss was found by enumeration of possible variants [20] using cycles in the FEM software ANSYS 12 environment. Enumeration was realized in three steps, at each step finding optimal field, then increasing precision by 10 times and finding new optimal field. Cable truss is modelled by two node link type compression less finite elements (LINK10 in ANSYS). The analysis type is geometrically nonlinear static including large deflection effects, because suspension cable structures are characterized with large deflections before stabilization.

3. RATIONAL STRUCTURE OF CABLE TRUSS

Rational characteristics of cable truss for prestressed suspension bridge, when load is applied to half of span, were found. Rational relation of top chord camber and bottom chord camber: f_t/f_b=0.71. Rational relation of bottom chord material consumption and material consumption of whole truss: g_b/g=0.6. Rational relation of web elements material consumption and material consumption of whole truss: g_w/g=0.05. Rational number of web elements inclined to the center of cable truss is achieved removing element from 5 to 11 from both sides.

Rational slope of web elements inclined to the edges of cable truss is expressed by rational value of distance x_2 of each web element depending on the distance x_1 and is expressed in the form of polynomial equation (1).

$$x_2 = -6.783 \cdot 10^{-4} \cdot x_1^2 + 0.8182 \cdot x_1 - 2.108, \qquad (1)$$

Position of web elements inclined to the center of cable truss was founded by mirroring elements inclined to the edges of cable truss.

4. COMPARISON OF CABLE TRUSS WITH SINGLE CABLE FOR PRESTRESSED SUSPENSION BRIDGE

The vertical displacements when the load is applied to half of span for suspension bridge with cable truss are by 49% smaller then displacements when load is applied for full span, so the case of half span loading is more important for suspension bridges. The vertical displacements of suspension bridge with cable truss and single cable were compared. Shape of displacements in non-symmetrical loading case is shown on the Fig. 4. Total displacements are calculated as sum of upwards and downwards displacements. The displacements of prestressed suspension bridge in case if load is applied to half of span are shown in Table 1. The difference between displacements upwards of prestressed suspension bridge with single cable and cable truss is 34%, the difference between displacements downwards is 8% and difference between total displacements is 16%.

Fig. 4. Shape of displacements when load is applied to half of span

Structure type	Displacement direction		Total, m
	Downwards, m	Upwards, m	
Single cable	0.6684	0.3039	0.9723
Cable truss	0.6157	0.1995	0.8152

Table 1. Displacements of prestressed suspension bridge with single cable and cable truss when load is applied to half of span

5. EVALUATION OF RATIONAL POSITION OF STABILIZATION CABLES.

The difference of displacements of left and right side of the bridge, when only half of bridge is loaded in transversal direction, is equal to 0.3565 m, or 1/51 of bridge span in transversal direction, or slope 1.12° for considered bridge.

Different variants of stabilization cable placement and connection with the deck were analyzed, such as structure with one chord and diagonal suspensions, two chords and vertical and diagonal crossing suspensions, with inclined and crossing suspensions, with three chords and vertical suspensions, with three chords and inclined and crossing suspensions and with four

chords and inclined and crossing suspensions. The material consumption of suspensions was constant in all variants. The analyses were done analytically using FEM program LIRA 9.6. Only transversal scheme was analyzed to simplify calculations. Elements of structure were modeled with geometrically nonlinear arbitrary 3D bar (cable) finite element (FE310 in LIRA). It was assumed, that the material of the deck is steel with dimensions 20 x 10 cm and modulus of elasticity 206000 MPa. The suspensions are made from steel cables with diameter 3 cm and modulus of elasticity 167000 MPa. The load is applied only to one side of the deck and is equal to 283 kN. The construction is initially prestressed. The design scheme is shown on Fig. 5 (a).
Rational from the point of view of displacements are structure with four bottom chords and inclined and crossing suspensions (Fig. 5 (b)).

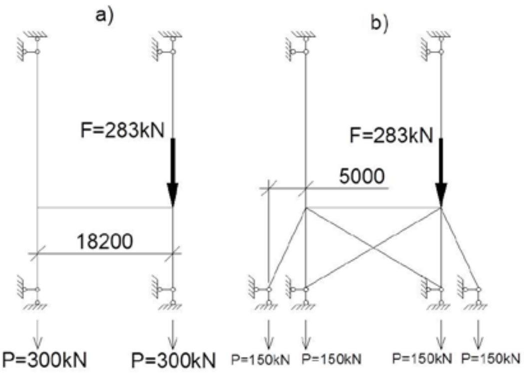

Fig. 5. Design scheme of the bridge in transversal direction. (a)- structure with two bottom chords and vertical suspensions; (b) – structure with four bottom chords and inclined and crossing suspensions

Applying of structure with four bottom chords and inclined and crossing suspensions instead of structure with two bottom chords and vertical suspensions for transversal construction of suspension bridge allow to reduce difference of displacements in transverse direction by 24 % or by 0.085 m.

6. PHYSICAL MODEL TESTING

Two small scale physical models of prestressed suspension bridge were constructed to confirm advantages of the cable truss in comparison with the single cable from the point of view of vertical displacements minimization.
The span of the models is equal to 2.1 m. Top chord camber is equal to 22 centimeters. The deck is connected to main load caring structure by suspensions in 15 points (Fig. 6).

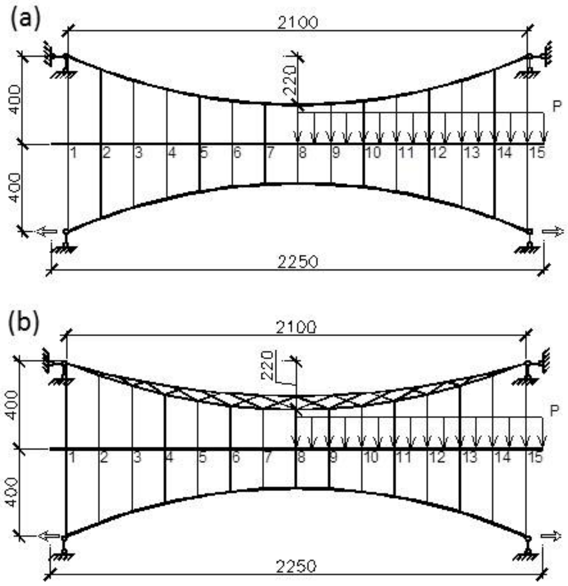

Fig. 6. Schemes of the physical models of prestressed suspension bridges. (a) – scheme of the model with single cable; (b) – scheme of the model with cable truss

The elements of the physical models are made from steel cables. Two types of cables are used: 6x7+WSC (wire steel core) and 6x19+WSC. Tensile strength of wires for both cables is 1770 MPa The modulus of elasticity was experimentally obtained and is 60000 MPa. The diameter of single cable and stabilization cable is 10 mm and 8 mm, respectively. The diameter of bottom chord, top chord and wed elements of cable truss is 8 mm, 5.5 mm and 2 mm, respectively. The diameters of elements are specially selected to produce the same material consumption single cable and cable truss physical models.

The prestression was organized in stabilization cable and is equal to 348 MPa. The load was applied to half of models span. The models were loaded up to load 1495 kg with step 155 kg.
The displacements of physical models when load is applied to half of span are shown in Table 2.

Structure type	Displacement direction		Total, mm
	Downwards, mm	Upwards, mm	
Single cable	23.81	13.83	37.64
Cable truss	21.04	11.61	32.65

Table 2. Displacements of physical models of prestressed suspension bridge with single cable and cable truss when load is applied to half of span

The experimental results shown, that replacing single cable with cable truss with cross web allows to decrease vertical displacements of prestressed suspension bridge model upwards by 16% and downwards by 12%. Total displacements can be reduced by 13%.

7. CONCLUSIONS

Rational structure of the cable truss for prestressed suspension bridge with span 200 m was developed. The vertical displacement was considered as criteria of rationality of cable truss structure. Rational relation of top chord camber and bottom chord camber is equal to 0.71, rational relation of bottom chord material consumption and material consumption of whole truss is equal to 0.6 and rational relation of web elements material consumption and material consumption of whole truss is equal to 0.05. It was stated, that usage of cable truss with the cross web for prestressed cable truss instead of single cable allows to reduce vertical displacements upwards by 34%, downwards by 8% and total displacements by 16% in the case when load is applied to half of span.
The results were verified on the small scale physical models of prestressed suspension bridges with single cable and cable truss. Model testing results indicate, that usage of cable truss with the cross web for prestressed suspension bridge instead of single cable allows to reduce vertical displacements upwards by 16%, downwards by 12% and total displacements by 13% in case when load is applied to half of span.
Applying of structure with four bottom chords and inclined and crossing suspensions instead of structure with two bottom chords and vertical suspensions for transversal construction of suspension bridge allow to reduce difference of displacements in transverse direction by 24% in case when only half of bridge is loaded.

8. ACKNOWLEDGMENTS

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9. REFERENCES

1. Chen, W.F., Duan, L. *Bridge Engineering Handbook*. CRC Press LLC, New York, 2000.
2. Juozapaitis, A., Idnurm, S., Kaklauskas, G., Idnurm, J., Gribniak V. Non-linear analysis of suspension bridges with flexible and rigid cables. *Journal of Civil Engineering and Management*, 2010, **16(1)**, 149-154.
3. Walther, R., Houriet, B., Isler, W., Moia, P., Klein, J.F. *Cable Stayed Bridges*. Second edition. Thomas Telford, London, 1999.
4. Juozapaitis, A., Norkus, A. Displacement analysis of asymmetrically loaded cable. *Journal of Civil Engineering and Management*, 2004, **10(4)**, 277-284.

5. Strasky, J. *Stress Ribbon and Cable Supported Pedestrian Bridge*. Thomas Telford Publishing, London, 2005.
6. Serdjuks, D., Rocens, K. Decrease the Displacements of a Composite Saddle-Shaped Cable Roof. *Mechanics of Composite Materials*, 2004, **40(5)**, 675-684.
7. Mihajlov, V. *Prestressed Combined and Cable Structures*. ACB, Moscow, 2002 (in Russian).
8. Tibert, G. 1999. *Numerical Analyses of Cable Roof Structures*. KTH TS-Hogskoletryckeriet, Stockholm, 1999.
9. Kachurin, V., Bragin, A., Erunov, B. *Design of suspension and cable stayed bridges.* Transport, Moscow, 1971 (in Russian).
10. Kirsanov, M. Suspension Structures with Increased Stiffness. Strojizdat, Moscow, 1973.
11. Goremikins, V., Rocens, K., Serdjuks, D. Rational Structure of Cable Truss. *World Academy of Science, Engineering and Technology. Special Journal Issues*, 2011, **0076**, 571-578.
12. Goremikins, V., Rocens, K., Serdjuks, D. Cable truss analysis for suspension bridge. *Proc. of Engineering for Rural Development*, 2012 (accepted paper).
13. Goremikins, V., Serdjuks, D. Rational Structure of Trussed Beam. *Proc. of the 10th International Conference "Modern Building Materials, Structures and Techniques" Vilnius, Lithuania,* 2010, 613–618.
14. Goremikins, V., Rocens, K., Serdjuks, D. Rational Large Span Structure of Composite Pultrusion Trussed Beam. *Scientific Journal of RTU. 2. series., Construction Science*, 2010, **11**, 26-31.
15. Goremikins, V., Rocens, K., Serdjuks, D. Rational Structure of Composite Trussed Beam. *Proc. of the 16th International Conference "Mechanics of Composite Materials" Riga, Latvia*, 2010, 75.
16. Bahtin, S., Ovchinnikov, I., *Inamov, R. Suspension and Cable Stayed Bridges*. Saratov State Technical University, Saratov, 1999.
17. *Eurocode 1: Actions on structures. Part 2: Traffic loads on bridges*. Brussels, 2004.
18. *Eurocode 3: Design of steel structures. Part 1-11: Design of structures with tensile components*. Brussels, 2007.
19. Feyrer, K. *Wire Ropes*. Springer-Verlag Berlin Heidelberg, Berlin, 2007.
20. Sliseris, J., Rocens, K. Rational structure of panel with curved plywood ribs. *Proc. of "International Conference on Building Science and Engineering", Venice, Italy*, 2011, **0076**, 317-323.

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