CABLE TRUSS ANALYSES FOR SUSPENSION BRIDGE

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Abstract. One of the main problems of suspended cable structures is initial shape change under the action of non-uniform load. The problem can be solved by increasing of the weight of the construction or by using of prestressing. But these methods cause increasing of material consumption of suspended cable structures. The cable truss usage is another way how the problem of the shape change under the action of non uniform load can be fixed. The cable trusses with the vertical and inclined suspensions, cross web and single cable were analyzed as the main load-bearing structures of suspension bridges. The suspension bridge was checked under the action of the different variants of non uniform loading in longitudinal and transversal directions. It was shown, that usage of cable truss as the main load-bearing structures of suspension bridges allows reducing the vertical displacements up to 32 % in comparison with the single cable in case when the traffic load is applied to the half of the suspension bridge span and the relation of the traffic load and permanent load is equal to 1.4. In the case of uniformly distributed load a single cable is preferable. The rational position of load bearing elements in transversal direction also was found.

Keywords: cable trusses, non uniform load, suspension bridge, vertical displacements.

Introduction

A suspension bridge is the most suitable type of structures for very long-span structures, because the main load carrying cables are subjected to tension. But one of the main problems of suspension bridges is the initial shape change under the action of non-uniform load, which is common for bridges [1]. The problem can be solved by increasing of structural dead weight or by prestressing. But these methods cause increasing of material consumption and make difficult the usage of modern materials with increased specific strength.

The cable truss usage is another way how the problem of the shape change under the action of non uniform load can be fixed [2].

It was shown [3; 4], that cable truss with cambered top and bottom chords and inclined web elements, where all truss elements are tensioned (Fig. 1), allows to decrease vertical displacements by 32 % in comparison with the single cable, in the case when non uniformly distributed load is applied. A possibility to decrease the vertical displacements of suspension bridges by the using of the cable truss as the top chord structure must be considered. A rational structure of the cable truss web also should be developed.

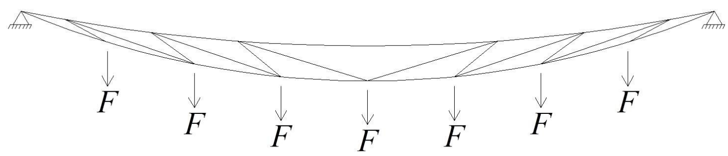

Fig 1. **Cable truss with cambered top and bottom chords and inclined web elements**

The other problem of the suspension bridge is non-uniform displacements, in the case when the load is applied to the half of the suspension bridge in transversal direction. The problem can be fixed by organizing of initial slope for precipitation drainage or by organizing the mechanism for changing the suspension lengths. Another way how to decrease non uniform displacements is to develop a structure, which align non uniform load.

The aim of the present study is to choose the best, from the point of view of vertical displacements minimization, type of the main load-bearing structure of a prestressed suspension bridge in longitudinal and transversal directions.

Materials and methods

1. General structure of the bridge

It was assumed, that the bridge span is equal to 200 m. The bridge pylon height is equal to 21 m (Fig. 2). The bridge has two lines in each direction and two pedestrian lines. The single cable or cable truss are the main load-carrying structures of the bridge. The deck is connected to the cables by suspensions and is made of pultrusion composite trussed beam with the step 5 m, pultrusion composite beams with height 300 cm and the step 1 m and composite pultrusion plank with the height 40 mm (Fig. 3) [5; 6; 7]. The bridge is characterized by reduced dead weight of the deck in comparison with the existing structures [8]. It was assumed that the deck dors not have stiffness in the longitudinal direction. The bridge is loaded by the load model LM:1 and load model LM:3 according to the Eurocode 1 [9]. The load can be applied to full span or to half of the span in longitudinal and transversal directions.

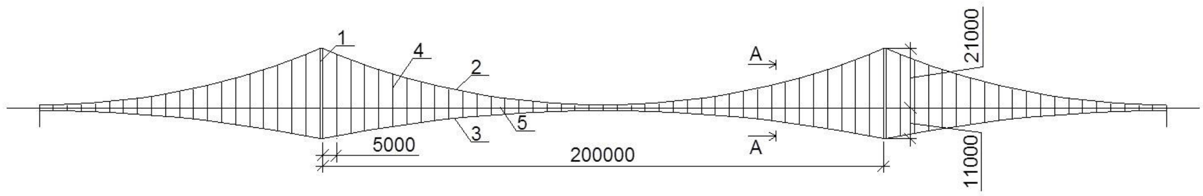

Fig. 2. **The bridge longitudinal view:** 1 – pylon of the bridge; 2 – main load caring cable; 3 – stabilization cable; 4 – suspensions; 5 – deck

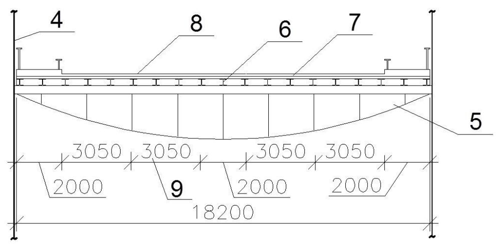

Fig. 3. **The bridge cross-section cut A-A:** 4 – suspensions; 5 – composite trussed beam; 6 – composite I type beams; 7 – composite plank; 8 – cover of the bridge; 9 – lines of the bridge

2. Design scheme of the suspension bridge in longitudinal direction

Cable truss with inclined suspensions or a single cable was chosen as the main load bearing element for the suspension bridge. The structural material of the cable elements is a prestressed steel rope with the modulus of elasticity 167 GPa. The diameters of the bottom chord, top chord, web elements, stabilization cable and suspensions are 18.9 cm, 16.6 cm, 2.5 cm, 23.7 cm, and 3.0 cm, respectively. The diameter of the single cable is 24.3 cm. It was assumed, that the pylons are completely rigid and the cables are connected by hinge joints. The variable characteristics of cable truss are the top chord camber, distribution of material consumption for the truss elements and the placement of the web elements. The placement of the web elements is evaluated in the form of the second order polynomial equation (1). The design scheme of the suspension bridge with cable truss in the longitudinal direction is shown in Fig. 4.

$$x_1 = a \cdot x^2 + b \cdot x + c \tag{1}$$

where x – distance from the pylon to the bottom chord node;
x_1 – distance from the pylon to the top chord node;
a, b, c – constants of the polynomial.

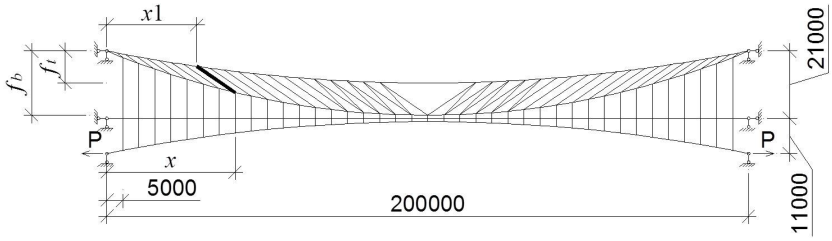

Fig. 4. **Design scheme of suspension bridge in longitudinal direction**

Prestressing of cable truss can be organized by prestressing of the stabilization cable or suspensions. When prestressing is organized in suspensions, each suspension can have its own level of prestression depending on it placement and is evaluated in the form of the second order polynomial equation (2):

$$P_i = d \cdot x^2 + e \cdot x + f \qquad (2)$$

where x – distance from the pylon to the bottom chord joint;
P_i – level of prestression in i-th suspension;
d, e, f – coalitions of the equation.

3. Design scheme of the bridge in transversal direction

Only the transversal scheme was analyzed to simplify the analysis (Fig. 5). It was assumed, that the material of the deck is steel with the modulus of elasticity E = 206 GPa. The dimensions of the cross-section of the deck are 20 × 10 cm. The suspensions are made of steel cables with the diameter d = 3 cm and modulus of elasticity E = 167 GPa. The load is applied only to one side of the deck and is equal to F = 283 kN. The construction is initially prestressed with load P.

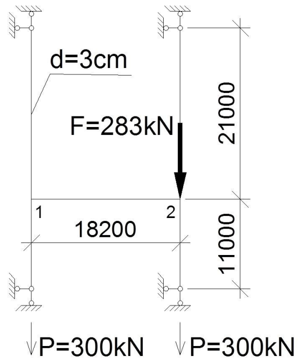

Fig. 5. **Design scheme of the bridge in transversal direction**

Results and discussions

1. Evaluation of rational parameters of the considered cable truss

The rational value of the top chord camber, rational distribution of material consumption among the cable truss elements and rational placement of the web elements where found [10]. The analyses were done by FEM software ANSYS. The rational relation of the top chord camber and bottom chord camber is equal to f_t/f_b = 0.71. The rational relation of the bottom chord material consumption and material consumption of the whole truss is equal to g_b/g = 0.6. The rational placement of the web elements is evaluated in the form of the second order polynomial equation (3):

$$x_1 = -6.783 \cdot 10^{-4} \cdot x^2 + 1.1817 \cdot x + 2.108 \, . \qquad (3)$$

2. Comparison of different types of cable trusses

Cable trusses with inclined elements of the web and cable truss with a cross web where analyzed and compared with a single cable (Fig. 6) in the case when the stabilization cable was prestressed. The aim was to decrease vertical displacements in the upper direction, because vertical displacements will summarize with construction raise. The material consumption is constant for all variants of the cable structures. The results are shown in the Table 1. From the table we can see that the displacements are large, when non-uniformly distributed load is applied. It was shown, that usage of cable trusses allow to decrease the displacements by 17 % and 32 % for the cable truss with inclined elements of the web and cable truss with the cross web, accordingly.

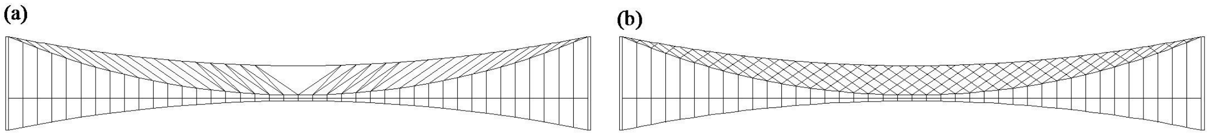

Fig. 6. **Types of constructions:** a – cable truss with inclined elements of the web; b – cable truss with the cross web

Table 1

Vertical Displacements of Cable Trusses

Construction type	Uniformly distributed load	Non-uniformly distributed load	
	Displacements downwards, m	Displacements downwards, m	Displacements upwards, m
Single cable	-0.4965	-0.6684	0.3039
Cable truss with inclined elements of the web	-0.6912	-0.6798	0.2522
Cable truss with the cross web	-0.5560	-0.6141	0.2076

Cable truss with the cross web (Fig.6, (b)) was compared with a single cable when the prestressing was organized in suspensions. The results are shown in Table 2. It is stated, that displacements can be reduced by 16 % in the case of cable truss usage instead of a single cable.

Table 2

Vertical Displacements of Cable Trusses

Construction type	Non uniformly distributed load	
	Displacements downwards, m	Displacements upwards, m
Single cable	-0.8866	0.5530
Cable truss with the cross web	-0.8183	0.4619

The cross web of the cable truss can be simplified by removing some elements of the web. It was stated that removing of some elements of the web allows not only to keep displacements downwards at the same level, but also to decrease displacements upwards by 4 %. A rational structure of cable truss for the suspension bridge is shown in Figure 7.

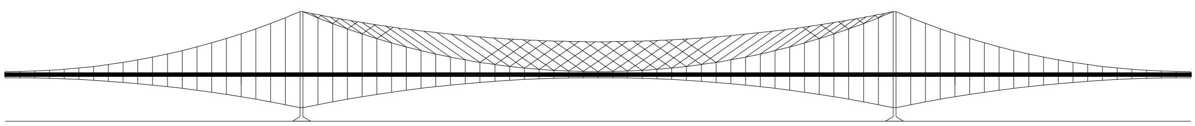

Fig. 7. **Rational structure of cable truss for suspension bridge**

3. Displacements of the suspension bridge under the action of non uniform load in transversal direction

The difference of displacements of the left and right side of the bridge is equal to 0.3565 m, or 1/51 of the bridge span in the transversal direction, or the slope 1.12° for the considered bridge. Such big difference of displacements is not acceptable. In this connection, the aim of this part of the article is to reduce the difference of the displacements of the left and right side of the bridge.

Different types of construction were analyzed, such as structures 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. All analyzed variants are shown in Figure 8. The material consumption of the suspensions was constant in all variants.

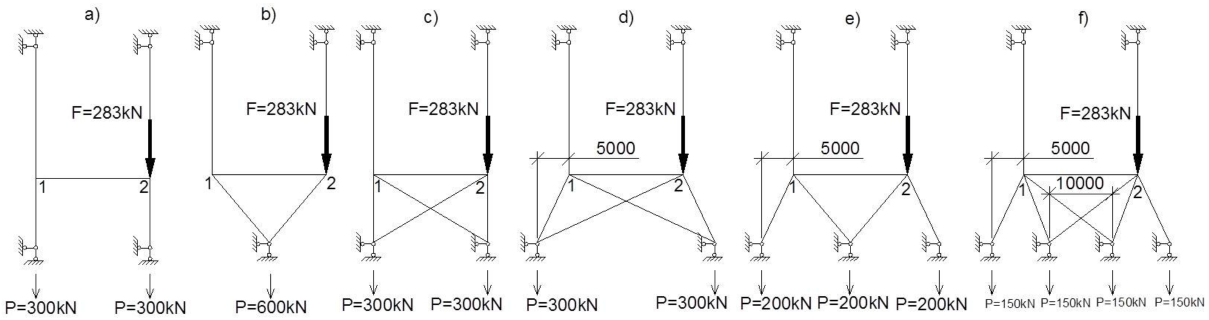

Fig. 8. **Types of transversal construction of the suspension bridge:** a – structure with two bottom chords and vertical suspensions; b –with one bottom chord and diagonal suspensions; c – two bottom chords and vertical and diagonal crossing suspensions; d – with inclined and crossing suspensions; e – with three bottom chords and inclined suspensions; f – with four bottom chords and inclined and crossing suspensions.

The analyses were done analytically using the FEM program Lira 9.6. The numerical results for the displacements are shown in Table 5. Rational from the point of view of displacements the construction types are f) – structure with four bottom chords and inclined and crossing suspensions, a) – structure with two bottom chords and vertical suspensions and h) – structure with three bottom chords and inclined suspensions.

Table 5

Displacements of constructions

Construction Type	Displacement in opposite side of load application, mm	Displacement in load application side, mm	Difference of displacements, mm
a) with vertical suspensions	0.00	17.30	17.30
b) with one bottom chord	-9.78	40.22	50.00
c) with crossing suspensions	-0.55	20.39	20.94
d) with inclined and crossing suspensions	0.49	22.18	21.69
e) with three bottom chords	0.50	17.55	17.05
f) with four bottom chords	0.08	13.95	13.87

The rational distance between the bottom middle supports was found for the construction f) – with four bottom chords and inclined and crossing suspensions. Dependence of the distance between the bottom middle supports on the difference of the displacement is shown in Figure 9.

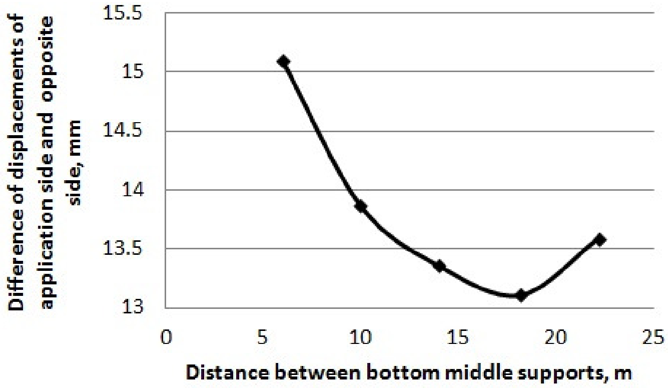

Fig. 9. **Dependence of distance between bottom middle supports on difference of displacement**

The rational distance between the bottom middle supports from the point of view of the difference of the displacements of the right and left side is equal to 18.2 m.

Different variants of initial prestressing level were analyzed for the construction. It was stated that initial prestressing load did not influence the difference of the displacement of the left and right side of the construction.

Conclusions

Different types of cable trusses where compared under the action of uniformly and non-uniformly distributed loads. It was shown, that the cable truss with the cross web is the best from the point of view of minimization of the maximum vertical displacements in the case when non-uniform load is applied. It was stated, that usage of cable truss with the cross web instead of a single cable allows to reduce the maximum vertical displacements up to 32 % in the case of non-uniformly distributed load, if the material consumption is the same and prestressing is applied by the stabilization cable. The maximum vertical displacements can be reduced up to 16 % in the case, if prestressing is applied by the suspensions.

A rational structure of the cable truss web was developed. It was shown, that the cross web can be replaced by the inclined suspensions in a part of the span.

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

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