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BEHAVIOURS OF TENSIONED HYBRID COMPOSITE ELEMENT WITH STRENGTHENED SECTIONS

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Abstract: *Hybrid composite tensioned element on the base of steel and carbon fiber reinforced plastic (CFRP) with strengthened sections was considered as an object of investigation. Strengthening of the most heavy loaded cable's sections is necessary to decrease the difference between maximum and minimum axial forces in the cable, which depends on the deflection. Strengthening of the cable's sections was carried out by the increase of volumetric fraction of steel in some sections by the length. The behaviours of tensioned hybrid composite element with strengthened sections were investigated analytically and by experiment. The hybrid composite tensioned element with strengthened sections was considered as a material of cable net of prestressed saddle-shaped cable roof 50x50 m in plan, together with the steel cables. It was stated, that the using of the tensioned hybrid composite element with strengthened sections enables to decrease consumption of cable net materials.*

Key words: composite element, strengthened sections, saddle-shaped cable roof.

1. INTRODUCTION

Reduce of materials consumption is one of the most significant problems at the present time. Reduce of structural materials consumption could be obtained by the use of rational type of structure and high strength structural materials.

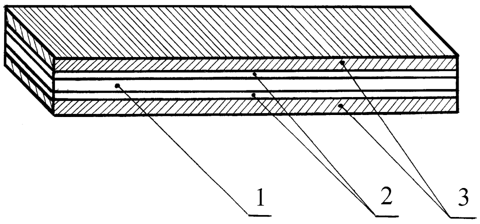
The rational is such type of structure, where high strength structural materials can be used in the full scale. Large span cable structures, where nearly all main load-bearing elements work at tension, are rational from the point of view of materials consumption [1]. The saddle-shaped cable roof is a probable example of tensioned structures. But the effect of high strength materials using in tensioned structures can be increased if the difference between the maximum and minimum axial forces in the cables will be decreased by strengthening of the most heavy loaded sections.

High strength materials such as FRP possess potential for their application as constructional materials in combination with the steel [2,3]. Carbon fiber reinforced plastic (CFRP) and glass fiber reinforced plastic (GFRP) are examples of such materials. As constructional materials they have high specific strength and relatively small elongation at break [4].

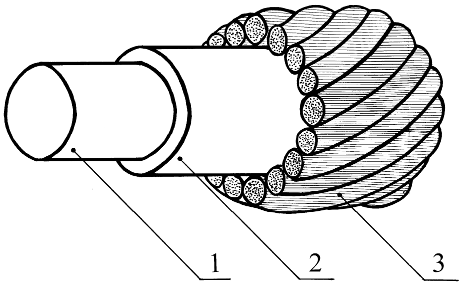
Small elongation at break significantly decreases safety of construction due to probability of brittle failure during short time growing of the load. This disadvantage could be improved by the adding of steel component, which enables to increase reliability of the tensioned element.

The hybrid composite tensioned elements can be created on the base of joined together separate tapes (Fig.1.*a*)) or strands (Fig.1.*b*)).

The volumetric fraction of steel should be bigger than 0.20 to prevent the failure of the hybrid composite tensioned element in emergency, when the entire component, excluding the steel, were disrupted.



a)



b)

Fig.1. Hybrid composite elements on the base of steel and FRP: *a*) – hybrid composite element on the base of joined together separate tapes; *b*) – hybrid composite element on the base of joined together separate strands;1 – FRP core; 2 – glue or FRP distributional layer; 3 – steel component.

So, the purpose of the study is to consider tensioned hybrid composite element as a material of saddle-shaped cable roof. Opportunity to decrease consumption of cable net materials also should be considered. The behaviours of tensioned hybrid composite element should be investigated analytically and by experiment.

2. EVALUATION OF BEHAVIOURS OF HYBRID COMPOSITE ELEMENT

2.1 Materials for hybrid composite element

The considered hybrid composite element consists from the external layers of steel and internal layer of CFRP. The layers are joined together by the epoxy glue.

The main directions of the considered hybrid composite elements application are prestressed nets of saddle-shaped cable roofs. Combination of high strength and increased ultimate elongation is the main requirement for the hybrid composite element.

Thus, the hybrid composite element should obligatorily contain two types of materials: one material with a large limit of strength and the other with an increased ultimate elongation.

Steel tapes can be treated as a material with an increased ultimate elongation for the hybrid composite element. Properties of CFRP (AS4/3501-6 graphite fibers and epoxy matrix at 60% fiber content) are taken in accordance with the sources [5-11]. The limits of strength and moduli of elasticity of CFRP and steel tapes are equal to 2800 and 305 MPa, $1.65 \cdot 10^5$ and $2.06 \cdot 10^5$ MPa, respectively. Ultimate elongations are equal to 43 and 1.8% for steel and CFRP, respectively.

2.2 Prediction of behaviours of hybrid composite element

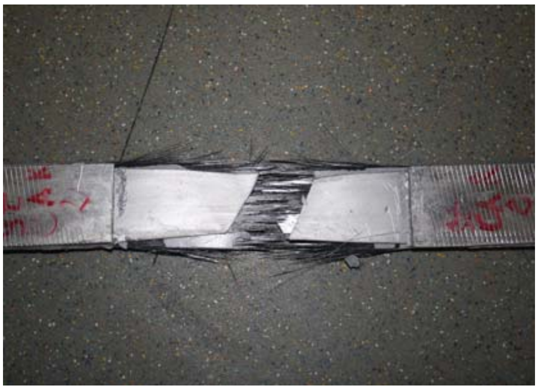
The behaviours of hybrid composite element were evaluated basing on the behaviours of separate component. The axial tension force, acting in the cable, was evaluated as a sum of axial forces in the separate components, which corresponds to the certain level of strains.

The mentioned model for prediction of behaviours of hybrid composite elements was checked by the experiment. Three groups of specimens were tested. The specimens of the first group consist from two steel and one CFRP tapes, which were joined together by the epoxy glue. The specimens of the second and third groups were single CFRP and steel tapes, respectively.

The dimensions of the tapes cross-sections were 50x1.2 mm. The length of the specimens was determined taking into account width of the tape and base of gage in accordance with the ASTM D3039/D3039M-95a. The length of base of the strain-measuring device was equal to 50 mm. The specimens were loaded until the failure by the testing machine with capacity in 300 kN.

The explosive type of failure was stated for all CFRP specimens, which occurs in the middle of the specimen (Fig.2.*a*)). The mode of failure of hybrid composite specimens is shown in Fig.2.*b*).

a)



b)

Fig. 2. The types of failure of CFRP and hybrid composite specimens: *a*) – CFRP specimen; *b*) – hybrid composite specimen.

The results of the test show, that the failure of carbon fibers in hybrid composite specimen occurs in the several sections. This is a reason, why the carbon fibers are visible in zone of failure of hybrid composite specimen (Fig.2.*b*)). The type of failure of hybrid composite specimens was characterizes by the types of failure of separate components. The failure of middle CFRP layer occurs when the strains exceed 1.8 %, what corresponds to the axial force in 204 kN. Than the axial force fall down until 36.6 kN and occurs yielding of steel component until the strains exceed 43%, and steel component also disrupt. The mean curves for all three groups of specimens together with the analytically obtained curve are shown in Fig.3.

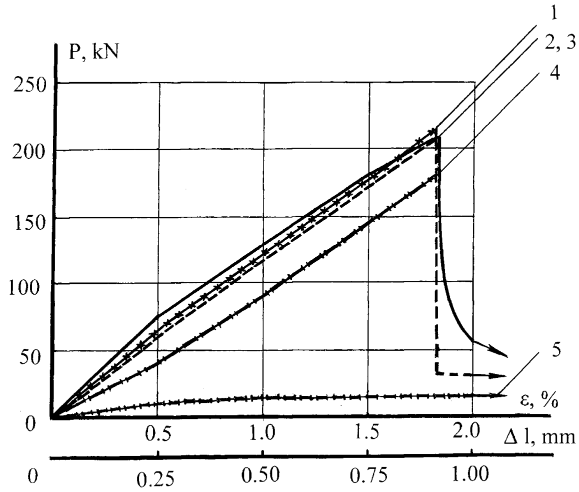


Fig.3. Behaviours of hybrid composite element: 1 – graph, which was obtained analytically for the composite material on the base of one CFRP tape and two steel tapes with taking into account of two layers of epoxy glue with thickness in 1 mm; 2 – graph, which was obtained by the experiment for the composite material on the base of one CFRP tape and two steel tapes; 3 – graph, which was obtained analytically for the composite material on the base of one CFRP tape and two steel tapes. Two layers of epoxy glue with thickness in 1 mm were not tacked into account; 4 – graph, which was obtained by the experiment for the CFRP tape; 5 – graph, which was obtained by the experiment for the steel tape. The results were obtained by the strain-measuring device with the length of the base 50 mm.

The behaviours of single steel tape and composite material on the base of two steel and one CFRP tapes are shown in Fig.4 until the failure of steel. The maximum deformation, which was obtained during the experiment, is equal to 24 mm or 48%.

The comparison of results, which were obtained by the experiment and analytically, indicates that the maximum difference does not exceeds 20%.

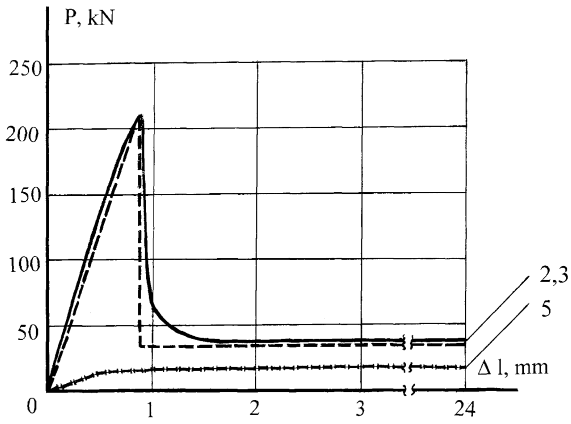


Fig.4. Behaviours of steel tape and composite material on the base of two steel and one CFRP tapes: designations as in Fig.3.

So, the model for prediction of behaviours of hybrid composite elements basing on the behaviours of the separate component can be used for coarse evaluations.

3. HYBRID COMPOSITE ELEMENT IN SADDLE-SHAPED CABLE ROOF

Let us to consider the using of hybrid composite element with strengthened sections as a material of saddle-shaped cable roof.

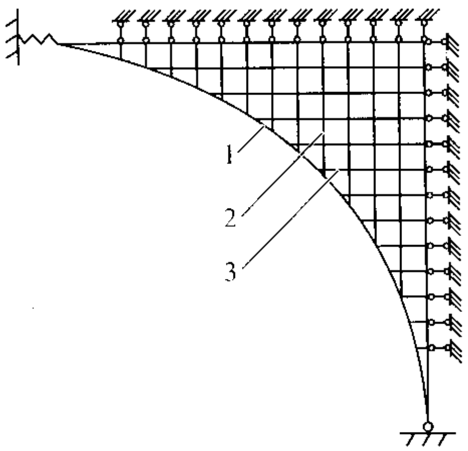


Fig.5. Design scheme of cable roof: 1 – contour (tension) cable; 2 – stressing cable; 3 – suspension cable.

A saddle-shaped cable roof 50x50 m in the plan was investigated. The existence of two symmetry planes allows us to regard, as a design scheme, a quarter of the cable net of a saddle-shaped cable roof. Three quarters of the cable roof are replaced by the bonds imposed on its one-quarter part (Fig.5.). Hybrid composite elements with strengthened sections on the base of steel and CFRP were assumed as a material of main diagonal suspension cable. The hybrid composite element was divided at three parts with the different cross-sections of steel components by the length.

The length of each part was equal to 27.20 m. The area of cross-section of CFRP component was constant by the length of the cable and equal to 0.00034 m^2. But the areas of cross-sections of steel components were equal to 0.00051; 0.00045 and 0.000385 m^2 for first, second and third part of the cable, respectively. The cross-sections of steel were determined to provide the constant level of stresses in CFRP component in the each part of the hybrid composite element. The moduli of elasticity of each part of the element were determined on the base of proportional components summation.

Steel cables with an elastic modulus of $1.3{\cdot}10^5$ MPa were assumed as a material for the suspension (excluding main diagonal), stressing and tension cables. From the viewpoint of material consumption, the saddle-shaped cable roof has rational geometrical characteristics: the initial deflection of the contour cables was 8.6 m, the initial deflection of suspension and stressing cables 20 m, and the step in plan of the latter ones was 1.414 m [1]. The structure was calculated for the basic combination of loads – the dead weight of the structure (0.27 kPa) [12] and the weight of snow (1.12 kPa) – evenly distributed on the horizontal projection of the roof. The design load in the form of pointwise forces was applied to the nodes of the cable net. The cable net was prestressed by applying tension forces to the suspension and stressing cables, such that the residual tension forces in the stressing cables were equal to 20% from their initial values under the vertical design load.

The calculations of saddle-shaped cable roof contain two stages. The axial tension forces and cable cross-sections were evaluated by the approximate method at the first stage of calculation. The maximum values of axial tension forces for suspension, stressing and tension cables were evaluated from the equation.

$$N = \sqrt{\left(\frac{ql^2}{8f}\right)^2 + \left(\frac{ql}{2}\right)^2}\ , \qquad (1)$$

where: q–uniformly distributed load, acting at the considered cable; f– initial deflection of the cables; l – span of the cable.

All cables in the group possess the equal areas of cross-sections, which were determined basing on the maximum axial tension force. The cross-sectional areas of the cables were found according to the recommendations given in [9] from the equation.

$$F \geq \frac{1{,}6N}{kR}\ , \qquad (2)$$

where: F is the cross-sectional area of the cable, N is the design force in the cable, k is a coefficient, taking into account the drop in the breaking force of the cable caused by the inhomogeneity of stress distribution, R is the ultimate strength of the cable material, and 1.6 is the reliability index of the material.

The precision of the forces, acting in the cables of the net was carried out using a computer program "ANSYS/ED 5.3" for WINDOWS. The program enables to calculate values of the tension forces acting in the cables of the net and maximum vertical displacements of the cable net. In calculating a cable net, the program uses the iteration method, which consists of the division of the applied vertical design load into several parts in an ascending order. The cable net was modelled by finite elements of LINK10 type, with three degrees of freedom for each node. Each finite element was divided into two parts of the same length.

It was shown, that the using of hybrid composite elements with strengthened sections on the base of steel and CFRP enables to decrease by 12.27% materials consumption for main diagonal suspension cable. But the maximum vertical displacement of the cable roof increase by 5% at the same time.

4. CONCLUSIONS

Model of prediction of behaviours of hybrid composite element was suggested and checked by the experiment. It was shown, that the maximum difference between the results, which were obtained by the experiment and analytically, does not exceeds 20%.

Hybrid composite element with strengthened sections was considered as a material of saddle-shaped cable roof 50x50 m in the plan. It was stated, that the using of hybrid composite element as a material of main diagonal suspension cable enables to decrease by 12.27% materials consumption. But the maximum vertical displacement of the cable roof increase by 5% at the same time.

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