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STRESS-RIBBON BRIDGES STIFFENED BY ARCHES OR CABLES

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SUMMARY

At present research on the development of new stress-ribbon pedestrian bridges is being carried out. The classical stress-ribbon deck is combined with arches or cables. The studied structures are two span stress-ribbon supported and stiffened by an arch and suspension structure formed by a straight or arched stress-ribbon. The paper presents structural solutions, methods of static and dynamic analysis as well as some results.

Keywords: stress-ribbon, arch, suspension stress-ribbon, modelling, load test

1. INTRODUCTION

Stress-ribbon pedestrian bridges are very economical, aesthetical and almost maintenance-free structures. They require minimal quantities of materials. They are erected independently from the existing terrain and therefore they have a minimum impact upon the environment during construction. One disadvantage of the traditional stress-ribbon type structures is the need to resist very large horizontal forces at the abutments. It determines the cost of that solution in many cases. Another characteristic feature of the stress-ribbon type structures, in addition to their very slender concrete decks, is that the stiffness and stability are given by the whole structural system using predominantly the geometric stiffness of the deck. At present research on the development of new structures combining classical stress-ribbon deck with arches or cables is being carried out.

The first studied type is a stress-ribbon structure supported by an arch designed by Prof. Strasky (Fig.1). The stress-ribbon deck is fixed into the side struts. Both the arch and struts are founded on the same footings. Due to the dead load the horizontal force both in the arch and in the stress-ribbon have the same magnitude, but they act in opposite

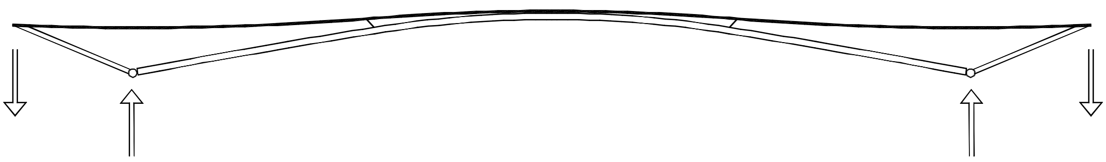

Fig.1 Stress-ribbon stiffened by an arch

directions. Therefore the foundation is loaded only by vertical reactions. This self-anchoring system allows a reduction in the costs of substructure.

The second type of studied structures is a suspension structure formed by a straight or arched stress-ribbon fixed at the abutments (Fig.2). External bearing cables stiffen the structure both in the vertical and horizontal directions. Horizontal movements caused by live load are eliminated by stoppers, which only allow horizontal movement due to temperature changes and creep and shrinkage of concrete.

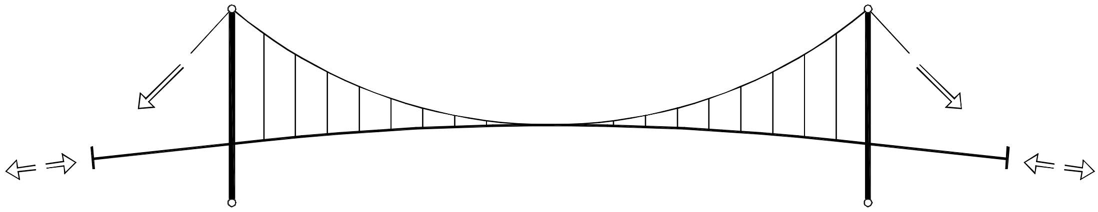

Fig.2 Suspension stress-ribbon

2. STRESS-RIBBON STIFFENED BY AN ARCH

The structure in Fig.3 was designed for study purposes. The structure combines a steel tube arch with a span length of 77 m with a modified stress-ribbon type deck. The arch is formed by two steel tubes. The steel tubes are supported on concrete foundations. The tubes have a diameter of 0.60 m and a thickness of 30 mm. The steel arches support the deck formed by a stress-ribbon of two spans assembled from precast segments. The deck is fix-connected at midspan with the arch. Steel plates supporting the deck extend for a short distance from the midspan outwards towards the sides to help keep a maximum variability in the slope of 8%. At both ends, the stress-ribbon is fixed to a diaphragm supported by two inclined cast-in-place concrete struts fixed in the foundations of the arch. The diaphragm is supported by tension pin piles. The foundation is supported by compression pin piles. The structure forms a self-anchoring system, where the horizontal forces from the stress-ribbon are transferred by the inclined concrete struts to the foundation where they are balanced against the horizontal component of the arch.

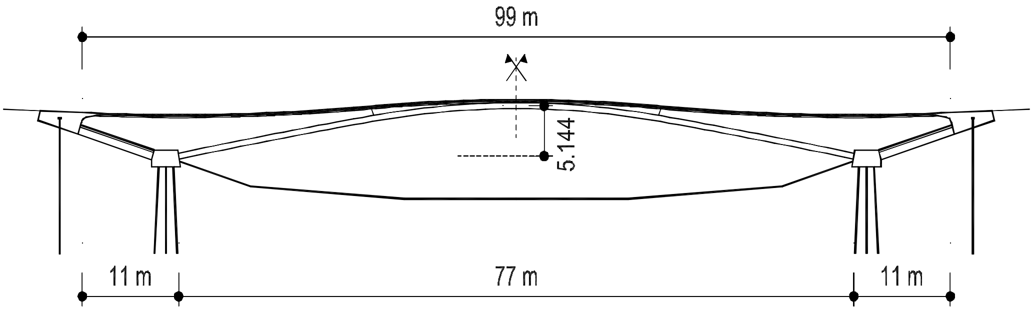

Fig.3 Studied structure

3. MODELLING OF THE STRESS-RIBBON STIFFENED BY AN ARCH

The development of the structure is carried out in two basic ways. The first type of development is based on detailed mathematical modelling. The bridge is analyzed by Ansys as a geometrically non-linear structure for both static and dynamic loads. In the beginning a preliminary plane frame model was prepared to design the dimensions of the members. At present a detailed three-dimensional model of the structure is being prepared.

Model tests are the second type of development. The dynamic response of the structure to wind load was tested using a scaled aeroelastic model. Tests were performed by Prof. Pirner at the Institute of Theoretical and Applied Mechanics, Academy of Sciences of the Czech Republic. The aerodynamic stability of the bridge was checked in a wind tunnel. At present a test model built to a scale of 1:10 is also being assembled in our department. The behaviour of the structural members and new details will be verified using this model by a static load test.

3.1 Model 1:10 - similitude

Similitude is based on conservation of the geometry of the model in its deformed state. This assumption allows the same level of stresses in the model as in the real structure.

Parameter	Real structure	Model	Scale
Length	L	L_m	$L / L_m = 10$
Displacement	d	d_m	$d / d_m = 10$
Area	A	A_m	$A / A_m = 10^2$
Moment of inertia	I	I_m	$I / I_m = 10^4$
Modulus of elasticity	E	E_m	$E / E_m = 1$
Force	F	F_m	$F / F_m = 10^2$
Bending moment	M	M_m	$M / M_m = 10^3$
Linear force	g	g_m	$g / g_m = 10$
Stress	σ	σ_m	$\sigma / \sigma_m = 1$
Strain	ε	ε_m	$\varepsilon / \varepsilon_m = 1$

Tab.1 Similitude scales

According to the scales in Tab.1 geometry, cross-sections and additional loads were determined. Additional dead load was calculated as follows:

concrete deck	$g_{m,add} = 2.250 \text{ kN / m}$
steel arch	$g_{m,add} = 0.759 \text{ kN / m}$

3.2 Structural solution of the model

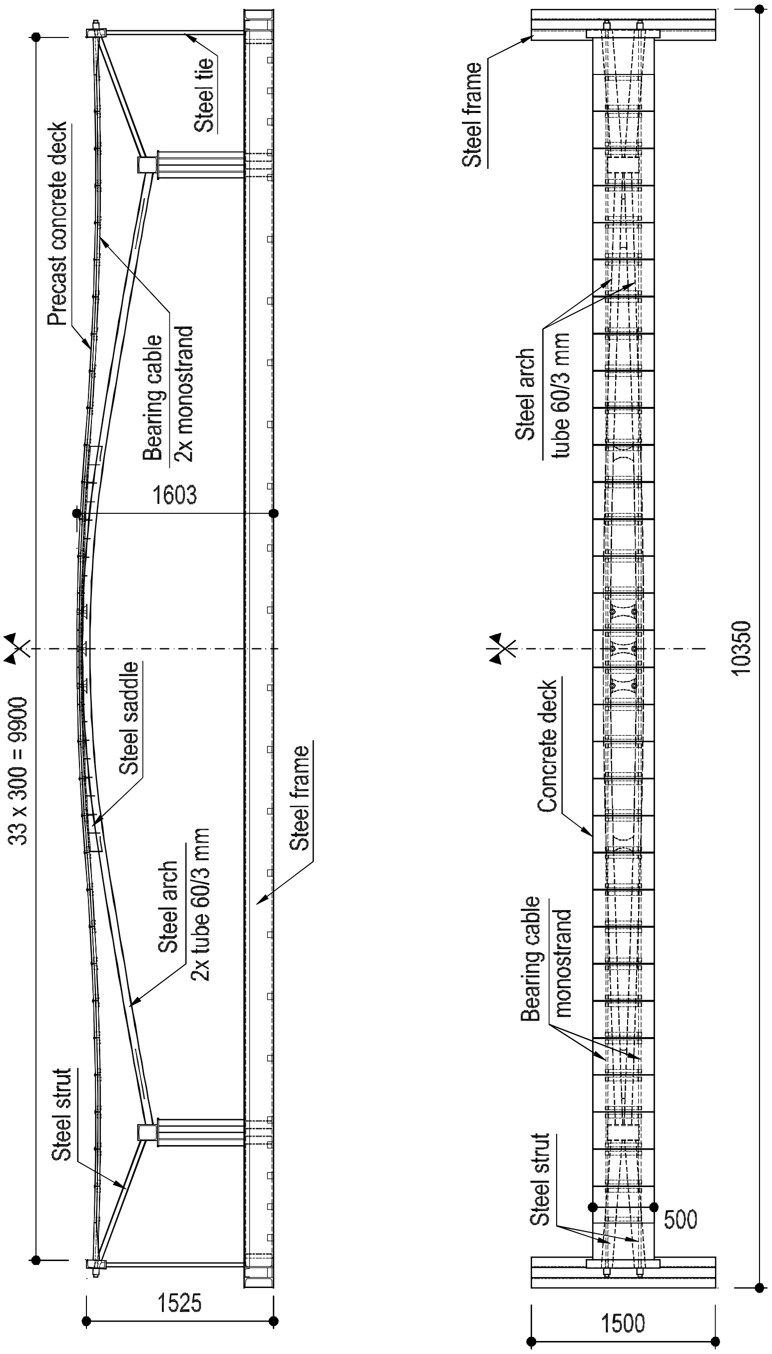

Fig.4 General view of the model - elevation and plan

The model approximately 10 m long is fixed to a steel frame anchored to a test room floor (Fig.4). The height of the model above the floor is sufficient to apply the additional dead load determined by the previous calculations. The arch is formed by using two steel tubes 60 mm in diameter and a wall 3 mm thick. Transfer of the horizontal component of the stress-ribbon axial force to the arch foundation is ensured by two inclined steel struts. The vertical reaction of the deck is anchored to the steel frame using steel ties. The bearing and prestressing cables are modelled by two monostrands 15.5 mm in diameter. The deck is assembled from precast segments and monolithically connected to the end diaphragm. The cross section shape was simplified to a rectangle 0.50 m in width and 18 mm thickness. Considering the similitude (Tab.1), the cross section area of the scaled segments corresponds to the real structure cross section area. The additional load will be applied through the steel bars anchored to the segments (Fig.5). Three segments are connected to the steel arch at midspan. The connection provides a sufficient stability of the arch and transfers the stress-ribbon axial force caused by an unsymmetrical live load to the arch.

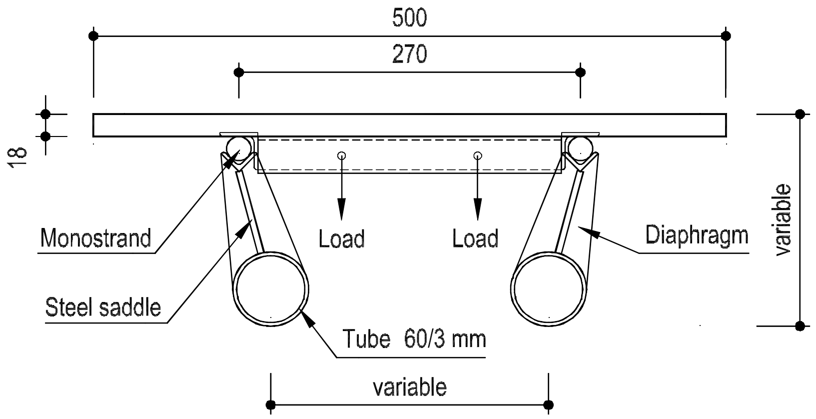

Fig.5 Cross-section of the model

3.3 Measurement

The strains of the concrete and steel will be measured at selected measuring points during the loading of the model. Furthermore, deflections of the deck and arch will be measured. The model will be loaded in two phases. Firstly the load test for standard load will be performed after the deck assembling and prestressing. The structure will be checked for several live load positions. The second phase of the test will be delayed to involve the influence of creep and shrinkage. A test of the ultimate bearing capacity will be carried out at the end of the experiment.

4. SUSPENSION STRESS-RIBBON

Pedestrian bridges formed by a suspension stress-ribbon are very slender structures. Structural stiffness and response of the structure to static and dynamic loads is given especially by a structural solution. A form of connection between the deck and external bearing cables, a kind of boundary condition at pylons or abutments and geometry of bearing cables influence structural behaviour. Slender suspension structure is especially sensitive to a live load placed on a part of the suspension span and to a wind load.

Support of the deck in a horizontal direction provided by a stopper was designed and analyzed during the study and development of this structural type. This device allows horizontal movement due to temperature changes and due to the creep and shrinkage of concrete. At the same time the device stops horizontal movement due to short-term loads like a live load, wind load or earthquake. Deck deflection and bending moments are reduced due to zero or very small horizontal movement. Natural frequencies and mode shapes were also determined during the dynamic analysis. The influence of the aforementioned structural arrangements on frequencies and mode shapes was studied. The structure allows one to place an observation platform at midspan. But dynamic behavior is influenced by platform positioning, weight and area. For this reason the aerodynamic stability of the structure was checked in a wind tunnel.

4.1 Parametric study

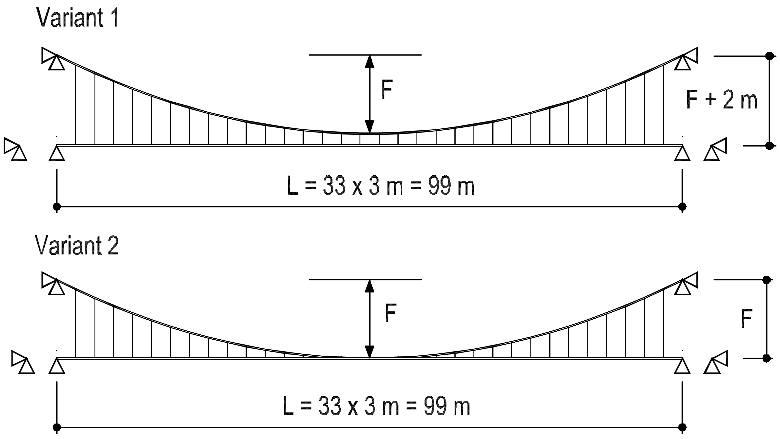

Fig.6 Geometry of the studied structure

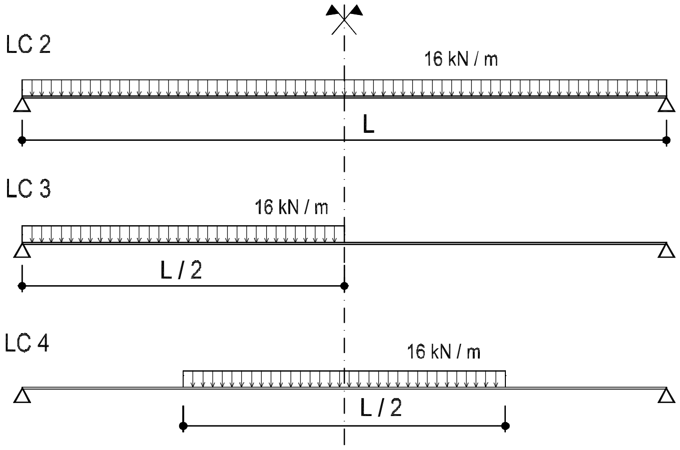

Fig.7 Load cases

A suspension pedestrian bridge formed by a straight stress-ribbon deck, external bearing cables and suspenders with a span length L = 99 m was analyzed in this parametric study (Fig.6). The structure was analyzed as a geometrically non-linear two-dimensional frame structure. Two basic types of deck-cable connection were designed. The deck was connected to the cable through the suspenders along the whole span length in the first variant. In the second one the cable was fixed to the deck at midspan. Both variants were analyzed for three different initial sags of the bearing cable : F = L / 8, F = L /10 and F = L / 12. In addition fixed hinge or sliding hinge supports of the deck together with four values of the deck moment of inertia were considered. All the structures were loaded by three basic load cases (Fig.7).

4.2 Results of the parametric study

The obtained results are here presented in graph form. The study was very extensive and that is why only some conclusions are presented in this paper. The influence of deck-cable connection at midspan is showed in Fig.8. The reduction of the deck deflection is the most important in load case 3. The deflection of flexible decks is positively influenced by fixed hinge supports (Fig.9). It is caused by an activation of higher deck axial force due to larger deflections (Fig.10). The same conclusion can be reached regarding deck bending stresses.

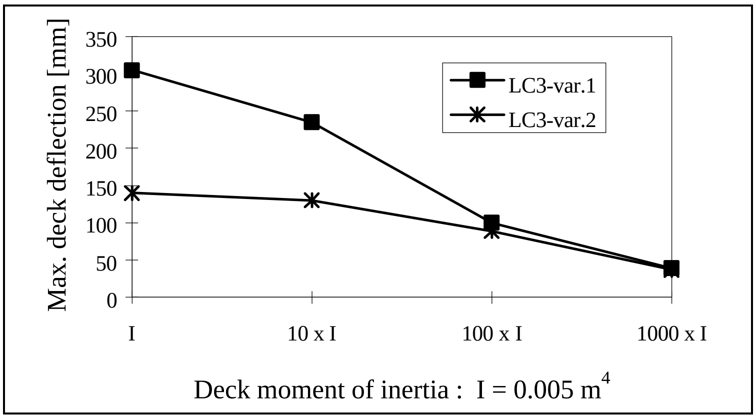

Fig.8 Influence of fixed deck-cable connection - fixed supports - F = L / 8

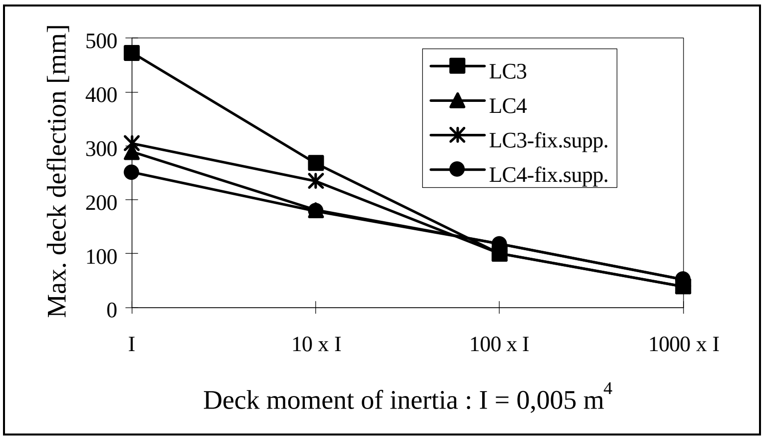

Fig.9 Influence of fixed hinge supports - variant 1 - F = L / 8

5. CONCLUSIONS

The main disadvantage of stress-ribbon pedestrian bridges is the large horizontal forces, which must be anchored to the ground. A new structural type combining stress-ribbon with a slender arch and eliminating this disadvantage is presented in this paper. The process of the development includes both mathematical modelling and experimental methods. The main goal of the research is to check the structural response to static and dynamic loads, design of structural members and finally design of new details. The results of the performed analyses and experiments will make a practical design of this aesthetic structure easier in the future.

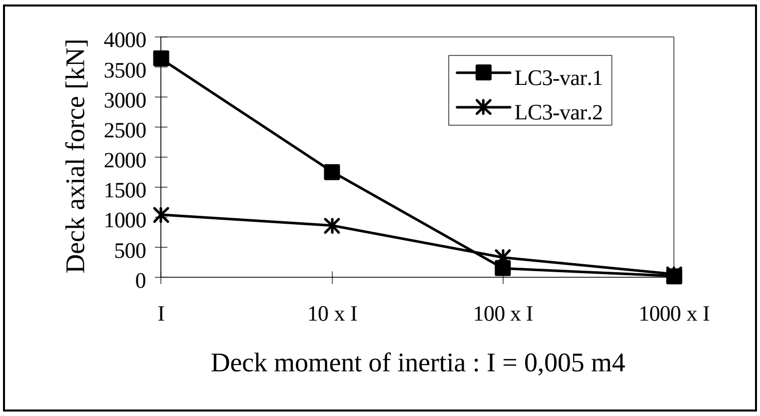

Fig.10 Influence of fixed deck-cable connection - fixed supports - F = L / 8

Different parametric studies were performed during the study of pedestrian bridges formed by a suspension stress-ribbon. The studies were focused on different structural arrangements and their comparisons. The bending stresses of the slender deck assembled from precast segments can be efficiently reduced by using stoppers. An appropriate choice of support type and bearing cable geometry can significantly stiffen the structure both in longitudinal and in transverse directions.

6. ACKNOWLEDGEMENTS

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