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Influence of Textile Membrane on Stability of Supporting Steel Arch

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Abstract: In the last few decades, the membrane textile surface structures became popular not only because of their visual attractiveness, but also as a light fully-load carrying systems. In comparison with use of a traditional roof decking these structures are much more economical and attractive. However, the complex analysis and computational design methods are demanding and still not codified. The real physical model of a membrane structure supported by two inner steel arches and covering a concert stage was constructed and tested in laboratory of CTU in Prague. The membrane used was the Précontraint 702S Ferrari [1] prestressed textile membrane with PVC coating. The arches were hot-formed in a workshop from Grade S355J0 steel. The full paper presents experimental results for: i) isolated inner arch, ii) complex structure of the membrane with supporting arches, both under symmetrical and asymmetrical loading. Furthermore the numerical nonlinear FEM model created in SOFiSTiK software package and its validation for the above structural configurations and loading is presented. Subsequent parametrical studies cover various levels of the membrane prestressing to show its significance for nonlinear behaviour and stability of the inner arch. Finally some recommendations concerning numerical modelling are presented.

Introduction

A rapid improvements and novelties of materials used in lightweight structures such as textile membranes, plastic foils, high strength steels, cables and rods, led in last decades to their huge expansion. Membrane structures with subtle supporting steelwork require demanding nonlinear analyses. Simplified separate modeling of membranes and supporting structures is usually unacceptable and can lead to incorrect results or even a collapse of the entire system. In general, the complex analysis of membrane surface and supporting structure is necessary [2,3]. Herein the complex analysis concentrates on stabilization effect of a membrane to the supporting steel arch.

Tests and numerical investigation

A model of real concert stage was constructed and investigated in laboratory of the FCE CTU in Prague. The main size LxBxH of the model is roughly 4500x2250x1200 [mm], inner and outer tubes of steel grade S355J0 Ø 26.9x3.2 [mm] and Ø 88.9x3.2 [mm], respectively. Loading points were defined along the arch and both symmetrical and asymmetrical loading was applied to two configurations: i) isolated arch alone; ii) complex membrane-arch assembly. Careful monitoring of deflections and strains at the required positions were performed during the given loading steps.

The SOFiSTiK software using geometrically and materially nonlinear analysis with imperfections (GMNIA) was used to model complex (entire) membrane-arch system. The deformed geometry obtained from measurement in laboratory and precise values of loading increments were introduced into analysis. Due to non-uniform membrane pretension in the tests and difficult measurements of the resulting membrane stress on the textile surface, various values of the membrane uniform prestress were analyzed.

Comparison of experimental results and results obtained from numerical analysis

First the isolated arch build-in in the supports (otherwise free) was analyzed. Numerical and test deflections at various points confirm excellent agreement (e.g. the in-plane vertical one in Fig. 1).

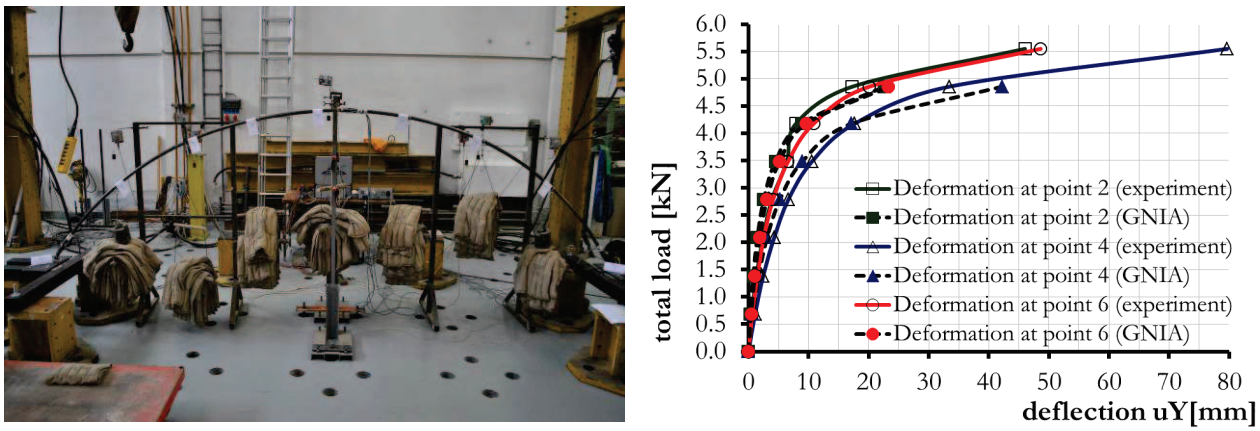

Fig. 1: Isolated arch under symmetrical loading (left); Comparison of experimental and numerical (SOFiSTiK) vertical deflections (uY) under symmetrical loading (right)

In the membrane-arch assembly the level of the membrane prestressing proved to be the most important parameter and rather low numerical prestressing gives corresponding results, Fig. 2.

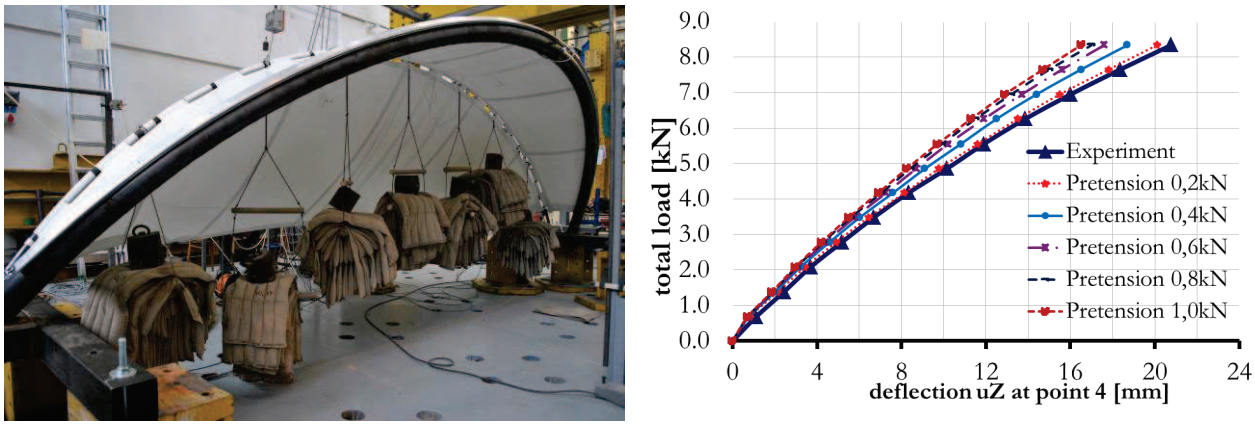

Fig. 2: Symmetrical loading of complex structure (left); Comparison of experimental horizontal deflections and numerical (SOFiSTiK) ones with various prestressing (right)

Conclusion

The stabilization effect of a membrane on supporting steelwork is enormous and membrane as a load bearing and stabilizing element must be included into the analysis to ensure safe and correct design. Real reasonable value of uniform directionless prestress was assessed as 0.4 kN/m'.

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References

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