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DESIGN OF INITIAL SHAPE OF MEMBRANE STRUCTURES

Abstract

The subject of this article is the question of design and analysis of membrane structures. The first part of this article deals with the problem of form-finding. It is the problem of searching for the initial shape of membrane structure. In the second part of the article, an example of design and analysis of the membrane structure of a stadium roof is presented. This work was carried out with respect to the intention of companies Dlubal Software, s.r.o. and FEM consulting, s.r.o. to create the module for finding initial shapes of membrane structures, which would consequently be implemented into the software RFEM.

Keywords

Membrane structures, form-finding, initial equilibrium state, nonlinear analysis, isotropic stress field, orthotropic stress field.

1 INTRODUCTION

Determining the initial shape and initial state of prestress is one of key issues for designing membrane structures. To achieve the required loading capacity, stability and shape stability, it is necessary to prestress the membrane structure, which results in geometric stiffness. Normal prestress component orientation is determined by the geometry of the structure. Therefore, the membrane structure cannot be separated into shape design and static or dynamic analysis - both these components are interconnected [2, 8, 9].

The initial equilibrium state of membrane structure must guarantee the existence of only tension stresses throughout its life. There cannot exist pressure stress for any load combination. The result of pressure stress would be wrinkling, which causes aesthetic and sometimes even static debasement of membrane structure [5].

The weight of membrane material is very low and therefore it does not contribute to the stabilization of the shape, as it may be for example in concrete structures. So in the process of finding the initial equilibrium shape of membrane structures, we usually create the shape based on requirement for the resulting stress [4,6].

In this connection, the so-called "soap film analogy" was established (Fig. 1), based on the search for such shape between the given boundaries whose surface is minimal [3]. Such a shape has a special feature, which is the isotropic tension. For many cases, this option is very convenient because it has large geometric stiffness. The pioneer in design of membrane structures Frei Otto pointed at this relationship in his work [1].

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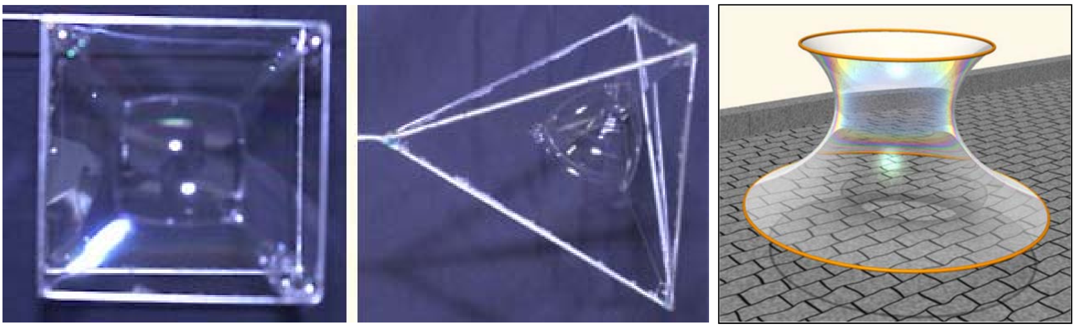

Fig. 1: Geometric shapes of soap bubbles between rigid boundaries, visualization of catenoid (right)

However, there are cases in which this requirement leads to erroneous solutions and another suitable shape must be found. For this purpose we use prescribing anisotropic (often orthotropic) stress field, which results in another suitable form of membrane structures. The actual requirement of resulting prestress is thus controlling parameter of shape design [7].

2 DESIGNING AND ANALYZING OF THE MEMBRANE STRUCTURE OF A STADIUM ROOF

The aim of the practical part of this paper was to design and calculate the membrane structure of a stadium roof, which was to verify the capabilities of the RFEM program to generate initial shapes of these structures, and also to propose the necessary modifications of the software. When designing the structure presented below, it was necessary to consider the design, layout and aesthetic requirements of the contemplated building. High attention was first given to the design of the supporting cable system and subsequently to the membrane carried with this cable system.

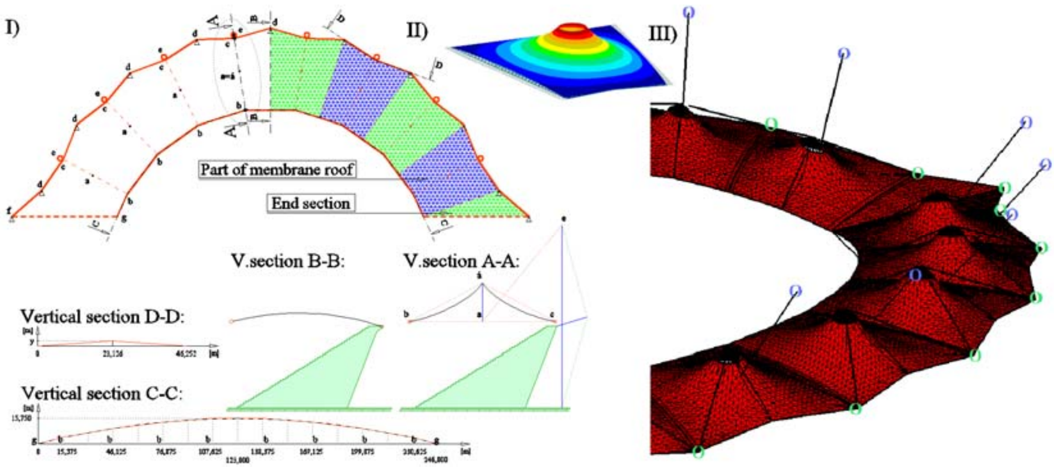

Fig. 2: I) Schematic plan shows of one half of the stadium roof,
II) Recurring motif of the resulting shape, III) Part of a global model of membrane roof

Cable system must provide both, the necessary static requirements, as well as a clear spectator´s view from the stands. The cable system is therefore transferred to the outside standing columns. The required properties are provided by appropriately designed curvatures of the cable system and the degree of their prestress.

On the left of Fig. 2, static plan scheme of one half of the stadium roof can be observed. The motif shown in the middle of Fig. 2 is repeated in this structure. On the right side of this image there is also presented a part of a global model, where the green circles show anchoring of the ropes to the external envelope of the grandstands and blue circles show the peaks of outside standing columns.

After completing the design of supporting cable system a suitable shape of the membrane itself was searched. First the membrane shape was searched on the fragment of the area, then analogously on the entire model. The membrane is formed by sixteen conical shapes, which are situated side by side (Fig. 3). These conical shapes are relatively low and therefore the requirement to minimize the area is relevant here.

The shape of the membrane was generated as follows. The membrane was first modeled in the plane and consequently elevation of internal borders and application of large prestress was applied. The shape was stabilized just in a position of minimal area, which could be verified by the existence of an isotropic stress field. Both, the forced deformation and applied shrinkage were used only to find the initial shape and have no connection with the requirement of the resulting prestress, or the assessment of the structure. After generating this shape, nodal coordinates were taken and all tension was removed, resulting in certain simulation of form-finders. After taking the shape of finite element mesh, required prestress was inserted into the membrane.

The model was further subjected to structural analysis. On Fig. 4 is presented deformation of fragment of the structure under load. On Fig. 5 is then presented part of the computational model.

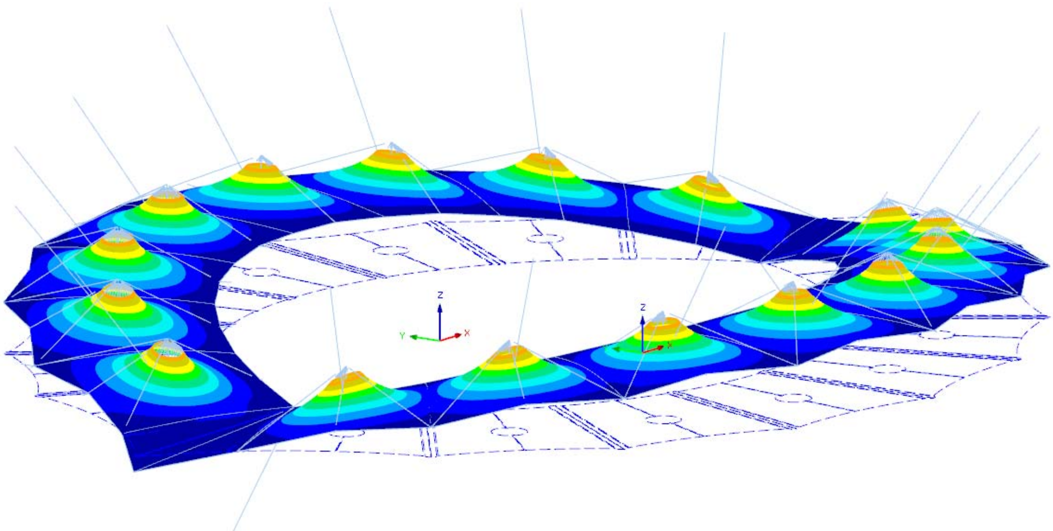

Fig. 3: Global model of the membrane structure

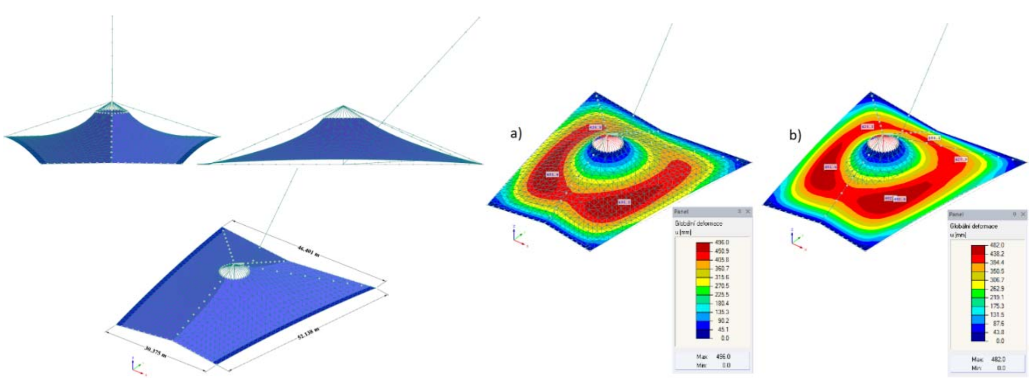

Fig. 4: The shape of finite element mesh, presented on one sixteenth of the membrane structure (left); Deformation by application of snow or wind, presented on one sixteenth of the model (right)

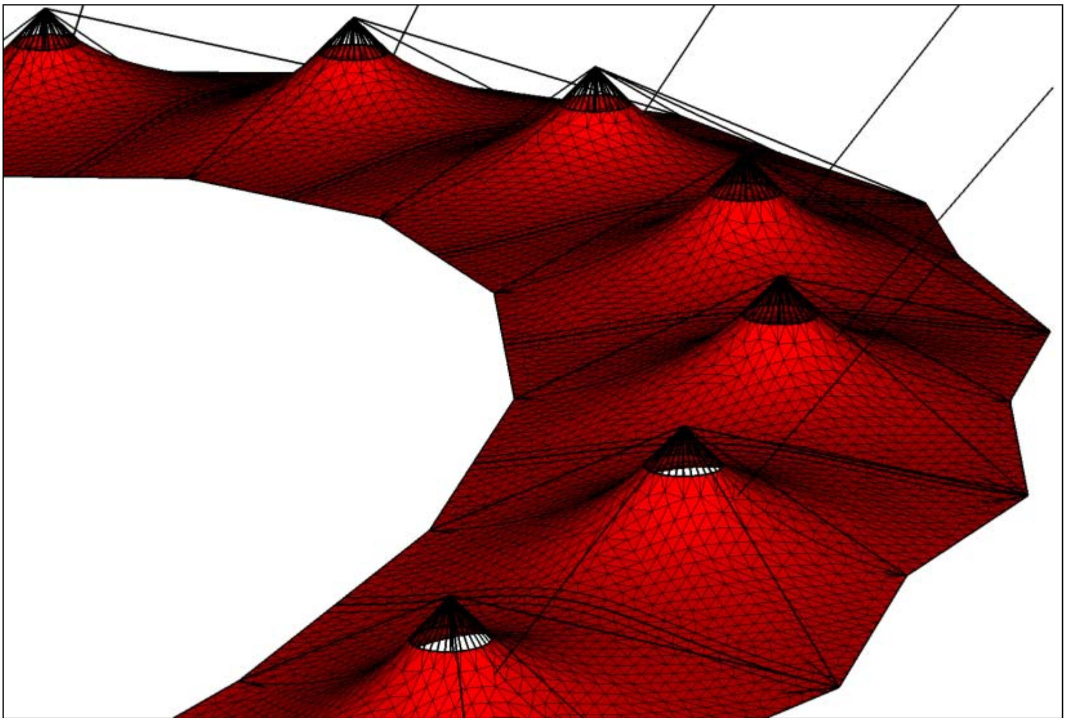

Fig. 5: Part of global model of the membrane structure

3 CONCLUSIONS

Possibilities of the RFEM program to generate a good initial shape of membrane structure were tested on the presented model. In this respect, the possibilities of the RFEM program to generate good shapes of membrane with isotropic prestress were showed. Possibilities of generating shapes for different prestress are still very limited.

Furthermore, the detailed analysis of necessary adjustments for creation of module for form-finding was made based on studies of latest findings from the field.

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