NUMERICAL MODELLING OF TENSION SYSTEMS WITH UNILATERAL CONSTRAINS

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ABSTRACT

The use of flexible structures appears to have continued increase in recent years. They have commonplace appearance and standard solutions, providing covering for unobstructed large areas, such as recreational and sport facilities, semi-permanent storage facilities, exhibition pavilions, or market places. These structures can be made of flexible materials like rubber, cloth, or translucent plastic sheets reinforced with cords, or steel or plastic cables. It is assumed that membranes and cables can carry only tension and work in plane or uniaxial stress state. They cannot withstand compression or bending, otherwise folded zones appear (lack of cables), which have to be taken into consideration.

There are two groups of membranes of this type. The first one whose shape can be maintained because of some initial internal stress state caused by internal pressure (i.e. pneumatic structures: car tires, balls, flexible containers, roofs over swimming pools and tennis courts, etc.) and the second group with shapes resulting from loading and hanging on cables, or special boundary conditions (very flexible structures: tents, parachutes, sails, etc.).

The common features of these objects are very large displacements, and usually very large strains. Therefore, for the analysis of these structures it is necessary to use the nonlinear theory of continuum mechanics. Various effects such as folded zones, finite slip between membrane and cable, and stress singularities associated with edge contact add considerable complexity to this analysis.

Our present work consists of an analysis of deformations of tension systems with unilateral constrains. Membranes, cable nets and membrane cable reinforced structures belong to such systems. Their shape strongly depends on the static condition on the surface, and the normal loads can be sustained only if the system is at least in uniaxial

tension. A lack of compression, bending and twisting rigidity of membranes (very low to compare with tensile stiffness) may result in local loss of stability caused by the development of one- or two- directional wrinkles. Similarly, in the case of cables, the compression results in a passive state. These phenomena resulting in unilateral constrains are considered in this work. In the case of wrinkling a new concept of taking wrinkles into account based on the *cable analogy* is proposed [1, 2]. Moreover, in a case of membrane wrinkling the author proposed an original idea of applying a verification of numerical data in order to satisfy the condition resulting from unilateral constrains.

Additionally, the work made an effort to analyse the large deflection and stability behavior of spherical inflatables subjected to axi-symmetric hydrostatic loads by FDM and compare the results with ones obtained by Numerical Integration Technique [3]. The geometries of membranes ranging from low-profiled to very lofty shapes were analysed.

The effect of horizontal contact of membrane with boundary, as well as vertical contact in the parts of membranes themselves was considered too.

In the research, the collaboration of membrane and cables in cable reinforced membrane systems was studied as well. Special attention was paid to the contact problems between membrane and cables. In the numerical analysis, the Finite Element Method was used and system NAFDEM (*Nonlinear Analysis of Finite Difference and Element Methods*) was applied [4]. Numerous tests and practical examples of large deformations of simple as well as complex shaped tensioned systems, with wrinkling admitted, were analysed. The results were confirmed with the solutions obtained by other methods and experiments [5,6].

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