



Analysis of Shell, Membrane and Cable Structures

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Introduction

The use of thin shells (membranes) and cables is increasing in both civil engineering and aerospace applications. Such structures experience significant geometric and material non-linear behaviour, which require efficient and robust finite elements and solution routines.

The wrinkling of a thin-film membrane antenna affects its electrical performance and it is therefore important to accurately compute the amplitude and wavelength of the wrinkles. Structural wrinkles are treated as a non-linear post-buckling problem, whereas material wrinkles are due to elasto-plastic material behaviour.

Rotation-free shell elements

The aim of this project is to simulate the deployment of lightweight structures using the finite element method. For most thin-film structures, i.e. airbags, the bending stiffness may be neglected and membrane elements can be used. Contrary, for space inflatables, where the folding-induced strain energy or wrinkling is of importance, the bending stiffness must be included.

A superposition of a plate element without rotational degrees of freedom and a simple membrane element offers a possibility to include bending stiffness without increasing the number of degrees of freedom compared to the pure membrane case. Only the translational displacements are needed since the out-of-plane rotations around the edges are approximated from the out-of-plane displacements of the main element and its three nearest neighbours, Fig. 1.

Furthermore, the stiffness matrix will be the same as for the membrane element and better conditioned compared to shell elements with rotational degrees of freedom if the bending stiffness is near zero.

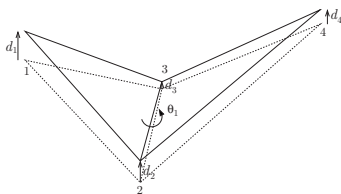


Fig. 1. The out-of-plane rotation θ is approximated from the displacements d_i of a patch of elements.

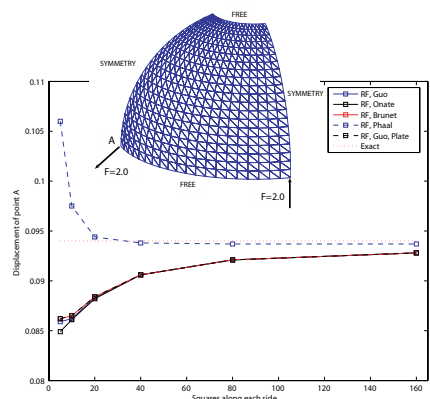


Fig. 2. The performance of some rotation-free (RF) shell elements on the hemispherical shell benchmark example.

Instability analysis of shells

This project concerns the analysis of complex instability in shells. The objective is to develop and implement efficient finite elements and path following procedures.

Co-rotational triangular flat shell elements are developed and tested. The main advantage of the co-rotational approach is that non-linear elements can be obtained by re-using well known linear formulations.

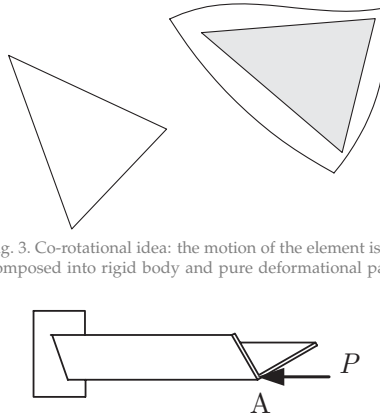


Fig. 3. Co-rotational idea: the motion of the element is decomposed into rigid body and pure deformational parts.

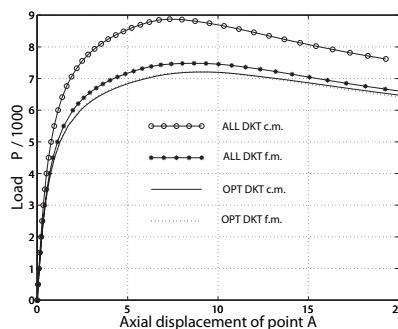


Fig. 4. A simple elasto-plastic instability problem exhibiting a limit point. Several linear local elements are tested.

Prestress optimisation of cable nets

Large deployable antennas for space are using the tension truss concept, in which the parabolic surface is divided into triangular facets. Depending on the configuration of the supporting structure, the geometry and topology of these nets must be optimised in terms of prestress and sensitivity to manufacturing errors to meet the requirements on surface accuracy.

The present optimisation technique involves several methods not encountered in the more common minimal mass optimisation of trusses.

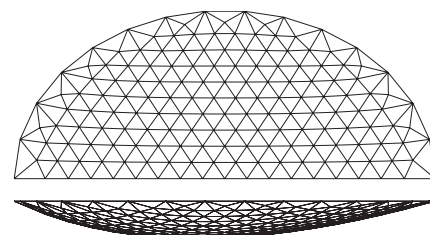


Fig. 5. Optimised prestressed configuration for an off-axis deployable reflector antenna.

Deployment of inflatable structures

Thin-film inflatable structures are suitable for use in space because of their low weight, small packaged volume and mechanical simplicity. As it is impossible to test such structures on Earth, numerical simulation is the only option.

This work investigated the possibility of using inflatable tubes as cables in a so-called tensegrity mast. Mast deployment is achieved by pressurising the tubes, which form one continuous volume.

The deployment simulations are performed using the explicit dynamics software LS-DYNA. The fluid-structure interaction is simulated using the control volume method (mesh-free fluid). A phased gas flow is simulated by assuming an ideal gas and letting the control volumes ventilate into each other. Folding is achieved by applying gravity and point loads.

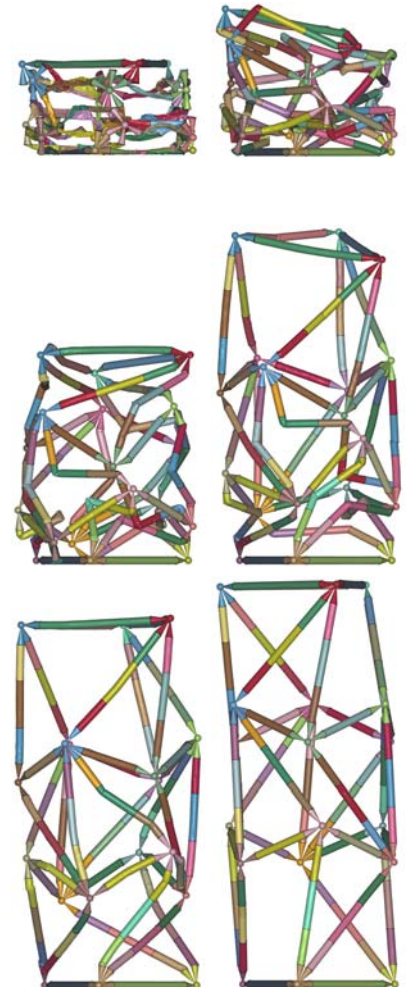


Fig. 6. Deployment simulation of a three-stage tensegrity structure.

Acknowledgments

The deployment simulations of the inflatable structures were performed by Colin Russell for his MSc thesis. Gunnar Tibert is sponsored by VR (Swedish Research Council, project 2002-5688).