The Use Of Non-standard Devices In Finite Element Analysis

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Membrane & Cable Structures

- Are able to undergo large deformations while remaining in the small strain regime.

  * geometrically non-linear problem

  -- analyses by digital methods require an evolutionary process

- Are generally under-constrained.

  * FE modeling leads to a singular stiffness matrix.

  -- FEA by an implicit solution scheme is prevented.

- Membranes and cables are uni-directional (no compression).

  * Slackness of a structural element may have to be dealt with in the analysis.

Under-constrained structures are common in technology applications

- Assessment of the structural response of such systems is important.
- The analyst must find ways to assess such systems.
- Practical designs generally have the uniqueness property;

  i.e. the system has destiny.

  * There is only one solution for a loading state; this solution is independent of the loading path (evolution).
- Systems that have several solutions do not only pose problems to analysis but also to deployment.

FEM processes that can aid analyses of under-constrained structures

- The dynamic response of a structural system with discrete masses can be analyzed without stiffness matrix inversion using an explicit solution scheme.

  * Requires sufficiently small time steps so that a signal cannot overstep an element.
- Artificial constraints can be used to guide the evolution to the loaded state.

  * Ideally these constraints should be diminished or removed towards the end of the evolution.
- In a non-linear FEA, the evolution to the loaded state can be started by displacement of the boundary to induce self-stress such that the tangent stiffness matrix for the next step has a geometric component that renders the stiffness matrix non-singular.

  * some sufficiently simple problems only

Pseudo-dynamic processes for static problems (No matrix inversion)

- Dynamic Relaxation

  * Arbitrary lumped masses and lumped viscous damping are applied to a static problem.

  * Masses and Dashpots are chosen to make the system nearly critically damped.

  * An explicit solution scheme is used to march through the transient. The post transient solution is the static solution.

  -- Time step size limitations apply to assure stability of the solution process. (Well established in the literature.)

- Evolution using lumped damping alone should work similar to Dynamic Relaxation.

Use of Artificial Constraints in Membrane Structures

- From 1^{st} Order Thin Shell Theory it is known that the membrane solution is essentially decoupled from the bending solution.

  * provided in the early 20^{th} century justification to use membrane analysis prediction for the interior field of a thin shell.

  * provides justification to supply small artificial bending stiffness to a membrane to enable and ease analysis of a membrane mechanics problem.

  -- there is a need to provide checks for validity

Other Methods to Deal With Under-constrained Structures

- One can write constraint equations for inelastic structures.

  * typically non-square matrices are obtained

  -- over-constrained systems imply the possibility of self-stress

  -- under-constrained systems are mobile

  * useful methods involve a pseudo-inverse of a constraint matrix

- Practical methods seem to be limited to structures with one dimensional elements.

- The inclusion of elastic response makes these methods unwieldy.

Slackness of Cables and Wrinkling of Membranes (approximate techniques)

- Slackness of elastic cables can be approximated using a bi-linear representation of the strain response behavior.

- The in-plane component of membrane wrinkling can be modeled by a tension field.

*Tension Field (TF) response can be implemented by a non- linear material model.

*TF response ignores the minutia of the wrinkles.

*Penalty parameter formulation avoids degradation of non-singular status of the stiffness matrix.

*Single integration point reduced integration membrane elements avoid toggling at the tension field boundary

Additional Comments on Wrinkling

- TF response cannot provide details on wrinkles.
- Some progress has been made on characterizing wrinkles in a TF.
- In some cases, the details of the wrinkles are determined by what happens at the boundary of the TF rather than in its interior.

Structural Lack of Fit

- Structural lack of fit can be used to obtain more efficient structural systems.
- In solid structures, structural lack of fit requires force fit at assembly/fabrication.
- Tension only structural elements can be assembled with lack of fit without requiring force fit.

FEA Analyses With Lack of Fit

- In solid structures and some special membrane structures lack of fit is easily implemented in a multi-step solution process; in most membrane structures it is not.
- Structural lack of fit can also be modeled analytically by non-linear material models.

Inclusion of Initial Slackness in Membrane Structures

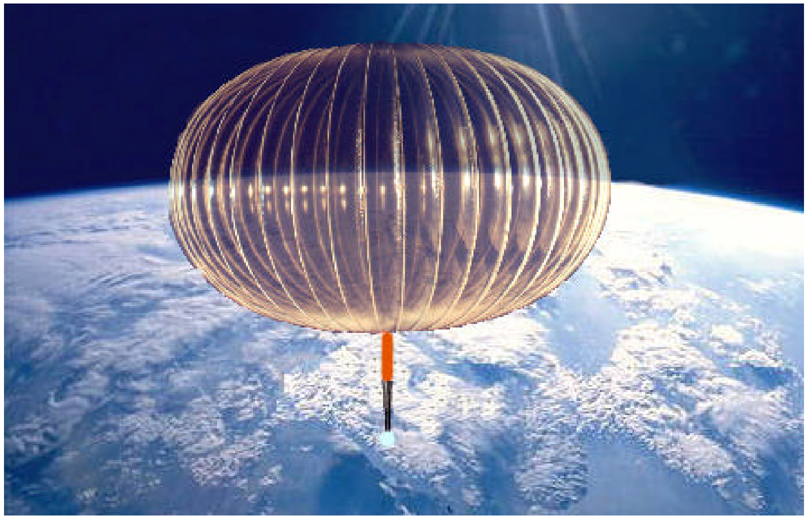
- Membranes with initial slackness

  * In a FE code material excess can be modeled in the material (constitutive law) module.

  * The material module must have Tension Field capability

Pumpkin Shape Super-pressure Balloon

Use of Non-standard Devices



- Small artificial bending stiffness

  *Large enough to overcome numerical difficulties

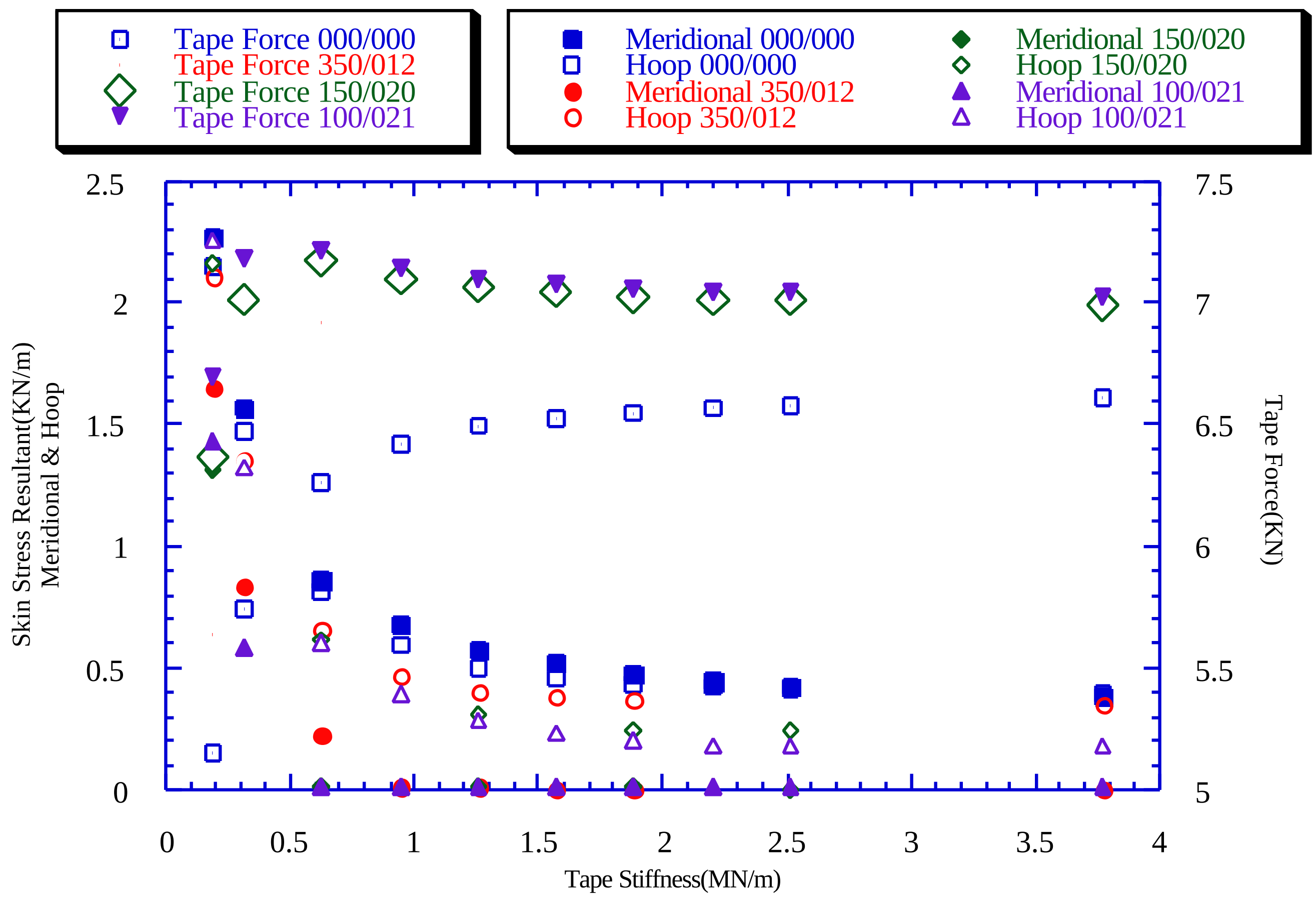
  *Small enough to only negligibly affect membrane solution

- TF to allow wrinkling of skin

- Material excess and lack of fit to obtain favorable strength requirements for design critical state

Pumpkin Shape Super-pressure Balloon

Parametric Study With Film Properties Fixed



Summary of Ideas

- Commercial General Purpose FE Codes provide an arsenal of usually proven tools for large classes of structural systems.
- There are analysis needs that cannot be met using proven commercial codes alone.
- Some of these needs can be met by cautious use of non-standard devices.
- Particular care must be taken to legitimize the use of such devices (possibly on a case by case basis).
- The use of Penalty parameters with the FEM is well established. It’s extension to TF modeling and other features is as legitimate as it’s use for example in contact problems.