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STABILITY LOSS OF TAPE-SPRINGS UNDER COMPRESSIVE LOADS: A FINITE ELEMENT ANALYSIS

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1. Introduction

Tape springs are thin, cylindrical shells that have versatile usage, ranging from simple measuring tapes, through clockwork springs, up to space antennas, hinges and self-deploying structures. They provide easy and compact storage, yet they can be extended to be used as beam-like load bearing elements. Under opposite-sense bending load they can easily lose their stability in a snap-through phenomenon. Although the same-sense bending theoretically also results in a snap-through, experience shows that this cannot be realized as a torsional buckling mode emerges earlier. The usual applications make use either of their storability [1,2], the snap-through phenomenon [3], or the propagating moment, as it provides a practically constant [4], curvature-independent bending characteristic. Although they can be used as load bearing construction elements, their stability under compressive loads (their buckling behavior) was not analyzed. To plan measurements later, it was necessary to perform preliminary investigations to examine the expected behavior of these shell types.

2. Modeling methods

As a first step of the research, an extensive finite element analysis was performed on an arbitrary geometry to investigate the possible modes of stability loss. The finite element model is shown in Fig. 1. In its essence it corresponds to the basic Eulerian pinned-pinned boundary conditions, without restricting the torsion of the shell. The end cross-sections of the beam are not allowed to deform; their degrees of freedom are kinematically coupled to the reference nodes. As in a real scenario it is hard to accurately center the load to the cross-section centroid, the effect of the load position was also investigated. The reference nodes were simultaneously moved around in the $x - y$ plane on a grid shown in Fig. 2, and the buckling analysis was performed with a z directional, 1N compressive load. The first 10 eigenvalues were extracted in the 0-300 range.

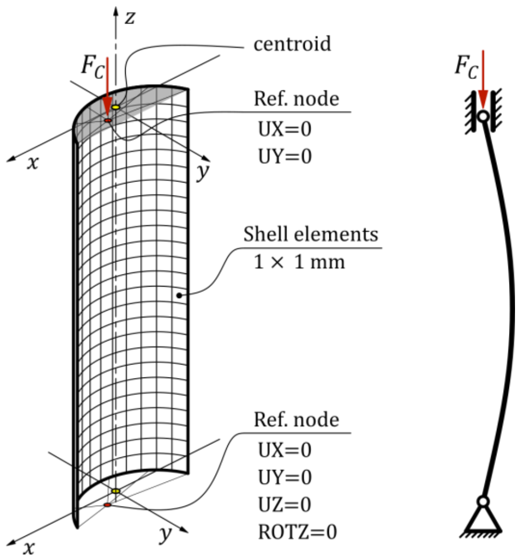

Fig. 1. The FE model and the load case

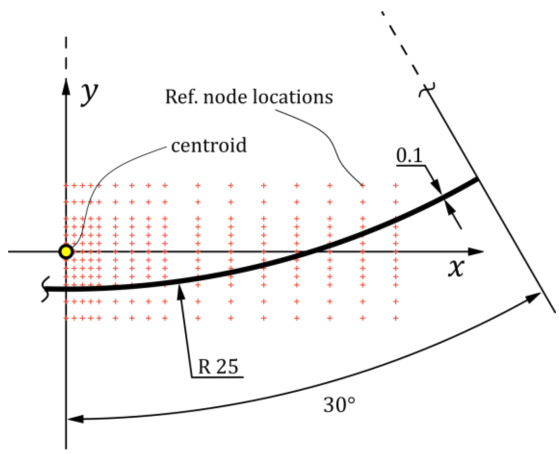

Fig. 2. The reference node locations and shell cross-section geometry

As the beam is prone to the local buckling of the cross-section, a nonlinear analysis was also performed on the shell with the same boundary conditions. For a stable simulation, the loading force was removed and replaced with a compressive displacement load.

3. Results

The results of the linear buckling analysis for the case when the reference nodes coincide with the cross-section centroid of the beam are shown in Fig. 3. Unexpectedly, the first three modes of stability loss include torsion, and only the fourth is the thoroughly investigated bending mode.

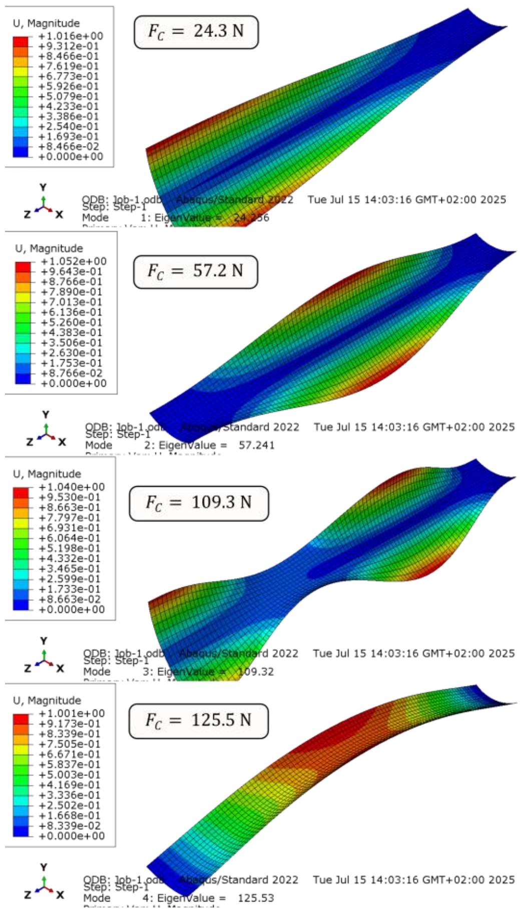

Fig. 3. The first four linear buckling modes when the shell is loaded through the centroid

The nonlinear solution led to a local buckling of the cross-section for every loading point, except for the centroid. The extracted critical force value was identified as the peak compressive load that the shell can withstand. To find the lowest critical force for each location, the first eigenvalue was plotted together with the results of the nonlinear simulations in Fig. 4.

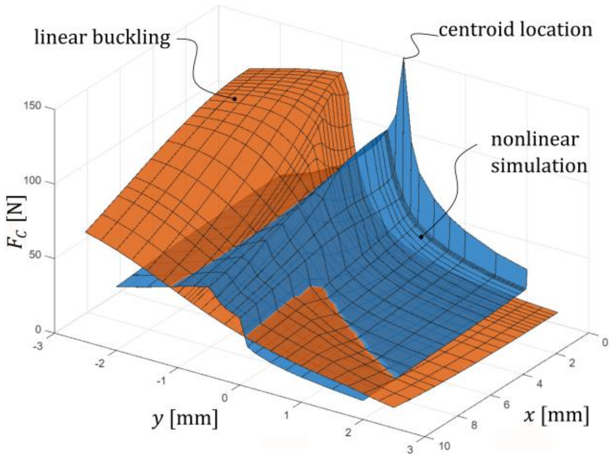

Fig. 4. Critical force values across the cross-section plane for both calculation methods

4. Conclusions

It was found that the critical force and the buckling mode may significantly be affected by the location of load. It was shown that both linear buckling and nonlinear simulations must be performed to find the expected critical force map if it cannot be guaranteed that the loading force is located at the cross-section centroid.

Acknowledgments

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