

Post-buckling analysis based on isogeometric analysis

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Abstract

Under the framework of isogeometric analysis (IGA), a nonlinear stability analysis and post-buckling paths computation procedure, which deals with buckling phenomenon appearing in beam, thin shell and membrane structures with large deformation, is proposed. The basis functions of NURBS (Non-Uniform Rational B-Splines) are employed to describe the displacement field of deformed flexible beam, thin shell and membrane structures. Constraint equations are used to impose the Neumann boundary condition due to the lack of the interpolation property for the NURBS basis functions. Besides, a compressible neo-Hookean model is used to describe the constitutive relation of a hyperelastic membrane material.

A modified version of the arclength method, which can effectively cope with the occurrence of complex roots when solving the quadratic constraint equation, is performed to follow the nonlinear equilibrium path. Then, via the approach of mode injection which can switch the fundamental path to bifurcated branches, the bifurcation analysis is carried out without assuming any initial imperfections in the structure.

Furthermore, in order to improve the computational efficiency, based on Koiter's initial postbuckling theory, a simplified Koiter-Newton approach is proposed to obtain an updated reduced order model to replace the full finite element model, which can be used to solve buckling problems of perfect structures with a relatively larger load step. Koiter's analysis is carried out as a predictor, and then the arclength Newton method is performed as a corrector so that it is accurate over the entire equilibrium path. Compared with the Koiter-Newton method, the proposed approach is more computationally efficient because the high order tensors of the equilibrium equation can be avoided being calculated. In addition, the proposed reduced order model can easily pass not only limit points but also turning points in the equilibrium path, while the Koiter-Newton Method fails when encountering a turning point in which situation the high order term in the reduced order model becomes too large.

Eventually, a set of popular benchmark problems are presented to assess the validity of the proposed procedure. Figure 1 presents a hinged cylindrical shell with a central point load. The full finite element model is computed based on ANCF using the arclength method and mode injection method. As is shown in Figure 2, there are limit points and turning points in the curve when the thickness of the shell is 6.35mm and the proposed reduced order approach succeeds in passing both of them. Figure 3 shows an example of an inflated torus which is made of the hyperelastic membrane material. The proposed approach is capable of correctly and efficiently solving the buckling behavior including both limit and bifurcation points as is shown in Figure 4.

Keywords: Post-buckling, IGA, NURBS, Arc-length method, Simplified Koiter-Newton approach, Bifurcation

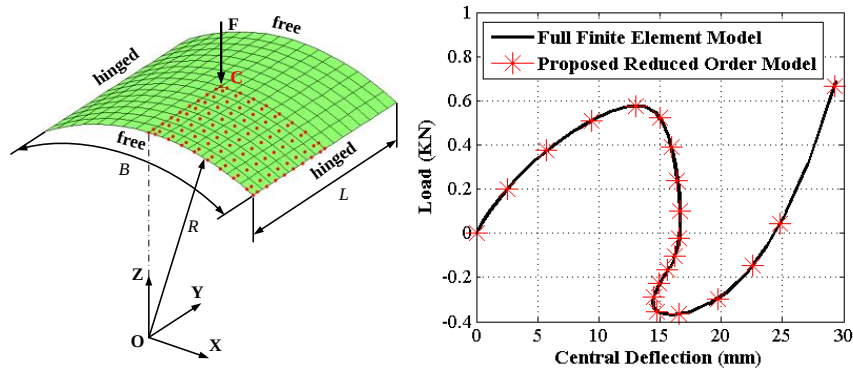


Figure 1. Hinged cylindrical shell with a central point load. Control points in red color.

Figure 2. Load versus displacement curve of the central point (th=6.35mm).

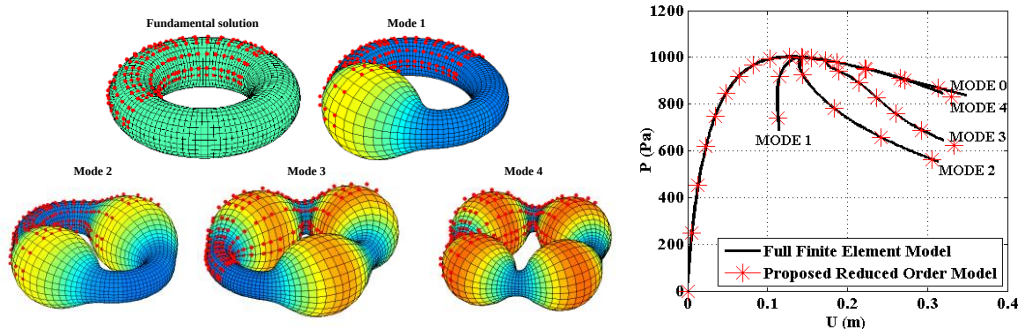


Figure 3. Fundamental solution and buckling modes of the torus with control points in red color.

Figure 4. Pressure versus displacement curves for the torus.

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