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A seven-parameter high-order model for stability analysis of variable angle composites

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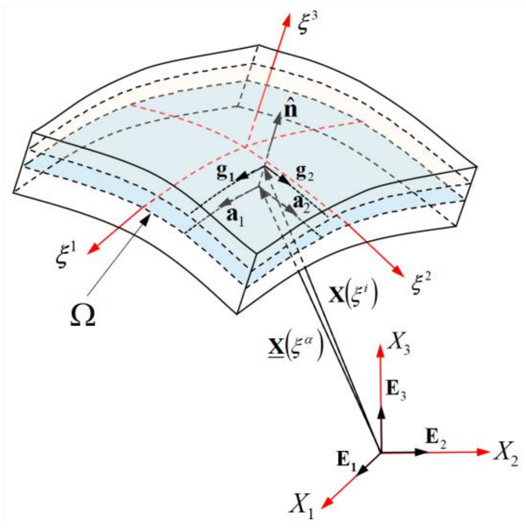
Abstract

This work aims to construct an accurate and efficient model for investigating multi-stable behaviors of variable angle composite. In this model, first a seven-parameter shell formulation [1] with Equivalent Single Layer theory, which is suitable for three-dimensional constitutive laws, is utilized to accurately characterize the large deformation. The fiber orientation angle is described by a linear variation from the center to the end of the shell. Then, to improve the accuracy and to reduce the computational cost, the spectral/hp element [2] with high-order polynomial basis functions is adopted for discretization. Finally, complex nonlinear equilibrium paths are effectively tracked by the Riks method. By comparison with ABAQUS solutions, the proposed model shows to be efficient and accurate for variable angle fiber laminates under various conditions, in which both the buckling, the snap-through and tristability behaviors [3] are studied. Moreover, variable angle fiber shells provide more design possibilities than straight fiber shells. By opportunely varying the fibers angle of each lamina, it is possible to control the stable states as well as to obtain multiple stable configurations (bi- and tri-stability).

Methodology and Context

Geometry of an undeformed shell structure.



Position verctor:

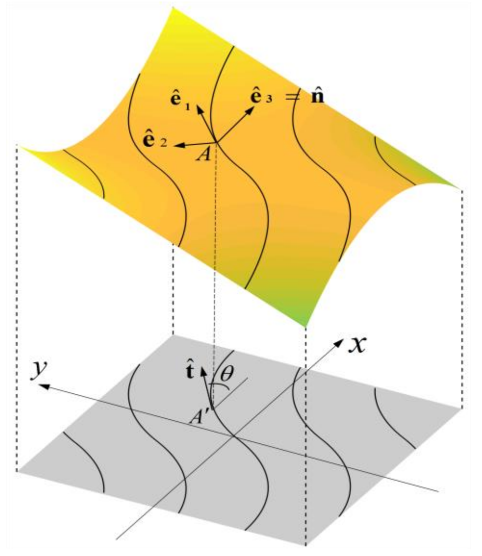
$$\mathbf{X}(\xi^1,\xi^2,\xi^3)=\underline{\mathbf{X}}(\xi^1,\xi^2)+\frac{h}{2}\xi^3\hat{\mathbf{n}}(\xi^1,\xi^2)$$

Displacement field:

$$\mathbf{u}(\xi^1,\xi^2,\xi^3)=\underline{\mathbf{u}}(\xi^1,\xi^2)+\frac{h}{2}\xi^3\boldsymbol{\varphi}(\xi^1,\xi^2)+\frac{h}{2}(\xi^3)^2\psi(\xi^1,\xi^2)\hat{\mathbf{n}}(\xi^1,\xi^2)$$

ψ mitigates the effects of Poisson locking, and avoids modifying the fully three-dimensional constitutive laws.

The definition of fiber path and local orthogonal Cartesian basis.



Definition of the curvilinear fiber path:

$$\theta(x')=\phi+\frac{T_1-T_0}{d}|x'|+T_0$$

Local orthogonal Cartesian basis:

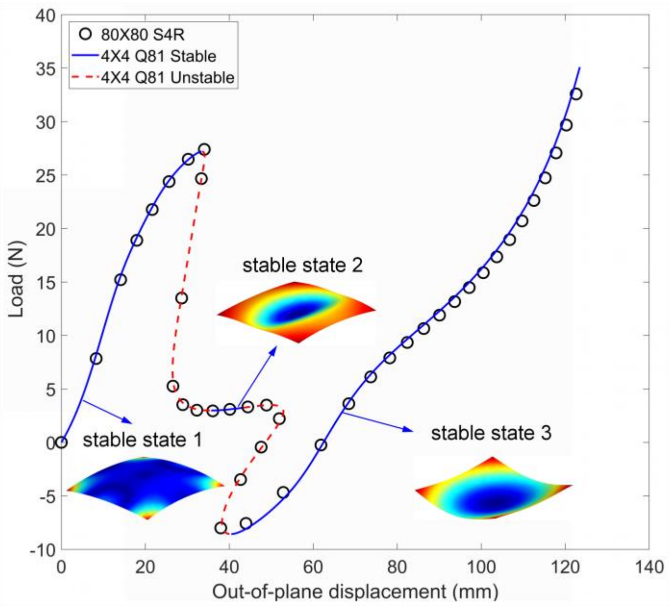
$$\hat{\mathbf{e}}_1=\frac{(\cos\theta,\sin\theta,z)}{\sqrt{1+z^2}}$$

$$\hat{\mathbf{e}}_2=\hat{\mathbf{n}}\times\hat{\mathbf{e}}_1$$

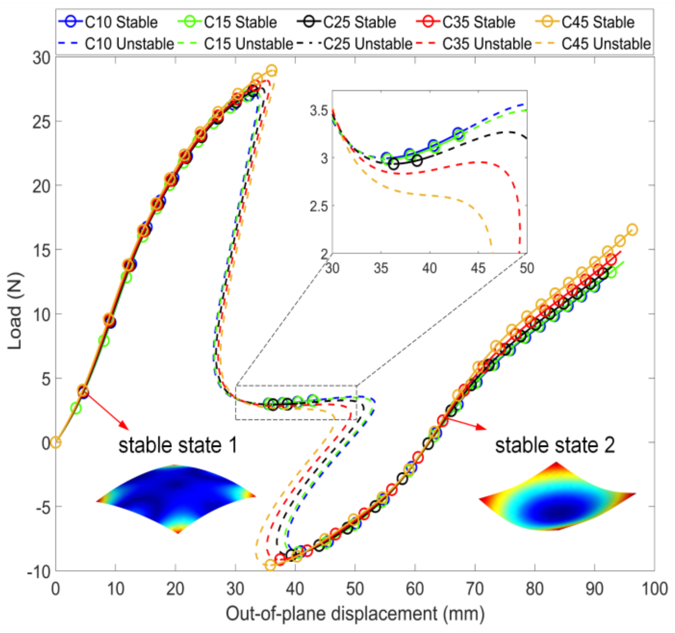
$$\hat{\mathbf{e}}_3=\hat{\mathbf{n}}$$

Results

Tristability of doubly curved shell.



Multistability of doubly curved shell with different fiber path.



Conclusion and perspectives

An accurate and efficient model is developed for the analysis of multi-stable behaviors of variable angle laminates. By comparison with ABAQUS solutions, the proposed model is demonstrated to be efficient and accurate for variable angle laminates analysis under various conditions. In addition, the multi-stability of a doubly curved laminated shell is investigated, which shows that the change of fiber angle makes the composite structure present different stable configurations.

References

[1] G. S. Payette, J. N. Reddy. A seven-parameter spectral/hp finite element formulation for isotropic, laminated composite and functionally graded shell structures. ***Comput Methods Appl Mech Eng*** 278, 664–704 (2014) .

[2] C. Pozrikidis, Finite and spectral element methods using matlab, University of California San Diego, USA (2005).

[3] Z. Kuang, Q. Huang, et al. A computational framework for multi-stability analysis of laminated shells. ***J Mech Phys Solids*** 149, 104317 (2021).