

A Model-Reduction Technique based on Perturbation Method for the Analysis of Variable-Stiffness Shells

Cheng Angelo Yan¹ and Riccardo Vescovini¹

¹ Dipartimento di Scienze e Tecnologie Aerospaziali Politecnico di Milano,
Via La Masa 34, 20156, Milan, Italy.

Email: chengangelo.yan@polimi.it, riccardo.vescovini@polimi.it

Key Words: *Variable-stiffness composite, Shell structures, Postbuckling analysis, Finite element method, Rayleigh-Ritz technique, Perturbation approach*

ABSTRACT

The analysis and design of Variable-Stiffness (VS) plates and shells have gained considerable attention in recent times for their improved performances over classical laminates. The modeling of these innovative configurations demands refined numerical models to capture the complex elastic couplings at different scale levels, from global to local. The solution of such models may be computationally challenging, especially for nonlinear problems.

To address these issues, we propose a novel analysis framework which combines an efficient Finite Element (FE) method, an effective reduction technique, and a fast solution procedure.

Within this approach, the FE formulation is based on the *ps*-version of the Finite Element Method (*ps*-FEM) [1]. Hence high-fidelity numerical models can be generated, with capabilities to capture both the global and local responses through advanced refinement strategies.

From the Full-Order Model (FOM) obtained via the *ps*-FEM, a Reduced-Order Model (ROM) is generated using a Rayleigh-Ritz (R-R) reduction technique [2]. The underlying idea is to decrease the size of the FOM by approximating the solution as a linear combination of a limited number of global shape functions.

Finally, the solution of the ROM is achieved by means of a perturbation approach, called the Asymptotic-Numerical Method (ANM) [3]. With the ANM the solution procedure is greatly accelerated by converting the set of R-R nonlinear equations into a sequence of linear ones, whose solution is very fast.

The present study aims at demonstrating the effectiveness of this framework for predicting the postbuckling response of VS panels. Numerical examples are presented to illustrate this approach can be a valuable tool to assist the analysis and design of VS structures.

REFERENCES

[1] C.A. Yan and R. Vescovini. Application of the *ps*-Version of the Finite Element Method to the Analysis of Laminated Shells. *Materials*, 16(4):1395, 2023

[2] A.K. Noor and J.M. Peters. Bifurcation and post-buckling analysis of laminated composite plates via reduced basis technique. *Computer Methods in Applied Mechanics and Engineering*, 29(3):271–295, 1981

[3] B. Cochelin, N. Damil and M. Potier-Ferry. The asymptotic-numerical method: an efficient perturbation technique for nonlinear structural mechanics. *Revue Européenne des Éléments Finis*, 3(2):281-297, 199