APPLICATION OF RZT-BASED SHELL FINITE ELEMENT FOR MODAL AND STATIC ANALYSIS OF CURVED AND WARPED MULTILAYERED AND SANDWICH STRUCTURES

Daniela Spinazzola[1,*], Giuseppe Credo[1], Marco Gherlone[2]

[1] Structures and NVH Group, Dumarey Automotive Italia, Corso Castelfidardo 36, 10129 Torino, Italy
*daniela.spinazzola@dumarey.com
giuseppe.credo@dumarey.com

[2] Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy
marco.gherlone@polito.it

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ABSTRACT

Advanced composite materials and laminated configurations are widely adopted in aerospace, automotive, naval, and energy sectors, where lightness, strength, and damage resistance are properties strongly required. However, accurately modelling these structures remains a current and intricate challenge due to their pronounced transverse shear deformability, high through-the-thickness anisotropy, and complex geometries. Equivalent Single Layer (ESL) theories use a fixed number of unknowns, but they fail to predict global responses as the stiffness and thickness ratios of the layers increase, whereas Layer Wise (LW) approaches offer higher accuracy at the expense of prohibitive computational cost. Zigzag theories, especially their refined versions, have emerged as an effective compromise, correctly modelling the structural behaviour of composites while preserving computational efficiency.

This work introduces a shell finite element formulation based on Refined Zigzag Theory (RZT) for static and modal analysis of curved multilayered and sandwich structures, also accounting for quadrilateral elements that may be warped (i.e., non-coplanar at the four nodes). The method employs first-order triangular and quadrilateral elements, constructed from a zigzag representation of the in-plane displacements through the laminate thickness while requiring only C^0 continuous shape functions for the interpolation of kinematic variables. Some key strategies adopted to address well-known issues include: anisoparametric interpolation to eliminate the shear locking phenomenon and provide a coarse drilling-rotation degree of freedom; stabilization matrices to add a fine drilling rotation and suppress spurious modes, and a Rigid Link Correction strategy to enable the accurate representation of curved geometries while correcting for element warpage when present, an aspect rarely addressed in RZT-based shell formulations.

An extensive range of applications is presented, including multilayered curved components with elements exhibiting warpage as well as structures with strong transverse heterogeneity. Results include global static response, natural frequencies, modal shapes, and detailed through-the-thickness strain and stress distributions. These outputs are compared with analytical RZT solutions and high-fidelity 3D finite element models.

Overall, the developed RZT shell elements overcome most of the limitations of traditional models and provide a robust, efficient, and broadly applicable framework for modal and static analysis of advanced multilayered and sandwich structures.

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