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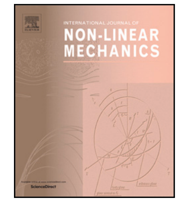

A unified buckling formulation for linear and nonlinear analysis of laminated plates using penalty based C^0 FEM-HSDT model

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ABSTRACT

In this paper, the effect of pre-buckling boundary conditions and the type of nonlinearity for stress stiffening used in different linear and nonlinear buckling approaches is studied for laminated composite plates. The study is conducted using a C^0 finite element (FE) plate model, employing a unified C^1 higher-order shear deformation theory (HSDT). The set of governing equations is derived using the principle of virtual displacement and solved using the tangent-based arc-length method in conjunction with a simple branch switching technique. The performance of the present C^0 FE model is assessed through a validation exercise and comparison with results obtained via the use of ANSYS and, for linear analysis, Navier solution, as well as solutions available in the literature. The influence of the different in-plane loads, boundary conditions, side-to-thickness ratio, fiber orientation, types of imperfection and penalty stiffness matrix are also examined. The results show that the same boundary conditions must be utilized in both pre-buckling and linear eigenvalue analyses for accurate and realistic predictions of critical buckling loads, as confirmed from the nonlinear buckling analyses. Furthermore, the critical buckling loads obtained using Green–Lagrange nonlinearity are observed to be more conservative than those obtained using von Kármán nonlinearity. The nonlinear buckling approach is a generalized approach while the nonlinear eigenvalue approach has a limited range of application.

1. Introduction

Laminated composite structures are finding increasing use across many industries. The primary reasons for their use include their high specific stiffness and strength, the ability to tailor their properties via optimized stacking sequence and ply thickness [1], improved manufacturing methods and understanding of their mechanical properties. Generally, laminated composite plate structures are widely utilized and are often subjected to in-plane mechanical loads that could lead to instability [2]. Further, these plate structures, irrespective of their thicknesses, are susceptible to transverse shear deformation due to their low transverse shear moduli relative to their in-plane Young's moduli. Thus, the importance of considering the effect of transverse shear deformation in the design and stability analysis of composite plates cannot be overemphasized [3].

The design and stability analysis of laminated composite or multilayered plates are commonly based on three approaches: equivalent plate theories [3], layerwise or zigzag [4], and Carrera's unified formulation (CUF) [5]. Equivalent plate theories are predominantly used to determine the response of composite plates in the presence of various loading scenarios because the resulting formulation has a tendency to produce results of acceptable accuracy at low computational cost and are easily implementable [6]. The first and simplest equivalent plate theory is the classical laminated plate theory (CLPT) which assumes transverse normality, constant transverse deformation, and the absence of transverse shear deformation [7]. This theory is suitable for thin

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