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Abstract

The free vibration of variable stiffness laminated composite rectangular plates is studied for the first time on the basis of three-dimensional elasticity theory combined with the *p*-version of the finite element method. Each layer is modeled as one brick *p*-element with curvilinear fibers. The element stiffness and mass matrices are derived based on the principle of virtual displacements. Inter-element compatibility is achieved by matching the generalized displacements at vertices, edges, and faces shared by elements. Results are obtained for frequencies, modal displacements, and modal stresses of symmetric and anti-symmetric laminates with various combinations of free, simply supported, and clamped boundary conditions. The method is validated through convergence study and comparison with published three-dimensional frequencies for constant stiffness laminated composite plates. The frequencies predicted by the equivalent single-layer classical plate theory and first-order shear deformation theory show deviation from three-dimensional solutions. Phenomena such as the discontinuity of inter-laminar modal flexural stresses, change of sign of modal transverse shear stresses through the thickness, and modal cross-sectional warping are observed and explained. New three-dimensional frequencies for variable stiffness laminated composite plates are provided, which may serve as a benchmark for future studies.

Keywords: laminated composite plate; variable stiffness; curvilinear fibers; three-dimensional elasticity; free vibration

1. Introduction

Laminated composite plates are increasingly being used in mechanical, civil, marine, and aerospace engineering applications. A laminate with a higher strength-to-weight ratio can be constructed by combining layers with different fiber orientations. In a constant stiffness laminated composite (CSLC) plate, each layer is reinforced by rectilinear fibers. In a variable stiffness laminated composite (VSLC) plate, each layer is reinforced by curvilinear fibers. The use of curvilinear fibers makes it possible to improve the rigidity and strength of a laminate without increasing its weight.

The free vibration analysis of laminated composite plates is generally based on the following displacement-based theories: the classical laminate plate theory (CLPT), first-order shear deformation theory (FSDT), higher-order shear deformation theories (HSDT), layer-wise laminate theories (LWLT), and three-dimensional (3D) elasticity theory. In the first three theories, a laminate is considered as an equivalent single-layer (ESL) with equivalent mechanical properties. Based on Love-Kirchhoff kinematic assumptions [1], the classical laminate plate theory neglects the effect of transverse shear deformations, which can be significant in all modes of thick laminates and higher modes of thin laminates. The first-order shear deformation theory [2,3] considers the effect of transverse shear deformations. However, a shear correction factor is introduced to account for the non-uniformity of transverse shear stresses through the thickness and the effect of cross-sectional warping is