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Aerospace Science and Technology 112 (2021) 106635

Contents lists available at ScienceDirect

Aerospace Science and Technology

www.elsevier.com/locate/aescte

Geometrically nonlinear flexural analysis of multilayered composite plate using polynomial and non-polynomial shear deformation theories

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A R T I C L E I N F O

Article history:
Received 18 November 2020
Received in revised form 16 February 2021
Accepted 2 March 2021
Available online 17 March 2021
Communicated by Jang-Kyo Kim

Keywords:
Green-Lagrange nonlinearity
Higher-order shear deformation theory (HSDT)
Finite element method

A B S T R A C T

In this paper, the geometrically nonlinear bending analysis of multilayered composite plates is carried out through a rigorous comparative study employing Green-Lagrange and von Kármán nonlinearity. The responses are analyzed for various transverse loads and boundary conditions, and emphasized the impending structural condition, which requires the consideration of full geometric nonlinearity. The study is conducted using a C^0 finite element plate model using third-order and non-polynomial shear deformation theories (TSDT and NPSDT). The principle of virtual work is utilized to formulate the weak-form of governing equations, and discretized using nine-noded Lagrange elements with seven degrees-of-freedom per node. The performance of the present model has been validated by comparing present results with those available in the literature and obtained ANSYS results. The results reveal that the consideration of Green-Lagrange nonlinearity is essential for plates with all sides subjected to movable simply supported boundary conditions or with one free edge. The present study also provides a clear idea about the utilization of TSDT and NPSDT for the anti-symmetric and symmetric cross-ply plate, respectively, to get more accurate solution. Further, the effect of penalty for various theories and problems is also highlighted, and its prominent impact is asserted for some cases.

1. Introduction

The multilayered composite structures such as laminated and sandwich plates are being widely used in the engineering nowadays, and by virtue of their application, they often undergo large deflection of the order of their thickness. The range of their applications lies in aerospace, automobile, defense, railways, shipbuilding, biomedical, polymeric electronic, and other fields. In other words, these multilayered composite material has almost covered every engineering sector ranging from the deep ocean to high in the sky. The reason for this wide application could be attributed to the high stiffness-to-weight ratio, high strength-to-weight ratio, which are accommodated by the composite material through the optimized ply-orientation and thickness variation of plies. Further, the transverse loads are often prominent in these areas of application, making it necessary to consider the shear deformation and the transverse direction characteristic behavior. The composite plate exhibits more transverse shear effects than the isotropic plate due to their low transverse shear moduli relative to the in-plane Young's moduli [1]. Hence, for a reliable prediction of flexural characteristic of multilayered composite plates, shear deformation need to be considered in the modeling.

Therefore, to facilitate the design and analysis process of the multilayered composite plate, different laminated plate theories have been proposed. First in such is the classical laminated plate theory (CLPT), which relies on the assumption of transverse normality and neglects the transverse shear deformation [2]. Following that, first-order shear deformation theory (FSDT) has been proposed, which relaxes the transverse normality condition and accounts for constant transverse shear deformation. However, this leads to a non-zero traction condition at the top and bottom surfaces of the plate [3]. Later, higher-order shear deformation theories (HSDTs) are developed, which ensure traction free boundary condition at the top and bottom surfaces along with parabolic variation of transverse stresses and yield accurate structural analysis [4].

For multilayered composite plates, HSDTs with five field variables are most popular due to the following properties: simple implementation, cheaper computation, and reasonable accuracy compared to other HSDTs with more than five field variables [4]. These higher-order

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https://doi.org/10.1016/j.ast.2021.106635
1270-9638/