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Dynamic analysis of folded laminated composite plate using nonpolynomial shear deformation theory

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In this paper, an efficient C^0 finite element modeling based on higher-order nonpolynomial shear deformation theory (NPSDT) is proposed for the dynamic analysis of folded laminated composite plate. The theoretical formulations are based on nine-noded Lagrange isoparametric finite element and inverse hyperbolic shear deformation theory (IHSDT) as NPSDT. The employed theory, IHSDT, assumes the nonlinear and realistic distribution of transverse shear stresses, and also satisfies the traction-free boundary conditions at the top and bottom surfaces of the plate. Hamilton's principle has been adopted to derive the system's governing equation. A penalty approach has been used to take into account the artificial constraints generated due to incorporation of C^0 Lagrange element. The free vibration pertaining to eigenvalue problem is solved using subspace iteration method. The transient analysis subjected to pressure load and vertical load is carried out using Newmark's direct integration scheme. The formulation has been validated with the available solution in the literature, and several novel solutions have been proposed to address the various practical aspects of folded plate. Numerical illustrations are presented to investigate the effect of various parameters such as crank angle, fiber angle, lamination scheme, fold location, and boundary conditions on the natural frequency and transient response of laminated composite plate.

1. Introduction

The advent of fiber-reinforced laminated composites brought a revolution in the field of structural design and manufacturing due to their high specific stiffness, high strength, and other mechanical properties such as, better tailoring ability through the varying lamination sequence and fiber orientation to meet the specific demand of the application. These advancements in the material properties resulted into the multifaceted utilization of laminated composite plate in various industries. That is why, it encompasses almost all the realm of structural design and manufacturing. Furthermore, structural engineering requires various kinds of structures to be analyzed for the better design and implementation; one such type is the folded plate structure. This type of structure is widely employed in the aircraft fuselages, winglet, vehicle chassis, ship hulls, buildings and bridges, etc. Moreover, the fold geometry structures are verily found in nature as well, such as palm leaves, seashells, etc. So, to understand the folded structure and its dynamic behavior, an extensive analysis need to be carried out considering all the facets of composite.

Initial work in this regard is pioneered by Goldberg and Leve [1] who investigated the exact static analysis of folded plate structures. Latter, Irie et al. [2] utilized Ritz method to calculate the natural frequencies of cantilever folded plates with and without structural symmetry. Ohga and Shinematsu [3] investigated the bending problem of folded plates employing boundary element-transfer matrix method as this method allows them to use for the large number of elements without dealing with the large matrices. Latter, several researchers employed various methods to model the mechanical behavior of folded structures, like finite strip method [4–6], transfer matrix method [7,8], spectral element method [9,10], etc. Further, Duan and Miyamoto [11] developed an effective hybrid/mixed shell element for the analysis of folded plate and curved shell by assuming compatible, non-compatible displacement and stress fields. Hernandez and Neito [12] used mixed interpolation tensorial component (MITC) element, enriched with drilling degree of freedom, to study free vibration

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