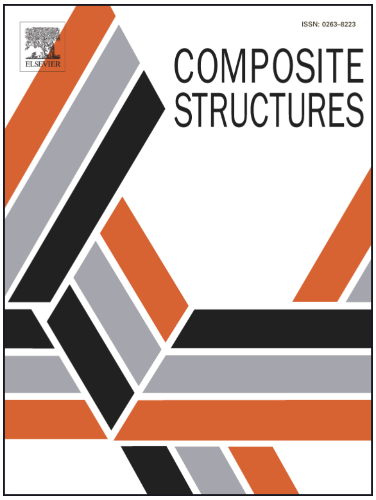

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A geometrically exact formulation of thin laminated composite shells

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Abstract A geometrically exact approach is employed to formulate the equations of motion of thin multi-layered composite shells subject to excitations that cause large strains, displacements, and rotations. Ad hoc truncated kinematic approximations of the obtained semi-intrinsic theory delivers, as a by-product, the kinematics of the Koiter and the Naghdi theories of shells, respectively. Numerical simulations are carried out both for cylindrical and spherical shells: nonlinear equilibrium paths are constructed considering a quasi-static load increase. The comparisons between the results furnished by the geometrically exact theory and those obtained by Koiter and Naghdi theories show the high accuracy of the proposed nonlinear approach. Classical theories become increasingly inaccurate at deflection amplitudes of the order of the shell thickness, evidencing that significant misrepresentations of the system behavior are possible if reduced-order kinematics are taken into account.

Keywords: Nonlinear shells, Composite laminates, Metric tensors, Finite strains, Nonlinear equilibrium paths.

1. Introduction

Thin shells as structural elements occupy a leading position in engineering and, in particular, in civil, mechanical, architectural, aeronautical, and marine engineering (Ventsel & Krauthammer 2001). The wide application of shell structures in engineering is conditioned by their following advantages: (i) efficiency of load-carrying behavior, (ii) high degree of reserved strength and structural integrity, (iii) high strength to weight ratio, (iv) very high stiffness and (vi) containment of space. Shell theories of varying degrees of accuracy were derived, depending on the degree to which the elasticity equations were simplified. The approximations necessary for the development of an adequate theory of shells have been the subject of considerable discussions among investigators in the field. Love (1892) was the first to present a successful approximation shell theory based on classical linear elasticity. E. Reissner (1941) developed the linear theory of thin shells (a first-order approximation theory) where some inadequacies of Love's theory were eliminated. Sanders (1959) and Koiter (1960) also developed a first-order-approximation shell theory from the principle of virtual work and by applying the Kirchhoff–Love assumptions. Timoshenko's theory of thin shells (1959) was very close to the Love theory: general relations and equations were obtained by applying the