Nonlinear Deterministic, Stochastic and Reliability Analysis of Laminated Composite and Functionally Graded Structures

Abstract:

The multilayered laminated composite and functionally graded plates and shell panels are being extensively used in various fields, such as aerospace, marine, civil and automobile industries due to their excellent mechanical properties like high strength and stiffness to weight ratio, low maintenance cost, excellent fatigue and corrosion resistance and ability to withstand high temperature environments. Composite structures are often subjected to severe loading and environmental conditions which cause large deformation, in such cases efficient nonlinear models are required for accurate static, free vibration and buckling analysis. Due to lack of complete control over complicated manufacturing and fabrication processes the randomness and uncertainties are introduced in the material and geometric properties. In addition to this, composites are usually subjected to random environmental and loading conditions; also uncertainties are introduced due to incomplete data or knowledge. For the safe and reliable design of composite structures, all these uncertainties must be accounted in analysis. Direct Monte-Carlo analysis is computationally very expensive for reliability analysis of composite structures using nonlinear finite element models and to handle epistemic uncertainty non-probabilistic methods are necessary. In the present work, the nonlinear C^0 continuous finite element models based on non-polynomial 2D and quasi-3D higher order shear deformation theories in conjunction with Green-Lagrange geometric nonlinearity are developed and utilized for nonlinear bending, buckling and free vibration analysis of laminated composite and functionally graded plates and shallow shell panels in deterministic and stochastic environments. Three surrogate models namely, response surface method, Kriging model and artificial neural network are constructed and employed for uncertainty quantification and reliability analysis in presence of aleatory uncertainty to reduce the computational cost of direct Monte-Carlo simulation. Evidence theory is formulated and utilized for uncertainty quantification and reliability analysis of composite structures in presence of epistemic uncertainty. Dempster's rule of combination is used to combine the information available from two or more experts. The accuracy of the proposed models is tested through the validation study and large number of numerical examples is presented to examine the impact of different material, geometric and loading parameters on nonlinear response of composite structures in deterministic and stochastic environments.

Keywords: Laminated composite shell panel, Functionally graded shell panels, Non-polynomial higher order shear deformation theory, Finite element method, Nonlinear bending, Nonlinear buckling, Nonlinear free vibration, Monte-Carlo simulation, Artificial neural network, Kriging model, Evidence theory.