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Geometrically non-linear static analysis of functionally graded material shells with a discrete double directors shell element

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Abstract

A general shell model, including both theories of thin and thick shells, Kirchhoff-Love and Reissner-Mindlin undergoing finite rotations is presented. Based on Higher-order shear theory, where the fiber is cubic plane, the developed model does not need any transverse shear coefficients. The implementation is applicable to the analysis of isotropic and functionally graded shells undergoing fully geometrically nonlinear mechanical response. Material properties of the shells are assumed to be graded in the thickness direction according to a simple power-law and sigmoid distribution. The accuracy and overall robustness of the developed shell element are illustrated through the solution of several non trivial benchmark problems taken from the literature. The effect of the material distribution on the deflections and stresses is analyzed.

Keywords:
Functionally graded shells; Finite element analysis; Geometrically nonlinear shell theory; Double director vectors; Third-order theory.

1. Introduction

Shells are widely used in various mechanical structures, civil engineering, aerospace and naval. These structures are more and more replaced by composites because of their superior mechanical properties. First, the abrupt change of the properties across the interface between different materials in conventional composite material is the source of cracks. Second, the presence of residual stresses due to the difference in coefficient of thermal expansion of different materials in conventional composite generates a decrease of the lifetime. Third, conventional composites are made to support a moderate temperature. To overcome these thermo-mechanical disadvantages, special kind of composite, known as functionally graded materials (FGMs) with a gradual transition of material properties from one material to another, are made.

The analysis of classical shell structures is based on four kinematic assumptions, which are membrane, Kirchhoff-Love, Reissner-Mindlin and the refined model. Membrane theory, where the bending and shear strain are neglected, is not applicable to thin flexible structures. Kirchhoff-Love theory, where the shear strain are assumed zero, is not acceptable for composite shell [1, 2]. Reissner-Mindlin theory gives a correct overall assessment. Nevertheless, it does not allow a good analysis through the thickness (constant shear). Another disadvantage of the Reissner-Mindlin theory is the need to introduce the transverse shear coefficients. Shear coefficients are easy to obtain for linear isotropic material (5/6). Nevertheless, it appears complex for composites mainly for non-linear behavior law. Some evaluation methods of shear correction coefficients were presented in [3, 4, 5]. To expand the application domain of the first-order models and avoid the shear correction coefficients associated to Reissner-Mindlin theory, a higher-order theories were developed.

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