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A global–local discontinuous Galerkin finite element for finite-deformation analysis of multilayered shells

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Abstract

We present a global–local finite element formulation for the analysis of doubly-curved laminated composite shells. The proposed formulation is applicable to a wide range of problems, including those involving finite strains/rotations, nonlinear constitutive behavior, and static or dynamic structural response. Moreover, in dynamic analysis applications, it can be combined with either explicit or implicit time integration schemes. The global–local framework is based on the superposition of a global displacement field, spanning the thickness of the entire laminate, and local (i.e. layerwise) displacement fields associated with each layer in the laminate. This approach affords highly-resolved representations in regions of critical interest, and allows a smooth transition from higher to lower resolution zones. Discontinuous Galerkin fluxes are used to enforce interlaminar continuity conditions in perfectly-bonded laminates, and the cohesive-zone methodology is used to represent interfacial delamination. Stresses and surface normals are referred to the initial configuration in the proposed total Lagrangian formulation. Assumed natural strain and enhanced assumed strain techniques are employed to alleviate shear locking and other pathologies that are known to afflict bilinear shell elements. The performance of the proposed finite element is examined with the aid of several numerical examples involving thick as well as thin shells.

Keywords: Laminated composite shells, global–local shell theory, dynamic structural analysis, discontinuous Galerkin method, cohesive-zone model, nonlinear finite element analysis, total Lagrangian formulation.

1. Introduction

Multi-layered composite plates and shells are light-weight, high-performance structural components utilized in a variety of application areas, ranging from sports equipment to aerospace and marine structures, where they are required to withstand demanding service conditions. For several decades, thin laminated structures of this type have been the focus of intensive research, aimed at the development of theoretical and computational formulations capable of predicting their performance characteristics and service life, both accurately and efficiently. Contributions to this field of research are surveyed and catalogued in several review articles [1, 2, 3, 4] found in the literature; see also Ref. [5] for a more detailed exposition.

Classical laminated plate/shell theories may be divided into three broad categories [3, 5]: equivalent single layer (ESL), layerwise, and zig-zag theories. In the ESL framework, the variation of the displacement field across the thickness of the entire laminate is assumed to be known *a priori*. Due to this fundamental assumption, ESL-based finite element formulations are simple and efficient, with a number of unknowns that is independent of the number of layers constituting the laminate. However, typically, they can only predict the global response of undamaged, relatively thin structures, and are incapable of resolving local field distributions within the laminate. To remedy these shortcomings, layerwise theories [6, 7, 8, 9, 10] assume independent displacement fields for each layer, thereby

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