A solid-shell finite element formulation based on the Cosserat point theory for modeling composite structures

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Abstract

Laminated structures are characterized by superior mechanical properties such as high strength-to-weight ratio, high-stiffness-to weight ratio, long-term durability, and the ability to be tailored for specific design criteria. Hence, laminated structures have been increasingly applied in various engineering fields including aerospace engineering, automotive engineering, bio-medical engineering, and structural engineering. The analysis of the complex response of such structures requires an advanced finite element formulations.

Recently, a free of locking solid brick element based on the Cosserat point theory has been developed and applied for solving highly nonlinear problems ([1], [2], [3]). The definitions of kinematic quantities and the additive decomposition of the strain energy function to homogeneous and inhomogeneous parts are features that characterize the Cosserat point formulation. In particular, the first part of the strain energy function is written in terms of the average deformation measure and can be defined by any three-dimensional strain energy function for anisotropic materials. The second part of the strain energy function, which controls the inhomogeneous modes of the deformation, is assumed to quadratically depend on the inhomogeneous strain measures. Jabareen and Mtanes [3] developed a new methodology for determining a closed form of the constitutive coefficients of the second part of the strain energy function and showed that brick Cosserat point element is robust, free of hourglass instabilities, and accurate in modeling both three-dimensional and thin structures that undergo large deformations. However, for very thin structures, the well-known locking pathologies in shell structures decrease the accuracy of the Cosserat point element.

Generally speaking, solid-shell elements are three dimensional elements, which involve only displacement degrees of freedom. Recently, a novel solid-shell element ([4]), which is based on the Cosserat point theory, has been developed. In [4], the pointwise Green-Lagrange strain tensor is additively decomposed into homogeneous and inhomogeneous parts, and only the latter part of the strain tensor is modified by the assumed natural strain ANS concept to avoid both curvature-thickness locking and transverse shear locking. Such modification is referred to as the assumed natural inhomogeneous strain ANIS concept. Due to the coupling between homogeneous and inhomogeneous deformations in multi-layered structures, a new methodology for determining the constitutive coefficients of the second part of the strain energy is developed in the present work. To demonstrate the accuracy, robustness, efficiency and applicability of the developed solid-shell Cosserat point element in modeling composite structures, both linear and nonlinear example problems are considered.

Keywords: Cosserat point element; Finite element formulations; Solid-shell; Assumed natural inhomogeneous strain.

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