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Triangular based prismatic finite element for the analysis of orthotropic laminated beams, plates and shells

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Abstract

In this paper, we revisit the FEM solution of laminated plates and shells that nowadays are mostly done by low order solid or shell finite elements enriched by stress or strain fields, or by specific kinematics dedicated to the analysis of such structures. We introduce a triangular based prismatic finite element of any approximation order capable of solving from very thin to very thick laminated plates and shells, with the following properties: (i) locking-free behavior; (ii) good stress distribution even for complex materials; (iii) geometrically exact description of large displacements; and (iv) geometry dedicated to evaluate plates and shells (laminated or not) free of problems due to distorted meshes or ill-conditioned systems as thickness decreases. This triangular based prismatic finite element can also be employed in laminated beams, holding the same properties. The proposed element uses total Lagrangian description based on positions, and its performance regarding the claimed properties is demonstrated in several examples.

Keywords: Finite element method; prismatic element; laminated beams; laminated plates and shells

1 INTRODUCTION

Laminated plates and shells are important structural elements to aeronautics, space, automotive and all sorts of up to date mechanical and civil industries. Its importance is related to their high stiffness and strength to weight ratios. Laminated plates and shells may be classified as very thin, moderately thin, thick and very thick. An analysis of laminated plates and shells must accurately evaluate the stress field, as well as the displacement and rotation fields. This last usually appears when shell elements are being used, and can be recovered when solid elements are employed. For thick and very thick plates and shells displacement and rotations are usually small and accurate results can be achieved considering small displacements and rotations. Nevertheless, a geometric nonlinear analysis is required when large displacements and rotations are present in the analysis of moderately thin and very thin plates and shells.

Nowadays, the Finite Element Method is the most used numerical technique to model laminated plates and shells. In this sense, one finds in literature two main approaches devoted, respectively, to model thick and thin laminates. The formulations dedicated to model thick laminates are concerned with stress and strain accuracy, assuming geometric linear analysis, while formulations concerned with thin laminates are interested with accurate description of large displacements and rotations leaving the accuracy of stresses and strain as a secondary matter.

Regarding large displacements and rotations of thin plates and shells, updated Lagrangian based formulations are the most used FEM techniques, which include corotational formulations [1-8] with ESL (Equivalent Single-Layer) kinematics. These formulations use the Euler-Rodrigues parametrization or quaternions for representation of rotation. Some alternative formulations based on total Lagrangian description for the analysis of geometric nonlinear plates and shells are also present in literature [9-10]. Regarding thick plates and shells, several techniques has also been proposed in order to improve the quality of stress distribution in laminated plates and shells [11-16]. Reference [9] provides an interesting overview of the subject, while an extensive literature review can be found in [17-20]. The works of [21-24] provide analytical solutions, which can be used as benchmarks for numerical analysis.

Historically, the incessant search for reduced computational efforts leads to the development of low-order elements, with a minimum number of degrees of freedom. These elements, however, suffer from locking that can be classified as volumetric locking, transverse shear locking and membrane locking [25]. The solution for these problems also leads to the development of different strategies, looking either for better stress distribution fields or for better displacement descriptions.