Finite strain quadrilateral shell using least-squares fit of relative Lagrangian in-plane strains

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1. Introduction

Finite strain plasticity and fracture simulations with finite elements (cf. [8,10]) are particularly demanding with respect to numerical efficiency. Newton iteration robustness and mesh distortion insensitivity. This is relevant in the edge-based algorithms recently proposed [12] when applied to quadrilaterals. Many of the intricate element formulations, such as enhanced-assumed-strain, hybrid stress, discrete Kirchhoff (DK, cf. [14]), are suitable for smooth problems where the mesh distortion sensitivity is not a crucial factor and governing equations do not contain discontinuities. In addition, costs associated with convergence difficulties and static condensation (specifically with EAS) can also be high. We take a different approach here: starting with a mixed 4-field functional (displacement field, director field, components of the local Cauchy–Green tensor and the corresponding stress-like Lagrange multipliers), we discretize the resulting Euler–Lagrange equations making use of suitable shape functions. A complete testing program is then performed. The set of obstacle problems for shells are the classical plate and shell benchmarks and extensions to finite strains. Testing elements in finite strains is also important since some instabilities have been found in the past (see [22] for a report with the Morley-based shell). Element technology for quadrilaterals is too vast to be accounted in a single article and many elements proposed in the last three decades vary only slightly in performance for the same number of degrees-of-freedom. Some important works must be mentioned. A milestone in the removal of transverse shear locking was achieved with the assumed natural strain (ANS) technique in 1984 and 1986 [24,36]. A decade earlier,