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A low-order locking-free hybrid discontinuous Galerkin element formulation for large deformations

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Abstract

In this work, a hybrid discontinuous Galerkin (dG) quadrilateral element formulation is presented. As usual in hybrid formulations, the interior of the elements is treated separately from the skeleton, which represents the element boundaries. These are kinematically decoupled, i.e., displacement jumps can occur between the skeleton and the interior of the elements. The global degrees of freedom (dofs) are defined on the skeleton as the displacements at the corners, which allows the implementation into existing finite element codes. As usual in hybrid dG-formulations, the degrees of freedom in the interior are condensed out on the element level, leading to the same number of global degrees of freedom as for continuous bilinear elements.
Instead of using conventional shape functions in the interior, the deformation gradient $\boldsymbol{F}$ is assumed constant within the element. Furthermore, $\boldsymbol{F}$ is connected to the skeleton degrees of freedom via the weak form. This leads to a very simple formulation and implementation. The element is tested for several computational examples from the literature. Special choices of the penalty parameter are investigated, which are partially derived analytically. It is found that the element is free of volumetric and shear locking. Moreover, the convergence is similar to that of other well-known locking-free finite element formulations.

Keywords: Discontinuous Galerkin, locking, geometrical nonlinearity

1 Introduction

Partial differential equations arise in various fields of engineering, like solid mechanics, fluid mechanics, acoustics or magnetics. Solutions are usually obtained by discretization schemes like the finite element method, dividing the continuous model into finite sub-domains. Most of these discretization methods are conforming, like the conventional continuous Galerkin methods. Nonetheless, novel methods have partially abandoned this necessity lately. One of these non-conforming methods, discussed in this paper, is the class of discontinuous Galerkin schemes. Since discontinuous Galerkin methods are rather uncommon in solid mechanics, an (incomplete) overview of the development of discontinuous Galerkin methods is given in the sequel, which is intended to describe some aspects of the history of this class of discretization methods to readers being unfamiliar with the field.
For the first time, a discontinuous Galerkin method was introduced by Reed and Hill (1973) in order to solve a linear first-order hyperbolic problem of neutron transport. Unlike conventional continuous Galerkin methods, discontinuous Galerkin (dG) methods allow discontinuities between the element sub-domains through integration by parts on the individual elements. However, this usually requires the solution to be stabilized, which is often achieved through a penalty term, which goes back to the ideas of Nitsche (1971). The study of dG formulations increased rapidly thereafter, in particular for hyperbolic and near hyperbolic problems (e.g. Johnson and Pitkäranta, 1986; Johnson, 1993; Krivodonova et al., 2004; Brezzi et al.,