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Hierarchic isogeometric large rotation shell elements including linearized transverse shear parametrization

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Abstract

Two novel hierarchic finite element formulations for geometrically nonlinear shell analysis including the effects of transverse shear are presented. Both methods combine a fully nonlinear Kirchhoff-Love shell model with hierarchically added linearized transverse shear components. Thus, large rotations can be taken into account while circumventing the peculiar task of finding a corresponding parametrization of the rotation tensor. The two formulations differ in the way the transverse shear effects are included, either using hierarchic rotations or hierarchic displacements. The underlying assertion is that in most practical applications the transverse shear angles are small even for large deformations. This is confirmed by various numerical experiments. The hierarchic construction results in an additive strain decomposition into parts resulting from membrane and bending deformation and additional contributions from transverse shear. It requires at least C^1-continuous shape functions, which can be easily established within the isogeometric context using spline based finite elements. As reported earlier, this concept is intrinsically free from transverse shear locking. In the nonlinear case it dramatically facilitates representation of large rotations in shell analysis.

Keywords:
Rotation-free Reissner-Mindlin shell, hierachic shell model, isogeometric analysis, locking, linearized transverse shear, large rotations

1. Introduction

Today, finite element formulations for geometrically nonlinear analysis of shells including transverse shear effects are state-of-the-art in both scientific and commercial finite element codes. Although an enormous amount of related work exists there are still some open issues. The present work focuses on the possibility of representing large rotations without actually parametrizing the corresponding rotation tensor. To the authors' best knowledge, such a so-called 5-parameter shell element formulation has not been described in the literature before.

Rotation-free parametrization is quite natural for Kirchhoff-Love type shells, where the rotations are obtained from partial derivatives of the displacement field or corresponding tangent spaces of the underlying manifold. But conventional Reissner-Mindlin type shell formulations, including independent rotations, require a feasible parametrization of the rotation space $SO(3)$ (the space of proper orthogonal transformations in three dimensions). The present paper describes a method for which this is not needed. As the underlying basic idea is closely related to the isogeometric concept, our brief literature overview is restricted to isogeometric shells.

Isogeometric Analysis has been proposed by Hughes and co-workers in 2005 [1], [2]. It is essentially an isoparametric finite element method using splines to generate shape functions. Discretization using splines or NURBS (Non-Uniform Rational B-Splines) provides control of polynomial order and inter-element continuity. In particular, the construction of C^1-continuous approximation spaces is more straightforward than for standard finite elements using Lagrange polynomials. It is quite easily done when using a single patch. For multi-patch analysis or when using T-splines further considerations are necessary.

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