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An Objective 3D Large Deformation Finite Element Formulation for Geometrically Exact Curved Kirchhoff Rods

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Abstract

The objective of this work is the development of a new finite element formulation for beams according to the Kirchhoff theory of thin rods, which includes the deformation states of axial tension, torsion and bending. The proposed formulation accounts for large deformations in three-dimensional problem settings consisting of slender, prismatic beams with arbitrarily curved initial geometries and arbitrary cross-section shapes. Like in geometrically exact Reissner theories the derived deformation measures are geometrically exact in the sense that they are consistent with the strong and weak form of the balance equations and the beam geometry for any configuration and for arbitrarily large translations, rotations and strains. A novel orthogonal interpolation strategy is applied to the triad field representing the cross-section orientation in order to fulfill the Kirchhoff constraint of vanishing shear strains in a strong sense and to preserve the objectivity of the spatially discretized problem. The continuity requirements resulting from the corresponding weak form are fulfilled by a cubic Hermite interpolation, thus leading to a C^1 -continuous representation of the beam centerline. Fundamental properties such as objectivity, path-independence, consistency and accuracy of the developed beam element are verified by means of suitable numerical examples.

Keywords: Geometrically exact Kirchhoff beams, Initial curvature, Large rotations, Objectivity, Finite elements, C^1 -continuous Hermite interpolation

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