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Locking-free variational formulations and isogeometric analysis for the Timoshenko beam models of strain gradient and classical elasticity

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Abstract

The Timoshenko beam bending problem is formulated in the context of strain gradient elasticity for both static and dynamic analysis. Two non-standard variational formulations in the Sobolev space framework are presented in order to avoid the numerical shear locking effect pronounced in the strain gradient context. Both formulations are shown to be reducible to their locking-free counterparts of classical elasticity. Conforming Galerkin discretizations for numerical results are obtained by an isogeometric C^{p-1} -continuous approach with B-spline basis functions of order $p \geq 2$. Convergence analyses cover both statics and free vibrations as well as both strain gradient and classical elasticity. Parameter studies for the thickness and gradient parameters, including micro-inertia terms, demonstrate the capability of the beam model in capturing size effects. Finally, a model comparison between the gradient-elastic Timoshenko and Euler-Bernoulli beam models justifies the relevance of the former, confirmed by experimental results on nano-beams from literature.

Keywords: Timoshenko beam, Variational formulation, Strain gradient elasticity, Isogeometric analysis, Size effect, Shear locking

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