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Mass Scaling for Hierarchic Shear Deformable, Rotation-free Timoshenko Beam Elements

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The goal of this work is to investigate the performance of hierarchic Timoshenko beam elements focusing on the developement of mass matrices. These shear deformable, rotation-free elements allow locking-free discretizations of the Timoshenko beam theory, based on a primal formulation. However, the hierarchic structure also promises advantages in the context of mass scaling, used to accelerate explicit dynamic analyses.

Hierarchic beam and shell elements based on B-splines and NURBS have been introduced by Oesterle et al [1]. They are intrinsically locking-free and their order of convergence is independent of the slenderness already in the pre-asymptotic range, i.e. for coarse meshes. The underlying formulation is based on a re-parametrization of the displacements and rotations by splitting the total displacement into shear and bending parts. This removes the imbalance in the kinematic equation and thus the source of transverse shear locking.

In standard formulation of Timoshenko beam elements, it is well understood that due to the coupling of bending and shear, locking is present and scaling the inertia of shear waves will also have an effect on bending. Selective modification of the shear modes is desirable in the context of mass scaling, but the mentioned coupling leads to non-diagonal mass matrices.

In the analysis of thin-walled structures, where it is desired to get the critical time increased without affecting the response of the system, Cocchetti et al [2] have presented a selectively modified mass matrix for solid shell elements which keeps the low frequency modes unaffected while increasing the critical time step. This has been achieved by a specific transformation of the degrees of freedom that enables direct modification of the modes of desire while retaining the diagonal structure of the mass matrix.

Using hierarchic Timoshenko beam elements, the same is possible in a straightforward manner, without any coupling of degrees of freedom. Due to the analogy of hierarchic Timoshenko beam elements and hierarchic shell elements, this investigation is considered as a proof of concept for a further study on hierarchic shell elements.

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