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A GENERAL MODEL FOR THE NONLINEAR ANALYSIS OF BEAMS INCLUDING THE EFFECTS OF SECTION DISTORTIONS

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A geometrically nonlinear beam model suitable to describe complex 3D effects due to non-uniform warpings including non-standard in-plane distortions of the cross-section or to the anisotropy and heterogeneity of the material is presented.
The basic idea of the proposal is that of generalizing advanced linear formulations for beams as those presented in [1, 2] to the case of large displacements but small strains through the Implicit Corotational Method (ICM) proposed in [3]. ICM extends the corotational description at the continuum level by introducing a corotational reference system for each cross-section. In this system, following a mixed approach, the linear stress tensor is shown to be a good approximation of the Biot nonlinear one, while a quadratic approximation of the strain is easily obtained from the symmetric and the skew-symmetric parts of the displacement gradient of the parent linear solution. The two fields so defined are introduced in the Hellinger-Reissner functional to describe the beam behaviour in terms of generalized static and kinematic quantities only, while change of observer algebra are used to complete the framework. The nonlinear model maintains all the information of its linear counterpart, but is objective and accurate up to the required order. This feature makes it suitable to be used within both a standard incremental iterative approach or FEM implementations of the Koiter asymptotic method. Readers are referred to [4] for its first application to the Saint-Venànt (SV) and the Kirchhoff solutions for beams and plates, while in reference [5] an extension to homogeneous and isotropic beams subjected to variable shear/torsion warping deformations is presented.
The linear formulations used in [1, 2] have been proved to be very effective for modeling beams made by isotropic and homogeneous material or by composites, also when important warping effects including non-standard in-plane distortions of the cross-section arise (see [1] in particular). These models are defined exploiting a semi-analytical solution of the Cauchy continuum problem for beam-like bodies under the usual SV loading conditions, based on a FEM discretization of the cross-section (see also [6] for details). The stress field considered in this way is potentially fully 3D, allowing to recover the SV solution for standard materials (see [7] for instance) or to generalize it to inhomogeneous and anisotropic cross-sections. Furthermore some additional relevant strain modes (generalized warpings) of the cross-section can be defined in a coherent and effective way. On the basis of these information, the 1D linear model is described in a mixed format as required by the ICM framework. As in [7], the displacement field is approximated in terms of a rigid section motion and other relevant

generalized warping modes independently amplified along the beam axial direction. The stress field instead enriches that provided by the generalized SV solution through the contributions due to all the generalized warping effects considered.
With respect to the nonlinear beam model, a mixed finite element suitable to interpolate both the kinematic and static generalized unknowns is proposed. It is implemented inside a Koiter-like asymptotic algorithm. A pseudo-compatible solution scheme is used to improve the computational efficiency of the numerical procedures.
In order to validate the new proposal, numerical tests are shown and results are compared with reference solutions obtained on the bases of solid or shell finite elements which are much more computationally expensive.

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