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Accurate reduced-order models for structures and materials undergoing large 3D deformations and rotations

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ABSTRACT

Structures and materials subject to extreme loads often exhibit large deformations and large rotations in 3D. Modeling of such phenomena is very challenging and has conventionally been done using detailed models of the structure or the material-system using continuum and/or structural finite elements. Using detailed continuum finite element models for large structures can be computationally infeasible and modeling of large deformations and rotations in 3D using structural finite elements (beam/plate/shell) requires complex numerical procedures to achieve good convergence. In this study, we present reduced-order models that utilize combinations of translational and rotational springs in 3D to model complex material and structural behavior. The kinematics of these models is described entirely using nodal coordinates as opposed to nodal rotational degrees of freedom so as to simplify the numerical implementation. The formulation enables us to express the response of every element in terms of not only its own coordinates, but also in terms of the coordinates of all its neighboring elements. The novel aspect of this study is that this approach, although being simple to implement, is able to account for all the dominant modes of response for a large class of problems involving large 3D deformations and rotations. We validate this approach using several benchmark tests and further use it to study two different types of problems. One set of problems involves the study of large frame structures subject to earthquakes and the modeling of their collapse. The other problem is the study of material-systems composed of cellular solids under extreme loads. Using several numerical examples, we show that, within certain limitations, this approach is able to capture the essential characteristics of the response of structures and materials undergoing large 3D deformations and rotations. We also compare its performance to that of conventional methods both in terms of accuracy and computational cost to show that these reduced-order models provide good results at minimal computational cost.