Finite Element Model of Faulting, Folding, and Fracturing of Rocks with Frictional Contact Mechanics

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ABSTRACT

In this work we present a mechanical model to study faulting, folding, and fracturing of geologic materials using finite element modeling and non-linear contact mechanics. We simulate the rigid body translation and finite rotation with nonlinear kinematics; the response of the rock layers with an elastoplastic constitutive law; and the displacement discontinuities along interfaces with finite deformation frictional contact mechanics. Our approach uses a node-to-segment (2D) and node-to-surface (3D) contact element, where arbitrary sliding of a node over the entire interface area is allowed. Our fully implicit finite element implementation considers a penalty scheme to impose the constraints and a regularized friction law to model slip along bedding planes. We employ a return mapping algorithm formulated in principal stress axes to integrate the stresses over discrete loading increments. To better capture the mechanical response of an interface in the tensile region, we present the formulation and numerical implementation of a new cohesive-frictional contact law. With this enhancement to the Coulomb friction law, we can capture the cohesion softening and quasi-brittle tensile failure of geologic interfaces. We show that slip on a thrust fault generates an asymmetric anticline and that the degree of asymmetry is a function of the fault dip and fault depth. We also capture the onset of localized deformations at the tip of the fault and on the forelimb of the fold. In addition, we us contact mechanics to simulate the evolution of existing fractures throughout the folding process. Depending on the orientation and location of these fractures (forelimb, hinge, or backlimb) and the type of folding (symmetric or asymmetric) the fractures open, shear, or close. This work enables us to follow the evolution of the stress state and the discontinuities throughout the deformation process, and to investigate the relationship between fold shape and fault configuration. It is also useful to integrate mechanical and geological principles in order to formulate models constrained by available geological data.