An interfacial model for mode-I and mode-II dynamic crack propagation in rocks with stick–slip contact transitions

Reza Abedi[1], Omid Omidi[1], Robert B. Haber[2], Ahmed Elbanna[3]

[1]Mechanical, Aerospace & Biomedical Engineering, University of Tennessee Space Institute
[2]Mechanical Engineering and Science, University of Illinois at Urbana-Champaign
[3]Civil and Environmental Engineering, University of Illinois at Urbana-Champaign

Abstract

Transitions between separation, contact–stick, and contact–slip modes generate sharp discontinuities in stress and velocity fields. For example, consider a potential contact interface, initially in separation mode, where the two sides approach each other with the same speed. At this stage, there is a nonzero velocity jump while the traction fields on both sides vanish. Upon contact, the response switches abruptly to a compressive stress state that defines the wave strengths and elastodynamic characteristic values, while the velocity jump suddenly vanishes. Discontinuities may also arise in numerical simulations at stick–slip transitions, depending on the details of the friction response and the algorithmic details of a particular computational model. Capturing these discontinuities and sharp transitions presents a significant challenge to the numerical analyst. The problem becomes more challenging when fracture is incorporated, as in dynamic scenarios where a given point on a fracture surface may experience mode-I, mode-II, or mixed-mode crack propagation followed by contact-stick or slip modes associated with crack closure.

We present an interfacial damage model in which the effective stress that drives damage evolution is consistent with a Coulomb friction model. The effective stress, in turn, depends on the normal and shear components of the traction, a friction-type coefficient and a shear strength parameter. This model is particularly relevant in rock contact and fracture applications. We present numerical results that demonstrate the effectiveness of this model in fracture applications where mode-I or mode-II response dominates. In the first example, we study fracture in a rock sample where there is a mismatch between horizontal and vertical compressive loads. A vertical compressive shock load induces maximum shear stresses at +/-45 degrees. We demonstrate that the proposed fracture model predicts cracks forming at a steeper angle closer to the vertical axis, and the fracture mode subsequently transitions to slip mode along the generated fracture lines. We will also present examples involving hydraulic and shock fracturing techniques, such as electrohydraulic discharge methods in rocks.