Dynamic fracture and contact in rocks using an interfacial damage model

Omid Omidi[1], Reza Abedi[1], Saeid Enayatpour[2], Ian McNamara[3], Robert Haber[3]

[1]Mechanical, Aerospace & Biomedical Engineering, University of Tennessee Space Institute (UTSI) / Knoxville (UTK), 411 B. H. Goethert Parkway, Tullahoma, TN 37388
[2]Petroleum and Geosystems Engineering, University of Texas at Austin, 1 University Station C0300, Austin, TX 78712
[3]Mechanical Science and Engineering, University of Illinois at Urbana-Champaign, 1206 W. Green St., Urbana, IL 61801

Abstract

Rocks are heterogeneous at different scales. At small grain scale, they are characterized by the presence of microcracks and granular miscrostructures. In fact, a rock material contains a large number of randomly oriented zones of potential failure in the form of grain boundaries. At large mass scale, they are described by the presence of different rock types, faults and weak features such as fracture networks. These inhomogeneities affect the mechanical response of rocks.

In this paper, an interfacial damage model implemented in a Spacetime Discontinuous Galerkin (SDG) framework is employed to numerically explore the mechanisms underlying rock fracture and contact under dynamic loading. Three main components of our model are: 1) Modeling complicated fracture patterns: Due to the existence of natural fracture networks in rocks, robust numerical methods must be employed for fracture modeling. We use the SDG method's powerful adaptive operations to directly track crack propagation directions with element boundaries. Consequently, unlike eXtended Finite Element Methods (X-FEMs) no basis function enrichments are required inside elements; 2) Contact-fracture mode transitions: Since rocks are often under large compressive loads they experience frequent transitions between various contact modes. We present a seamless framework to transition from the dynamically-consistent contact modes presented in [1] to tensile/shear crack propagation mode; 3) Material inhomogeneities: We employ two approaches to model rock inhomogeneities. First, fractures with random size, location and orientation model natural pre-existing crack-like defects. Second, a probabilistic nucleation approach is used to model generation of new cracks due to excessive loads.

Rocks exhibit two principal responses to stresses being exerted on them, one in tensile mode and another in shear mode. We present two applications where one of these modes is the dominant mechanism of crack propagation. In the first example, hydraulic fracturing, we utilize the adaptive meshing schemes of the SDG method to track new crack surfaces generated by hydraulic pressure on the fracture surfaces. We performed a sensitivity analysis of input variables such as the magnitude of in-situ stress components, number and orientation of induced fractures to demonstrate the effectiveness of our approach in resolving hydraulic fracturing in shale plays. For the second example, a rock specimen with randomly-distributed defects is simulated under dynamic compression. While being mainly in compressive mode, the high shear stresses induced from the impact cause the nucleation of new cracks and propagation of pre-existing microcracks. We will discuss how the initial distribution of defects affects macroscopic fracture patterns.

References
[1] R. Abedi and R. Haber. Riemann solutions and spacetime discontinuous Galerkin method for elastodynamic contact. Comput. Methods Appl. Mech. Engrg., Vol. 270, 150-170, 2014.