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Numerical simulation of rock dynamic fracturing and failure including microscale material randomness

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Abstract

Fracturing simulations in rock as a heterogeneous brittle material, having significant inherent randomness, require including probabilistic considerations at different scales. Crack growth in rocks is generally associated with complex features such as crack path oscillations, microcrack and crack branching events. Two approaches are employed herein to address rock inhomogeneities in dynamic fracture simulations. One is based on considering fractures explicitly with random size, location and orientation as the natural preexisting crack-like defects. In the other one, a probabilistic nucleation technique is applied to implicitly incorporate creation of new cracks during the analysis. Both approaches can be used for rocks in which the natural fractures are oriented in a specific angle, which is applicable to the simulation of sedimentary rocks.

In this study, an interfacial damage model implemented in a Spacetime Discontinuous Galerkin (SDG) framework is utilized to capture the effects of microscale material randomness on dynamic fracturing in rocks. The SDG method offers many advantages over conventional and extended finite element methods including dynamic adaptive meshing, interface tracking, and element-wise conservation. A powerful dynamic mesh adaptivity scheme is implemented to track arbitrary crack paths and align them with element boundaries. Besides, the transitions between different contact modes are well undertaken using a dynamically consistent damage-contact model fitting for rocks under compressive and shear loadings.

Our approach is applicable to rock fracturing as a well stimulation method where an induced major crack propagates and intersects natural fractures. Incorporation of macro-micro crack interactions can explain discrepancies for tracking efficiency between real productivity and computational estimations. The angular bias of the rock formation is also modelled either by having a nonuniform distribution of crack angles, if they are explicitly modelled, or by generating a random strength field that depends on both location and orientation of implicit cracks.