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Explicit and implicit approaches for characterization and fracture analysis of anisotropic rock

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Abstract

Fracture in rock as a heterogeneous brittle material, having significant inherent randomness, requires including probabilistic considerations at different scales. Crack growth in rocks is generally associated with complex features such as crack-path oscillations as well as microcrack and crack branching events. Two methods will be presented to address rock inhomogeneity and anisotropy. In the first method, microcracks are explicitly realized in a domain based on specific statistics of crack length and location. In the second, a statistical model implicitly represents an inhomogeneous field for fracture strength. We use statistical volume elements to derive an angle-dependent fracture strength for a given population of in-situ microcracks and construct a mesoscopic fracture-strength field, In contrast to the explicit approach, no macroscopic cracks exist at the initial time of a failure analysis. Cracks are only nucleated at weak points of the domain (based on the mesoscopic fracture-strength field) and / or at stress concentration points. Both approaches can be applied to rock in which the natural fractures are biased to specific orientations. as in, for example, bedding planes in sedimentary rocks.

At the macroscale, crack growth is modeled by an interfacial damage / contact model. We will present an effective stress (a scalar stress value to derive the damage evolution) that is consistent with the Mohr-Coulomb model. The Mohr-Coulomb model and the interaction between friction angle and rock bedding planes produce interesting physics. Under a uniaxial stress loading and an isotropic rock strength, the Mohr-Coulomb model predicts cracks at angles +/-(45 - ϕ/2), where ϕ is the friction angle. Introduction of anisotropic rock strength not only alters the angles, it also favors one angle over the other. We will present numerical results that demonstrate the effect of anisotropy on compressive rock fracture with explicit and implicit approaches. In addition, we demonstrate how the statistics of an in-situ population of microcracks, e.g., the mean and standard variation of microcrack length, affects the macroscopic response. For a given problem set-up we show that a more uniform population of in-situ microcracks results in higher fracture strength and toughness at the macroscale. However, these advantages are offset by more brittle rock response.