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Numerical simulations of mixed shear and opening modes fluid driven fracture propagation on pre-existing discontinuities

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Hydraulic stimulation of pre-existing fractures is used in deep geothermal development in order to increase reservoir permeability and achieve economical flow rates – with mixed success [1, 2]. Although the primary idea is to shear dilate these pre-existing discontinuities via injection, in a number of field tests [3], a large increase of permeability is only observed when fracture opening has been reached (sometimes denoted as hydraulic jacking). Shearing of pre-existing discontinuities can also occur during more traditional hydraulic fracturing operations in oil and gas reservoirs, either by direct fluid pressurization or via stress transfer from the main fractures. In this contribution, we investigate the fluid-driven growth of a shear crack along a frictional discontinuity and its transition to hydraulic fracturing. We focus on the case of constant friction coefficient, and account for permeability changes associated with both shear dilatancy and fracture opening. An elasto-plastic constitutive relation with a non-associated flow rule is used to model the frictional behavior of the pre-existing discontinuity. We notably present a fully coupled hydro-mechanical solver for this class of problem. This numerical solver combines a boundary element discretization of the fracture(s) for the solution of the quasi-static balance of momentum of the rock mass with a finite element discretization of the width-averaged fluid mass conservation and momentum in the fractures. Using implicit time-stepping, the resulting non-linear system of coupled equations is solved via a Newton-Raphson procedure using the consistent tangent elasto-plastic operator obtained from the local integration of the constitutive relation via a predictor-corrector scheme. We present a number of verification problems for strictly frictional as well as strictly hydraulic fracturing conditions [4]. We then investigate the evolution of both the shear and opening front in terms of the properties of the pre-existing discontinuities (friction and dilatancy), the in-situ and injection conditions. We highlight relevant conditions associated with deep geothermal reservoirs, and discuss the occurrence of different propagation regimes from purely frictional to hydraulic fracturing type. Relevance of the physical model in the scope of naturally occurring small slip events will also be discussed.

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