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Modeling nonlinear diffusion in fractured rock with deformable fractures and applications to injection induced seismicity

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In many applications such as geothermal energy, geological carbon sequestration, unconventional gas recovery, and injection induced seismicity (IIS), there is a need to model flow and transport phenomena in fractured rock. In fractured rock, the hydraulic and mechanical properties of the fractures are extremely sensitive to fluid pressure and other perturbations. Although the general problem of hydromechanical coupling in fractured rock requires a simultaneously coupled solution of the pressure and stress fields, a partially uncoupled solution employing pressure-dependent fracture properties (with a time-invariant stress field) is still insightful. Here we present a model for hydromechanical coupling in fractured rock, implemented within the general-purpose finite element solver FEniCS. The model allows representation of a discrete fracture network (DFN) within a rock mass. Fracture aperture and permeability are allowed to vary with fluid pressure, according to the Bandis constitutive model. Fracture permeability is also allowed to change due to slip events. Pressure diffusion is permitted in the fractures and rock matrix, including hydraulic interactions between them. The model can handle both incompressible and compressible fluids.

We present applications of the model to IIS, interpretation of hydraulic tests in fractured rock, and evaluate concepts such as effective storativity and generalized radial flow dimension. For IIS in particular, we attempt to replicate a seismic cloud dataset collected in Greely, CO –providing insights into how the DFN structure effects the propagation of pressure increases throughout a fractured formation, leading to certain spatial-temporal patterns in induced seismic events. Using a frozen background stress field, seismic events are identified with the Mohr-Coulomb failure criteria. This approach to modeling pressure diffusion in the context of IIS improves over uncoupled approaches that typically only model diffusion (most commonly linear diffusion, with some previous works allowing for nonlinear diffusion) in equivalent porous continua. We also revisit other seismic cloud datasets to further explore relationships between DFN structure and seismic clouds.

References

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