Motivation

Several technologies linked with energy resources inject fluids into the subsurface, which in turn affects the stress field and could possibly reactivate existing faults.

Approaches developed to model coupled multi-phase flow, poromechanics and possible fault reactivation vary in:

- the fault representation (phase-field models, interface elements, finite-thickness elements)
- the description of the slip event (e.g., friction coefficient depends on the slip rate, simple reduction of the friction coefficient)

Here, we propose an approach based on energetic considerations.

Model concept

Equations

Mass and momentum balance of the fluid phases $\alpha$:

$$\frac{\partial (\rho_\alpha \phi_\alpha S_\alpha)}{\partial t} - \text{div} \left( \rho_\alpha \frac{\alpha}{\mu_\alpha} \left( \text{grad} p_\alpha - \phi_\alpha g \right) + \phi_\alpha S_\alpha \frac{\partial \mathbf{u}}{\partial t} \right) = q_\alpha, \quad \alpha \in \{w, n\}.$$  

Momentum balance of the solid:

$$\text{div} (\Delta \sigma + \Delta \sigma_{\text{eff}}) - \phi_{\text{eff}} S_{\alpha} (\phi_\alpha - \phi_\alpha) \mathbf{g} = 0.$$  

Effective porosity (after Han and Dusseault [4]):

$$\phi_{\text{eff}} = \frac{\phi_0 - \text{div} \mathbf{u}}{1 - \text{div} \mathbf{u}}.$$  

Effective permeability (from Rutqvist and Tsang [5]):

$$k_{\text{eff}} = k_0 \exp \left[ 22.2 \left( \frac{\phi_{\text{eff}}}{\phi_0} - 1 \right) \right].$$

Shear failure evaluation

The Mohr-Coulomb criterion is used to evaluate the potential for shear fault reactivation.

A pressure margin between the critical pressure for shear slip $p_{\text{crit}}$ and the effective pressure $p_{\text{eff}}$ can be defined after Rutqvist and Tsang [5]:

$$p_{\text{min}} = p_{\text{eff}} - p_{\text{crit}}.$$  

If $p_{\text{min}}$ is greater than zero, shear failure will happen.

Modelling of shear failure

Characteristics of shear failure

- constant stress drop ($\approx 1$ - $10 \text{ MPa}$) (e.g. Abercrombie and Leary [1]).
- transformation of elastic energy into seismic waves, heat, fracture creation $\rightarrow$ seismic event $\rightarrow$ dissipation of elastic energy

Phenomenological equivalent to shear failure

A combination of a spring and a dashpot in series (“Maxwell material”) transfers elastic energy into heat. If the viscosity $\eta$ of the dashpot is chosen accordingly, the constant stress drop can be reproduced during shear failure. The irreversible displacement of dashpot is then equivalent to the slip on the fault plane.

References