A new phenomenological approach to modelling of shear failure in porous media

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Martin Beck, Gabriele Seitz, Holger Class and Rainer Helmig
Department of Hydromechanics and Modelling of Hydrosystems

LH²
University of Stuttgart
Germany

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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 α:

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

Momentum balance of the solid:

$$\text{div}(\Delta\sigma' + \Delta p_{\text{eff}}\,\mathbf{I}) - \phi_{\text{eff}}\,S_\text{n}\,(\varrho_\text{n} - \varrho_\text{w})\,\mathbf{g} = 0.$$

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

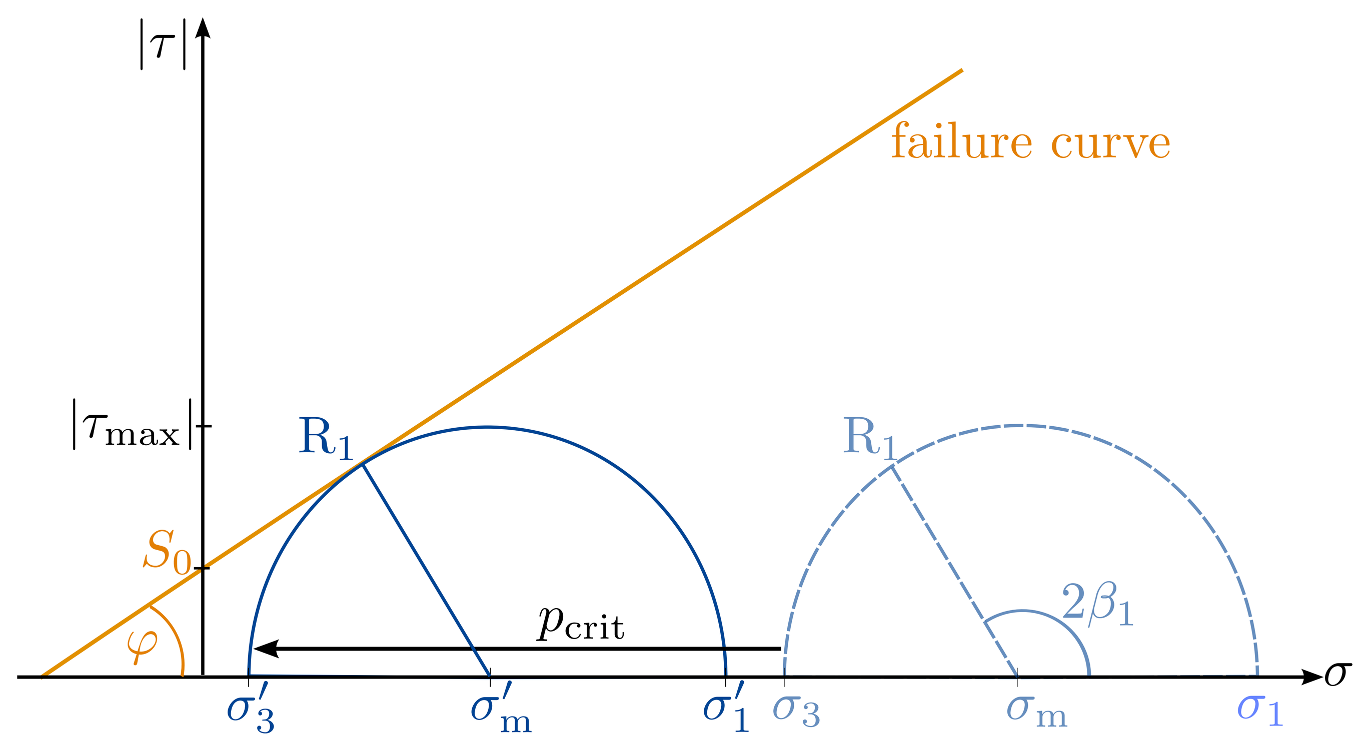
$$\phi_{\text{eff}} = \frac{\phi_0 - \text{div}\,\mathbf{u}}{1 - \text{div}\,\mathbf{u}}$$

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

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

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_{crit} and the effective pressure p_{eff} can be defined after Rutqvist and Tsang [5]:

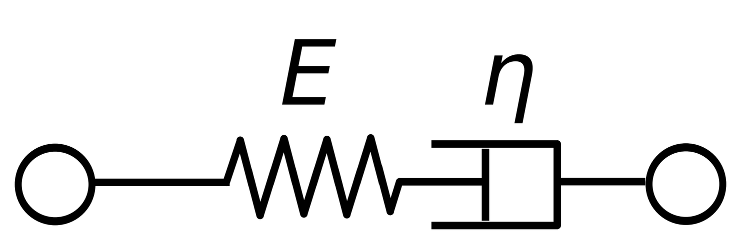
$$p_{\text{sm}} = p_{\text{eff}} - p_{\text{crit}}$$

If p_{sm} is greater than zero, shear failure will happen.

Modelling of shear failure

Characteristics of shear failure

- constant stress drop (≈ 1-10 MPa) (e.g. Abercrombie and Leary [1]).
- transformation of elastic energy into seimic waves, heat, fracture creation → seismic event ≙ 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 η 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.

Numerical experiments

Radial injection scenario

Hydraulic BC

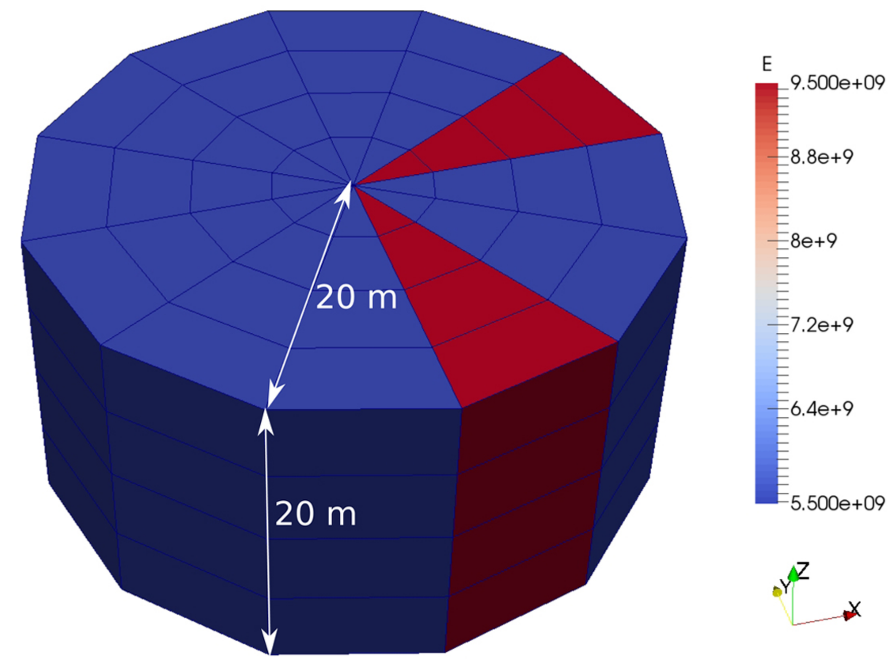
Neumann no-flow for all faces except the borehole, where 40 kg/s (0.032 m^3/s) are injected.

Geomechanical BC

Dirchlet u_x, u_y, u_z = 0 for all lateral faces and the bottom.
Neumann $\Delta\sigma$ = 0 for the top.

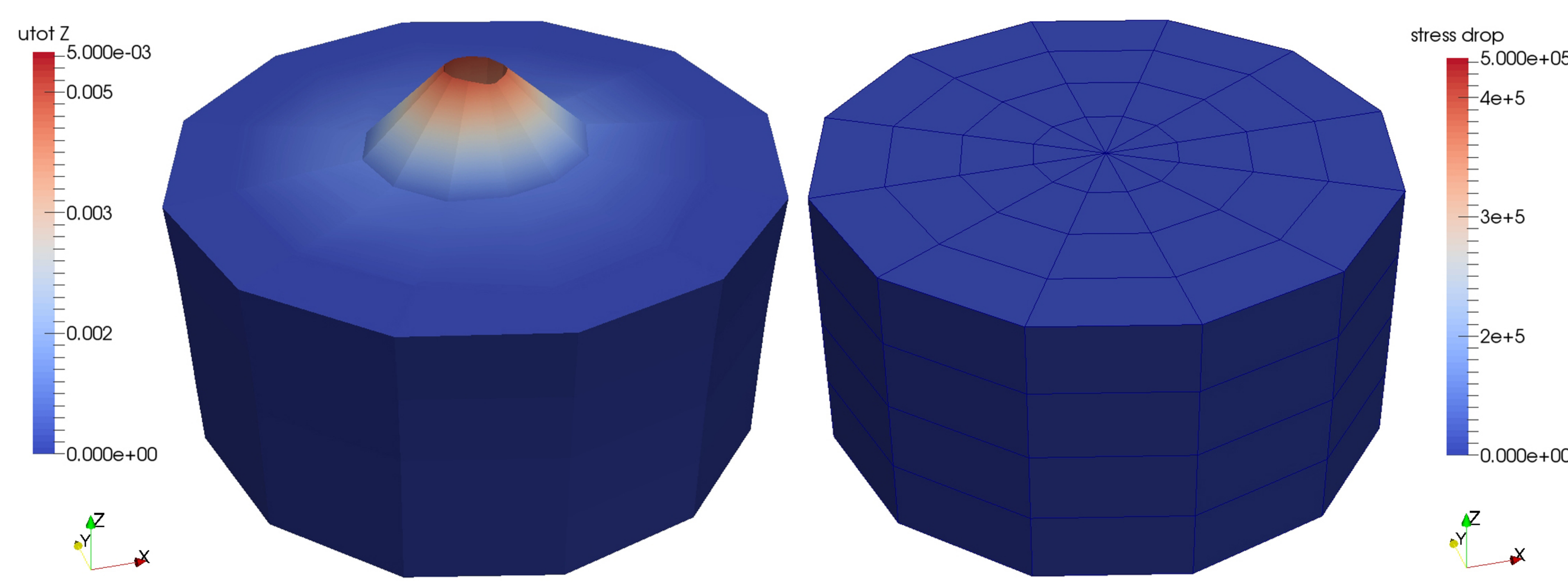
Spatial parameters

$\phi_0 = 0.2$, $K = 1 \cdot 10^{-14}$ m^2 / s

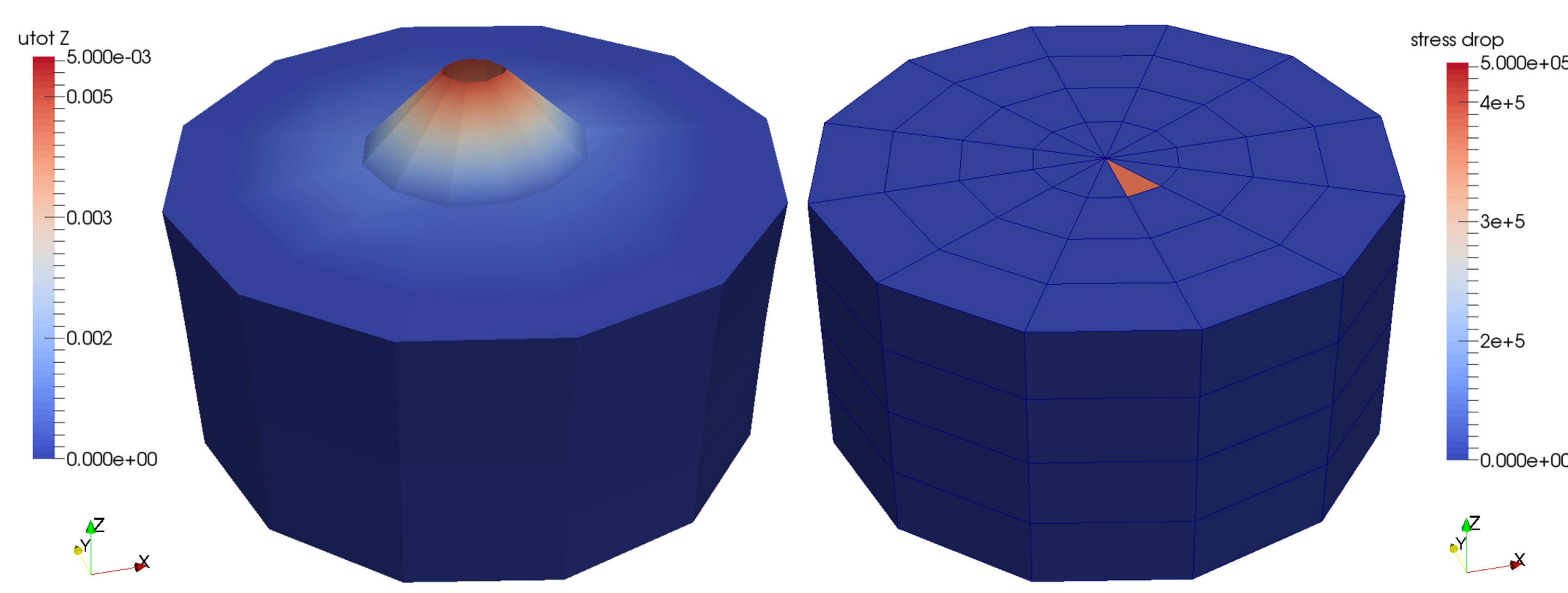


Results

Before failure



After failure



Outlook

- short-term
  implement constitutive relations for porosity and permeability valid for both elastic and plastic deformation
- long-term
  Simulate more representative scenarios, compare setups used by other approaches → benchmark study

References

[1] Abercrombie, R. and Leary, P. (1993). Source parameters of small earthquakes recorded at 2.5 km depth, cajon pass, southern california: implications for earthquake scaling. *Geophysical Research Letters*, 20(14):1511–1514.

[2] Becker, B., Beck, M., Fetzer, T., Flemisch, B., Grüninger, C., Hommel, J., Jambhekar, V., Kissinger, A., Koch, T., Schneider, M., Schröder, N., and Schwenck, N. (2015). DuMuX 2.7.0.

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[5] Rutqvist, J. and Tsang, C.-F. (2002). A study of caprock hydromechanical changes associated with co2-injection into a brine formation. *Environmental Geology*, 42(2-3):296–305.

DuMu[x]
Simulations are performed using the open-source simulator DuMu[x].

DFG
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Link to this poster.