1. Model and problem formulation

Plane strain
Impermeable medium

\( \tau_p = f_p \sigma_o' \)

Friction neutral
\( \tau_r = f_p \sigma_o' \)

\( p_o + \Delta p \)

Friction weakening
\( \tau_w = f_w \sigma_o' \)

\( \delta_w = \delta_w = \infty \)

\( \delta_w = \delta_w = \infty \)

\( f(\delta) = \begin{cases} \frac{f_p - f_w}{f_r} \delta \leq \delta_r & \delta > \delta_r \end{cases} \)

\( f(\delta) = \frac{f_p - f_w}{f_r} \)

\( f_p \)

\( f_r \)

2. Numerics

- Displacement discontinuity method for elasticity (BEM)
- Finite volume scheme for fluid flow
- Fully coupled implicit solver (HFPx2D) developed at EPFL
- Adaptive time stepping based on current crack velocity

3. Theoretical developments

A linear relation between the crack half length and the position of the fluid pressure front due to pore pressure diffusion along the fault exists. Defining the dimensionless half-crack length \( \gamma = \frac{x}{\sqrt{4 \alpha t}} \) (with \( \alpha \) the fluid diffusivity), using the solution for 1D diffusion and stating that \( \tau(\xi) = \tau_p \) inside the crack, the elasticity equation reduce for a planar fault to:

\[ \frac{\tau(\xi) - \tau_o}{f_p \Delta p} = \frac{\tau_r - \tau_o}{f_r \Delta p} = \text{Erfc}[\gamma(\xi)] - \frac{1}{2\pi} \int_{-\infty}^{\xi} \frac{d\xi'}{\sqrt{4\alpha t}} \text{Erfc}[\gamma(\xi')] \]

Dimensionless parameter \( T \) balances stress criticality (prior to the injection) and magnitude of the over-pressure. Asymptotic solution following [Uenishi, K., and J.R. Rice (2003), Gara-gash, D. and Germanovich, L. (2012)] (linear frictional weakening).

4. Benchmark

- Numerical simulations (HFPx2D)
- Marginal pressurized
- Critically stressed
- Asymptote
- Numerical prediction for \( T = 0.2 \)
- Numerical prediction for \( T = 0.3 \)
- Numerical simulation (HFPx2D)

5. Remote activation on weaker part of fault

Stress perturbation ahead of aseismic mother crack tip (superscript \([1]\)) for critically stressed cases, where \( \xi = \frac{x}{\sqrt{4 \alpha t}} \). This can lead to a remote activation of a daughter crack (superscript \([2]\)), on a heterogeneity with lower strength, possibly nucleating dynamically (if frictional weakening occurs).

6. Conclusions

- A-seismic crack tip and pore pressure front can significantly differ:
  - marginally pressurized (fluid pressure front \( \gg \) aseismic crack front)
  - critically stressed (aseismic crack front \( \gg \) fluid pressure front)
- Critical stress faults with a weaker frictional weakening part can exhibit remote fracture nucleation (far away from the pore-pressure disturbance), i.e. activation of a daughter crack with a possible subsequent nucleation of a dynamic rupture
- The dynamic nucleation lengthscale of the daughter crack scales as \( a_w = \delta_w \frac{E'}{2(\gamma_o)} \) following [Uenishi, K., and J.R. Rice (2003), Garagash, D. and Germanovich, L. (2012)] (linear frictional weakening).