Canadian Nuclear Safety Commission
Commission canadienne de sûreté nucléaire

Mathematical Modelling of a Fault Slip Induced by Water Injection

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Content

- Rationale for fault injection experiments and modelling
- Mont Terri fault injection experiments
- Mathematical model for secondary fault injection
- Model results
- Conclusions and future work

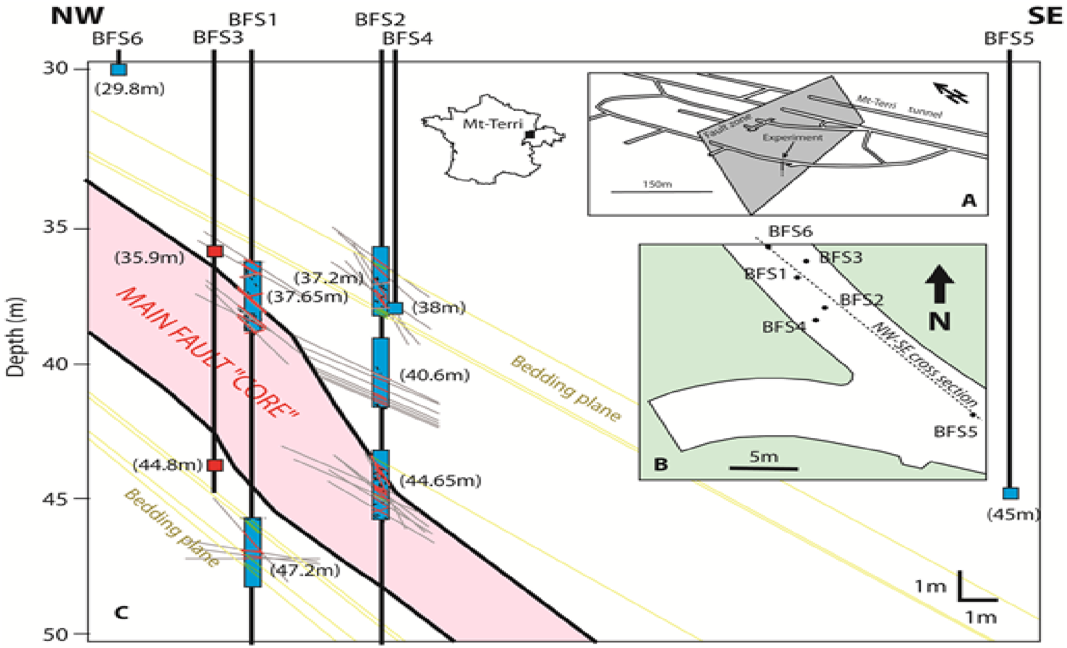
Need to Better Understand Fault Slip Mechanisms

- Induced seismicity due to waste water injection (petroleum industry), CO_2 storage and other activities
- For geological disposal of radioactive waste, potential re-activation of a nearby fault can be caused by several factors such as pore pressure increase due to radiogenic heat or water infiltration after future glaciation-deglaciation cycles

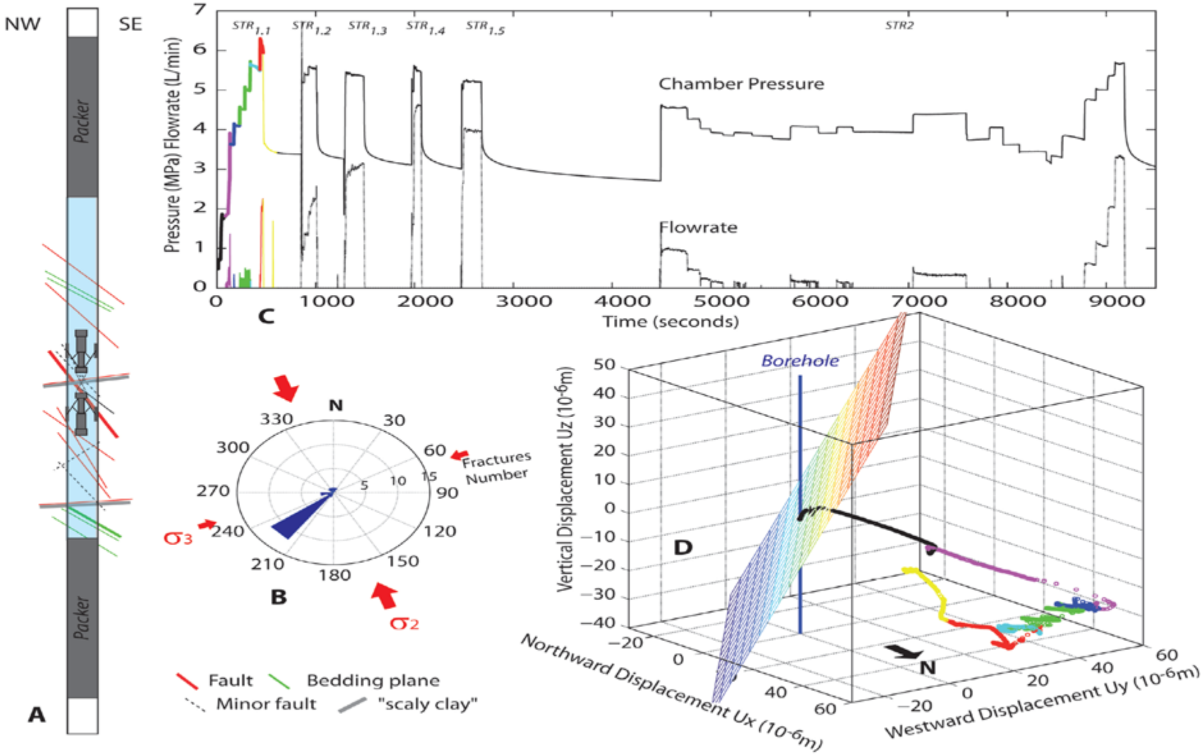
The CNSC Involvement in Fault Slip Modelling

- The Canadian Nuclear Safety Commission (CNSC) is Canada's nuclear regulator
- The CNSC performs independent research on safety aspects related to the deep geological disposal of radioactive waste
- In this example of research, the CNSC collaborates with other researchers on the modelling of fault slip experiments at the Mont Terri underground research facility
- This research will allow a better understanding of fault slip mechanisms and how they might impact the long-term safety of deep geological repositories

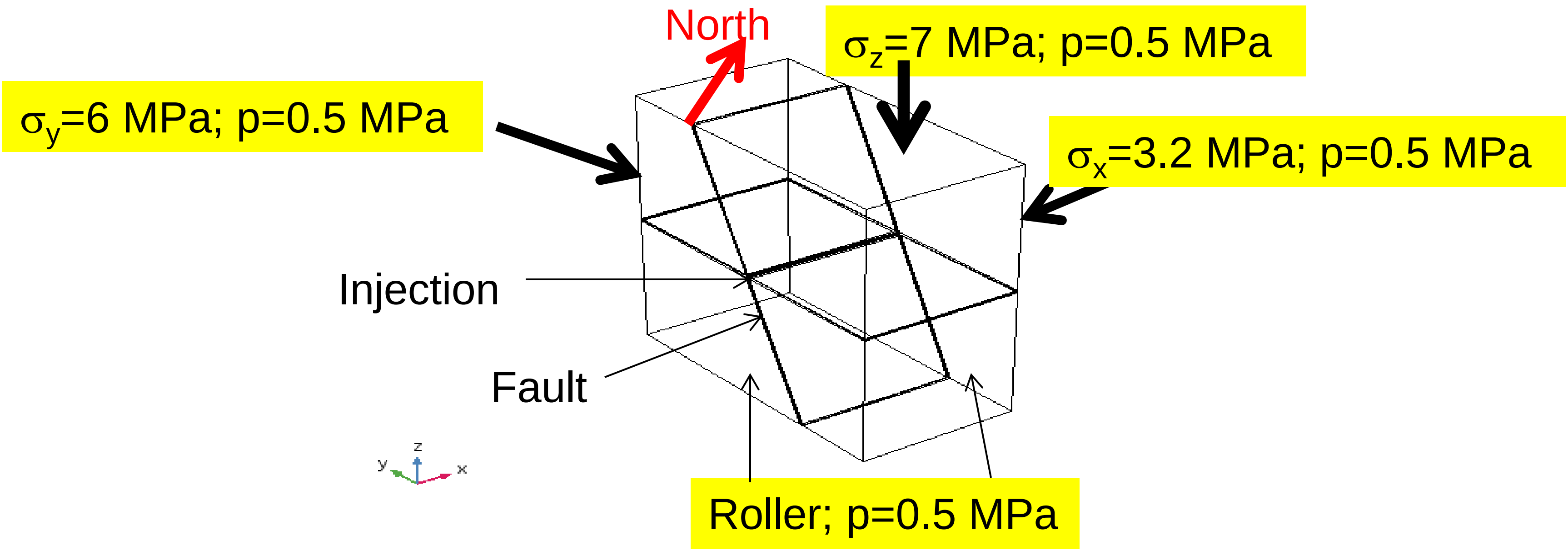
Fault Slip Tests at Mont Terri



Secondary Fault Injection – Experimental Set-up



Secondary Fault Injection – FE Model



Fault plane dip 65°, strike N45°E

Rock Matrix Model

- Rock matrix modelled as isotropic poro-elastic medium:
  - bulk modulus 5.9 GPa, shear modulus 2.3 Gpa
  - permeability 10-20 m2

Fault Mechanical Properties

- Fault modelled as transversely isotropic poro-elastoplastic medium:
  - young moduli: 15 Gpa (perpendicular to fault) 60 Gpa (in fault plane)
  - shear modulus: 4GPa
  - Mohr-Coulomb yield criterion with non-associated flow rule: friction angle 22^{o}, dilation angle 17^{o}

Fault Permeability Model

- Fault permeability:

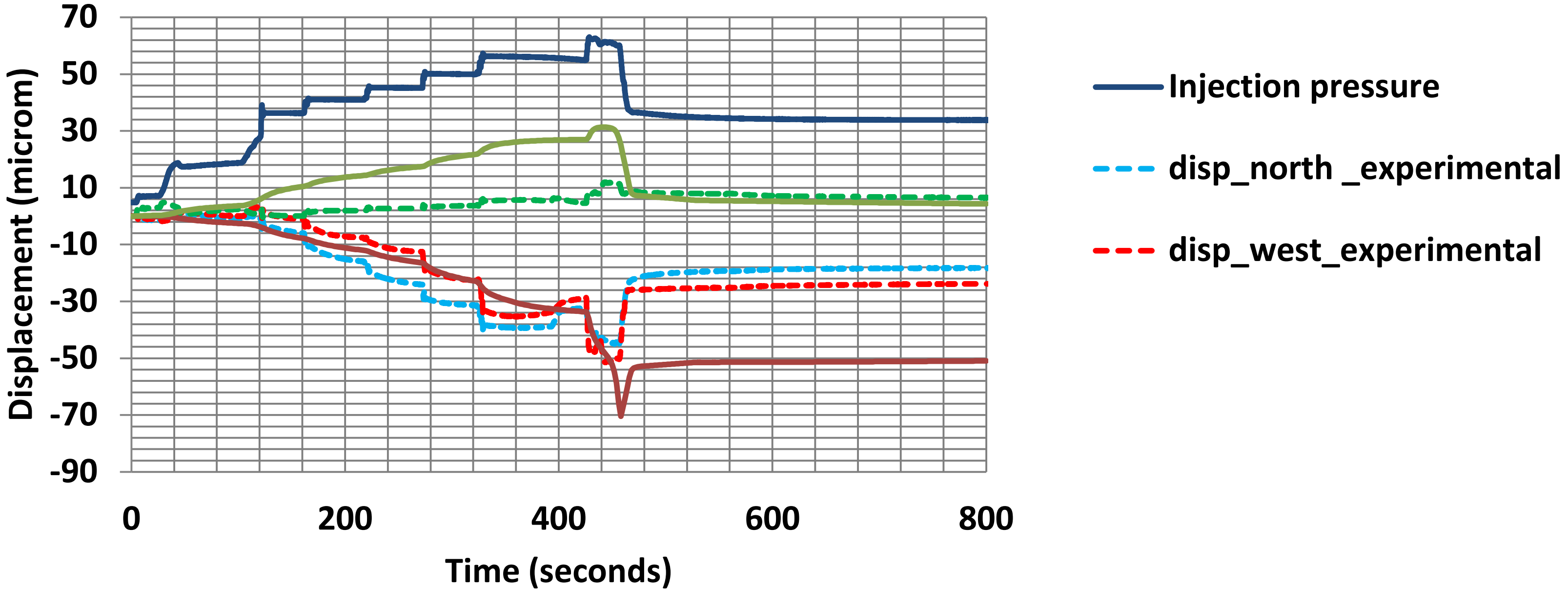
$$k = \frac{b_h^3}{12s}$$

  - s: fracture spacing
  - b_h: hydraulic aperture of each fracture

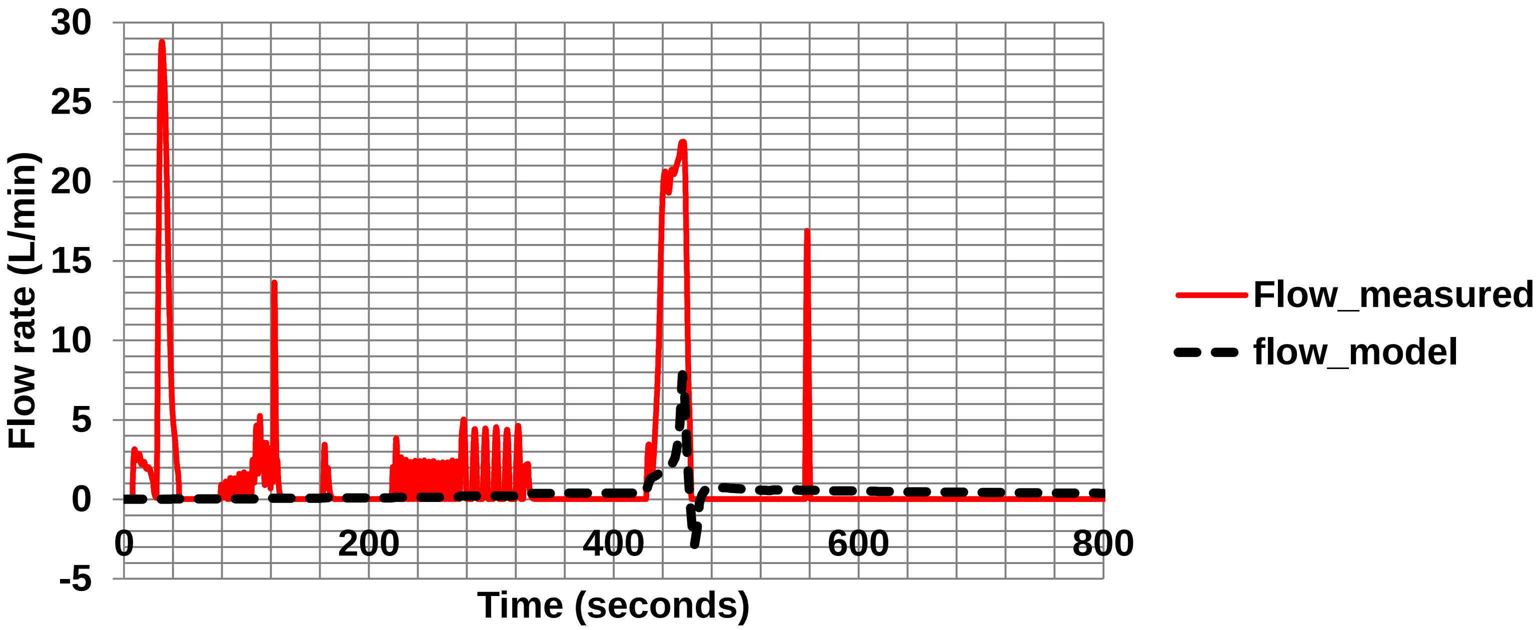
$$b_h = b_{hi} + \Delta b_{he} + A\Delta b_{hp}$$

  - where Db_{he} elastic fracture opening; Db_{hp} plastic opening; A damage enhancing factor

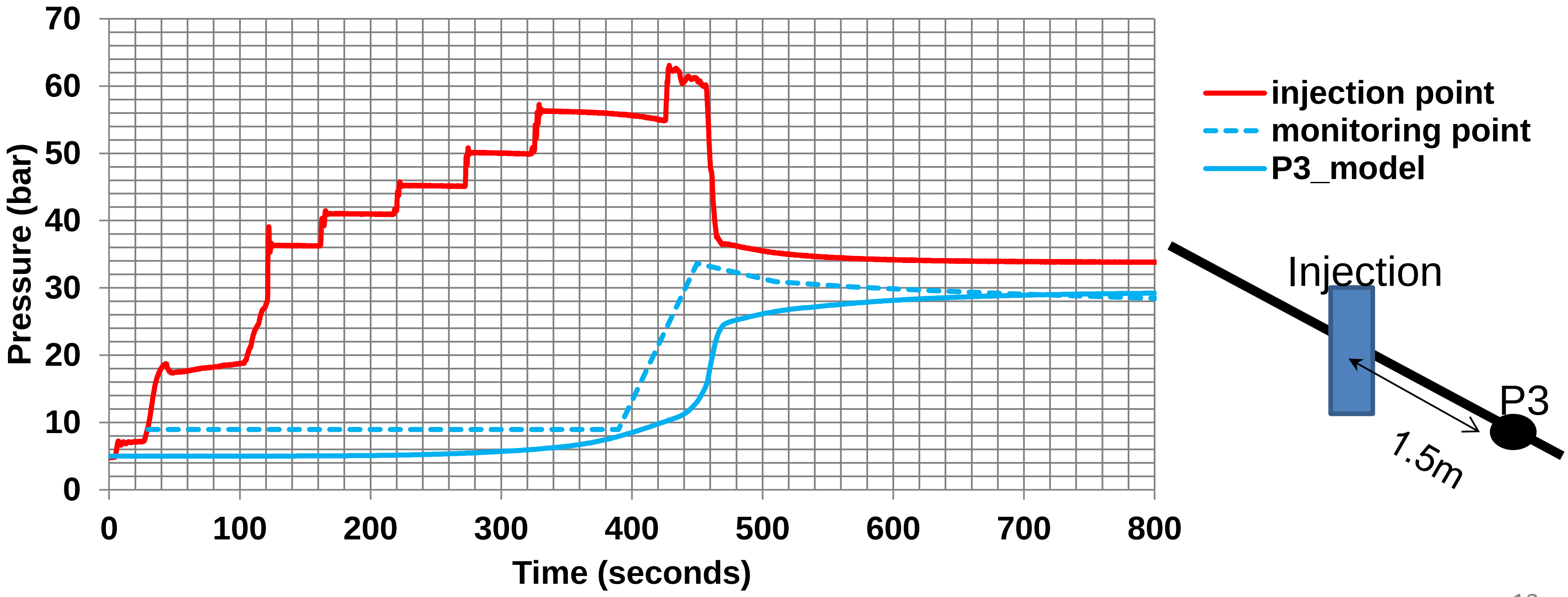
Displacement at Injection Point



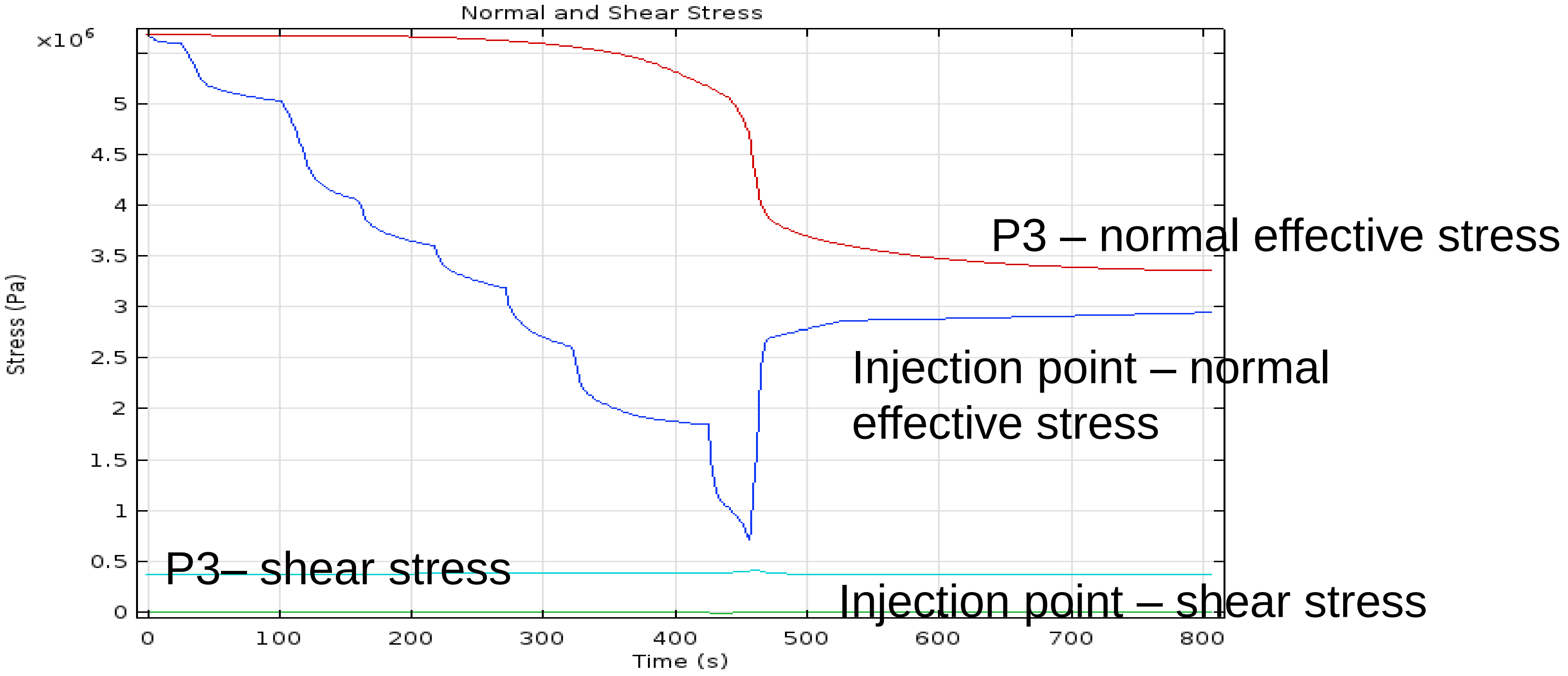
Injection Flow Rate



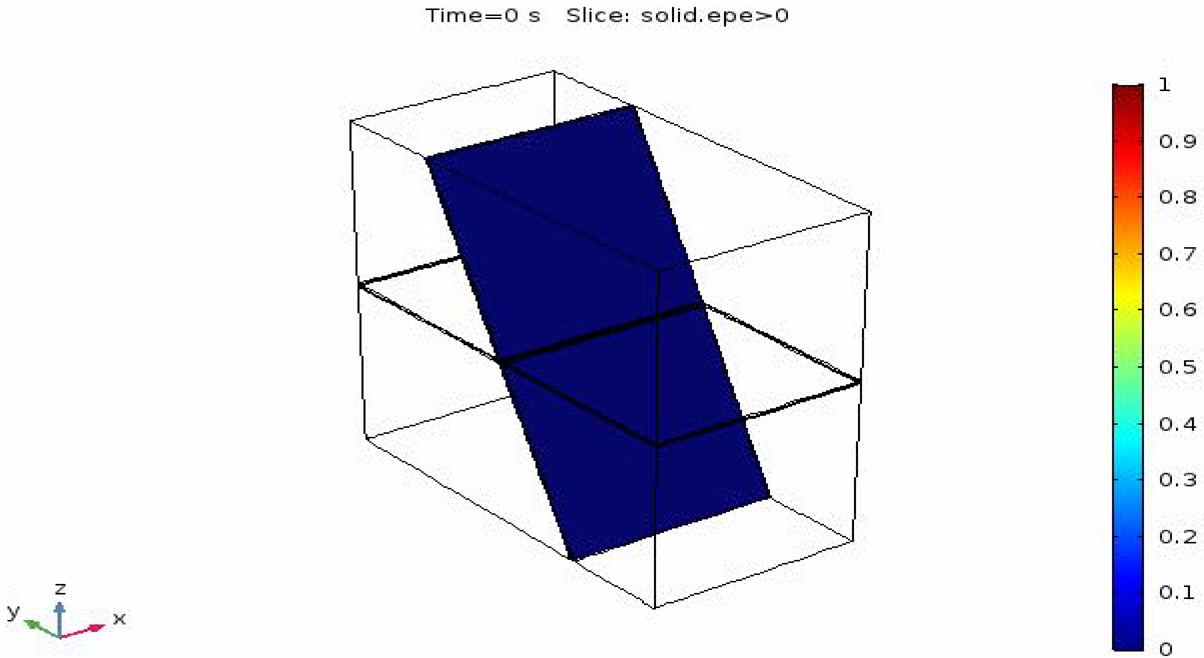
Pressure at Monitoring Point P3



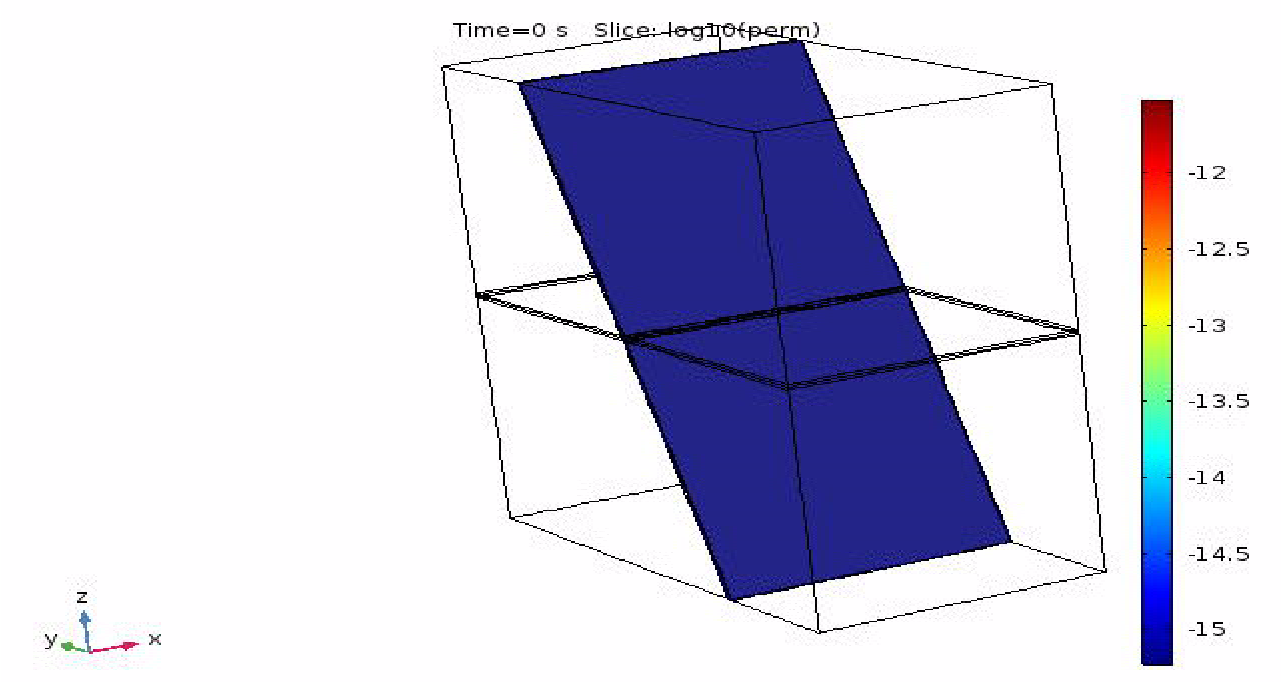
Stresses Along Fault



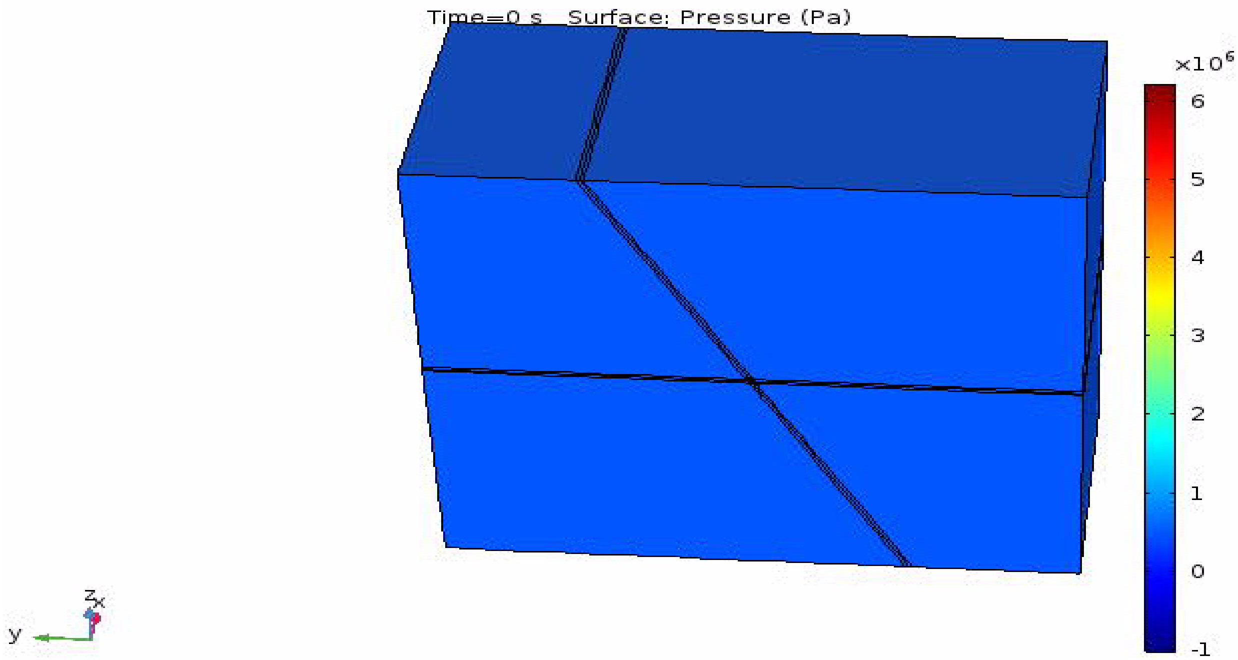
Fault Failure



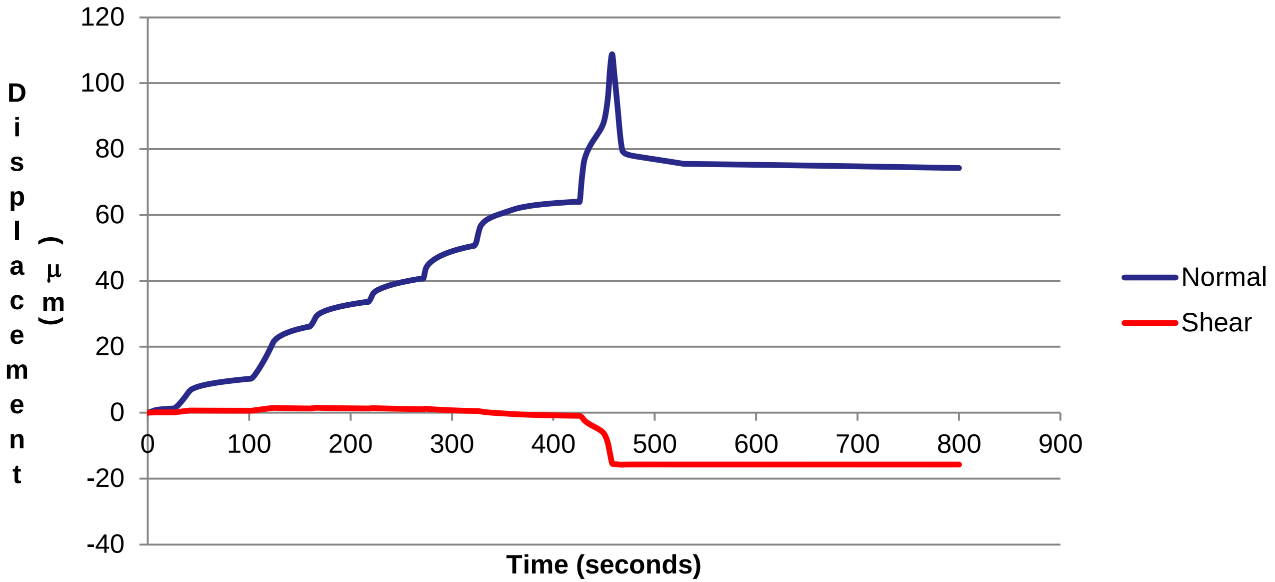
Fault Permeability



Fault Opening and Pressure



Normal and Shear Displacement at Injection Point



Conclusions

- Simulation of fault slip test using poro-elastoplastic framework
- Cause of fault slip and induced seismicity: pore pressure increase
- With increasing injection pressure:
  - the fault permeability first increases imperceptibly
  - at high injection pressure, shear failure develops and propagates, resulting in permeability increase by a few orders of magnitude around the injection point and a sharp increase in the injection flow

Conclusions (2)

- Basic mechanisms seem to be sufficiently captured with poro-elastoplastic framework
- Difficulty resides in characterization of fault properties: heterogeneity, scale effects, anisotropy, spatial variability, permeability relationship with stress and strain
- Future work:
  - modelling of injection in major fault
  - different permeability functions, directionally-dependent plasticity
  - modelling of seismic events triggered by fault slip
  - scoping analysis: effects of radiogenic heat from a waste repository on nearby fault

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