



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), CO₂ 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

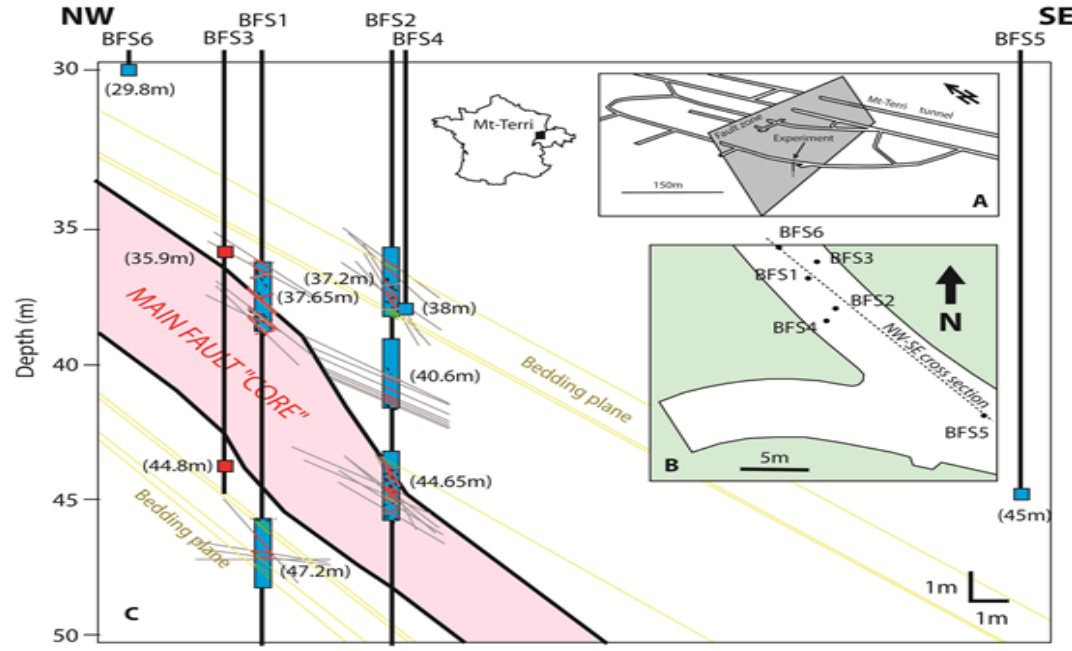


The CNSC Involvement in Fault Slip Modelling

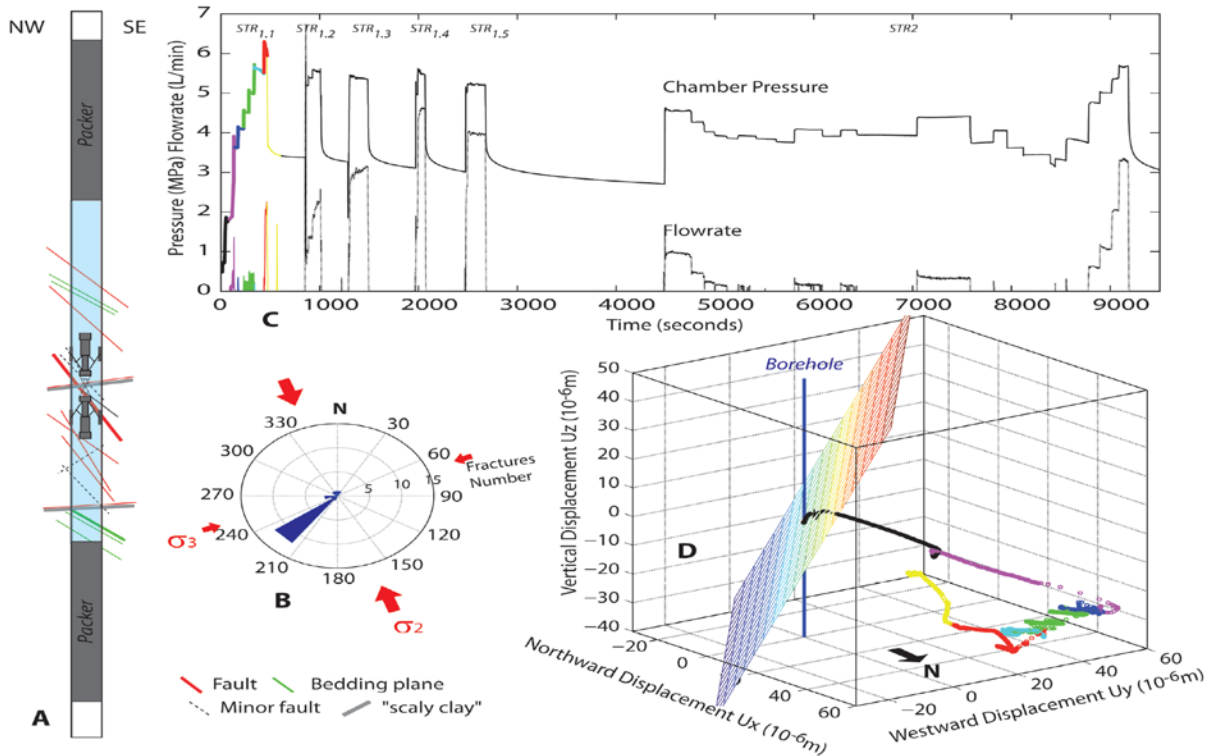
- The Canadian Nuclear Safety Commission (CNSC) is Canada's nuclear regulator
- The CNSC performs independent research on safety aspects related to the deep geological disposal of radioactive waste
- In this example of research, the CNSC collaborates with other researchers on the modelling of fault slip 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

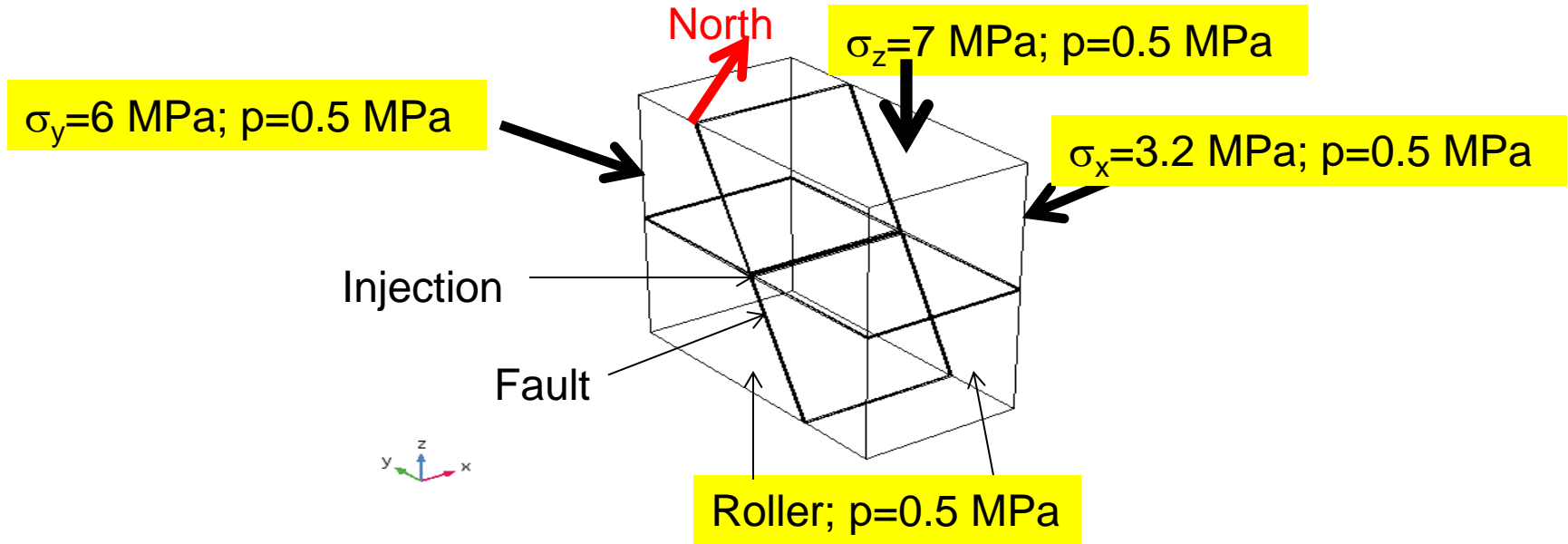


Secondary Fault Injection – Experimental Set-up





Secondary Fault Injection – FE Model



Fault plane dip 65° , strike $N45^\circ E$



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° , dilation angle 17°

Fault Permeability Model



➤ Fault permeability:

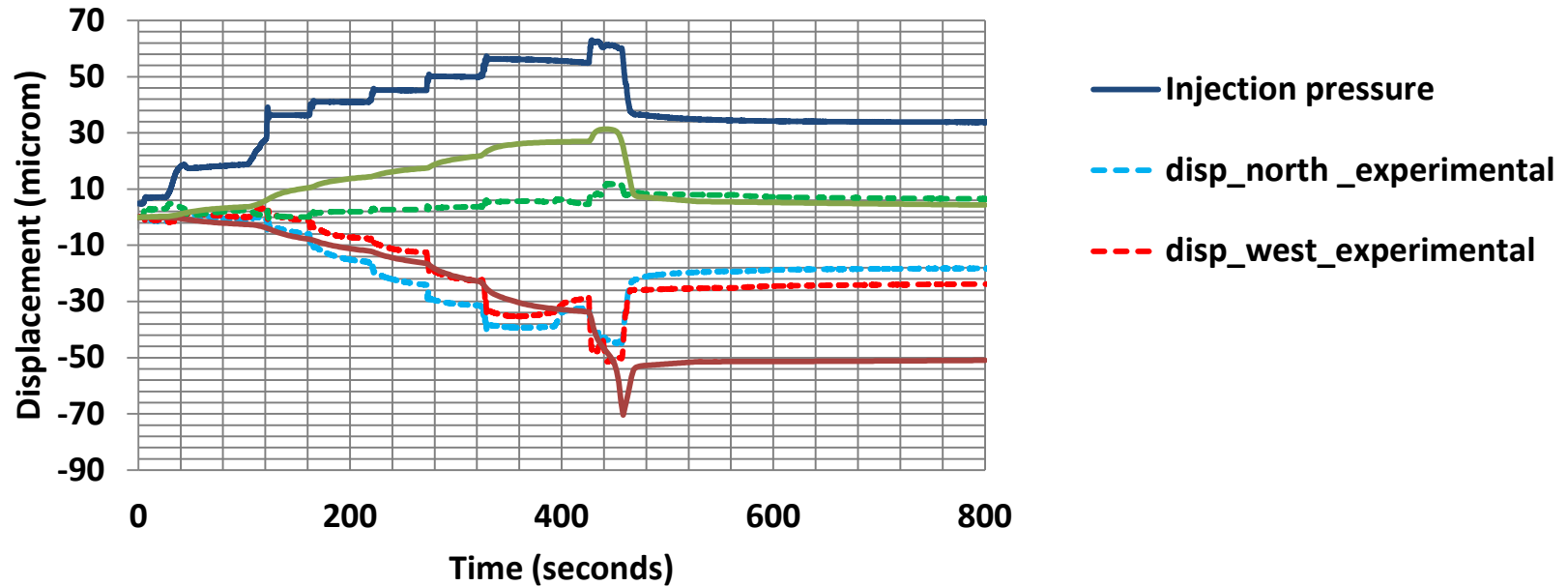
$$k = \frac{b_h^3}{12s}$$

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

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

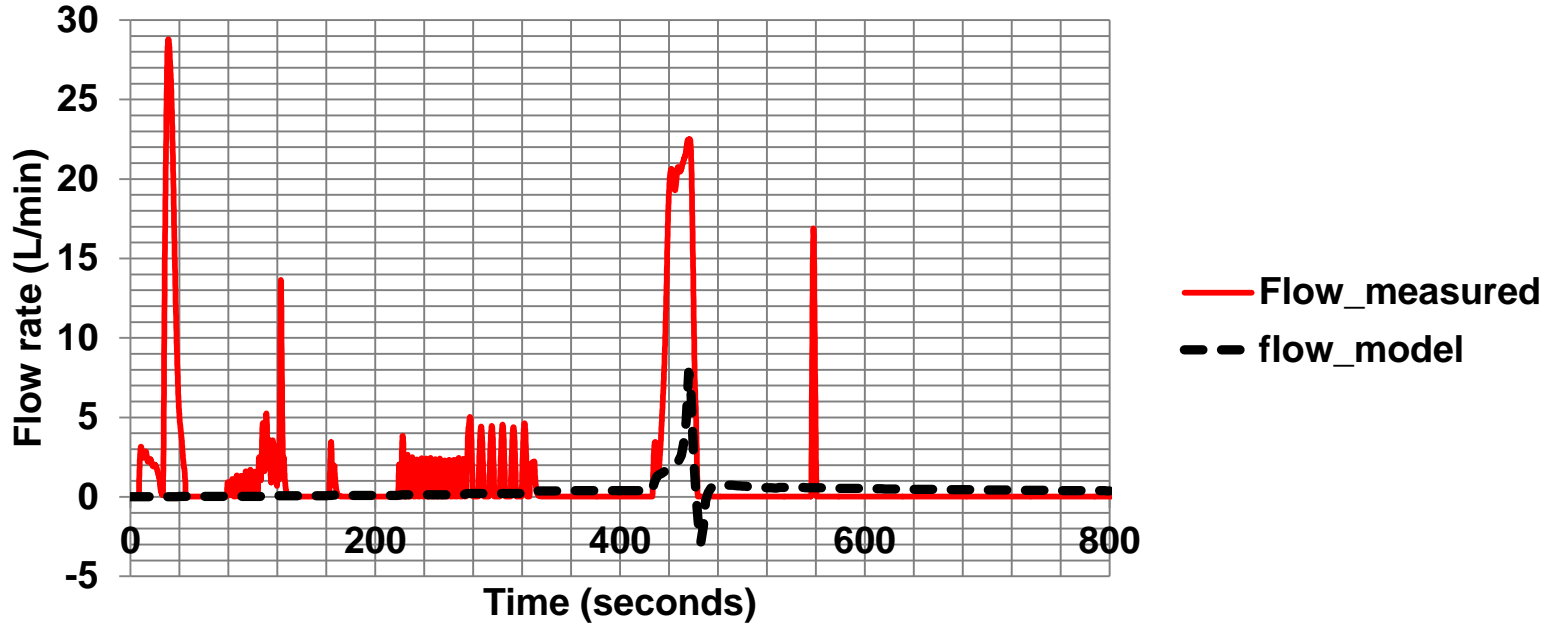
- where b_{he} elastic fracture opening; b_{hp} plastic opening; A damage enhancing factor

Displacement at Injection Point

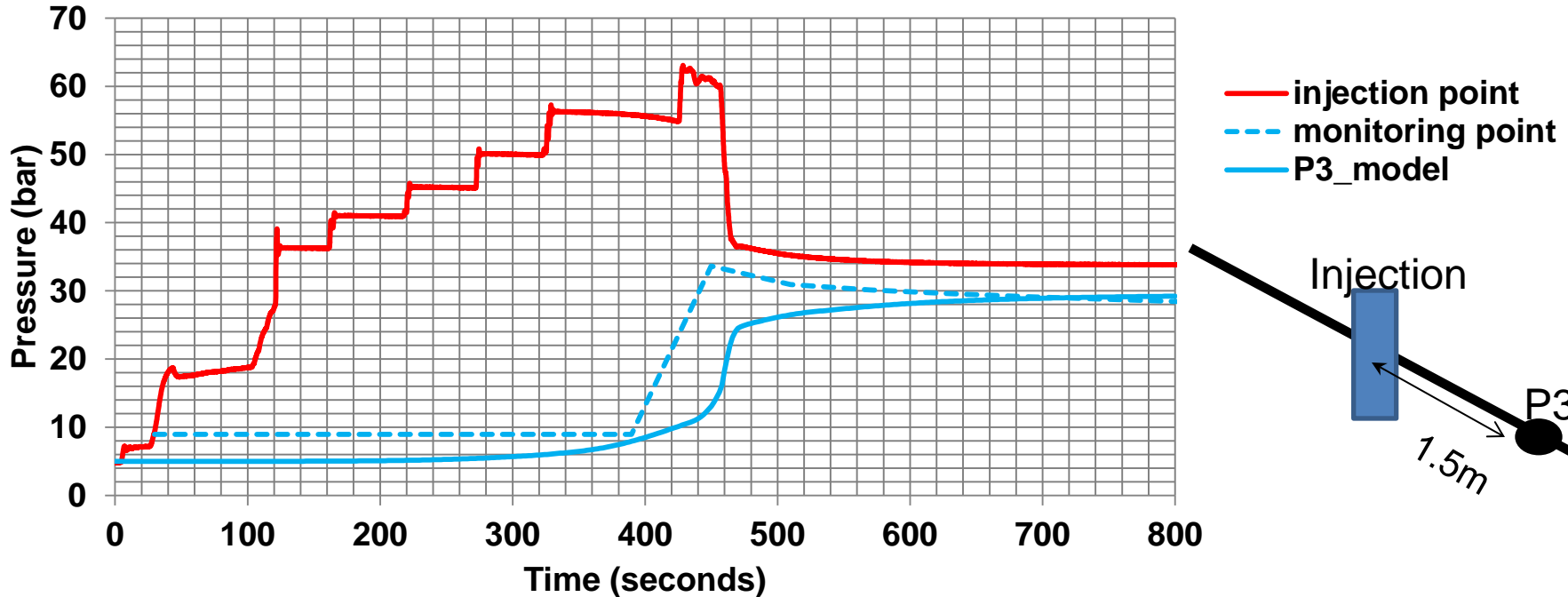




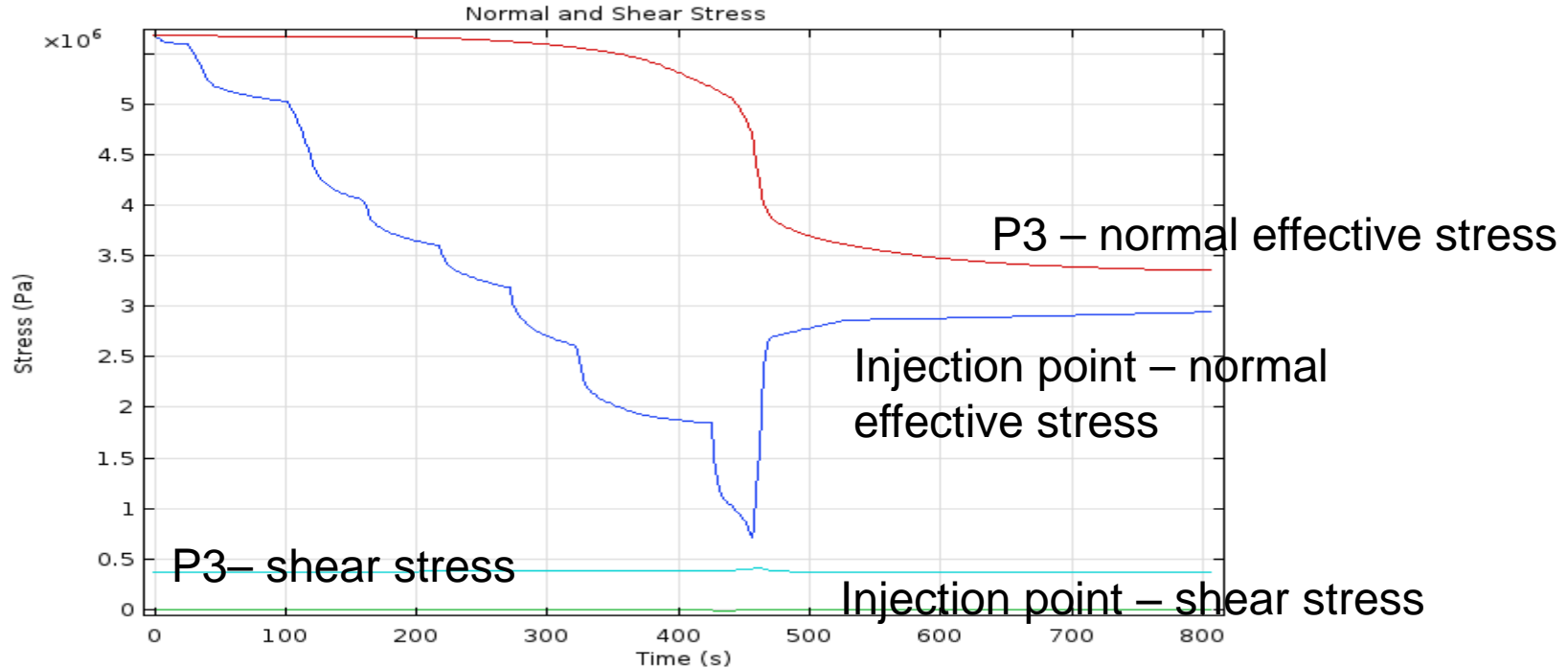
Injection Flow Rate



Pressure at Monitoring Point P3



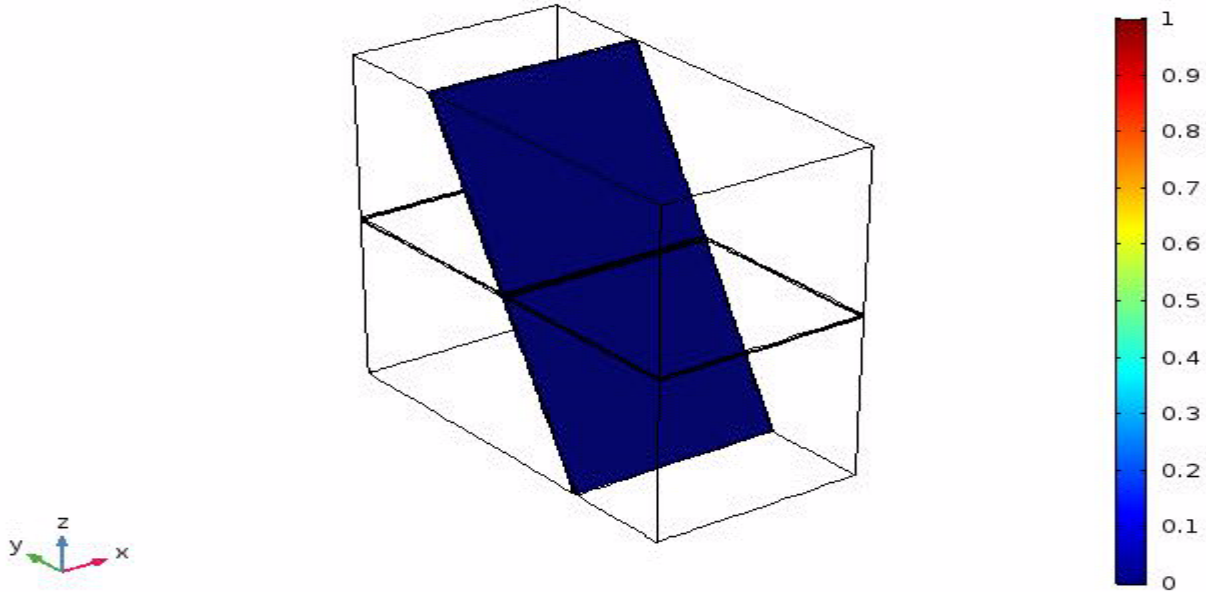
Stresses Along Fault





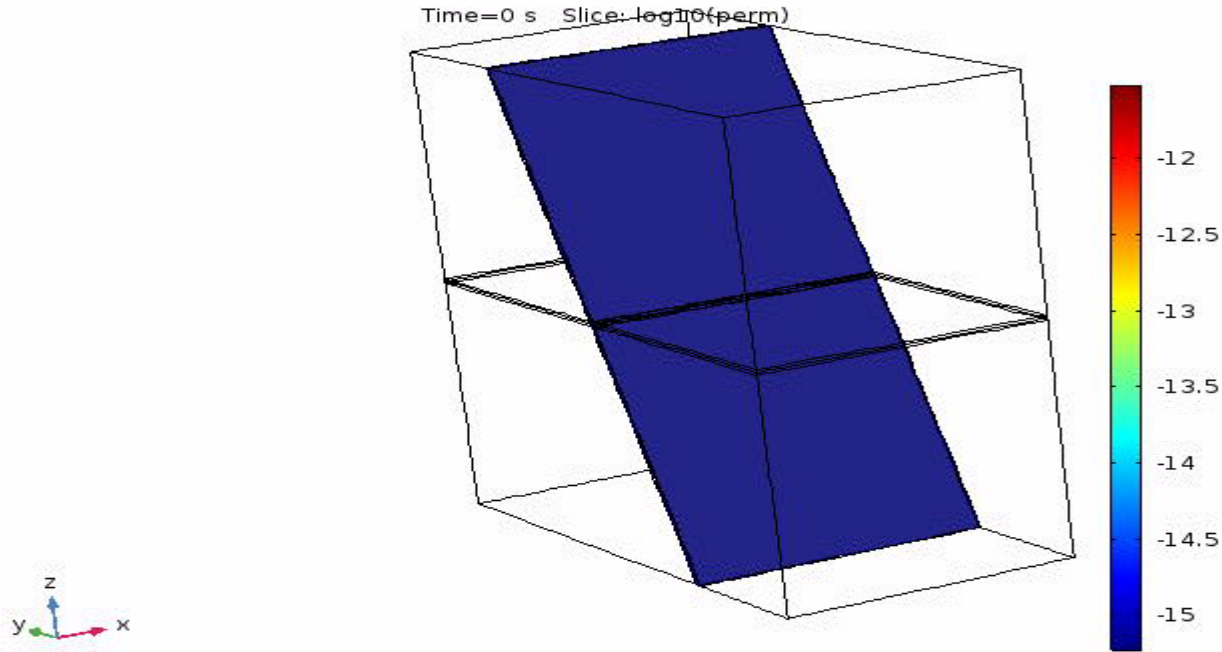
Fault Failure

Time=0 s Slice: solid.epe>0



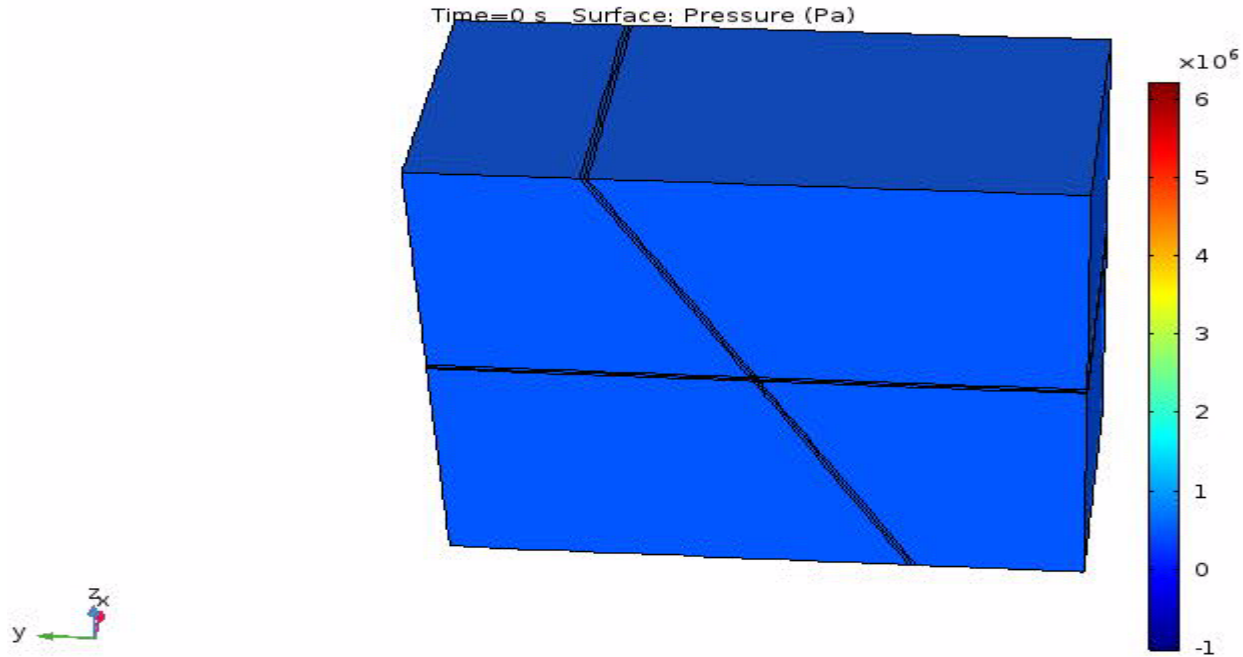


Fault Permeability

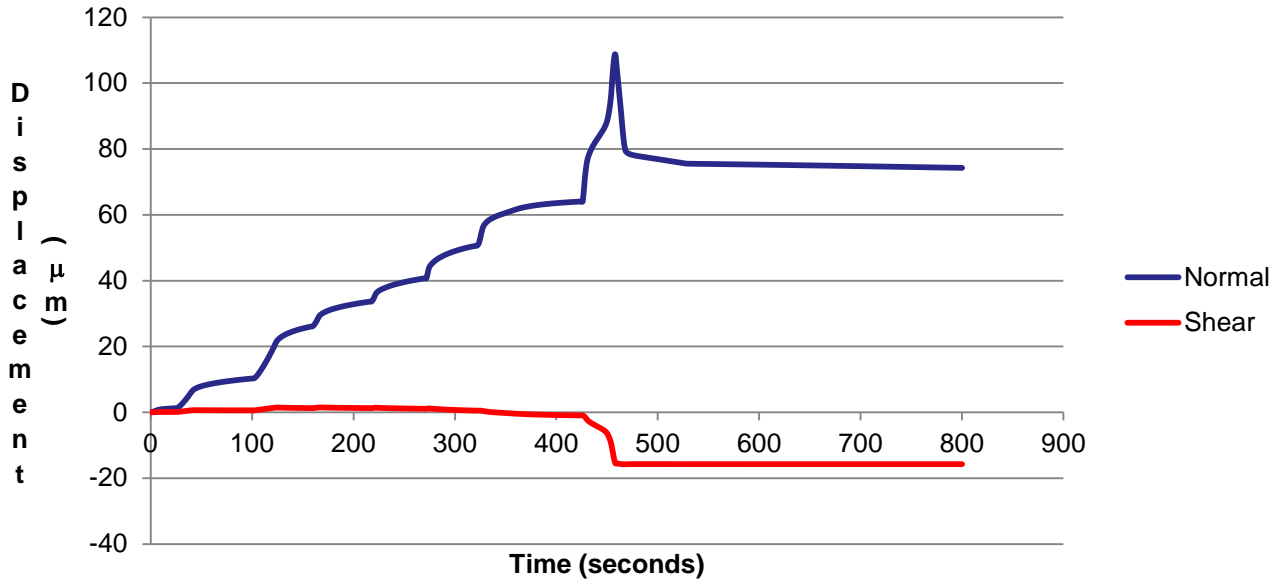




Fault Opening and Pressure



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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