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Swelling mechanisms in artificial fracture experiments

BELBaR annual workshop 2015, Madrid

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Background

- Plexiglass surfaces are very smooth if compared to natural fracture surfaces

  - Bentonite can swell easily into the artificial fracture in the experiments

  - No or limited swelling into real fractures in disposal conditions

→ the swelling mechanisms should be separated to compare the effect of lowering salinity

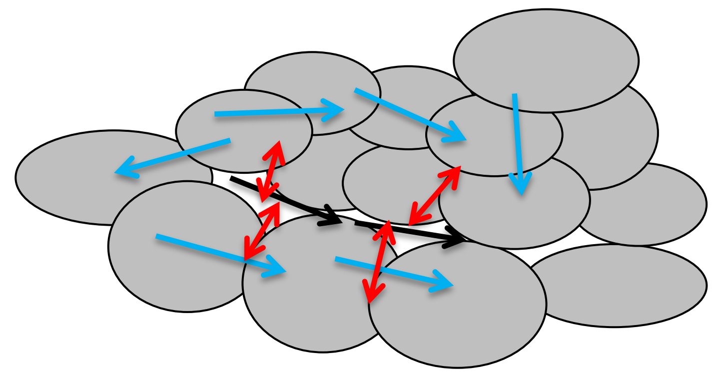
Background: sample preparation

- Compaction of partially saturated bentonite
  - Wetting and swelling simultaneously
    - Wetting causes swelling

- Compaction to fully saturated state
  - Bentonite and water mixed such that bentonite is fully saturated in certain dry density
  - Initial swelling stress
    - Bentonite swells when the artificial fracture is opened
  - Water moves into interlayer space → higher salinity in free pores
    - Swelling when excess salts diffuse out of bentonite

Model concept

- Double porosity model
  - "Bound water"
    - Induces swelling of bentonite structure
    - "Interlayer water"
  - "Free water"
    - No swelling
    - Compare to pores between sand grains
    - Salinity
  - Movement of water between the pores



Movement of water and solutes

- Diffusion of bound water

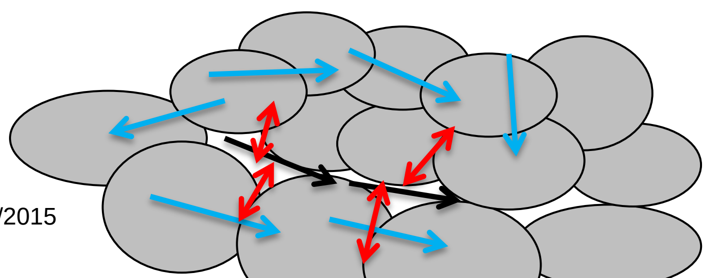
$$\mathbf{j}_{\mathrm{m}} = \rho_{\mathrm{water}}\mathbf{v} = -\rho_{\mathrm{water}}\frac{D}{RT}\nabla\mu = -\rho_{\mathrm{water}} D\nabla\log\left(p_p(w)\right) = -\frac{\rho_{\mathrm{water}} D}{p_p(w)}\frac{\partial p_p(w)}{\partial w}\nabla w$$

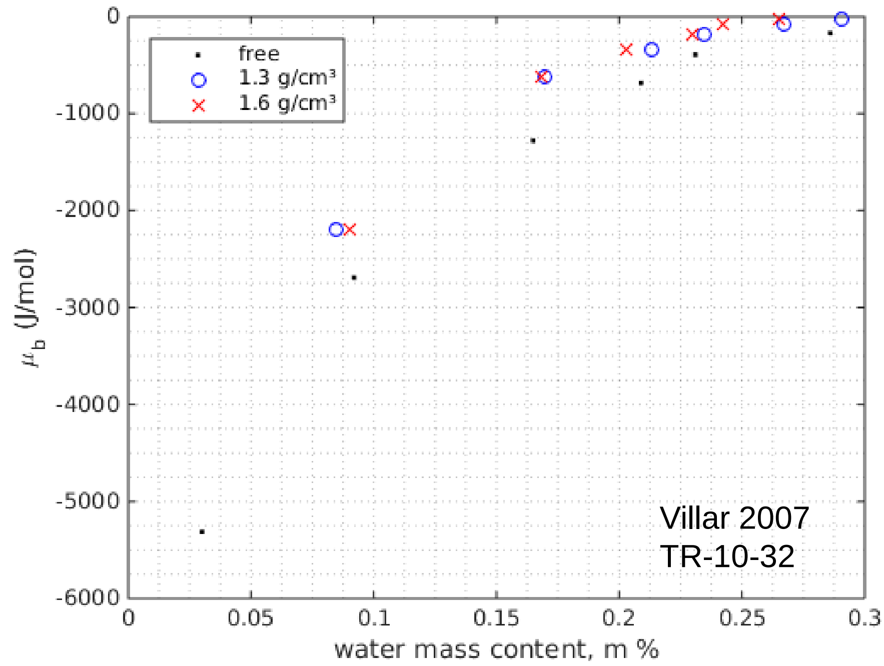
$$\mathbf{j} = \alpha\frac{\rho_{\mathrm{dry}} w}{\rho_{\mathrm{water}}}\mathbf{j}_{\mathrm{m}} = -\alpha\rho_{\mathrm{dry}} D\left(\frac{w}{p_p(w)}\frac{\partial p_p(w)}{\partial w} + \frac{M\frac{1}{3}\mathrm{trace}(\boldsymbol{\sigma})}{RT\rho_{\mathrm{dry}} w}\right)\nabla w$$

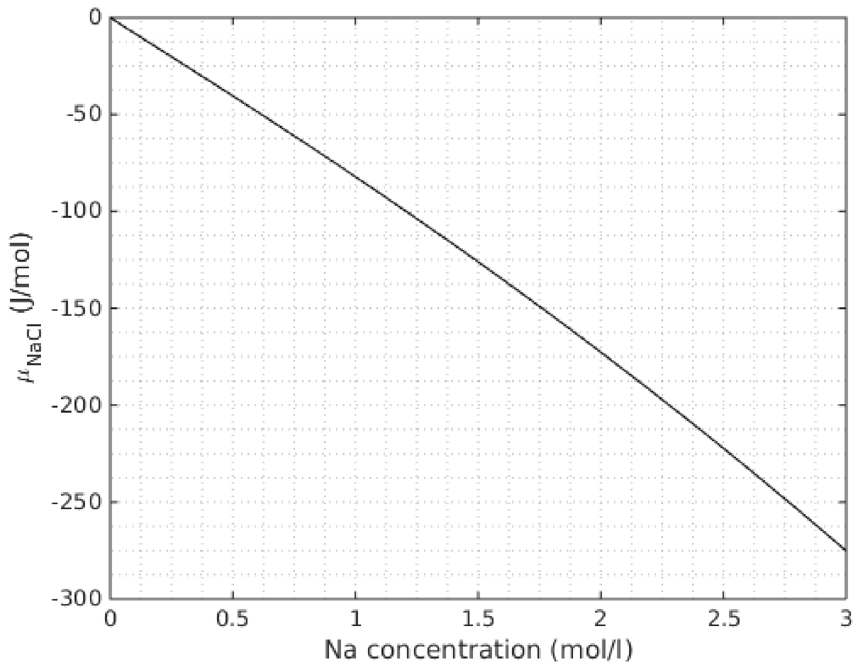
- Diffusion of salt

- Interchange of water

$$R = kS_{\mathrm{free}}\left(\mu_{Na} - \mu_b\right) \qquad \mu_b = \mu_0 + RT\ \log \mathrm{p}_p(w) - \frac{M\frac{1}{3}\mathrm{trace}(\boldsymbol{\sigma})}{w\rho_{\mathrm{dry}}}$$

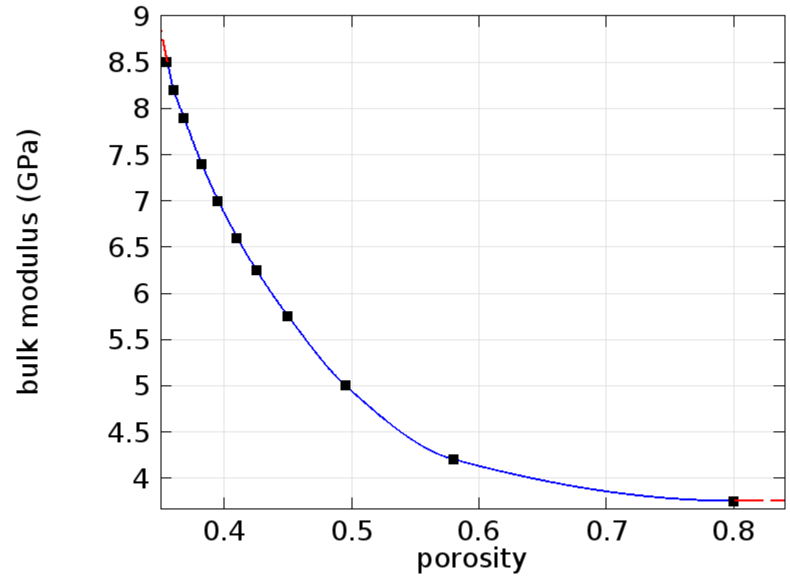


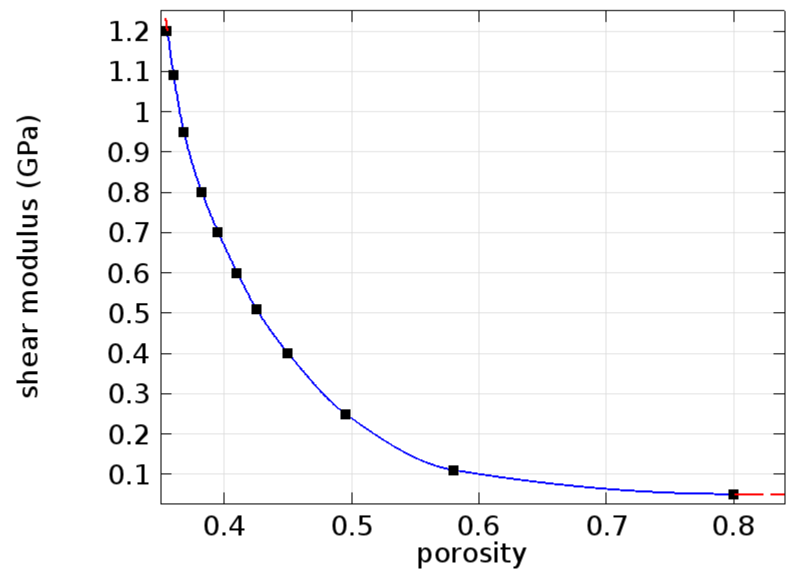




Mechanical model

- Elastic model
  - Bulk modulus and shear modulus at different densities
- von Mises perfect plasticity
  - should be improved
- Bound water induces volume change
  - Compare to thermal expansion of metals





Moyano et al. 2012

Simulations

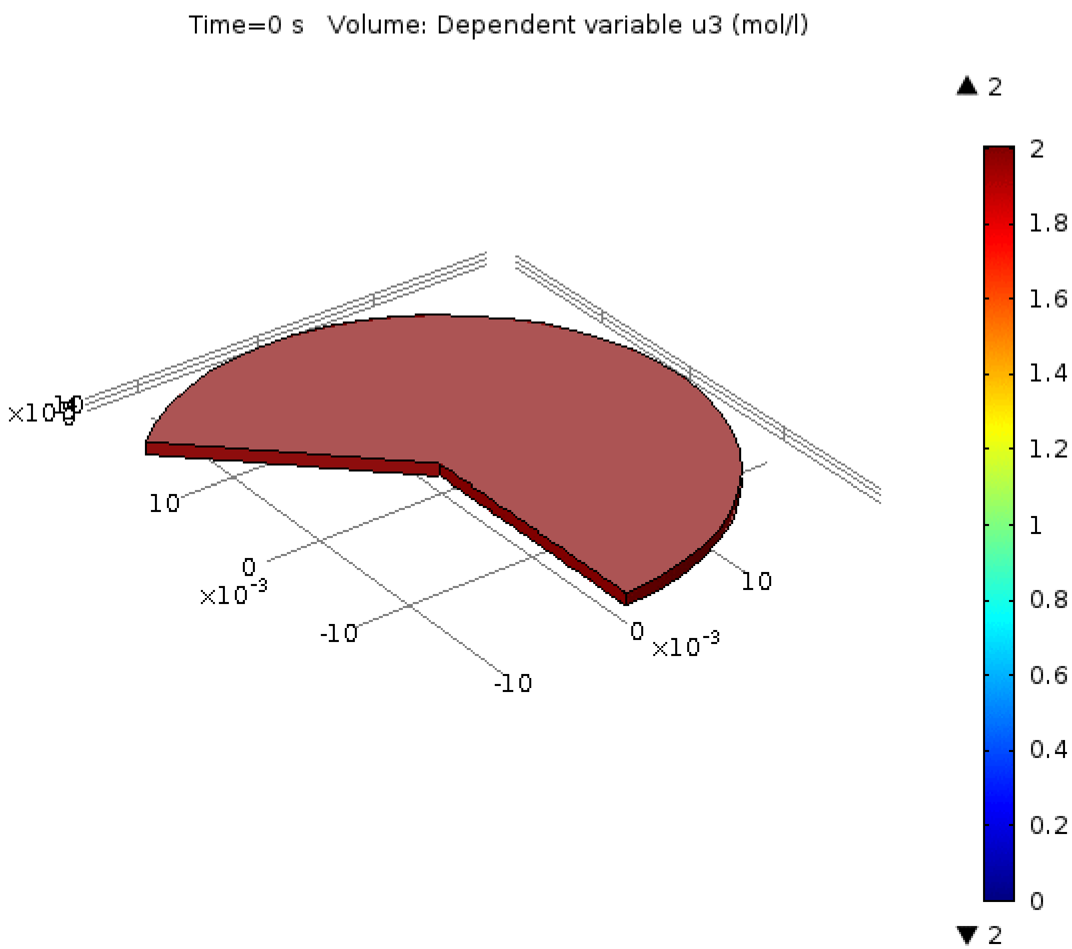
- Swelling by initial swelling stress release
  - Stepwise approach
    - Water added to bentonite while it is let to swell
    - No time dependency needed for mechanical model

- Swelling by lowering salinity
  - from the initial concentration to a lower concentration
  - from the lower concentration to zero concentration

- Simple geometry

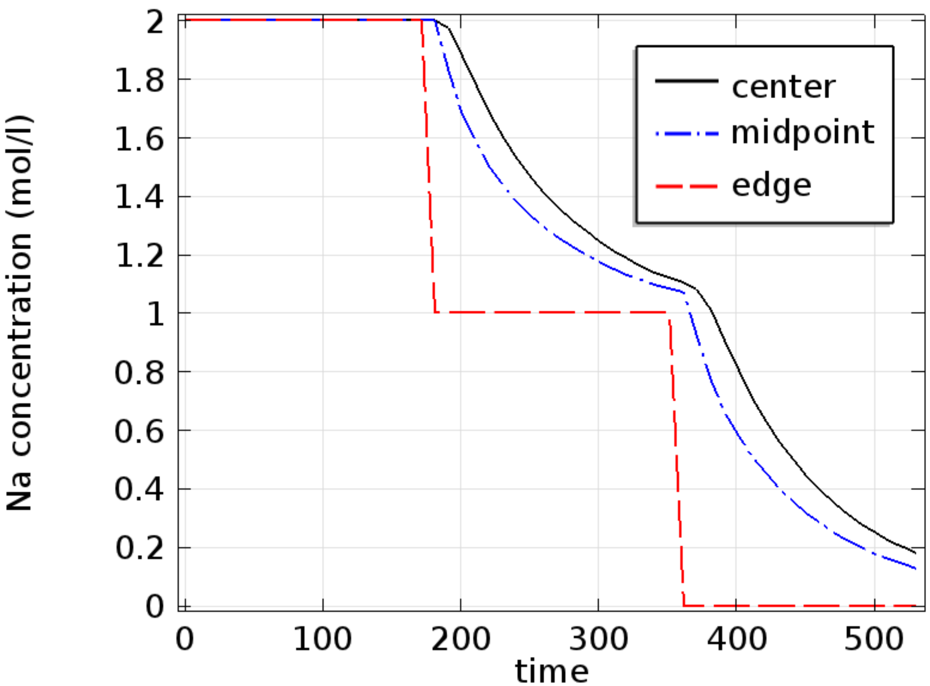
- Effect of mechanical coupling

Preliminary results

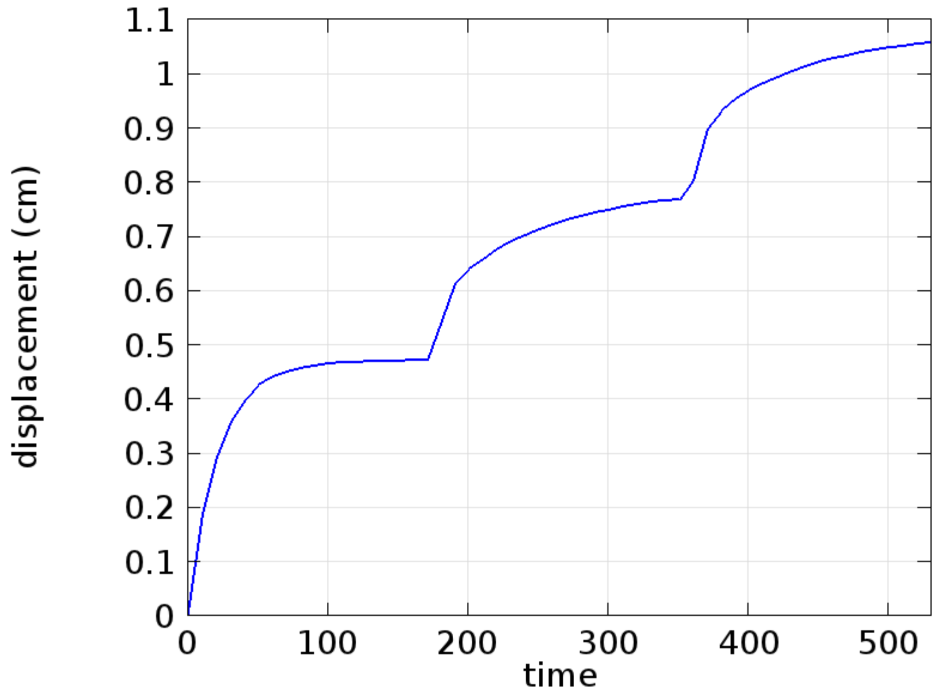


No mechanical coupling for water movement

Preliminary results

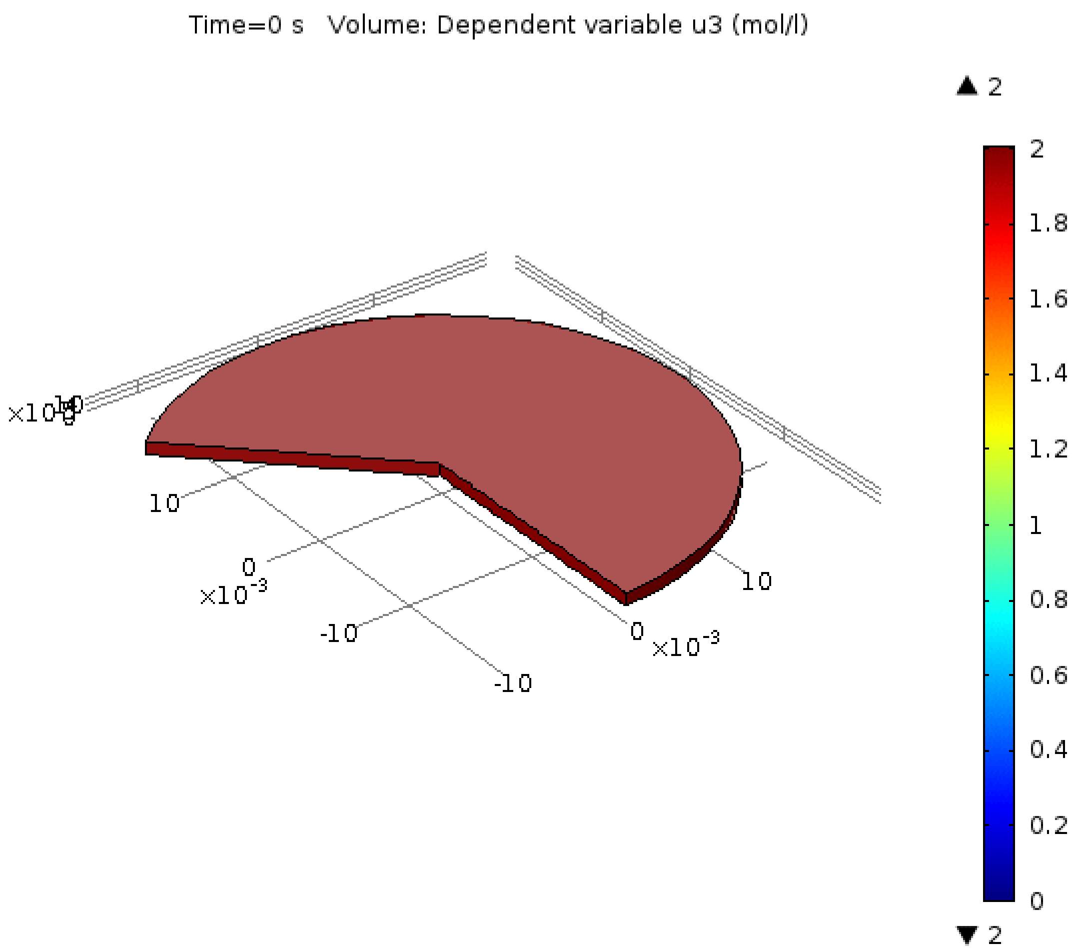


Na concentration



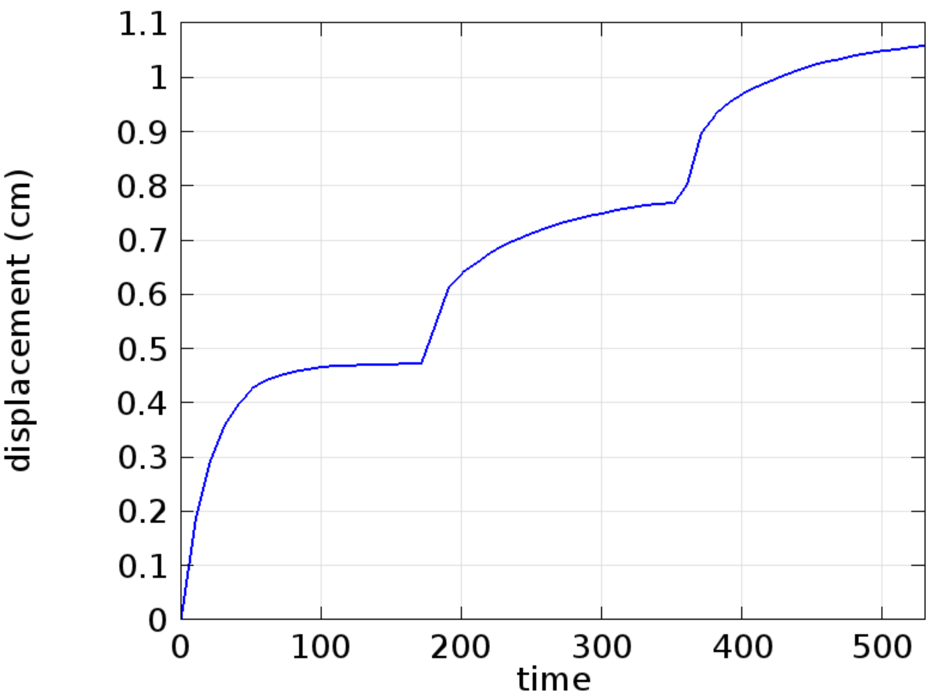
displacement of bentonite edge

Preliminary results

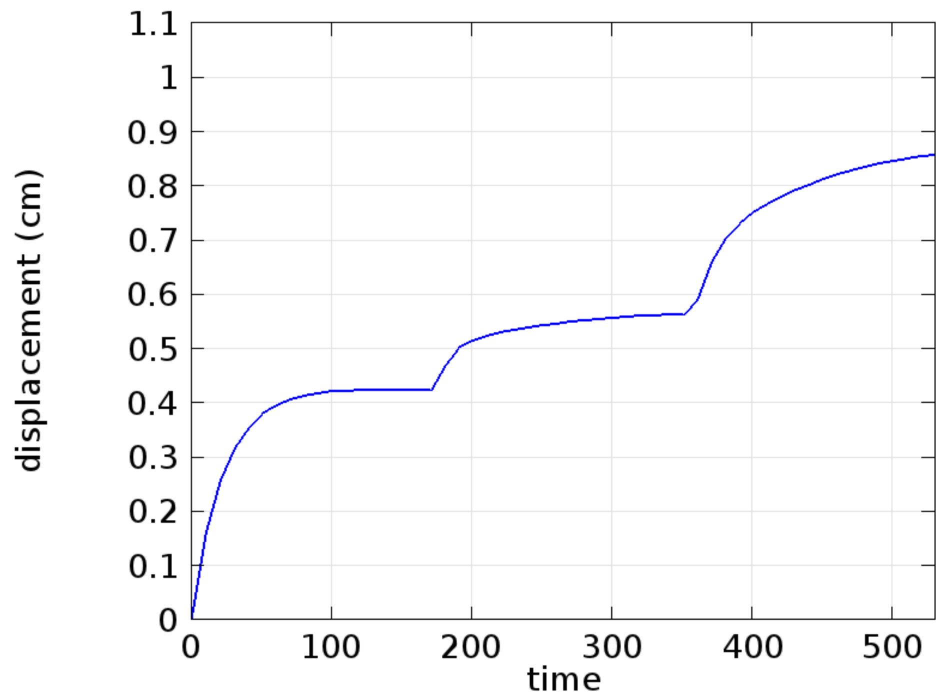


Mechanical coupling

Preliminary results



No mechanical coupling



mechanical coupling

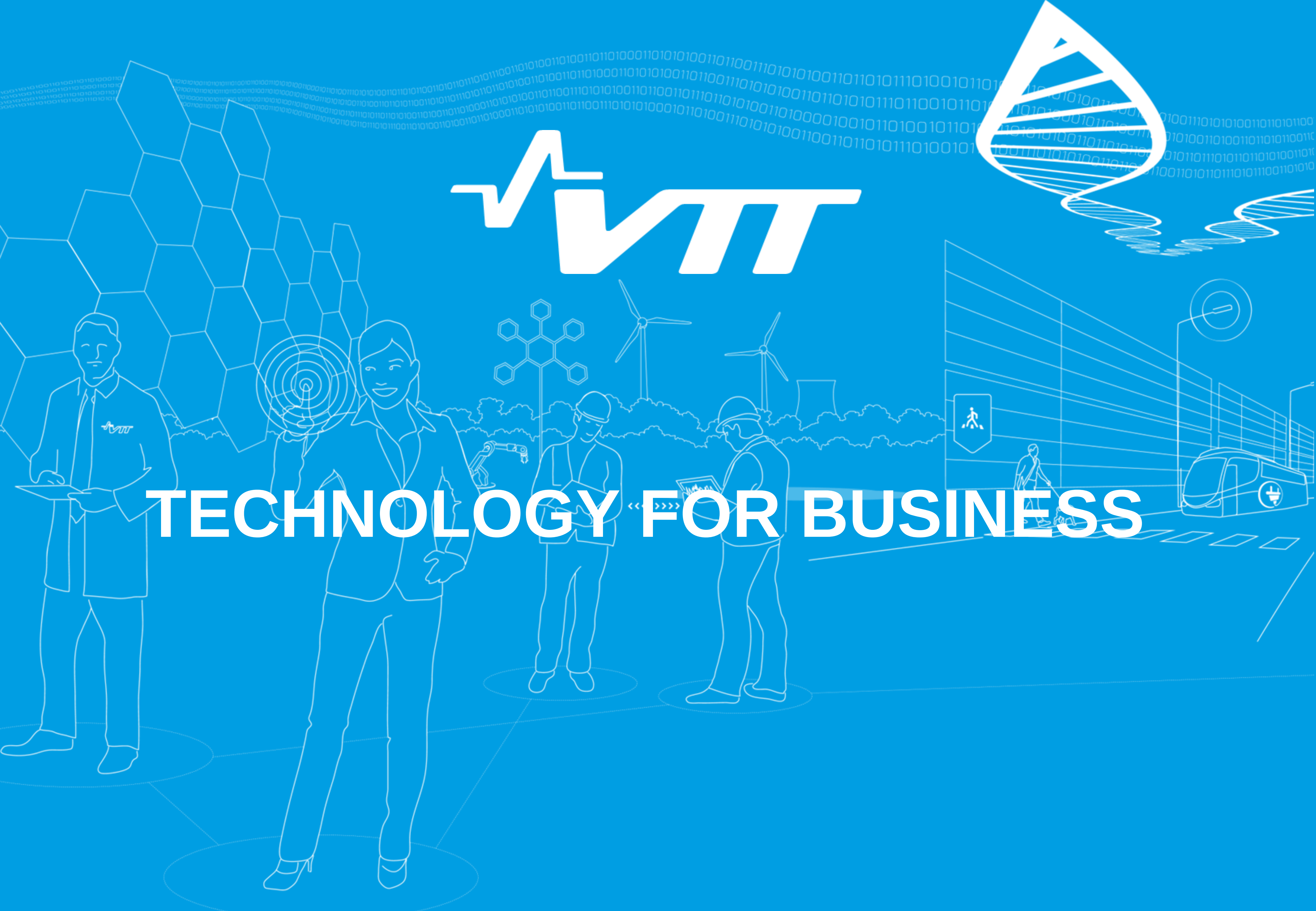
Conclusions

- The initial swelling effects seem to be significant in the artificial fracture experiments

- When interpreting the results, the swelling effects should be separated to get the correct erosion rates

- Model needs to be further developed and compared to simple experiments

- Break down mechanism should be added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