Hydro-mechanical behaviour of a pellets based bentonite seal: Numerical modelling of lab scale experiments

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4th European Conference on Unsaturated Soils
E-UNSAT 2020
October 19th 2020
ONLINE CONFERENCE

Outline:

1. Introduction;
2. Materials and method;
3. Experimental results;
4. Coupled hydro-mechanical model;
5. Numerical results and analysis;
6. Conclusions.

1. Introduction

BENTONITE = clay material that primarily consists of montmorillonite:

- MECHANICS

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- significant swelling upon hydration (swelling deformation, swelling pressure dry density dependent);

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BENTONITE = clay material that primarily consists of montmorillonite:

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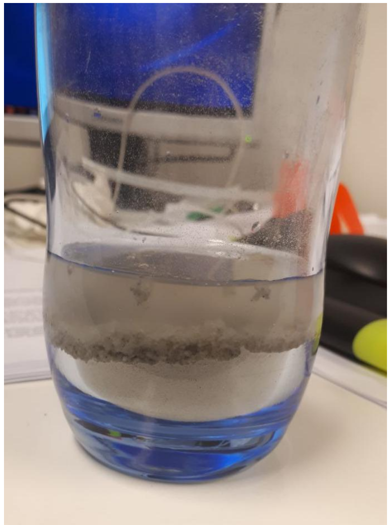
  - significant swelling upon hydration (swelling deformation, swelling pressure dry density dependent);
- HYDRAULICS
  - very low permeability (~10^{-20} - 10^{-21} m^2 in saturated conditions);



1. Introduction

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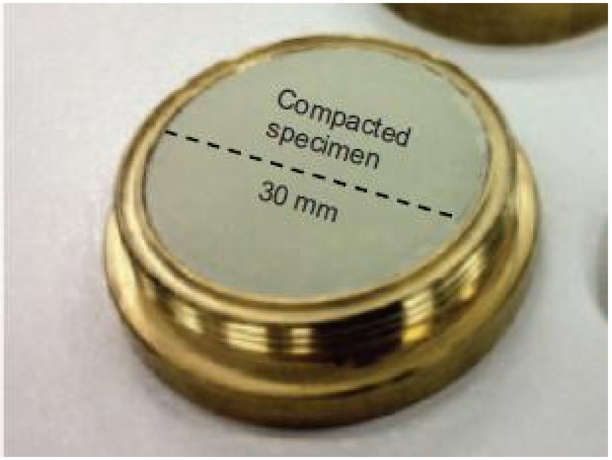

Seiphoori et Al. 2014

- ENGINEERING

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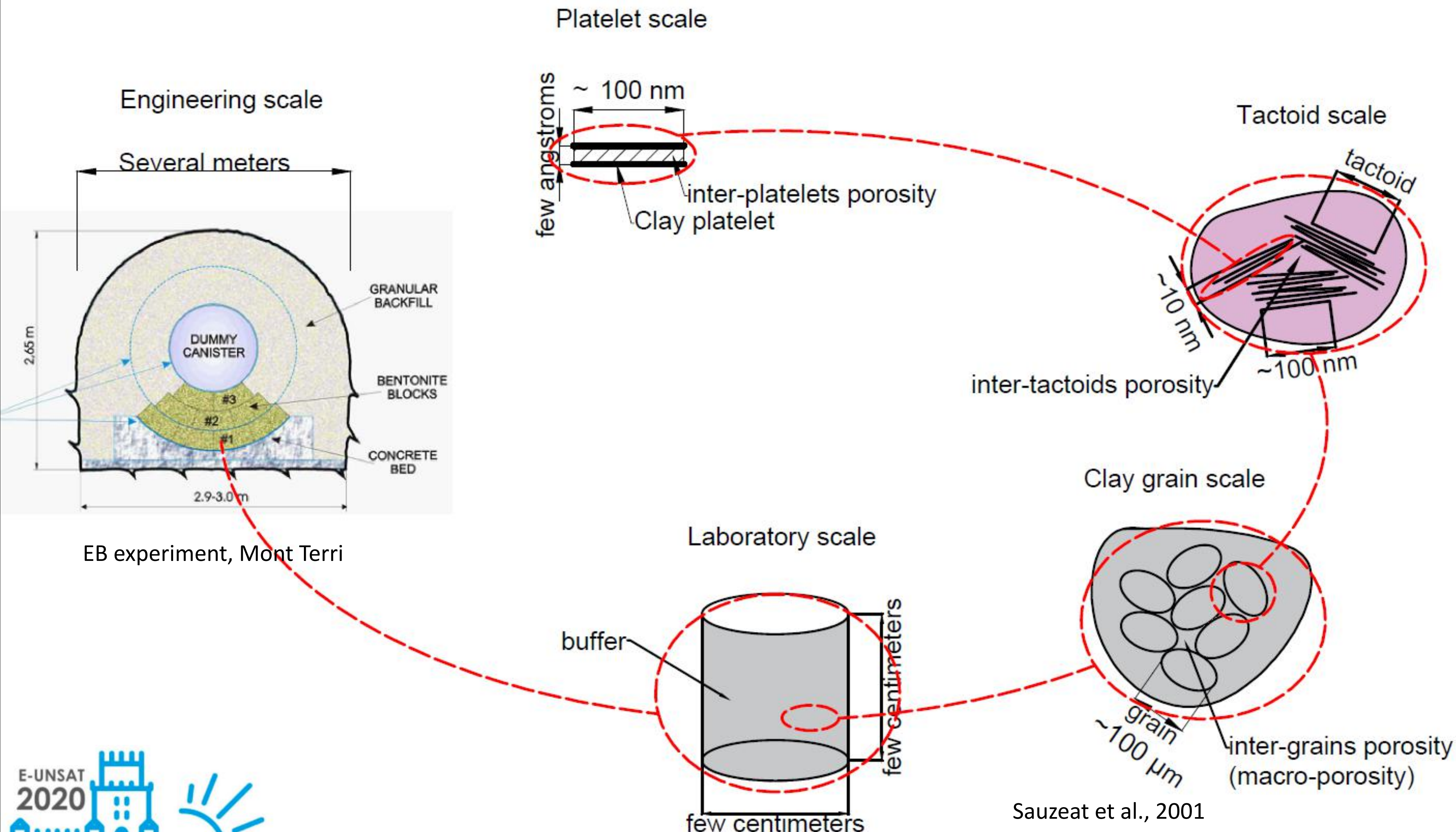
- different forms (powder, pellets, compacted blocks...)
- different types (Febex, MX-80, Kunigel...);

1. Introduction

Multi-scale structure of bentonite materials



EB experiment, Mont Terri

Sauzeat et al., 2001

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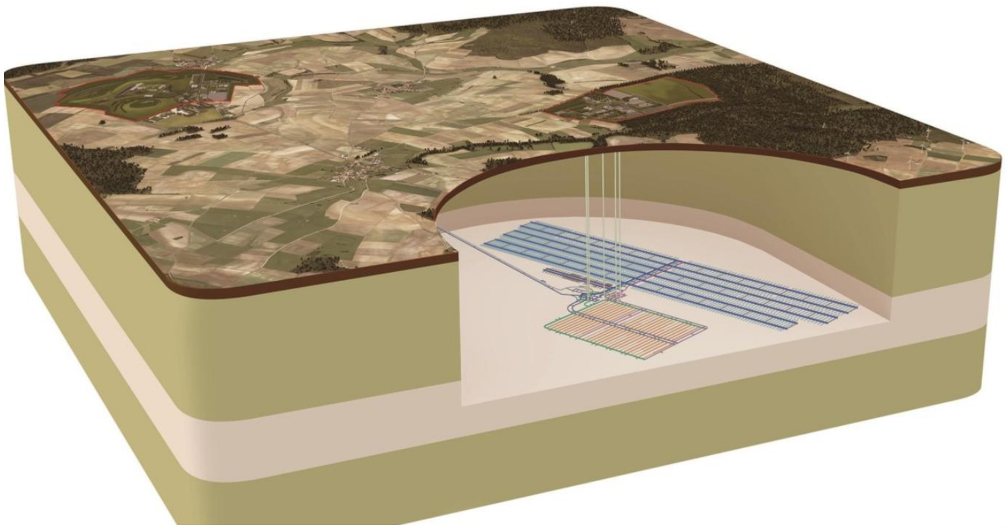
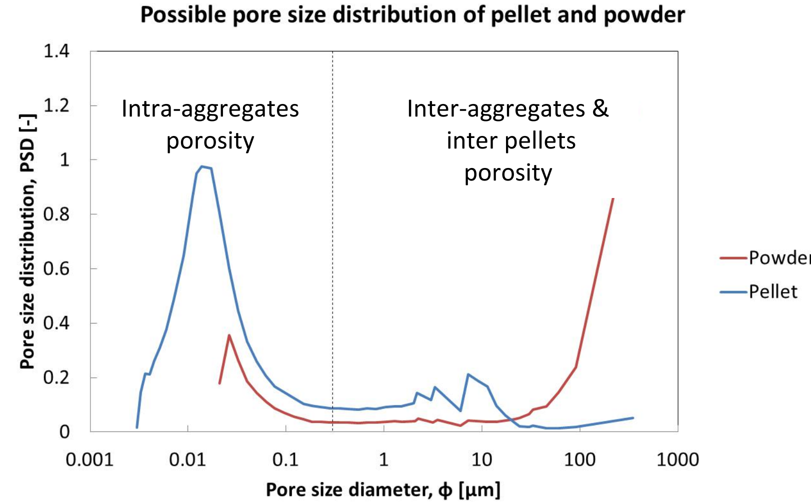
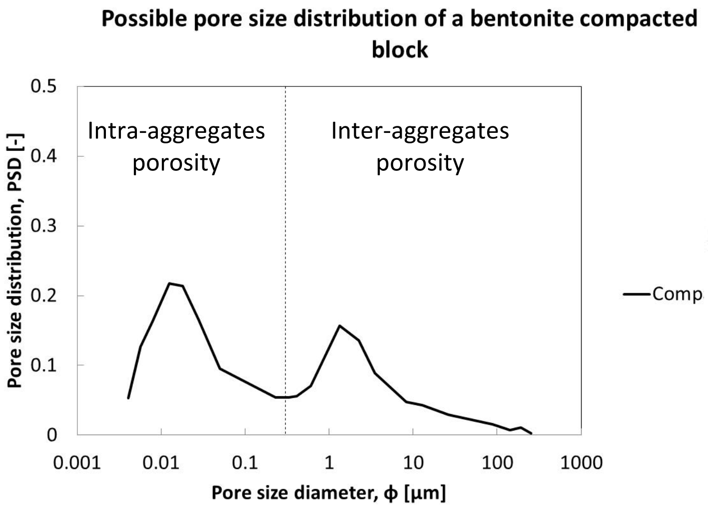
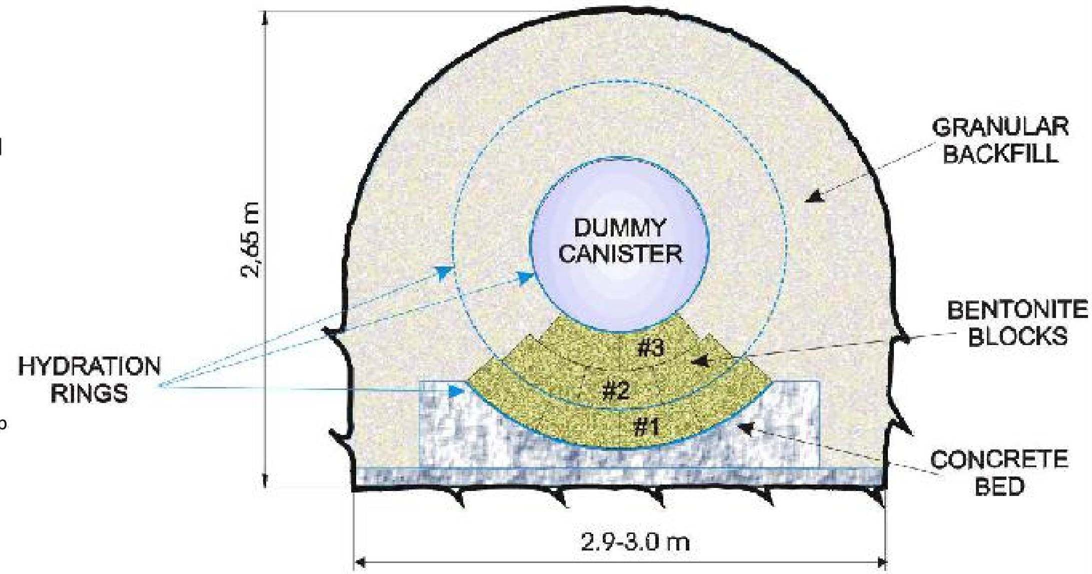


French CIGEO concept for ILW [ANDRA]





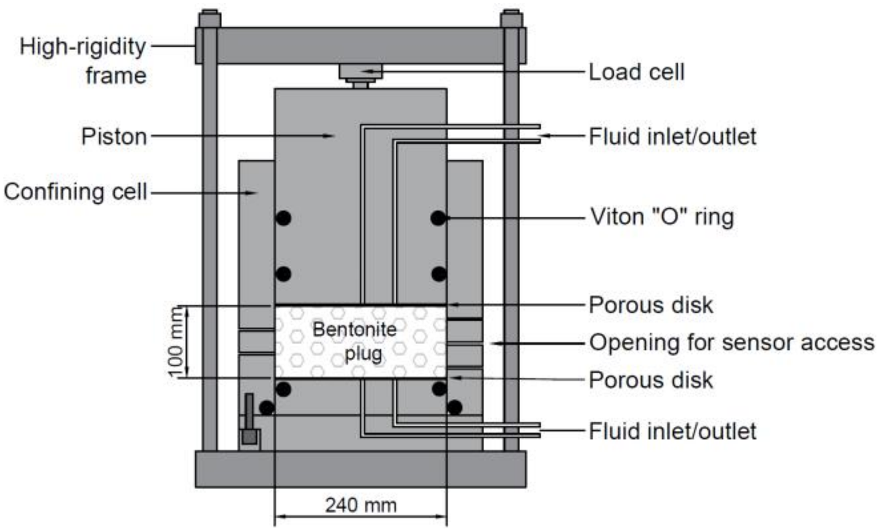


EB experiment, Mont Terri

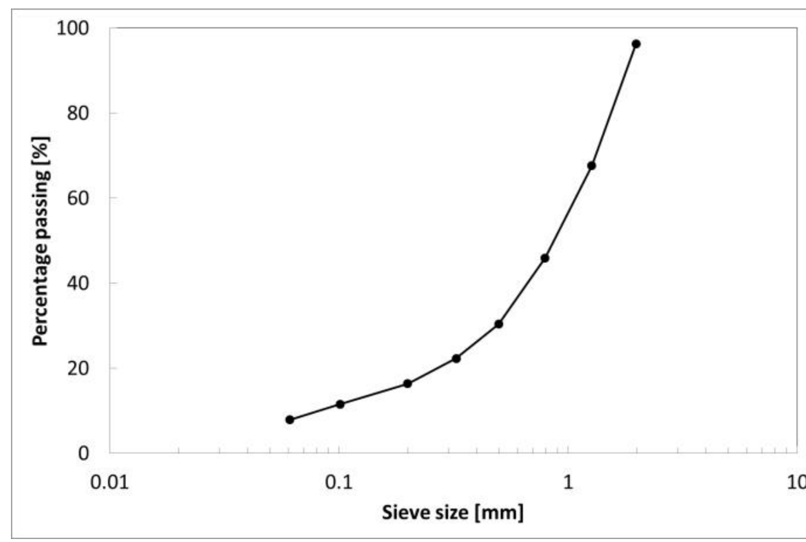
2. Materials and method

Second layer with crushed pellets during installation

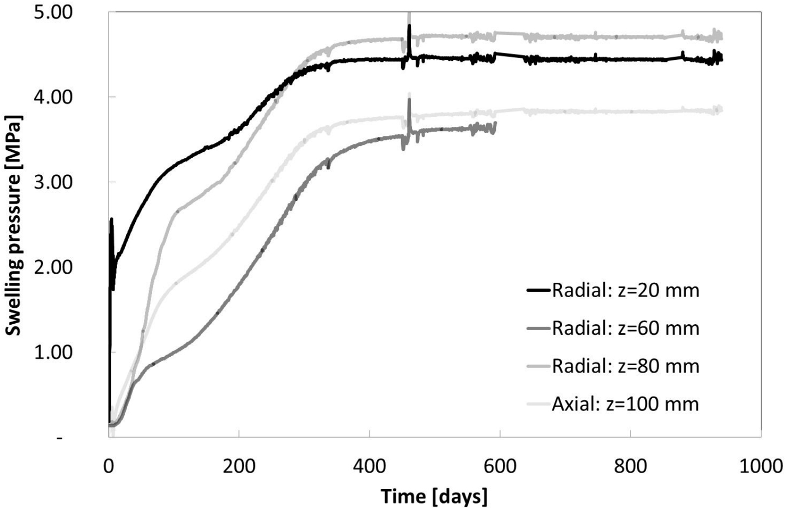
32 mm pellets and crushed pellets grain size distribution



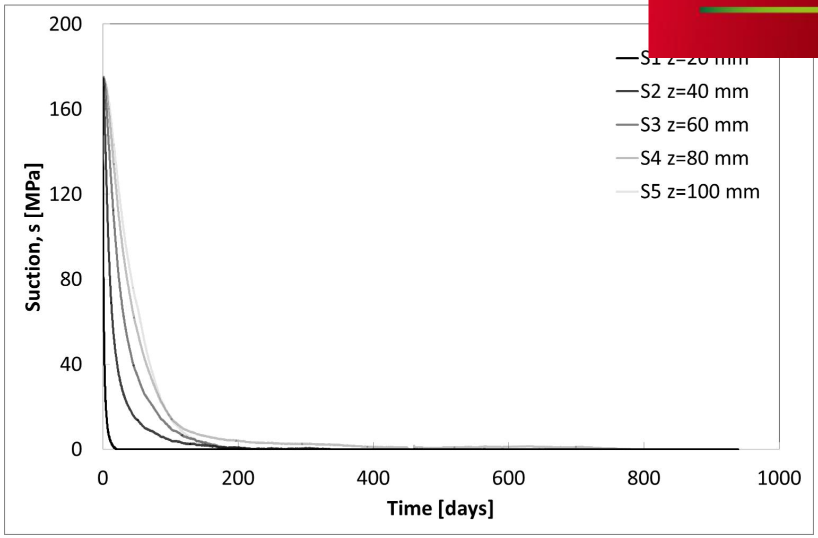
Schematic representation of the experimental set-up



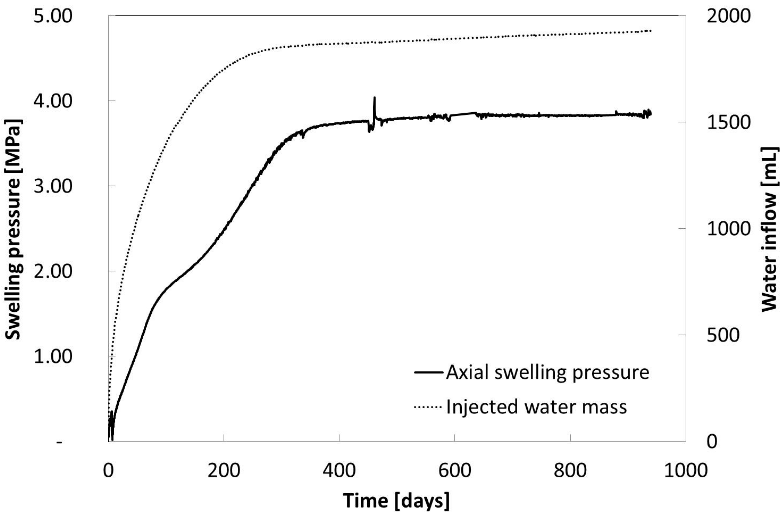
3. Experimental results



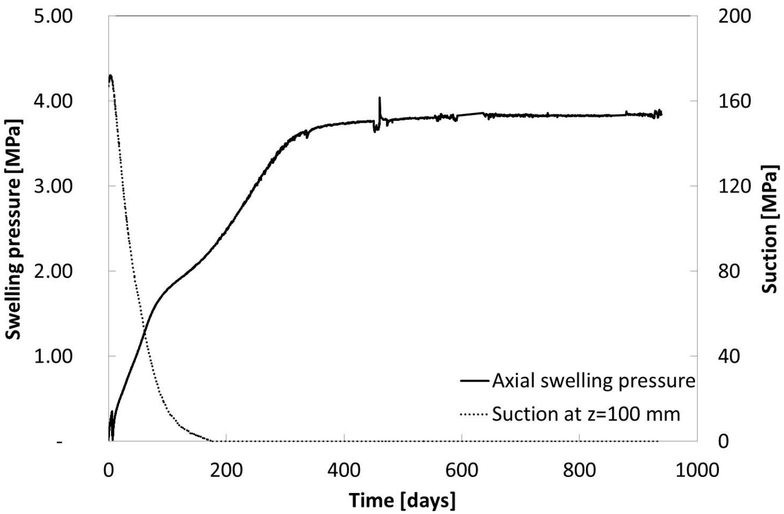
Swelling pressure in radial and axial directions function of time



Suction function of time



Swelling pressure in axial direction and water intake function of time.



Swelling pressure in axial direction and suction measurement at z=100 mm from the bottom face function of time.

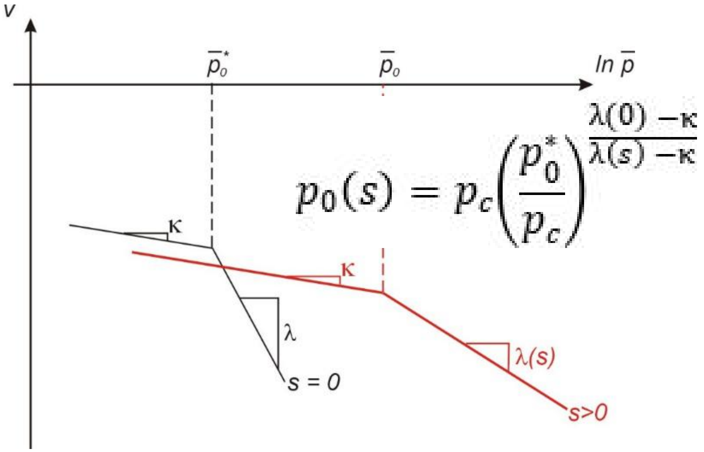
Suction – Mechanics

Modified CamClay - Barcelona Basic Model

(Alonso et al 1990)

$$\boldsymbol{\sigma} = \boldsymbol{\sigma}_T - u_a \boldsymbol{I}$$

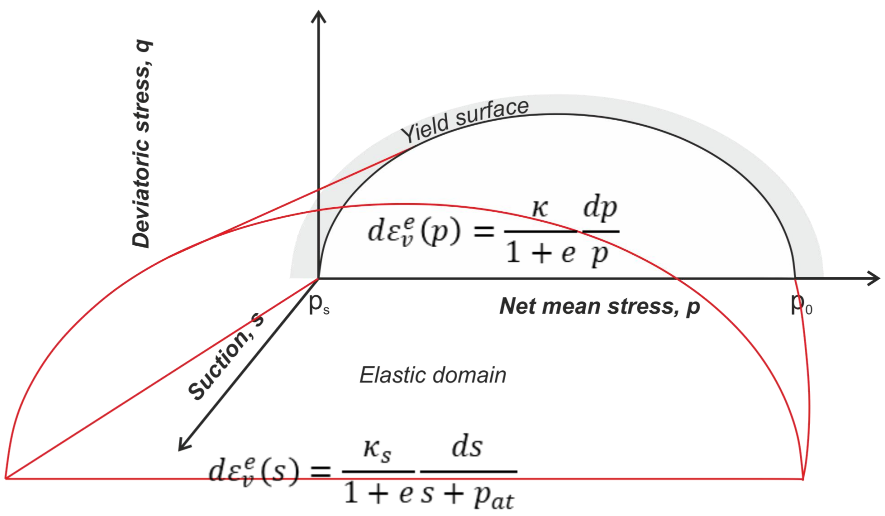
$$d\varepsilon_v^e = \frac{\kappa}{1+e}\frac{dp}{p} + \frac{\kappa_s}{1+e}\frac{ds}{s+u_{atm}}$$



$$p_0(s) = p_c\left(\frac{p_0^*}{p_c}\right)^{\frac{\lambda(0)-\kappa}{\lambda(s)-\kappa}}$$

$$\lambda(s) = \lambda(0)[(1-r)\exp(-\omega s) + r]$$

Plastic yield surface



For constant volume conditions:

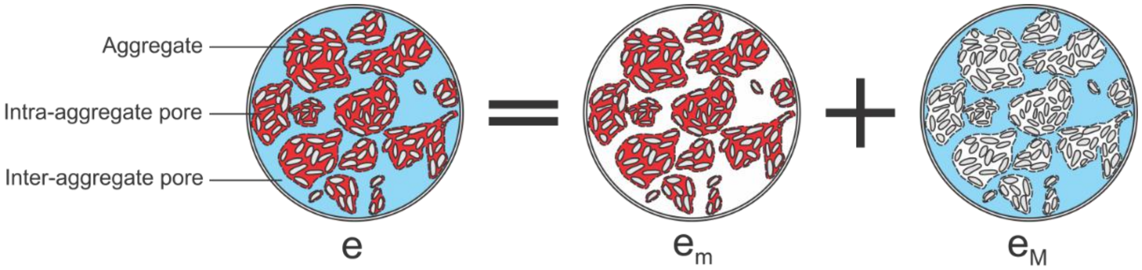
$$p(s) = p_A\left(\frac{s_A + u_{atm}}{s_B + u_{atm}}\right)^{\frac{\kappa_s}{\kappa}}$$

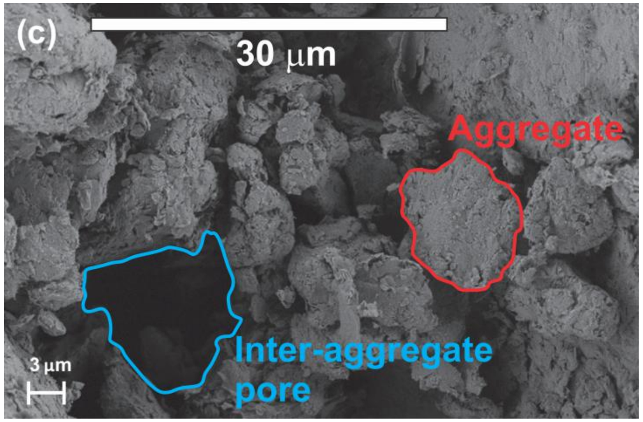
$$\kappa_s(p) = \kappa_{s0} * \exp(-\alpha_p * p)$$

4. Coupled hydro-mechanical model

4.2 Hydraulic model: Water retention behaviour-double-porosity structure

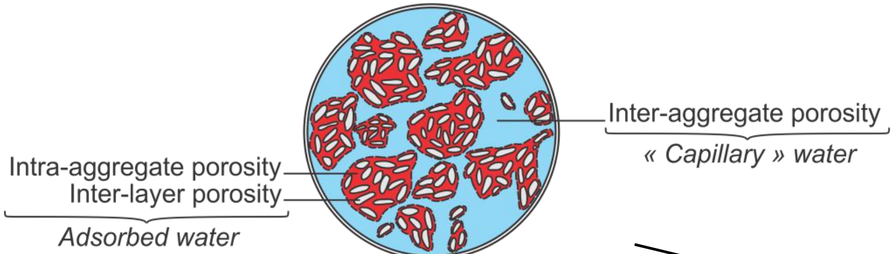
(Dieudonne' 2016)





(Seiphoori et Al. 2014) SEM on MX-80 bentonite

$$e_w = S_r \,.\, e = e_{wm} + e_{wM}$$



Dubinin model

$$e_{wm}(s, e_m) = e_m \exp[-(C_{ads} s)^{n_{ads}}]$$

$$e_m = e_{m0} + \beta_0 e_w + \beta_1 e_w^2$$

« Van-Genuchten » model

$$e_{wM}(s, e, e_m) = (e - e_m)\left[1 + \left(\frac{s}{a}\right)^n\right]^{-m}$$

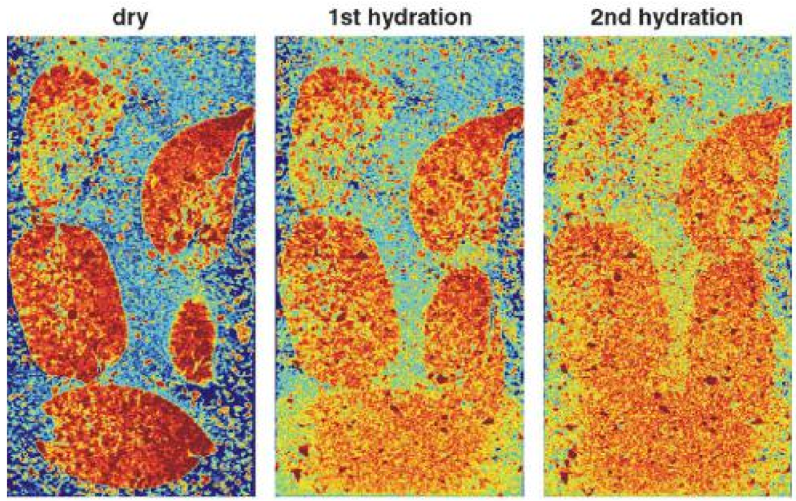
$$a = \frac{A}{e - e_m}$$

4. Coupled hydro-mechanical model

4.2 Hydraulic model: Permeability - double-porosity structure

$$K_w = K_{w0} \frac{e_M^{expn}}{(1 - e_M)^{expm}} \frac{(1 - e_{M0})^{expm}}{e_{M0}^{expn}}$$

Fo-Ca-clay powder and pellets



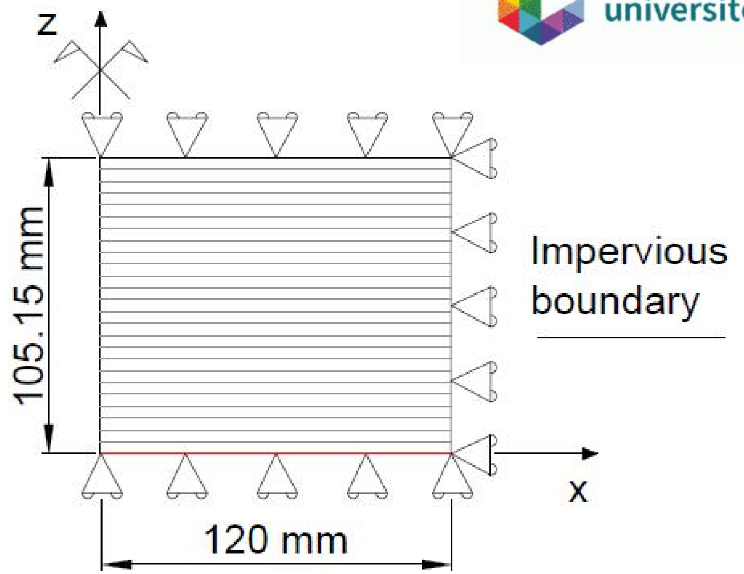
(Van Geet et al 2005) –X-ray tomography on pellet mixture during hydration test (Dry density)-

The permeability evolution affects the velocity of the swelling pressure development, but in pellet-mixture is a difficult process to evaluate.

5. Numerical results and analysis

5.1 Geometric configuration of the simulation

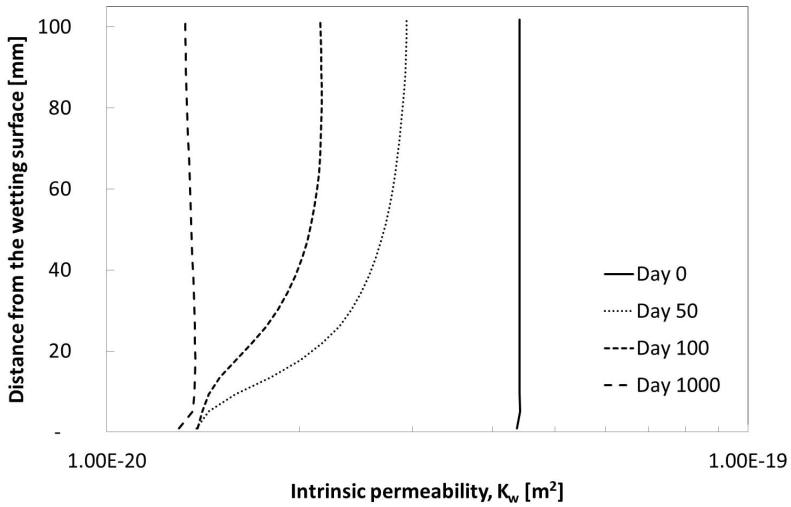
- Monodimensional problem;
- Homogeneous medium (same mechanical and hydraulic properties);
- Homogeneous initial state (suction=171 MPa and confining stress σ_a= 0.02 MPa and σ_r = 0.2 MPa).



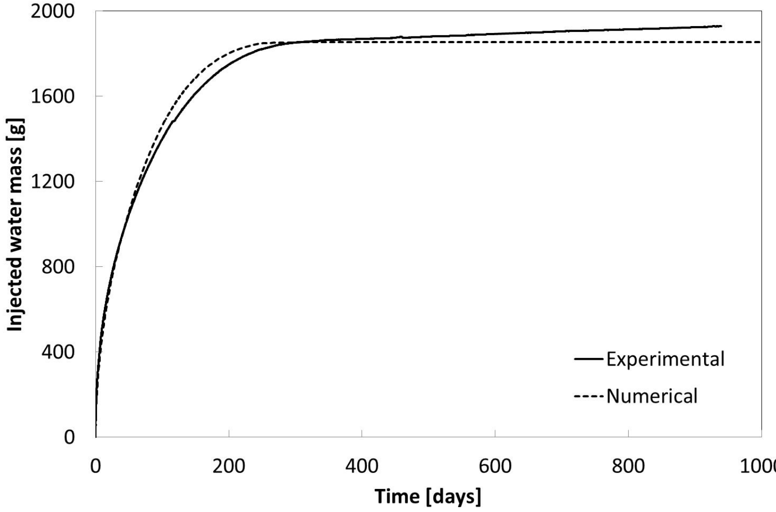
Boundary condition of the model

5. Numerical results and analysis

5.2 Permeability evolution and water intake



Evolution through time of permeability over the height of the sample during water injection (numerical results)

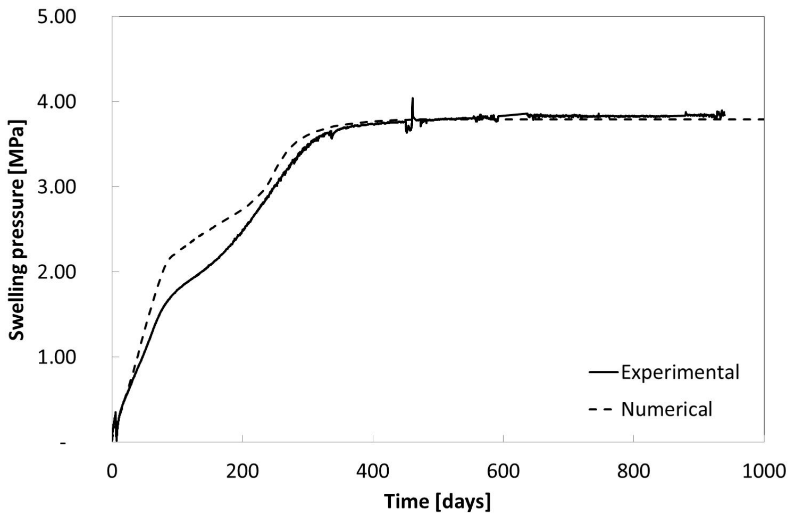


Water mass injected from the bottom end. Comparison between experimental data and model predictions

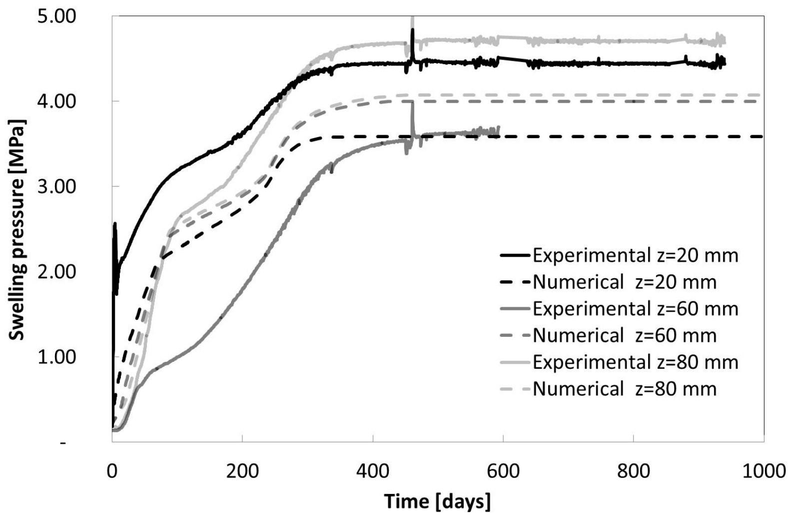
$$K_w = K_{w0} \frac{e_M^{expn}}{(1-e_M)^{expm}} \frac{(1-e_{M0})^{expm}}{e_{M0}^{expn}}$$

5. Numerical results and analysis

5.3 Swelling pressure



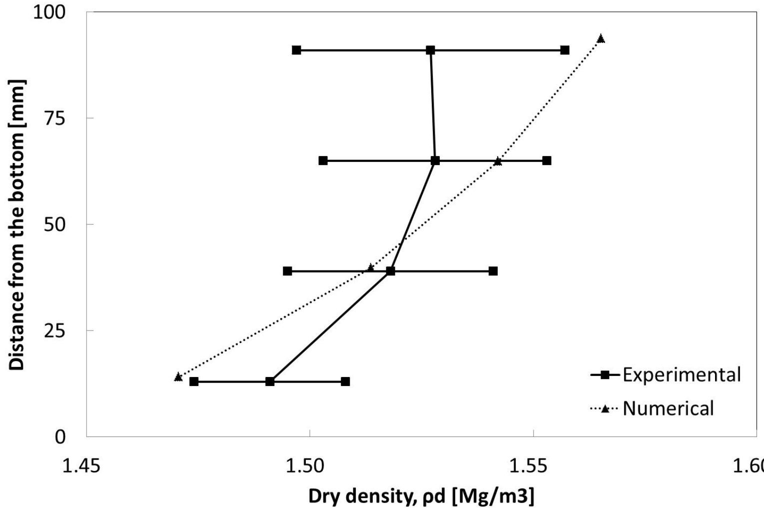
Swelling pressure in axial direction. Comparison between experimental data and model predictions



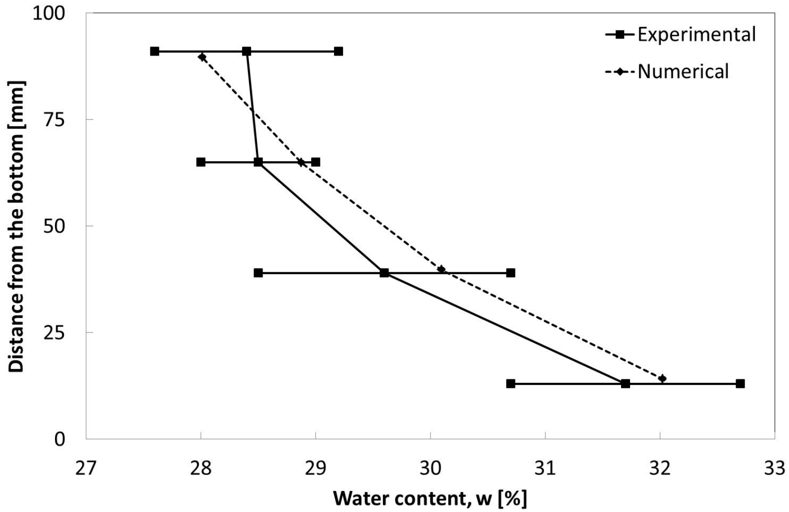
Swelling pressures in radial direction. Comparison between experimental data and model predictions

5. Numerical results and analysis

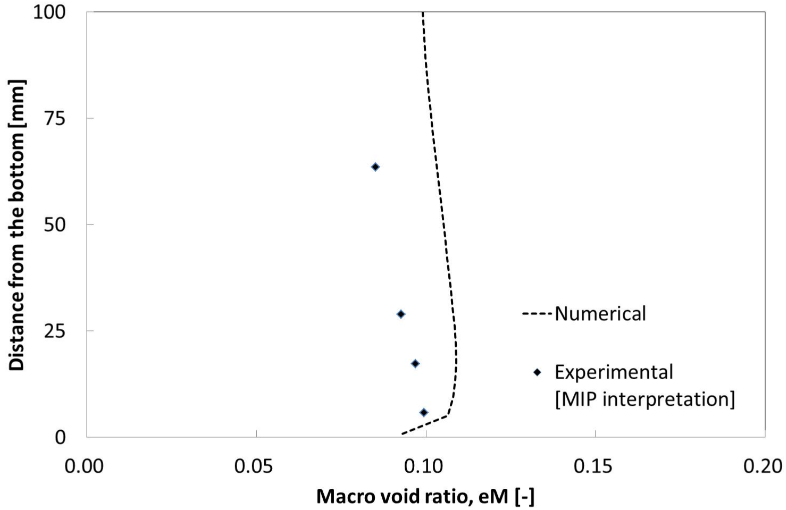
5.4 Post mortem analysis



Dry density distribution over the height of the sample at the end of the test. Comparison between experimental data and model predictions



Water content distribution over the height of the sample at the end of the test. Comparison between experimental data and model predictions



Macrovoid ratio distribution over the height of the sample at the end of the test. Comparison between experimental data and model predictions

6. Conclusions

- The analysed sample presented a prominent initial **heterogeneous pore structure distribution** which is **not considered** in the numerical strategy...

- Nevertheless the numerical model is able to **predict remarkably well** the experimental results in terms of:

- **swelling pressure** (especially its non-monotonic evolution);

- **water intake** (direct consequence of the selected permeability law evolution);

- **final dry density and water intake distribution.**

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Acknowledgment

BEACON
Bentonite Mechanical Evolution

This project receives funding from the Euratom research and training programme 2014-2018 under grant agreement No 745942

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