ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Numerical analysis of a near-to-real scale experiment of a deep geological repository

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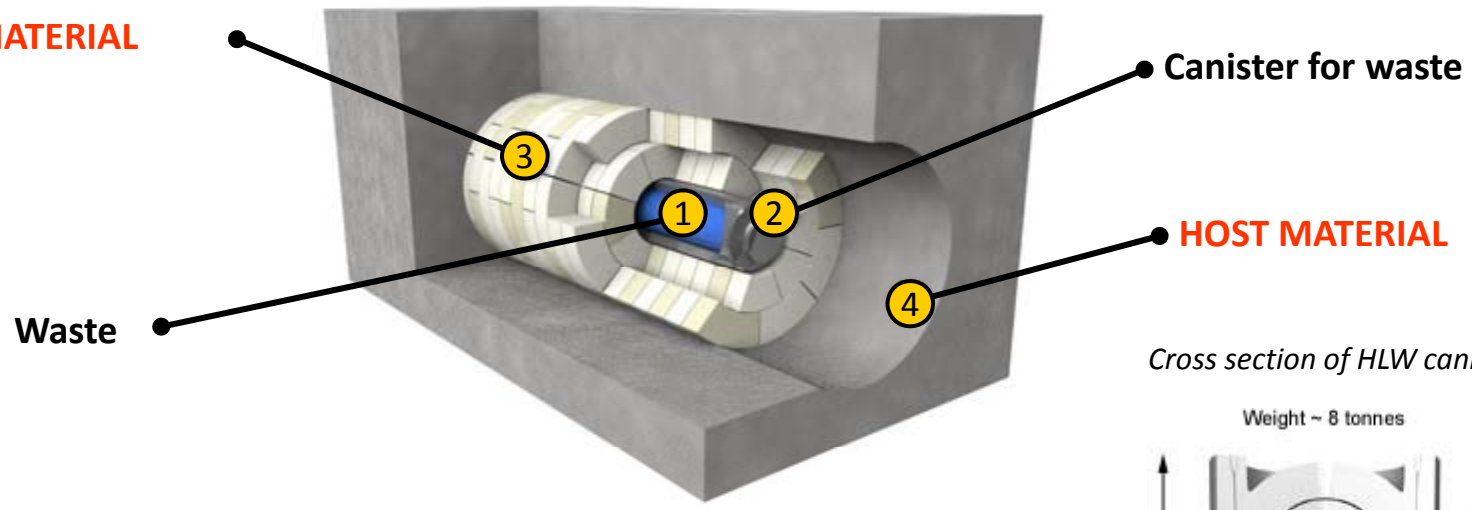
Outline

- Concept of EBS and FEBEX experiment
- Model and materials
- Comparison of results with the experiment

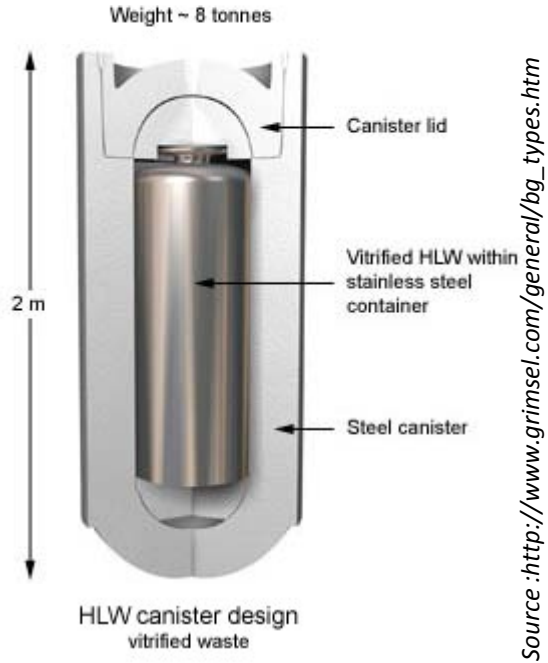
The concept of multi-barrier system (MBS)

Multiplying the number of barrier increases the safety

Source :http://www.grimsel.com/febex/febex_intro_1.htm



Cross section of HLW canister



Source :http://www.grimsel.com/general/bg_types.htm

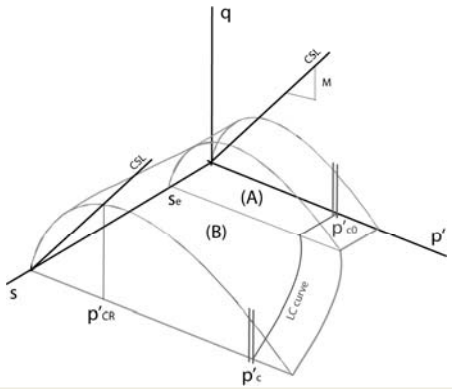
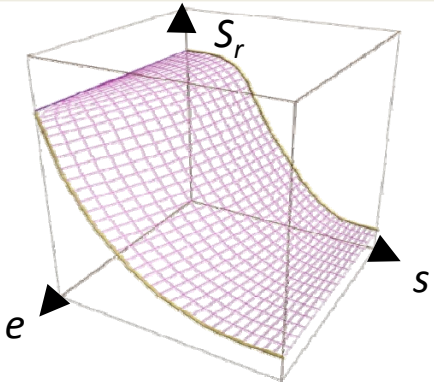
Host material is **granite** or argillaceous material**.**

Buffer material is made of **argillaceous material (bentonite)**:

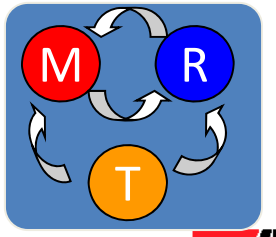
- **restriction of the contact between groundwater and waste**
- **limitation of radionuclides migration after container failure**

Adequate model for the THM behaviour of bentonite is a key to modeling the response of MBS

ACMEG-TS : Stress-strain framework in non-isothermal conditions

Modelled behaviour	Stress variable	Strain variable	Constitutive Relation
M echanical 	$\sigma'_{ij} = \sigma_{net\,ij} + S_r s$ ***Generalised effective stress***	ε ***Skeleton strain***	$d\sigma'_{ij} = \mathbf{D}_{ijkl} : d\varepsilon_{kl}$ $d\sigma'_{ij} = \tilde{\mathbf{D}}_{ijkl}(T) : (d\varepsilon_{kl} - \beta_{kl} dT)$
R etention 	$s = (p_a - p_w)$ ***Matric suction***	S_r ***Degree of saturation***	$ds = A.dS_r$ $ds = \tilde{A}(T).dS_r$ *A:* Retention properties

+ T emperature T → Thermo-hydro-mechanical couplings



ACMEG-TS : Non-isothermal unsaturated yield limits

Temperature effect

$$\tilde{p}'_c(T) = p'_{c0}\left[1-\gamma_T \log\left(\frac{T}{T_0}\right)\right]$$

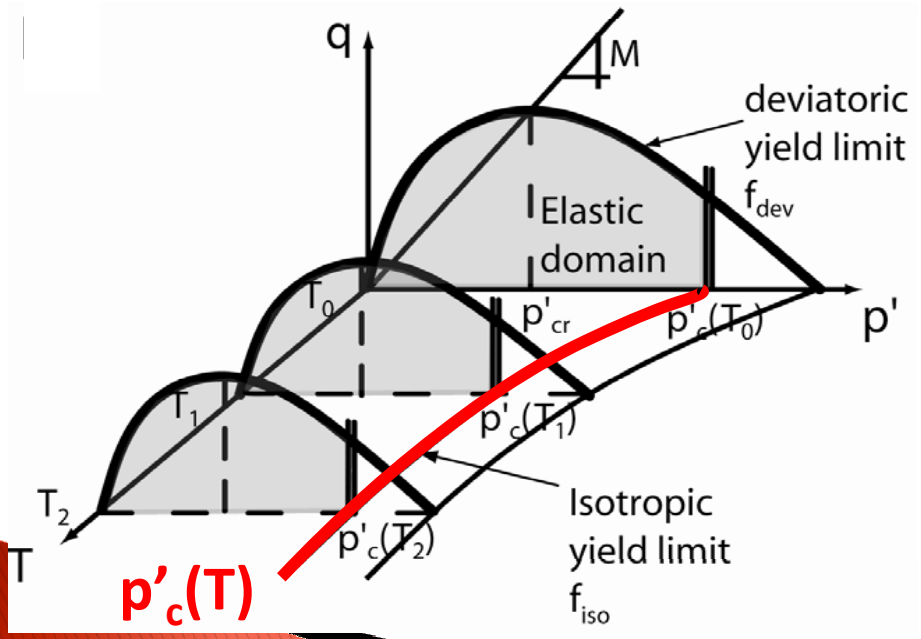
Suction effect

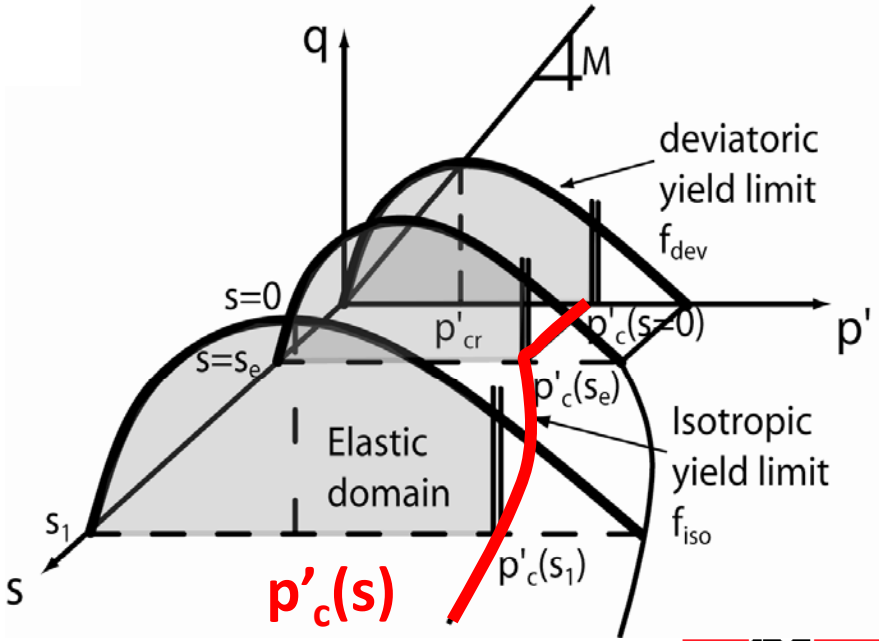
$$\tilde{p}'_c(s) = p'_{c0} \quad \text{for } 0 < s < s_e$$

$$\tilde{p}'_c(s) = p'_{c0}\left[1+\gamma_s \log\left(\frac{s}{s_e}\right)\right] \quad \text{for } s > s_e$$

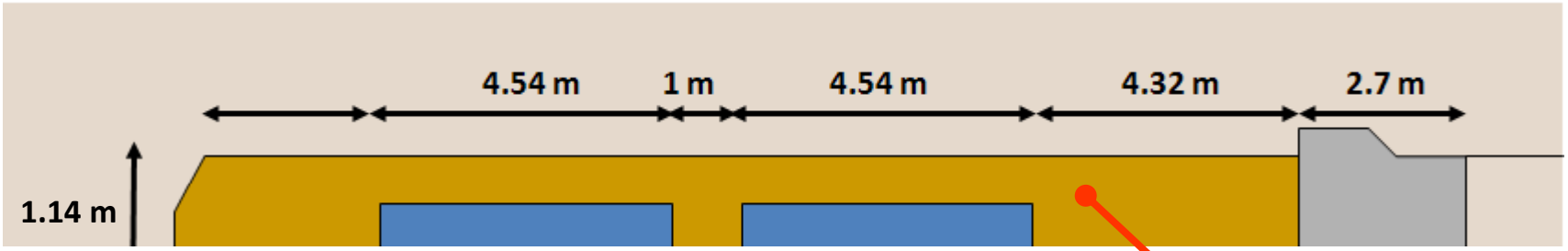
$$\tilde{p}'_c(T,s) = p'_{c0}\left[1-\gamma_T \log\left(\frac{T}{T_0}\right)\right] \quad \text{for } 0 < s < s_e$$

$$\tilde{p}'_c(T,s) = p'_{c0}\left[1-\gamma_T \log\left(\frac{T}{T_0}\right)\right]\left[1+\gamma_s \log\left(\frac{s}{s_e}\right)\right] \quad \text{for } s > s_e$$

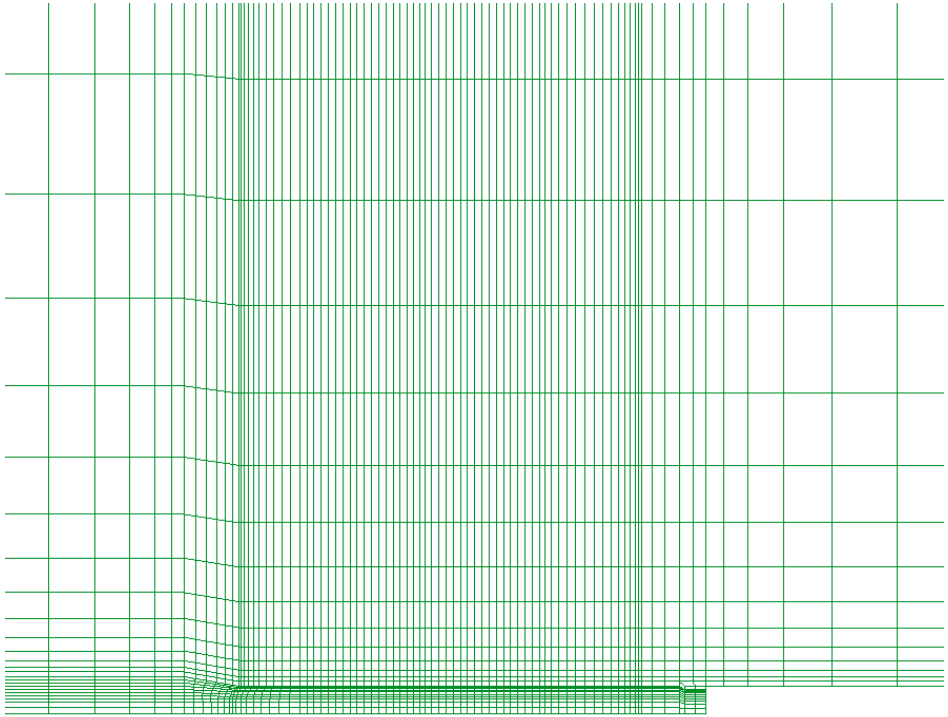




Febex in-situ test : Model



Dimensions



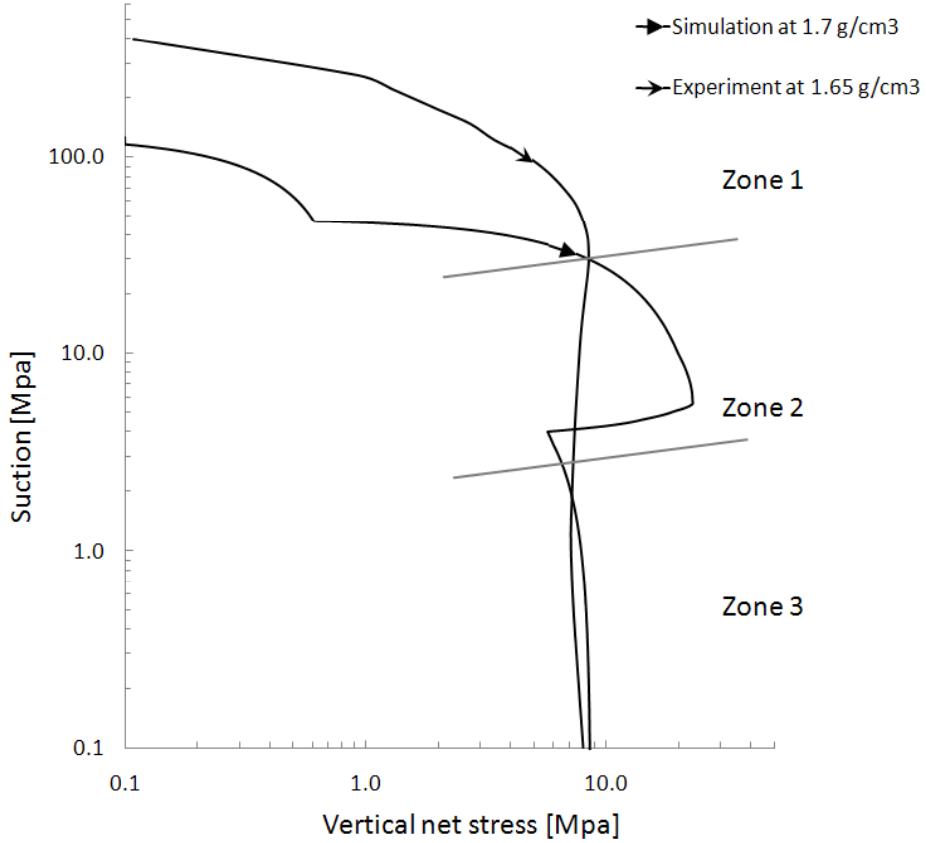
Mesh

Buffer
Bentonite
Hardening plasticity
Thermal and suction effects

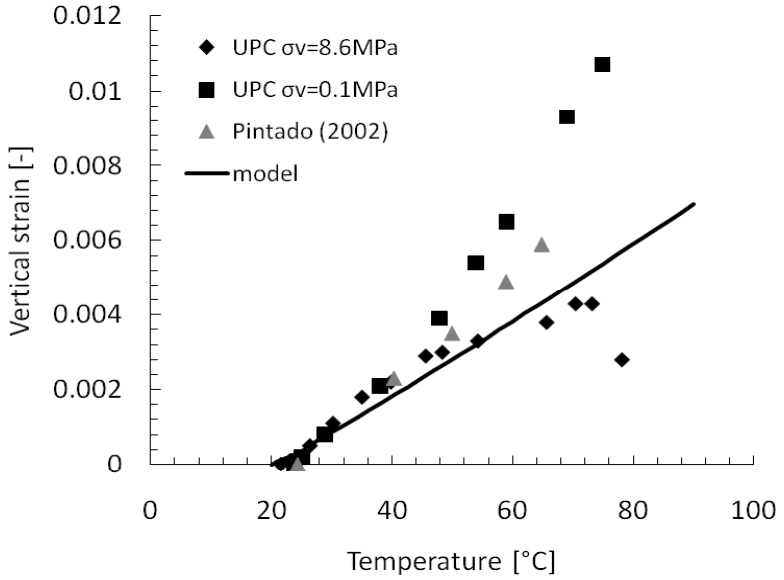
Other materials
Thermo-elasticity

Febex in-situ test : Materials

Identification procedure



Constrained swelling behaviour

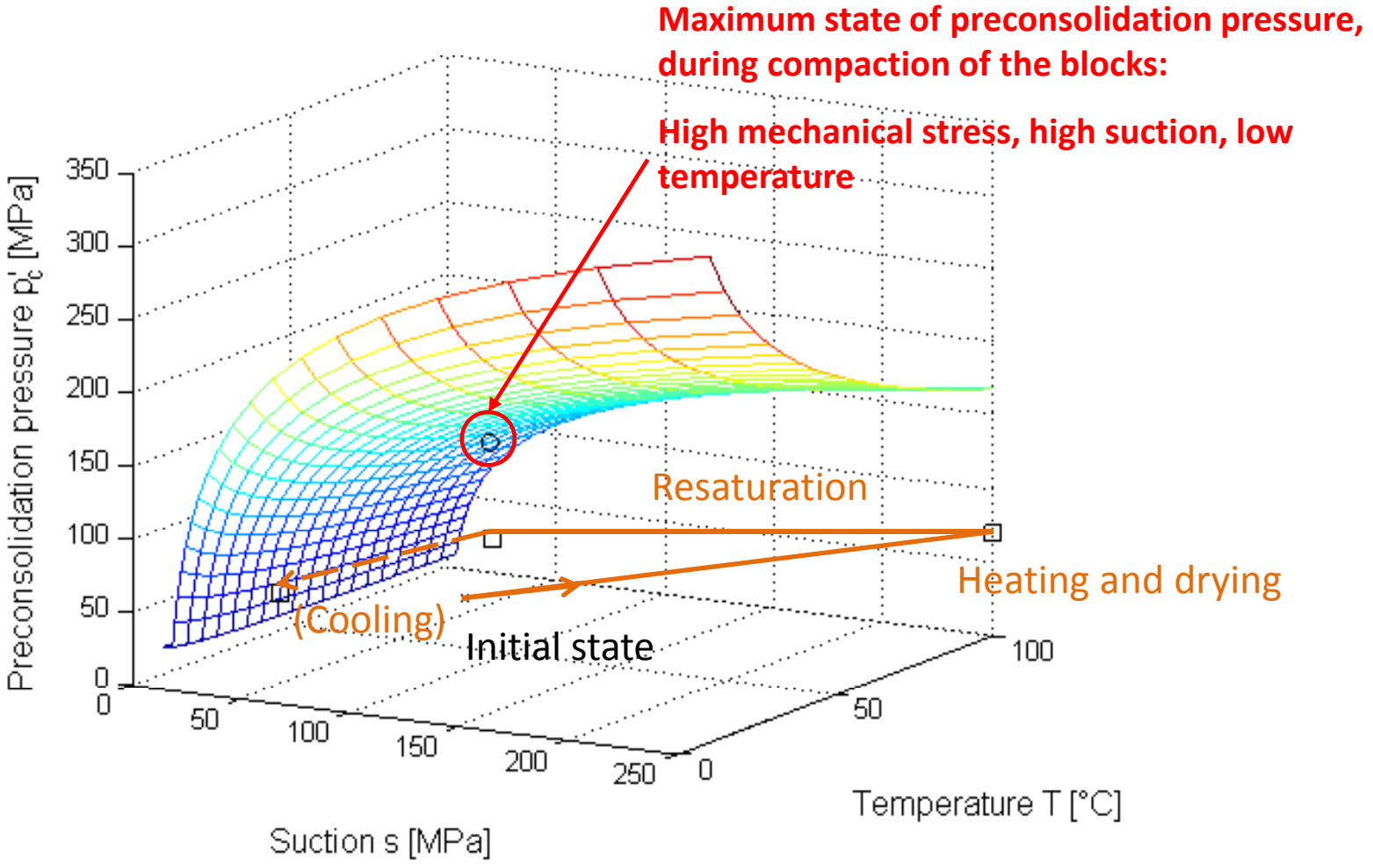


Thermal dilation

Experiments by Romero et al., Pintado et al.

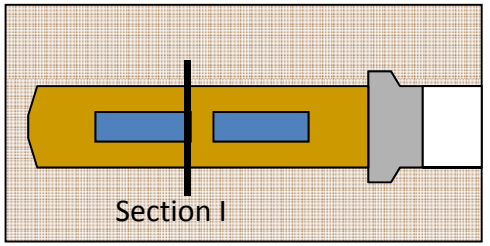
Febex in-situ test : Materials

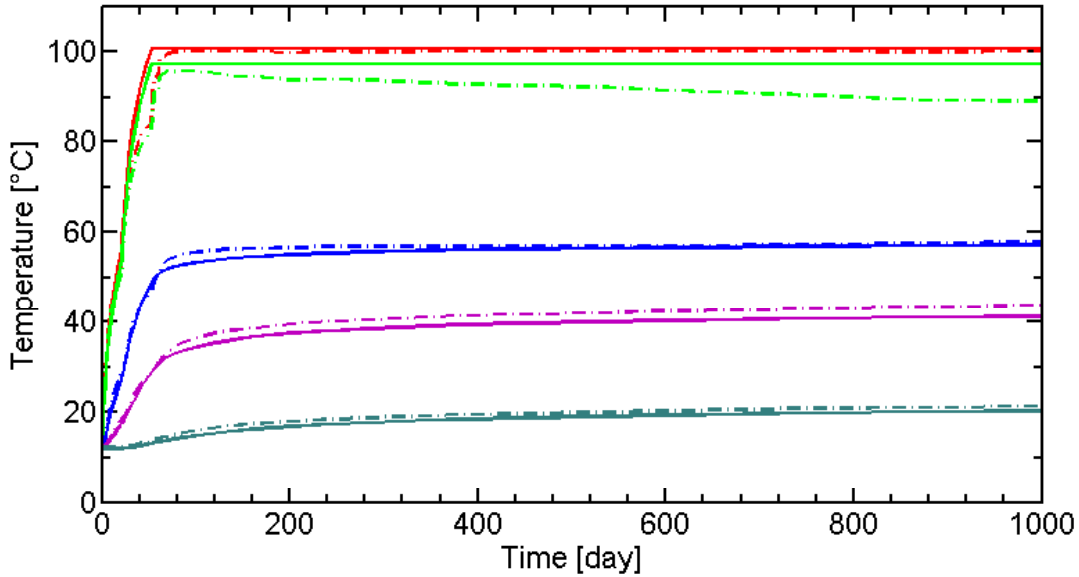
Identification procedure



Febex in-situ test : Results

Temperature in bentonite

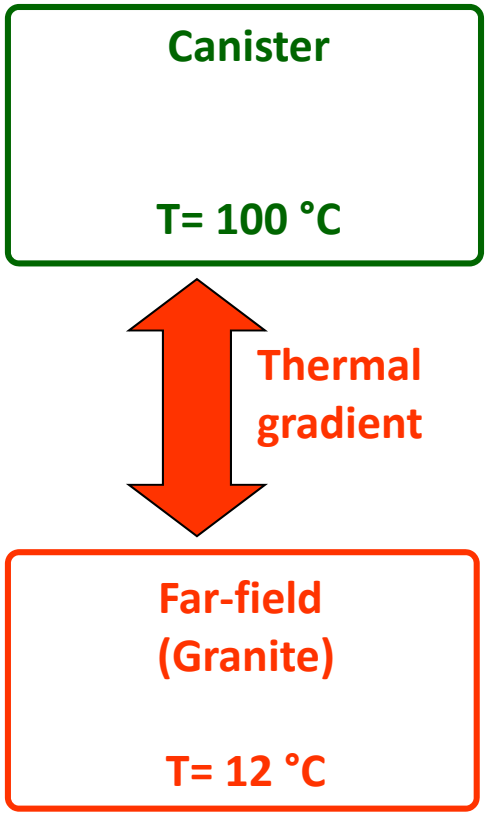




Numerical simulation

Experiment

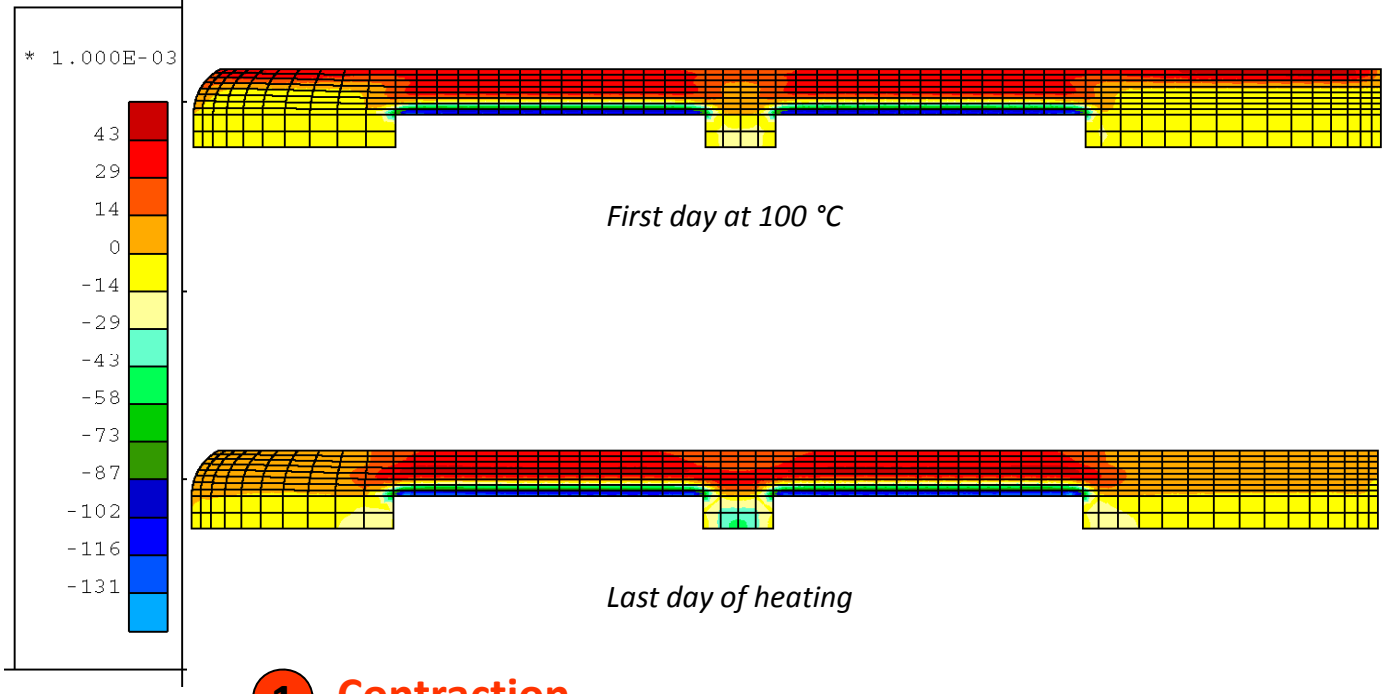
Experimental data from ENRESA



Febex in-situ test : Results

Strains and stresses

Radial strains



Granite-bentonite Interface
Swelling
Higher radial stress

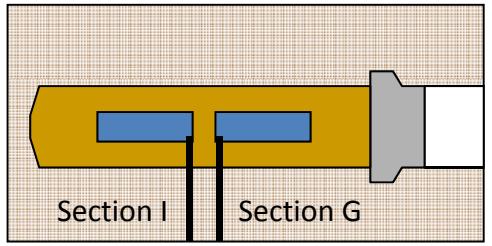
Stress gradient

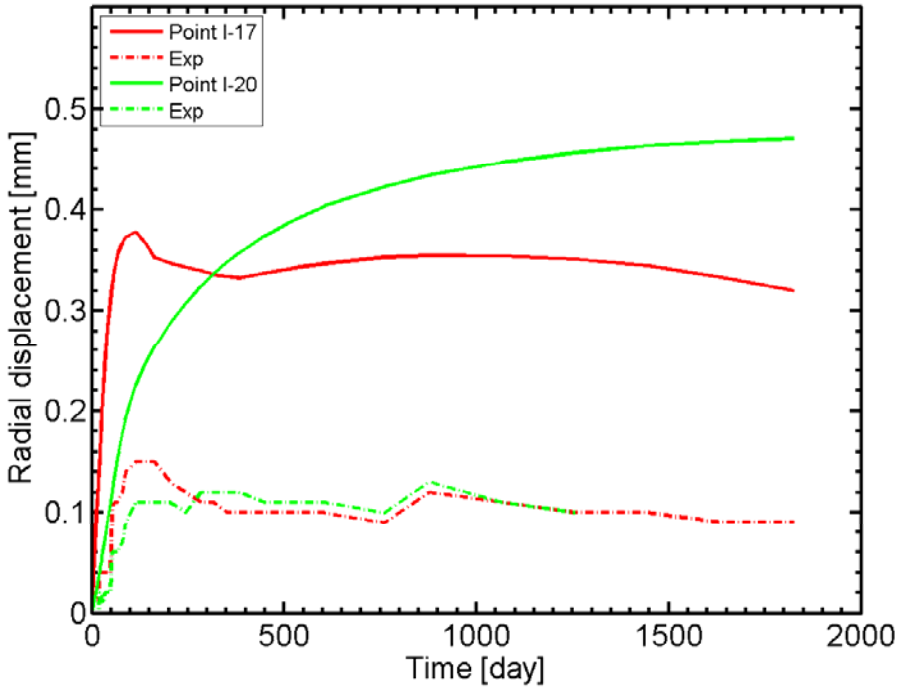
Canister-bentonite Interface
Shrinkage
Lower radial stress

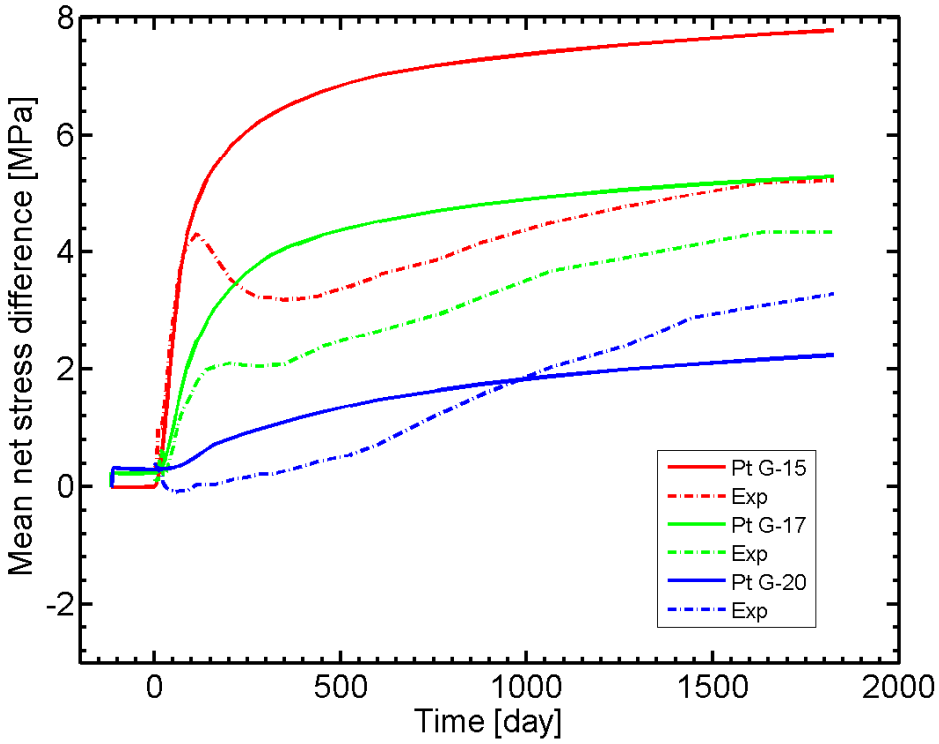
1. **Contraction**
   Thermo-plasticity + hydraulic shrinkage
2. **Dilatation**
   Thermal expansion + hydraulic swelling
3. **Consequence**
   Displacement of bentonite towards heater

Febex in-situ test : Results

Strains and stresses

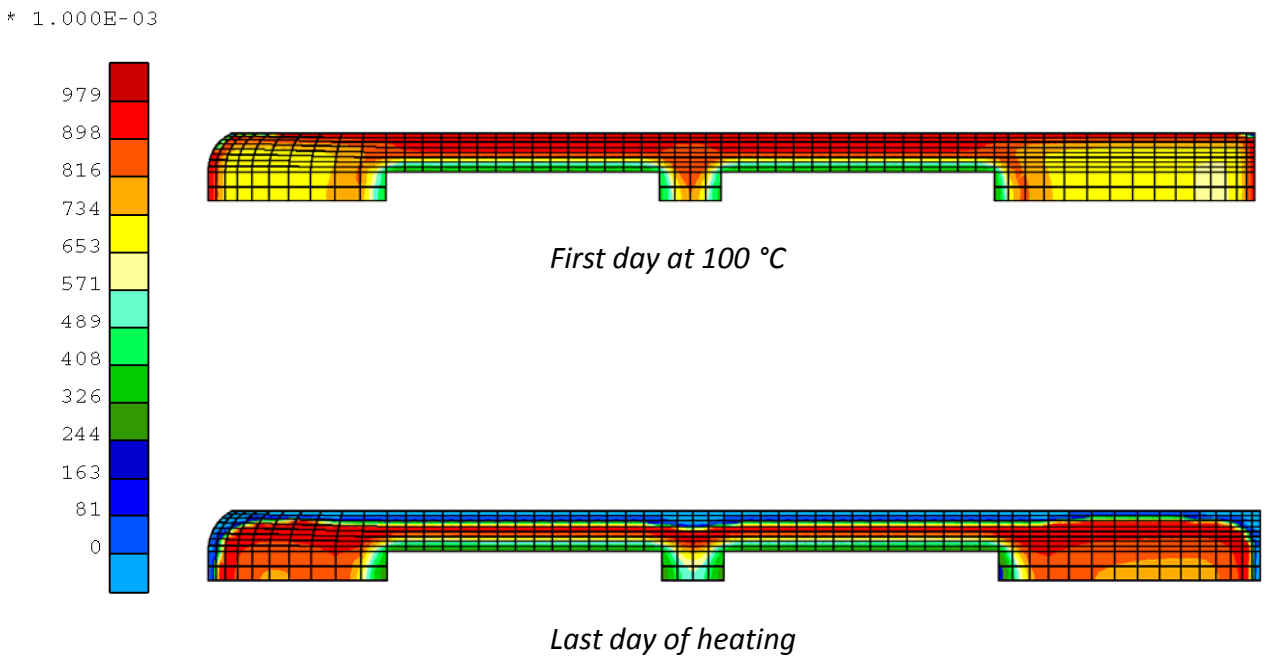






Febex in-situ test : Results

Relative humidity



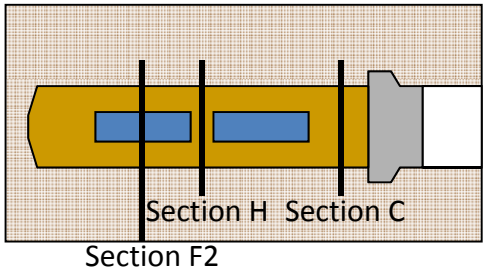
Granite-bentonite Interface
Resaturation of the bentonite

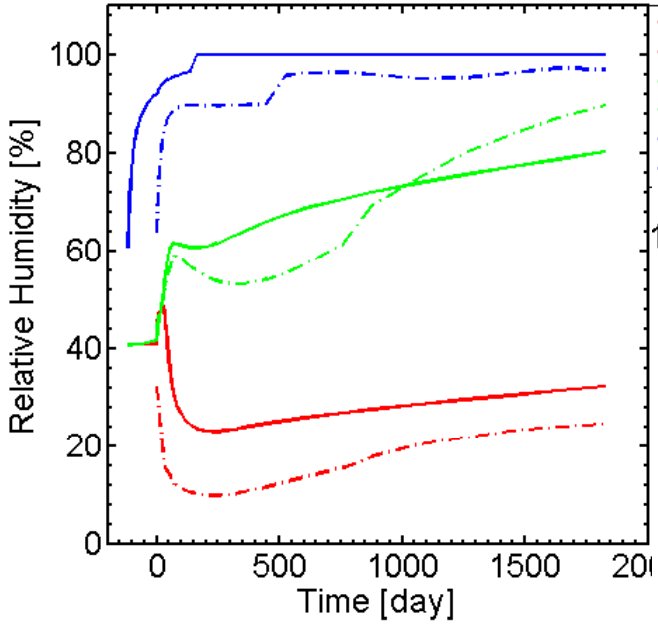
Hydraulic gradient

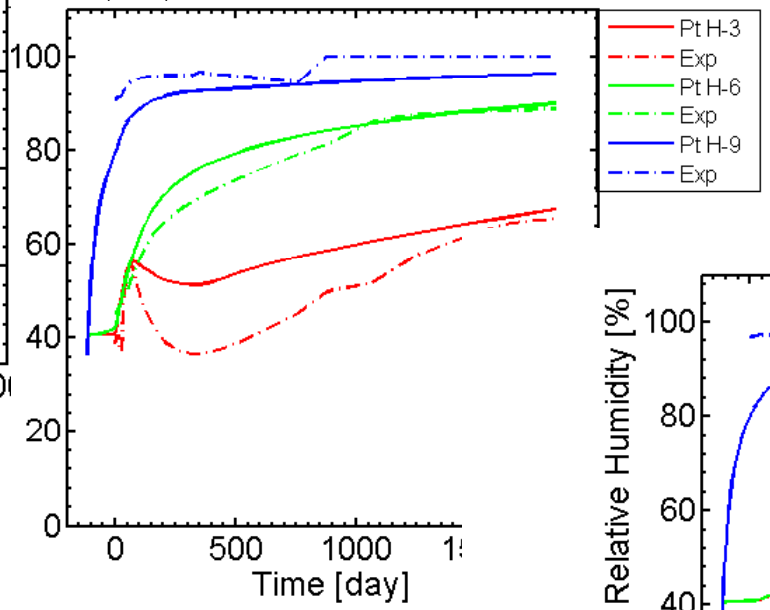
Canister-bentonite Interface
Drying of the bentonite

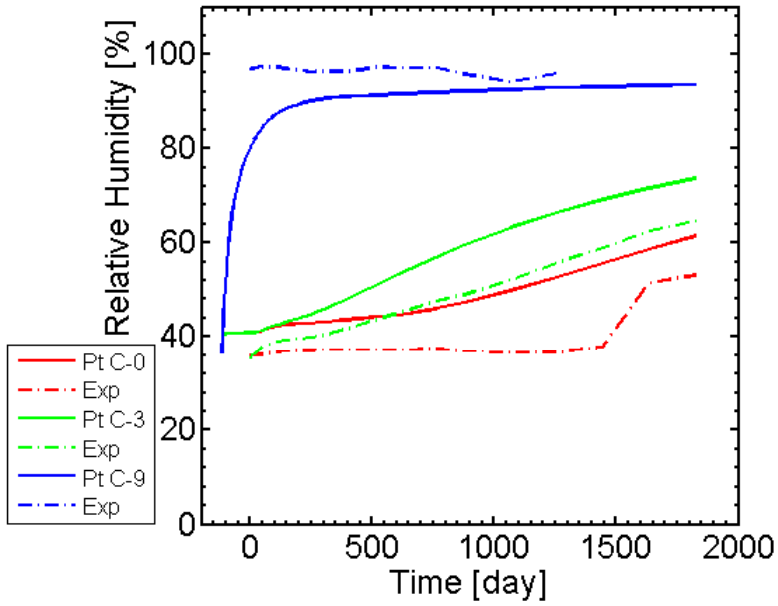
Febex in-situ test : Results

Relative humidity









Febex in-situ test : Results

Degree of saturation and suction

Non univocal S_r-s relation

Interface canister-bentonite

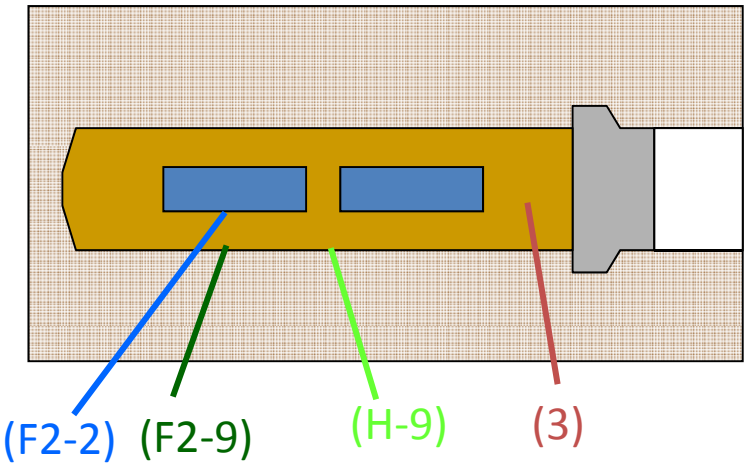
(1) Contraction
Increase of retention capacity
But hardly visible due to drying

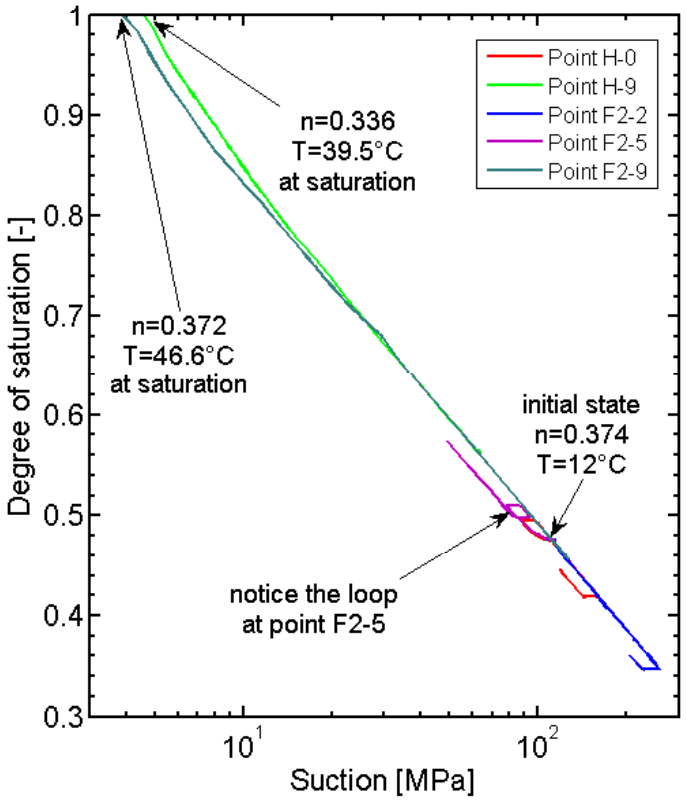
Interface granite-bentonite

(2) Swelling followed by thermal collapse
Contraction (strong for H-9)
Visible difference between H-9 and F2-9

Far field

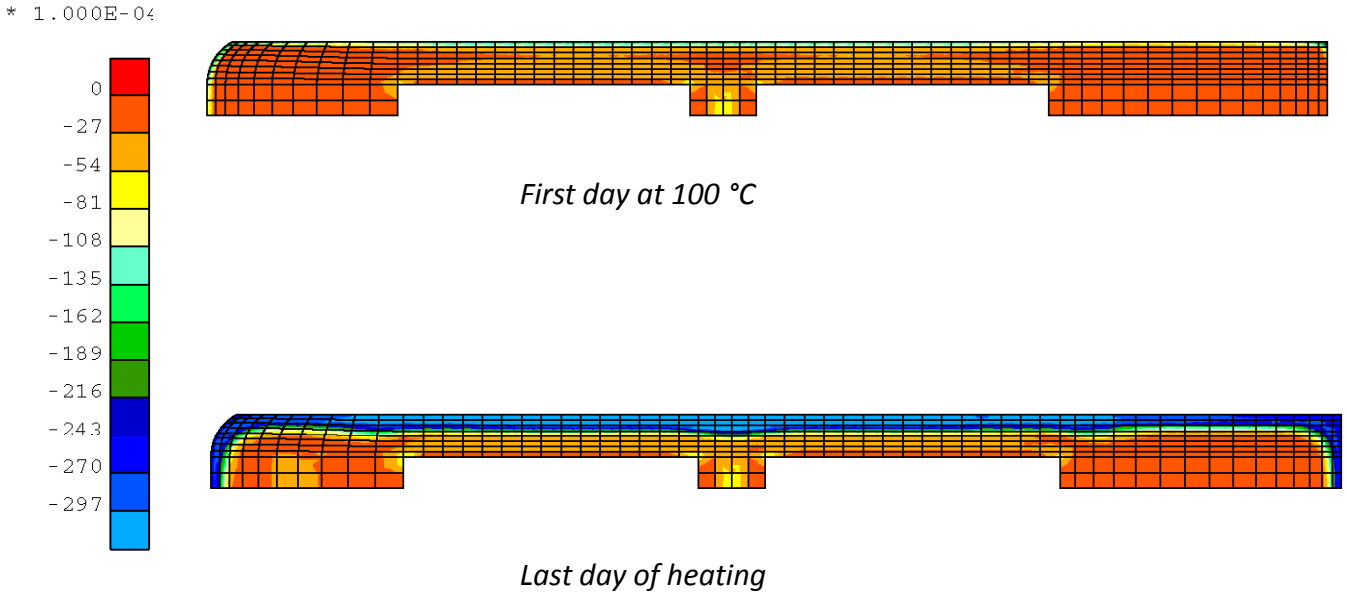
(3) No significant strain
No significant effect on water retention curve





Febex in-situ test : Results

Plasticity due to heat or suction change



Granite-bentonite Interface
Resaturation
High plastic strains

Canister-bentonite Interface
Drying
Little plastic strains

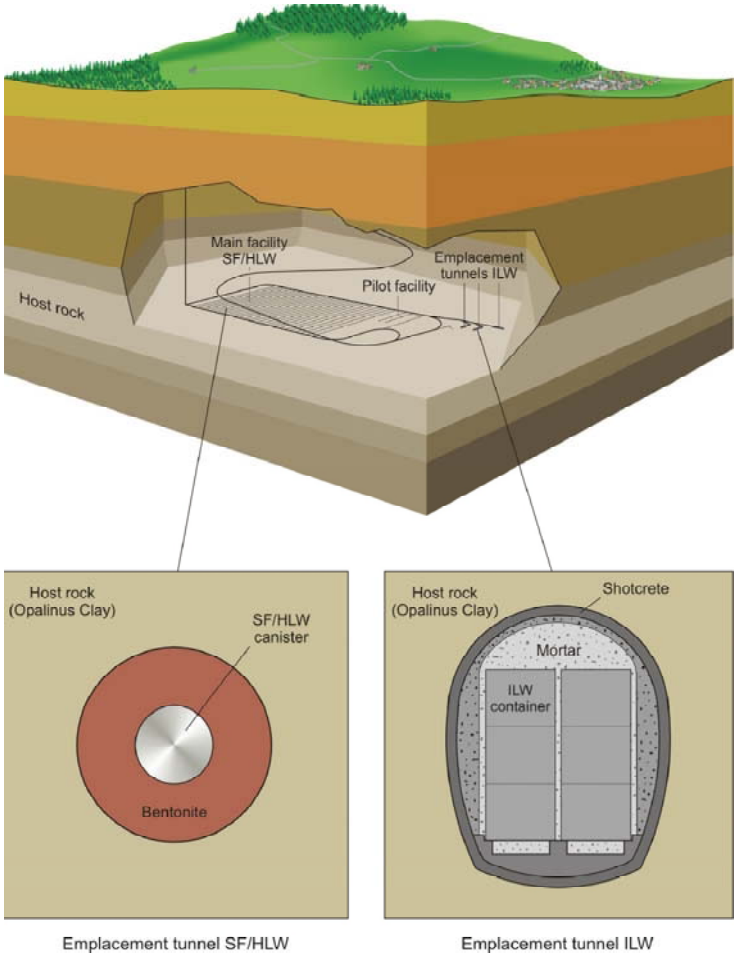
Conclusions

- **Unsaturated soils mechanics is significantly contributing to the field of radioactive waste disposal and generalized effective stress approach gives adequate results in this field.**

- **The proposed THM ACMEG framework, in which attention is given to the basic phenomena and to their governing laws, is motivated by its universality.**

- **The comparison of this simulation with actual experiment reveals excellent agreement in most quantitative aspects, and explains qualitatively observed data that could not be simulated with other models, such as the peak in swelling pressure.**

This research was made possible by the FEBEXe consortium, enresa, and nagra.



Thank you for your attention

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