The Thermal-Hydro-Mechanical behaviour of the Praclay mixture

Laboratory mechanical test results and analysis

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Outline

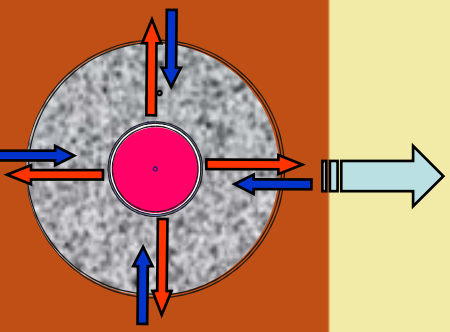
- Objective of the Lab. THM characterization program
- Guide line for the lab. tests program
- Tests realised (initial backfill and exposed backfill)
    - Basic " saturated " behaviour : ULg and ULB
    - Saturated – unsaturated at different temperatures : UPC

      => E. Romero
- Analysis and conclusions (II)

Objective : Why a THM characterization program ?

To study the THM behaviour of the backfill

To obtain the input data for the THM modelling



Heating

Hydration

Saturation - desaturation (?) => T-H

Swelling - collapse (?) => M

Alteration of initial physical properties

etc.

Coupled THM !!!

Numerical Modelling (theory and laboratory)

T => heat transport

$\lambda_T(s_w, \rho, T)$, etc.

H =>multiphase fluid flows

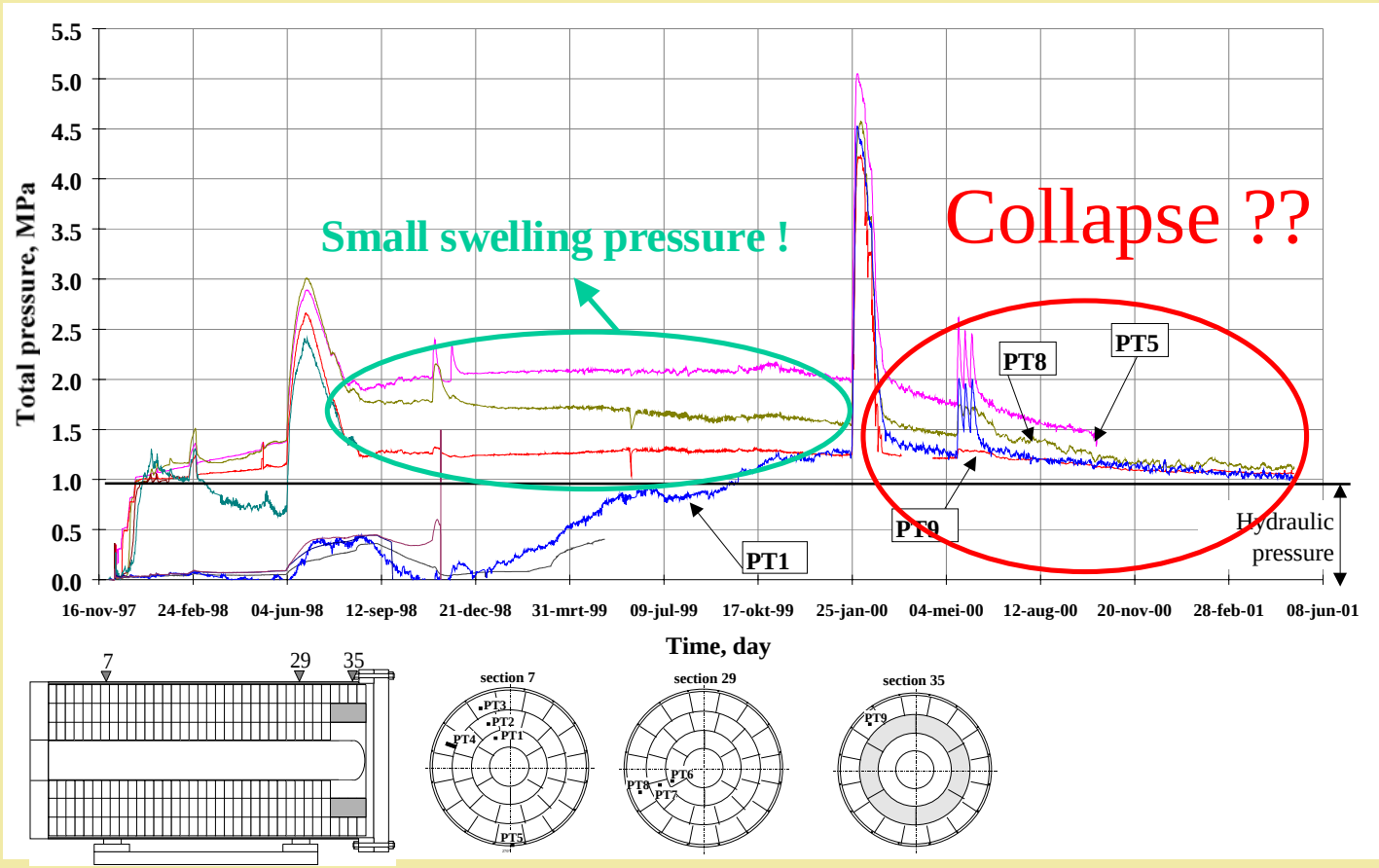
$s_w(s, T, \rho)$, $k_{rw}(s_w, T, \rho)$, $k_{rg}(s_w, T, \rho)$

M => constitutive law (σ–ε relationship)

s_w/s ,T effects : s +T controlled tests

Objective : Why a THM characterization program ?

To understand some phenomena observed in OPHELIE



Guide line for the Lab. tests program (constitutive law building)

Unsaturated EP laws

BBM (Basic Barcelona Model)

Wheeler - Sivakumar law

Cui - Delage law

Bolzon -Schrefler -Zienkiewicz law

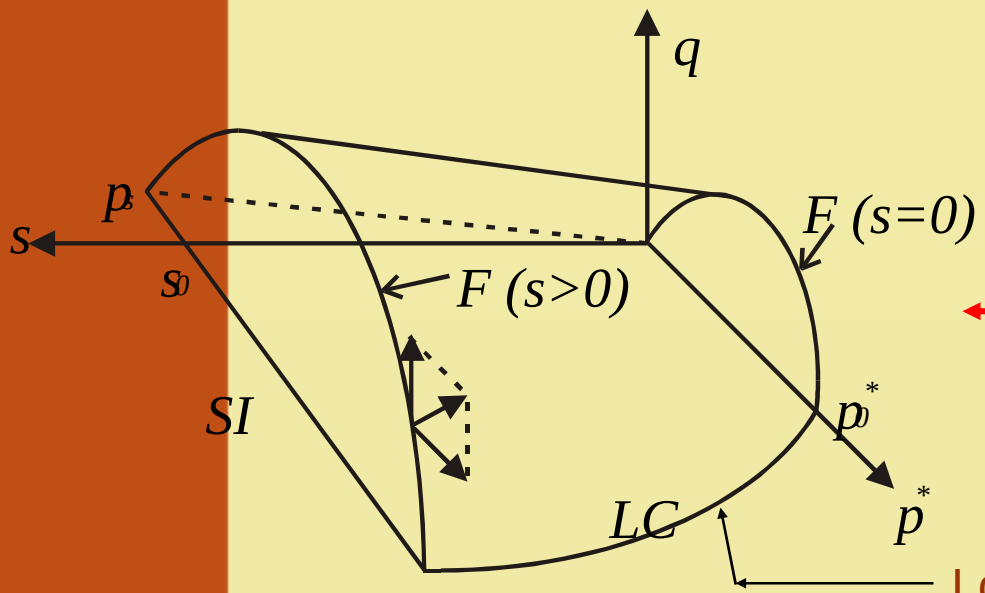
Double structure law (Barcelona)

Etc.

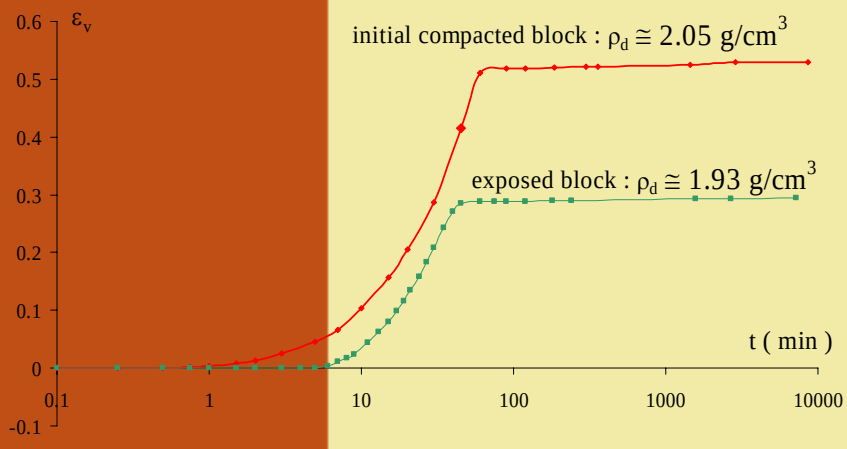
Basic tests program

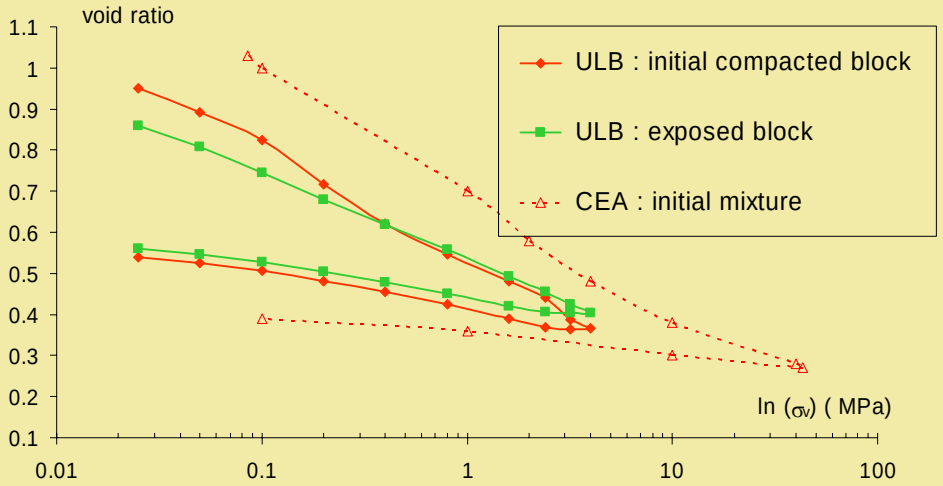
Volumetric aspect	Deviatoric aspect
Odometer (isotropic)	triaxial
s and T controlled	s and T controlled

UPC, ULg, ULB, CEA



" Saturated " odometer tests : stiffness against loading (ULB and CEA)





Saturation phase : swelling

Swelling : exposed < initial

$\Delta\rho$, T , others

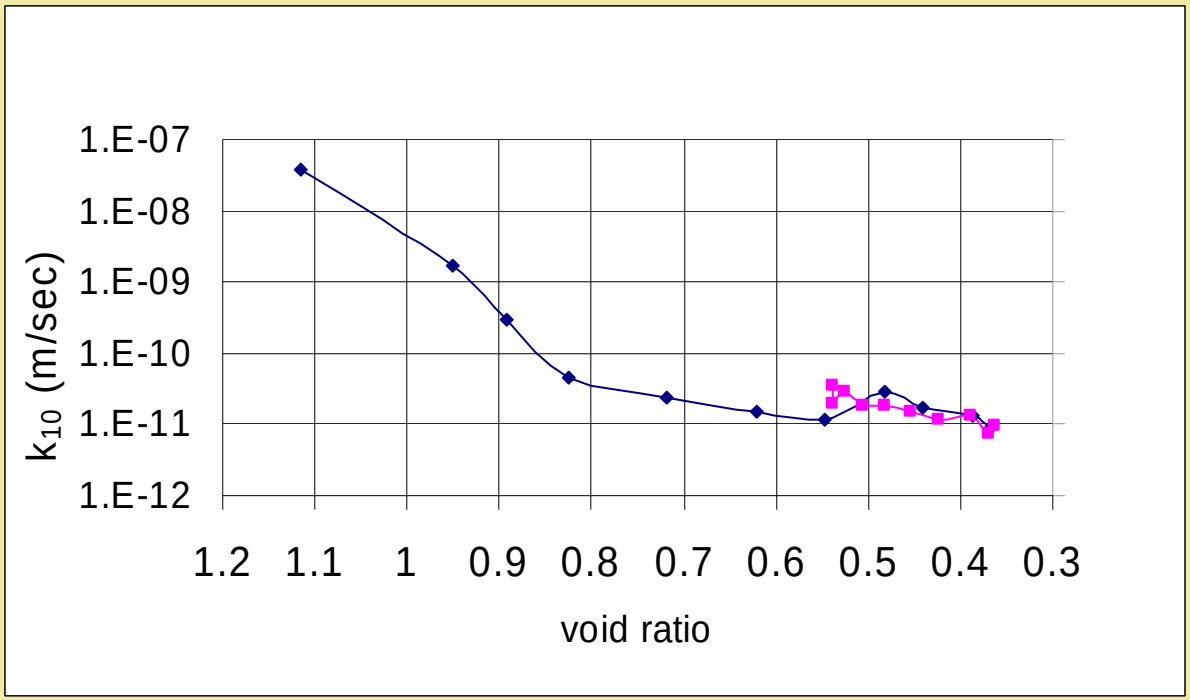
↓

Consistent with swelling pressure measurement (Claude)

Compressibility curves

- Results of CEA and ULB are consistent
- Stiffness : exposed > initial !!
- loading-unloading suggest very low saturated yielding stress !

" Saturated " odometer tests : stiffness against loading (ULB and CEA)

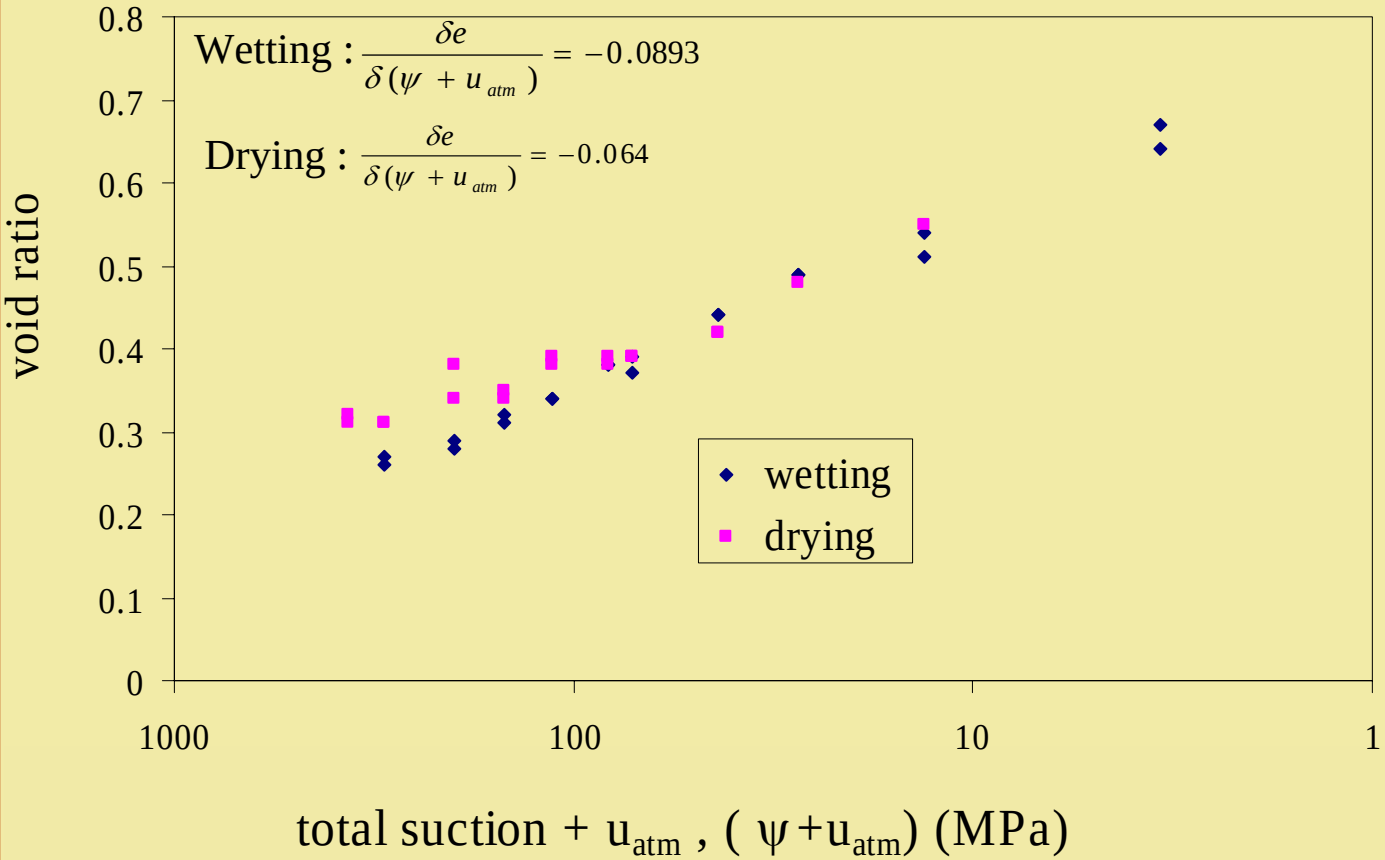


Permeability :

Clearly density dependence (saturated state)!

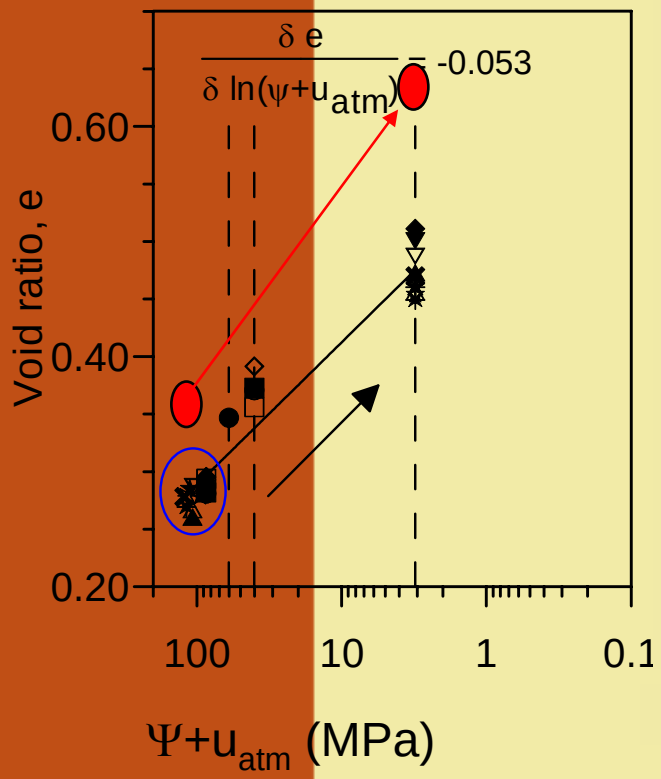
Stiffness against total suction changing (UPC and CEA : unstressed wetting- drying)

CEA : deduced from water retention tests



Stiffness : drying ≥ wetting, under high suction (initial backfill)

Stiffness against total suction changing
(UPC and CEA : unstressed wetting- drying)



UPC : deduced from equalization stages

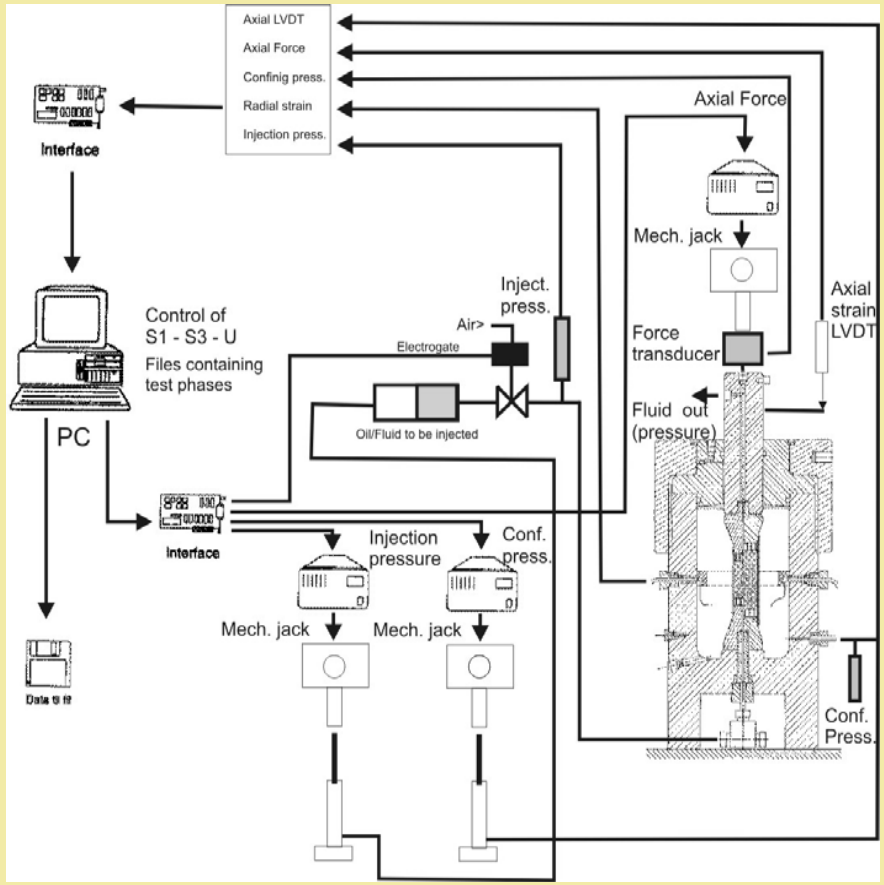
Results obtained by CEA and UPC are consistent ,

Stiffness : CEA < UPC

Results of CEA

" Saturated " triaxial tests results (ULg)

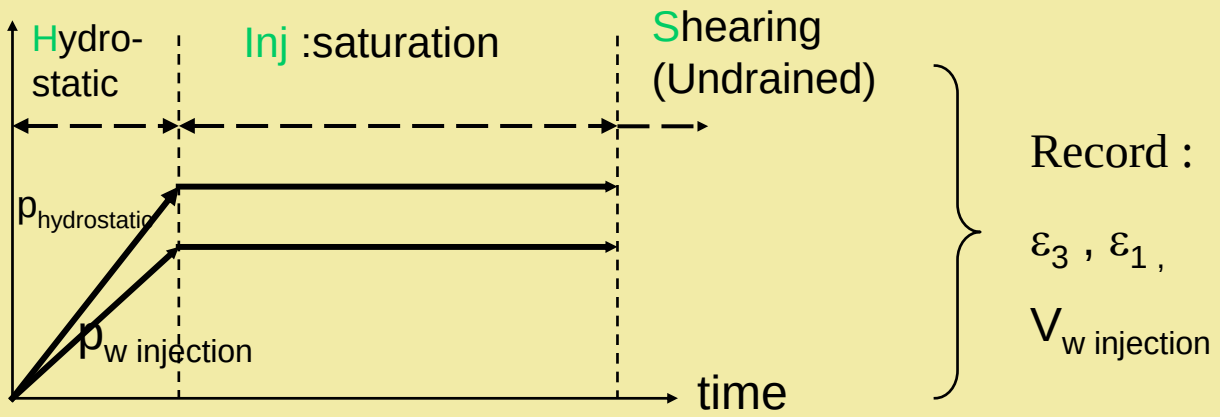
- confined pressure σ_3:70 MPa
- measure and control : $\varepsilon_1, \varepsilon_3$
- water injection : 50 MPa ($< \sigma_3$)
- Kw test : inlet /outlet fluid volume recording
- automatic data log



Radial strain measurement device

" Saturated " triaxial tests results (ULg)

Tests Program :



Initial objective : determine the **saturated** shear strength (input parameters for modelling)

In practice :
- hiiiiigh $p_{w\ injection}$ => σ_3
- looooooong time for saturation

} loooow Kw of backfill ! + others

Difficulties : Interpretation quantitatively : saturation ?? Suction ?? Inside stress state (non homogeneity) ??

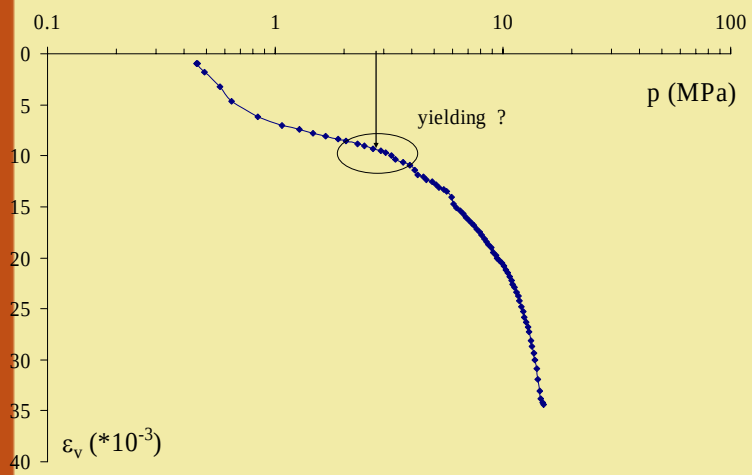
But : Important behaviour observed !

" Saturated " triaxial tests results (ULg)

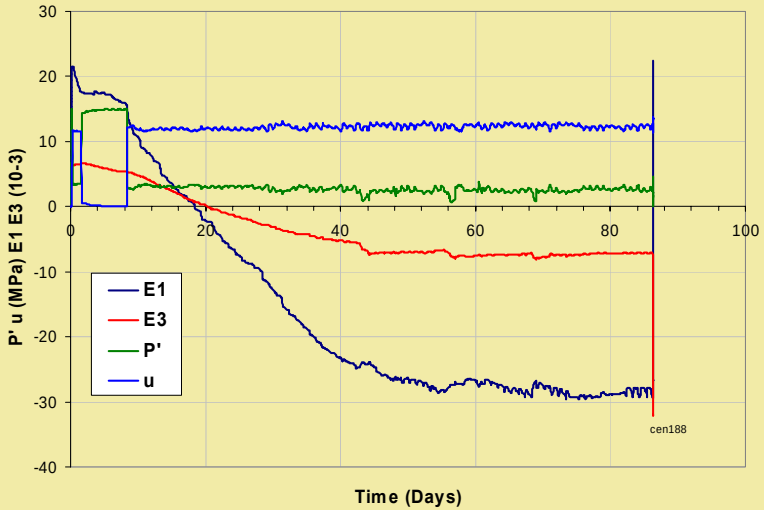
Volumetric Aspect

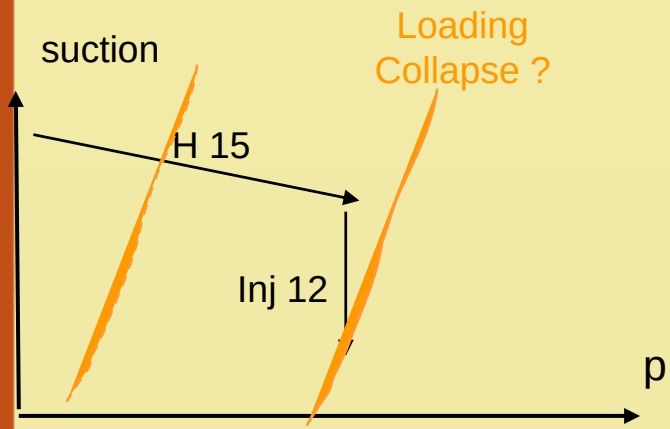
Initial backfill

Hydrostatic loading



Inj : saturation





H phase :

about 3 % of ε_v (compression)

Inj phase :

about 7 % of ε_v (swelling) : high $P_{hydrostatic}$

non apparent collapse observed

Yielding surface (LC)?

Suggest that the swelling dominate % collapse !

" Saturated " triaxial tests results (ULg)

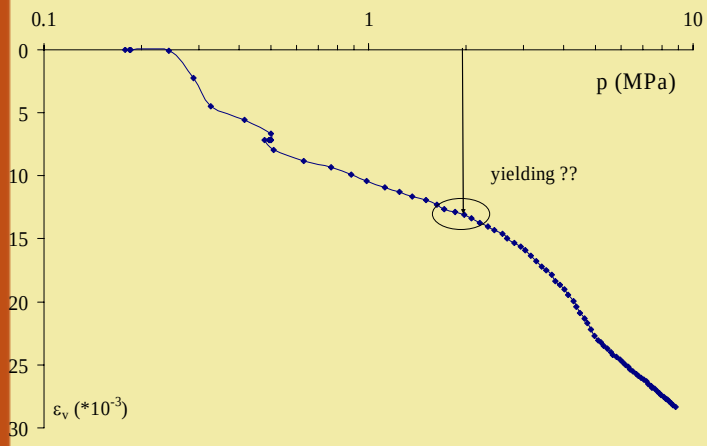
Volumetric Aspect

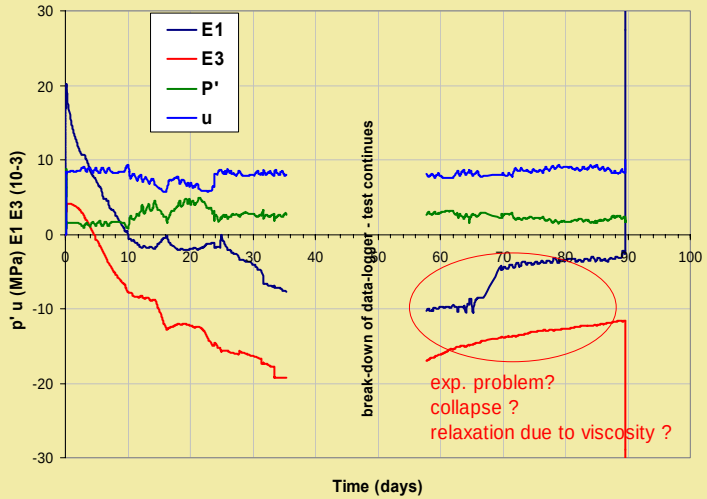
Initial backfill

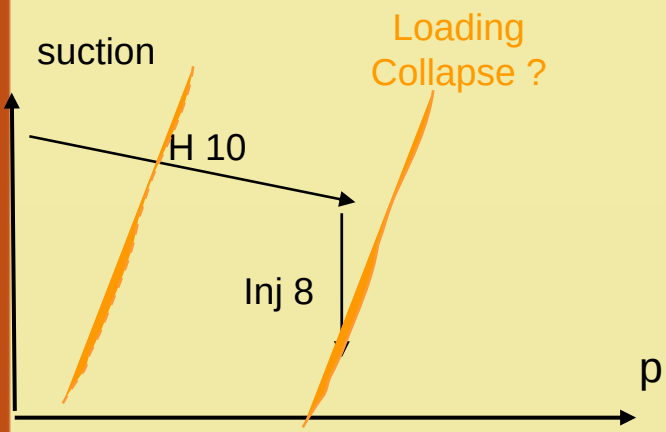
Hydrostatic loading
($P_{hydrostatic}$ = 10 MPa)

Inj : saturation

$P_{w\ injection}$= 8 MPa







H phase :

about 3 % of ε_v (compression)

Inj phase :

about 7.5 % of ε_v (swelling) : high $P_{hydrostatic}$

Collapse ? Viscosity ?

Yielding surface ? Swelling dominate !

" Saturated " triaxial tests results (ULg)

Volumetric

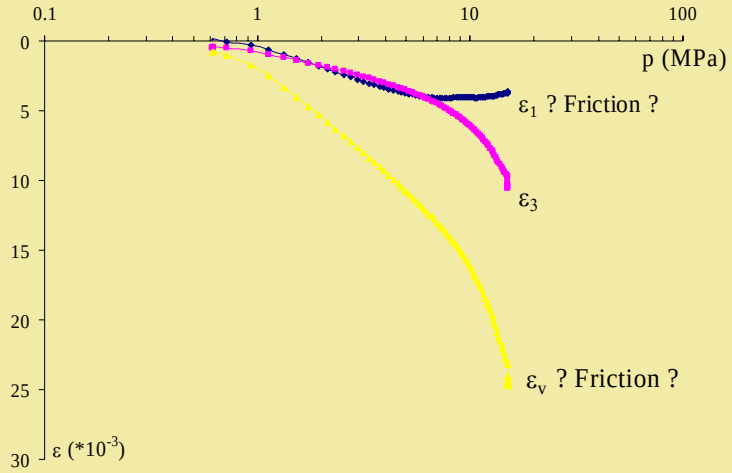
Aspect

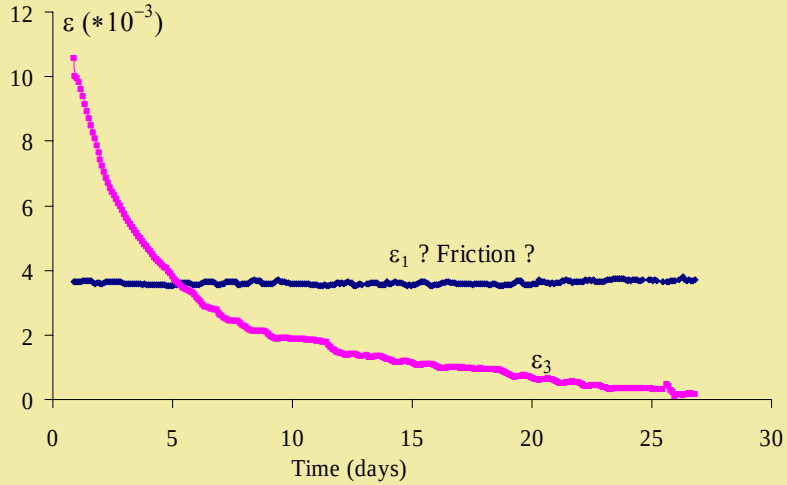
Exposed backfill

Hydrostatic loading
($P_{hydrostatic}$ = 15 MPa)

Inj : saturation

$P_{w\ injection}$= 12 MPa





H phase :

2.5 % of swelling ? (stiffness decreased ?)

Inj phase :

Radial swelling preserved (high $P_{hydrostatic}$)

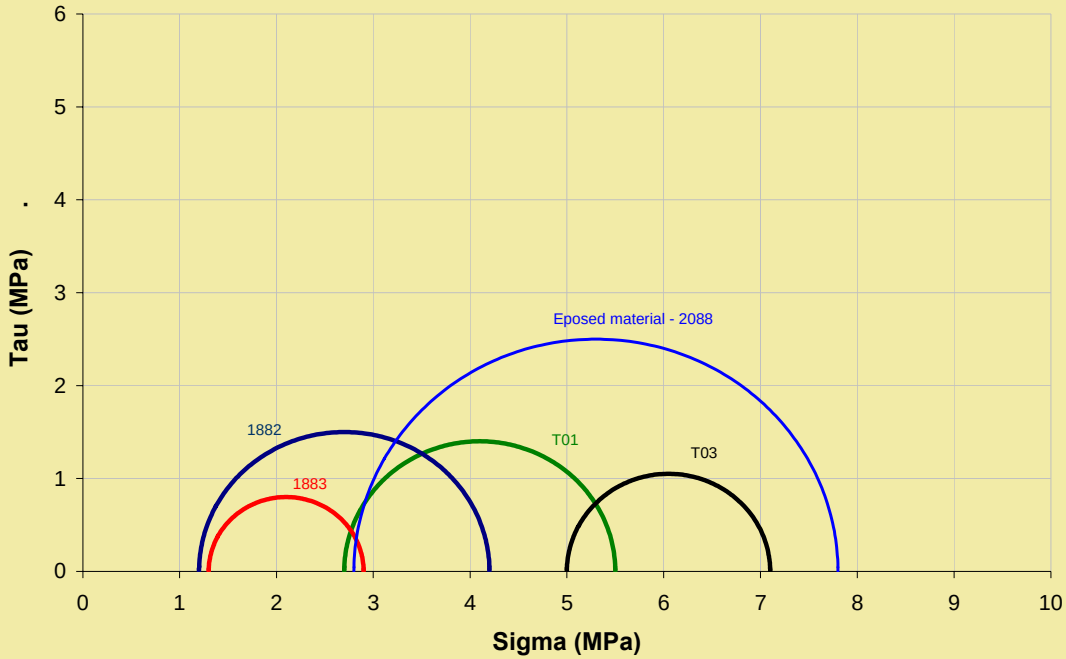
" Saturated " triaxial tests results (ULg)

Deviatoric Aspect

Initial backfill

Sample after shearing

Mohr circles



Failure at lower part of sample

Non clear shear band

Difficult to get a shear strength envelop

} Non homogeneity

Saturation, stresses

But : shear strength : exposed > initial

' Saturated " triaxial tests results (ULg)

- diiiiifficult to saturate the sample
- under hydration phase, non obviously collapse observed, swelling dominate !
- swelling even under high hydrostatical pressure
- non clear shear plane observed due to non homogeneity of stress state , but showing shear strength
- exposed material :
    - swelling behaviour preserved (at least radial deformation)
    - shear strength seems to be increased

Can be served as " small scale " tests for validation the constitutive law !

Conclusions

General :
relative consistent behaviour are observed by different laboratories

HydroMechanical behaviour :

- Permeability :
  - Very low
  - highly depends on the density
- Stiffness against loading : increased for exposed backfill
- Swelling : high , depends on the density
- Collapse : non obvious collapse during hydration has been observed ! Swelling always dominate !!!
- Shear strength : increased for exposed material

Thank you very much !

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