Experimental and numerical studies of the anisotropic behaviour of Boom Clay

A thesis submitted in partial fulfilment of the requirements for the Degree of Master in Civil Engineering

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Nuclear waste in Belgium

Activity	Low	Medium	High
Short half-life period	A	A	C
Long half-life period	B	B	C

Table : Radioactive waste classification (ONDRAF/NIRAS)

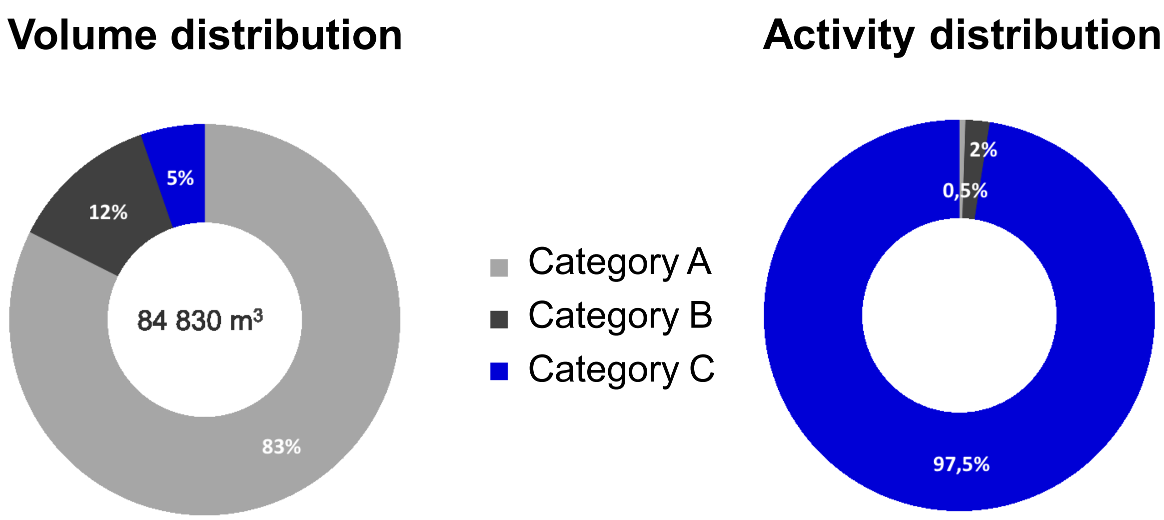

Figure : Cumulated waste volume by 2075 without retreatment and without Tihange-1 overtime (ONDRAF/NIRAS 2008)

Management and strategies in Belgium

Strategy

Physical confinement

Reduce accidental release of pollutants

Restrict access

Category A

Near-surface disposal (min. 300 years) beginning 2016

Figure : Dessel Belgium – cAt Project (ONDRAF/NIRAS)

Categories B & C

Geological disposal (> 100,000 years) still under study

Host rock

Natural barrier against any accidental release of radionuclides to the biosphere

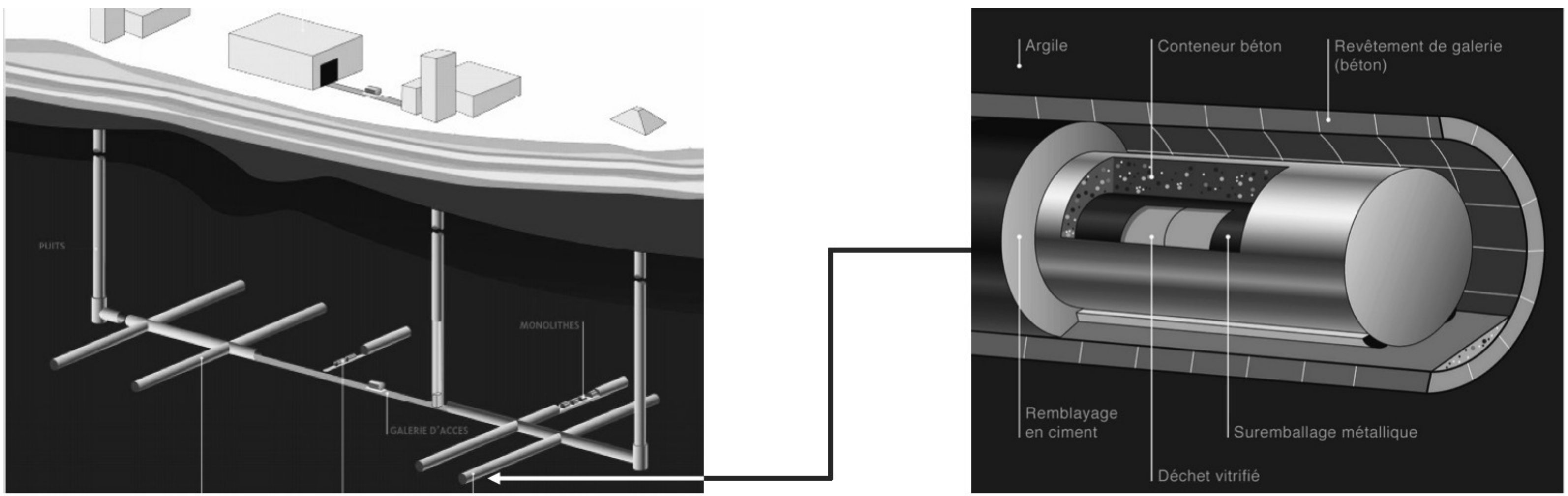

Figure : Geological disposal project (ONDRAF/NIRAS)

Research programs – ONDRAF/NIRAS

Underground laboratory (223 m deep) – Boom Clay

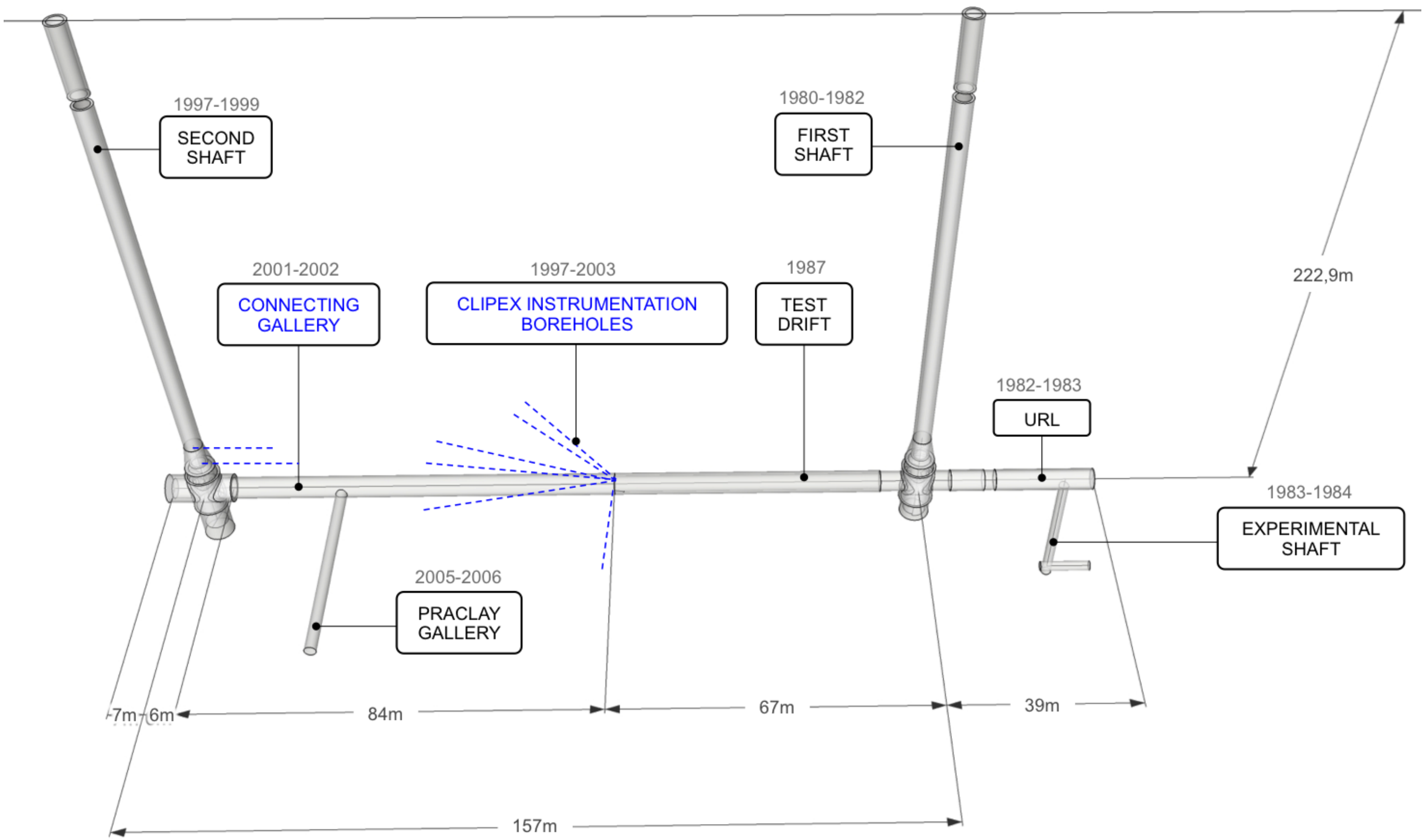

Figure : Mol (Belgium) – HADES Laboratory (High Activity Disposal Experimental Site)

Experimental studies

Studies

- Determination of retention curves (suction/relative humidity)
- Study of the unstressed unsaturated mechanical behaviour
- Evidences of the material anisotropy through size variation

Boom Clay

Marine clastic deposit (3.9-28.4 million years – subtropical climate)

Location : Campine bassin

Properties : plastic, self-healing, porosity 35%

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Boom clay

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Experimental protocol

① Specimens (cylinders H = 30 mm, D = 13 mm) in chambers with constant relative humidity (h_r) fixed by saline solutions

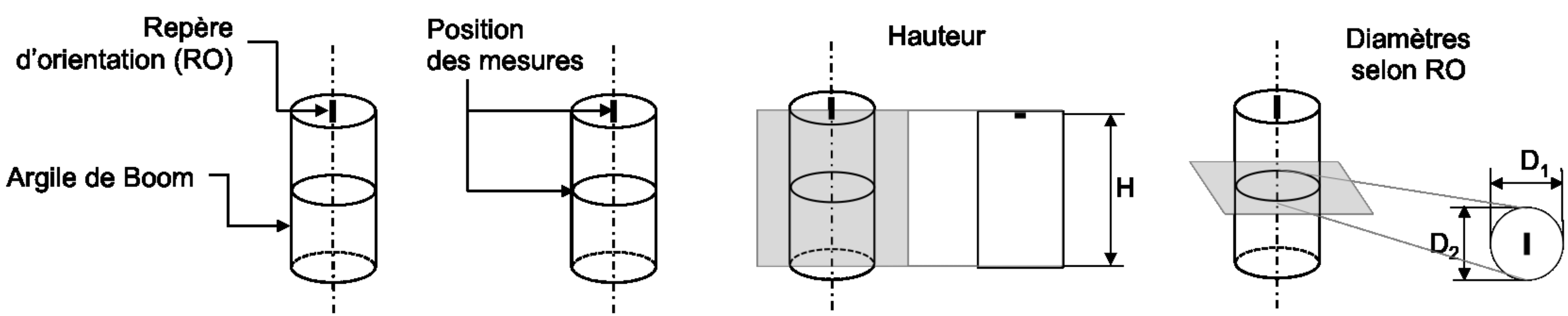
② Suction (p_c) in the sample deduced from h_r (Kelvin's relation)

③ Measurement of water content at the equilibrium (w)

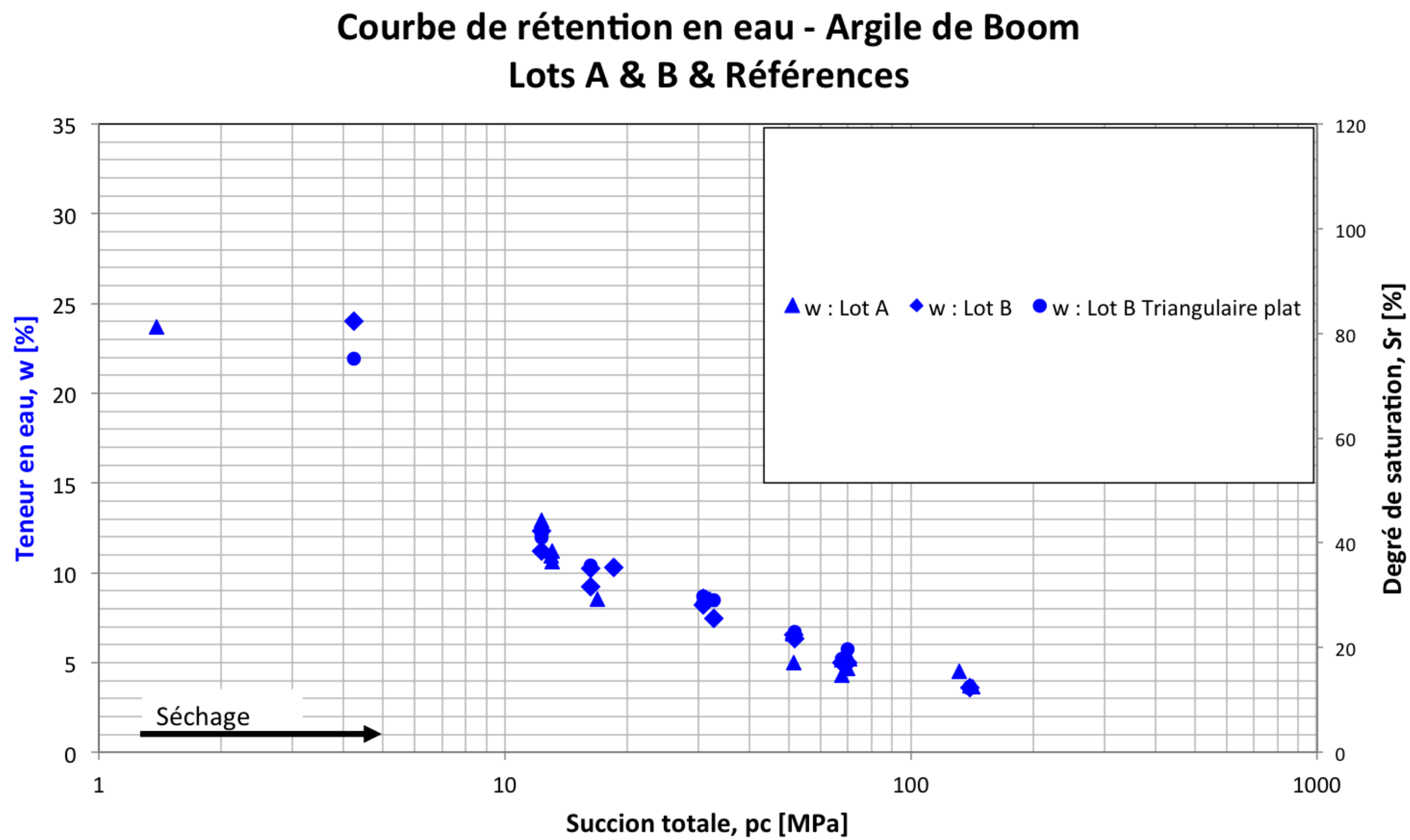
④ Measurement of size variations

⑤ Determination of the saturation degree (S_r) thanks to the dimensions and the water content

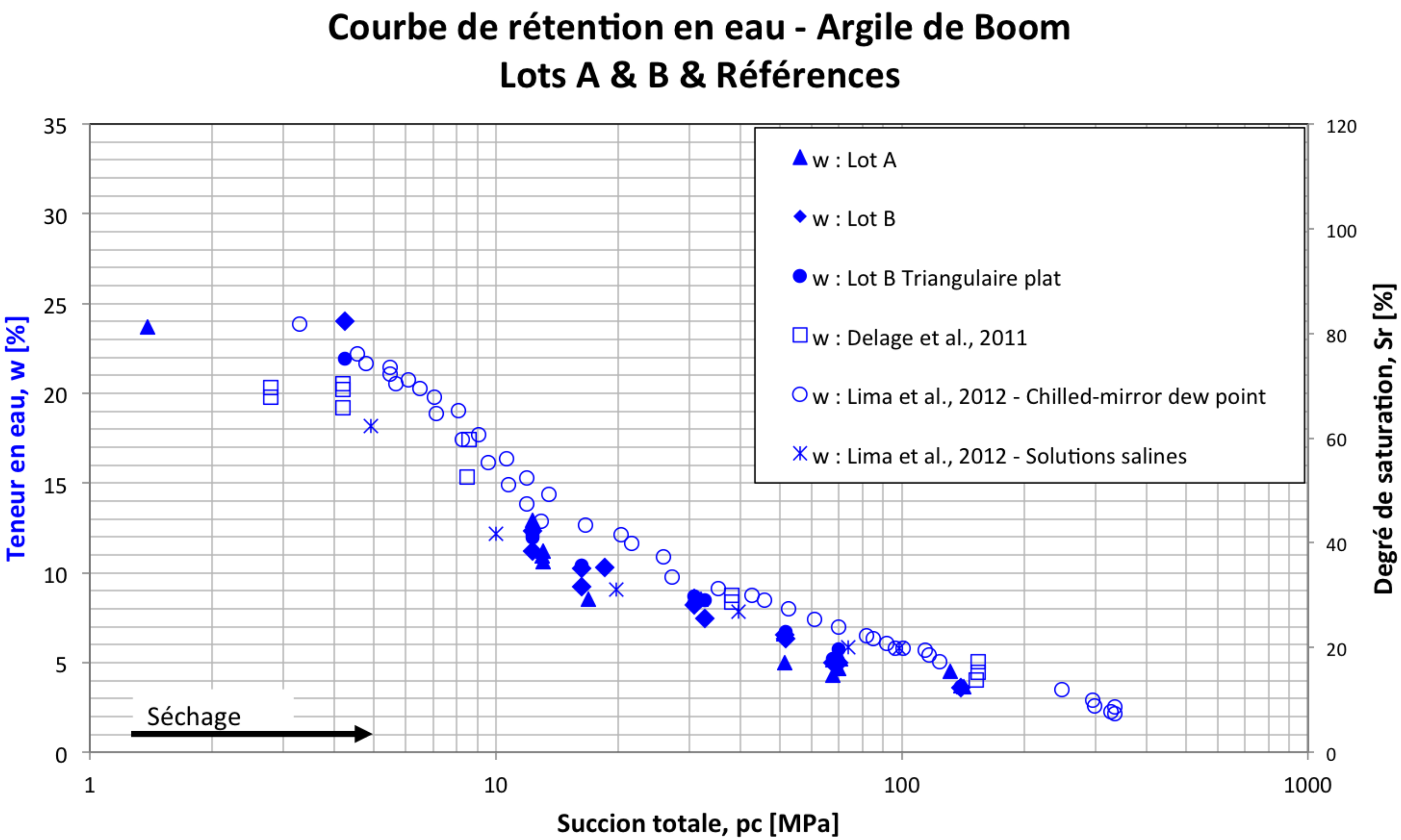
$$p_c = p_a - p_w \qquad w = \frac{M_w}{M_s} \qquad S_r = \frac{V_w}{V_v}$$



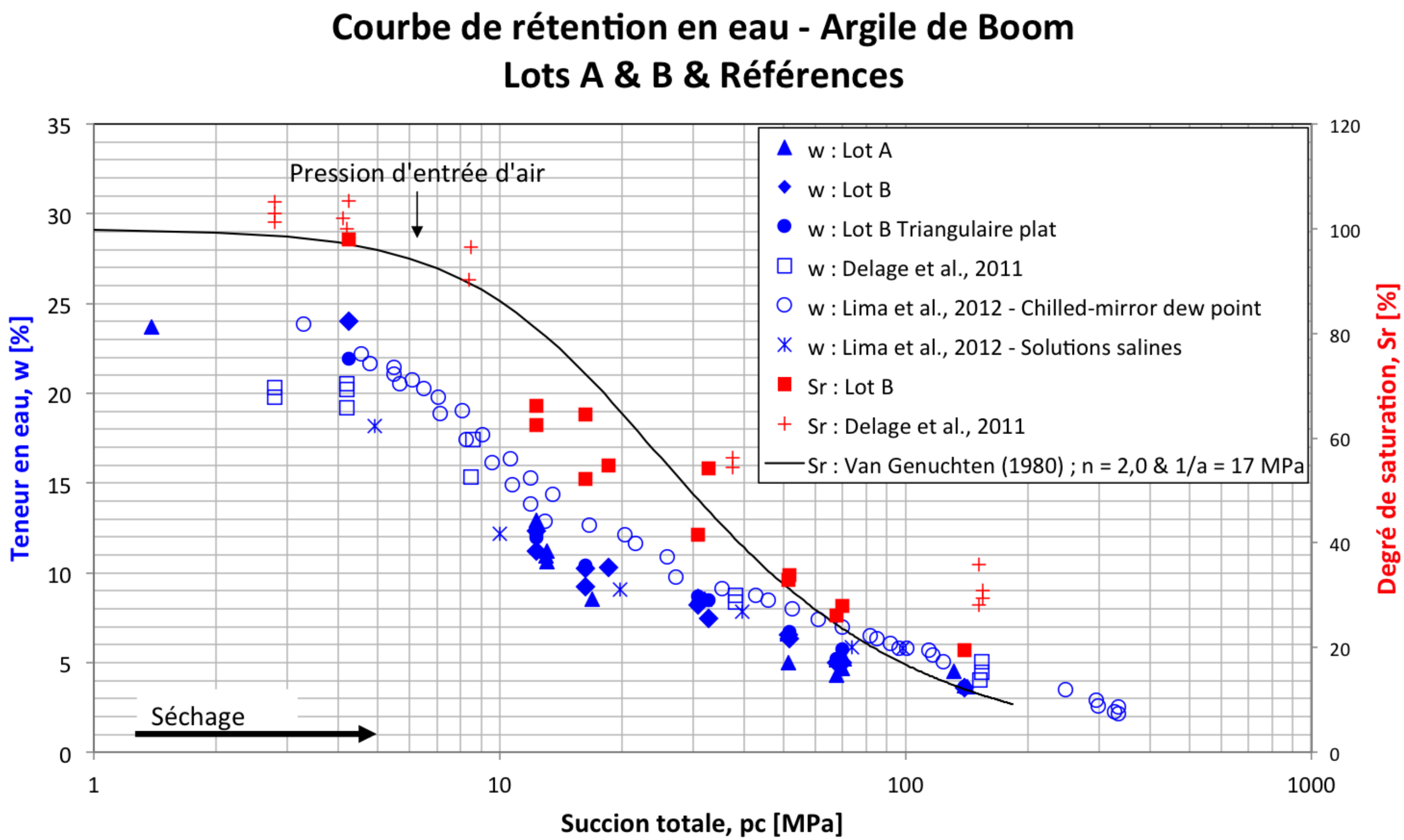
Retention behaviour



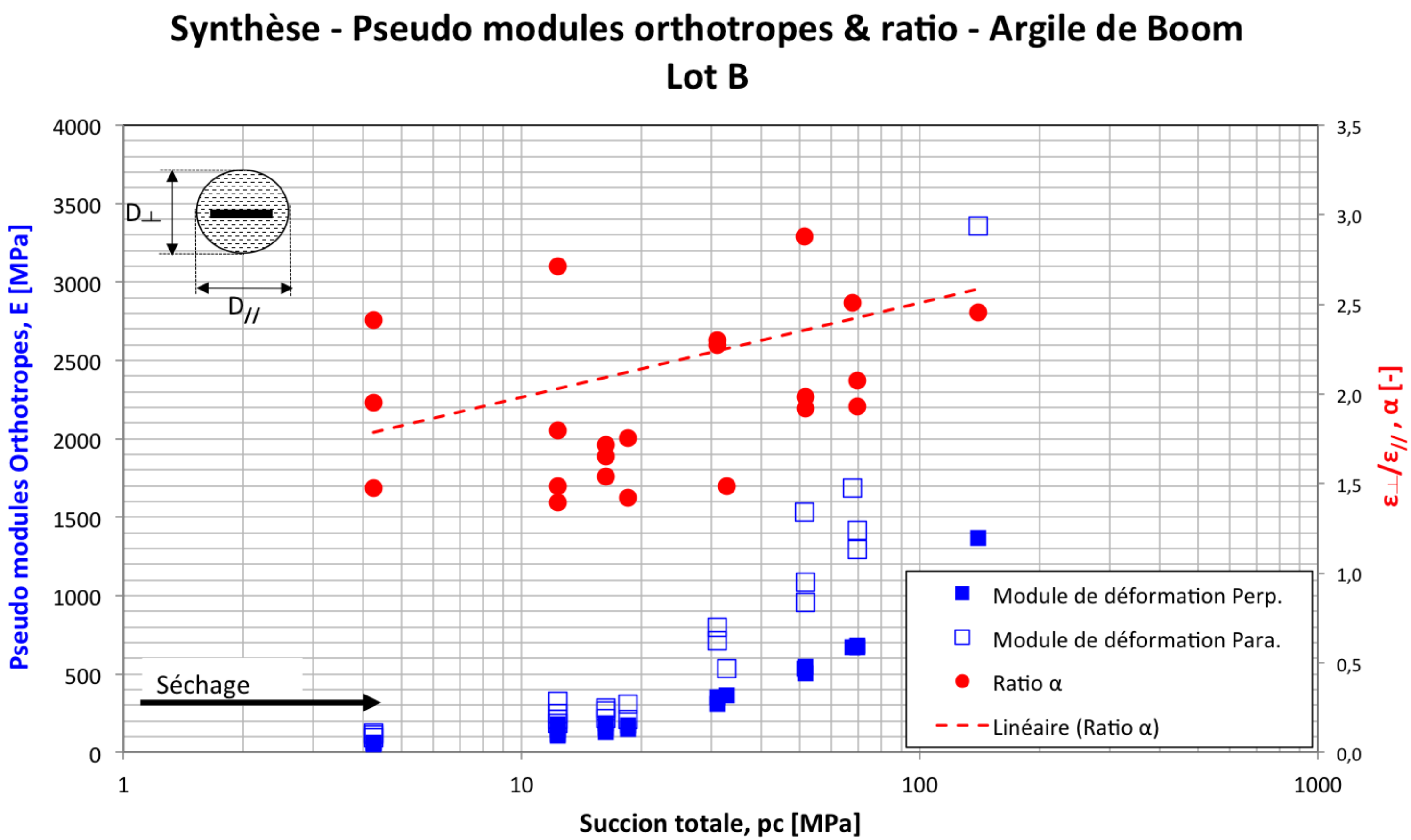
Retention behaviour



Retention behaviour



Unsaturated behaviour: material anisotropy



Orthotropic pseudo modulus : $E_\perp(p_c) = \frac{p_c}{\varepsilon_\perp}$ et $E_\parallel(p_c) = \frac{p_c}{\varepsilon_\parallel}$

Ratio : $\alpha(p_c) = \frac{\varepsilon_\perp}{\varepsilon_\parallel} = \frac{E_\parallel}{E_\perp}$

Conclusion

Retention curve

Good agreement with the literature (w, p_c)

Results depend on experimental procedure

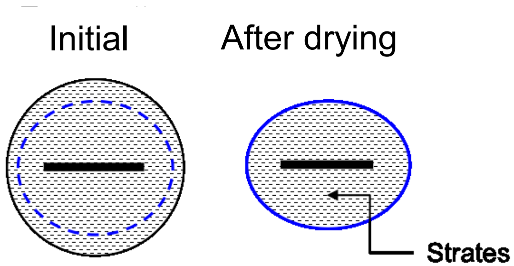
Precision of the size measurements

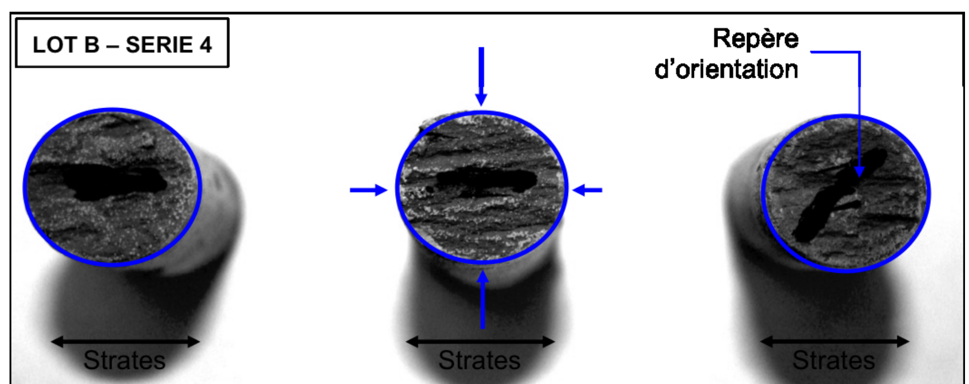
Material anisotropy

Ratio α = 1.8-2.5

Deformation twice larger in the normal direction to bedding

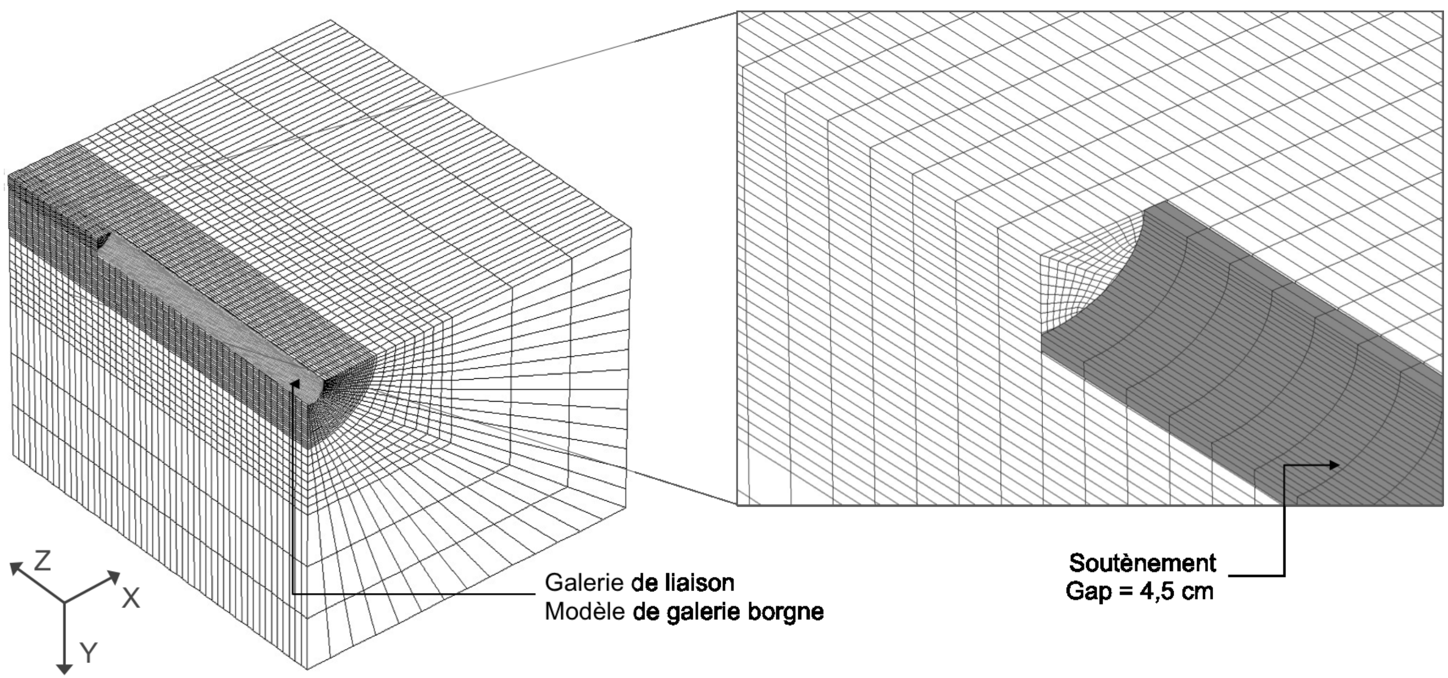
Increase of clay's stiffness with drying





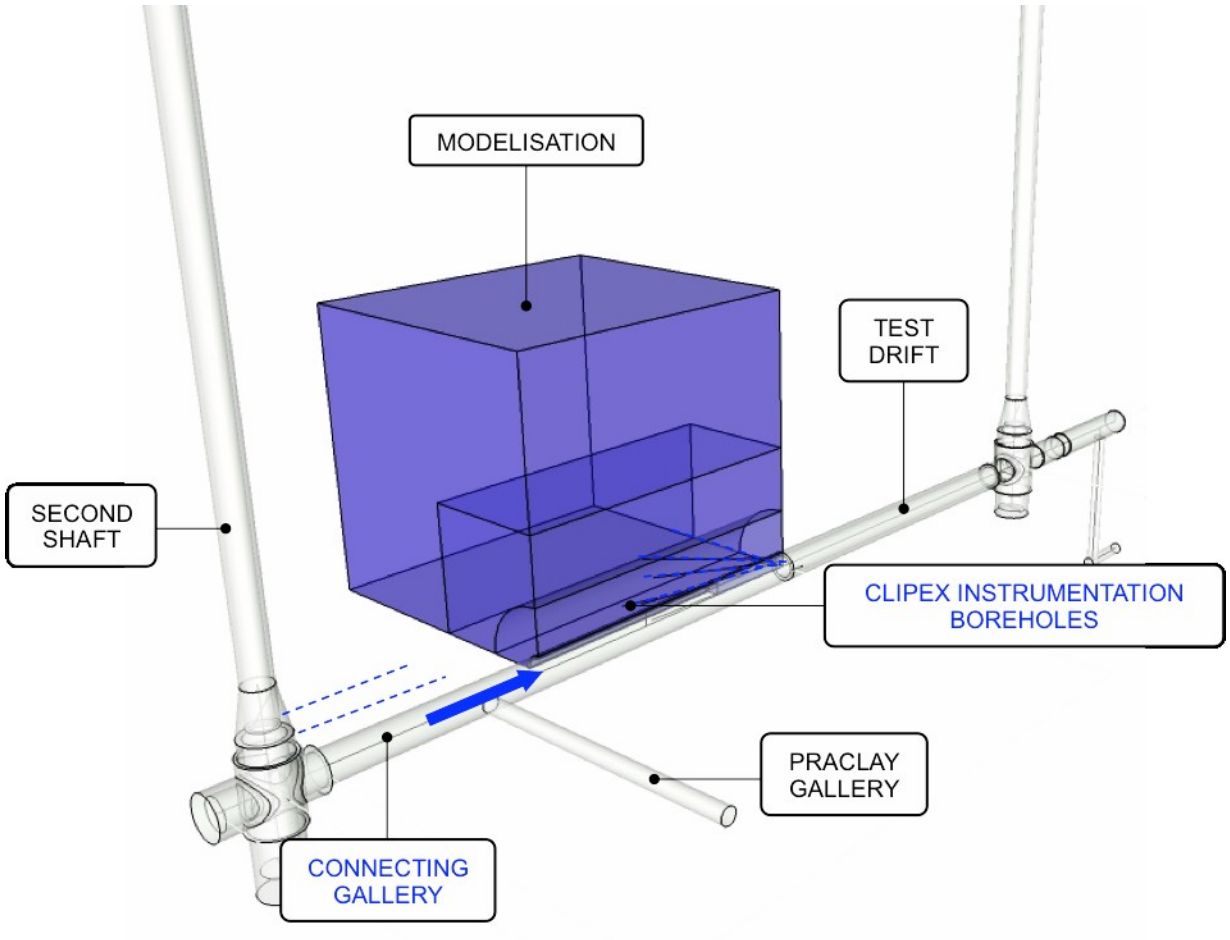
Numerical studies

- Improvement of preliminary 2D modelling : basic physical and validation studies
- Final modelling in 3D accounting for material and stress anisotropy (hydro-mechanical coupling)
- In situ results comparison (water pressure)



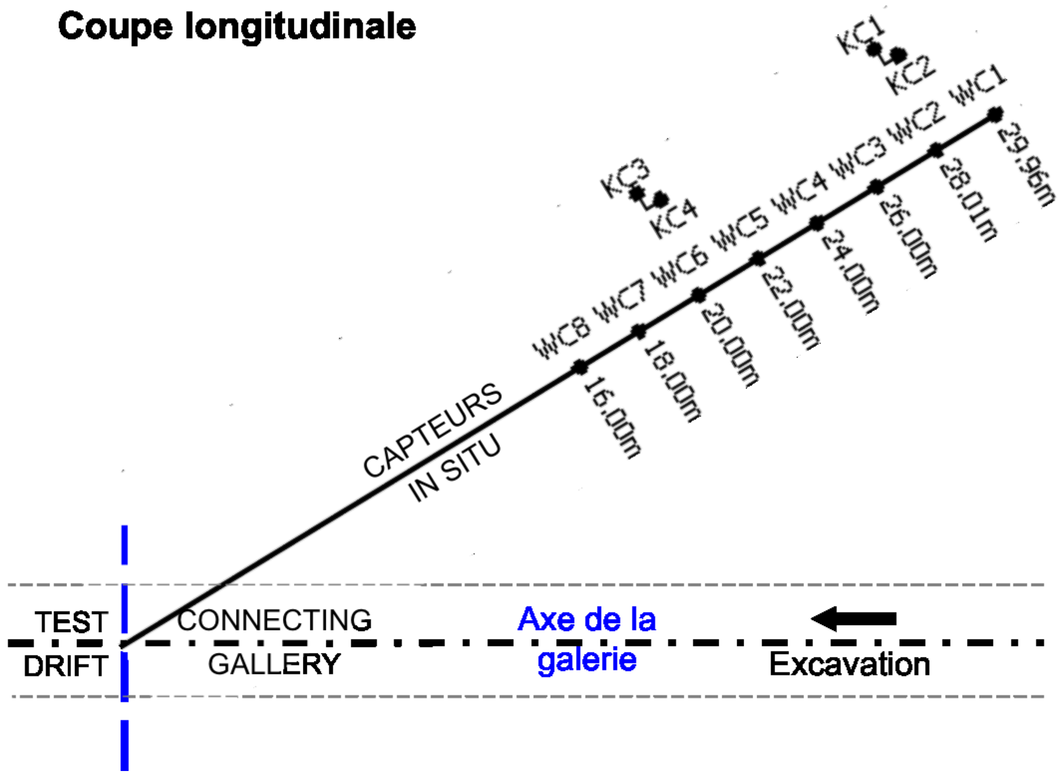
Numerical studies

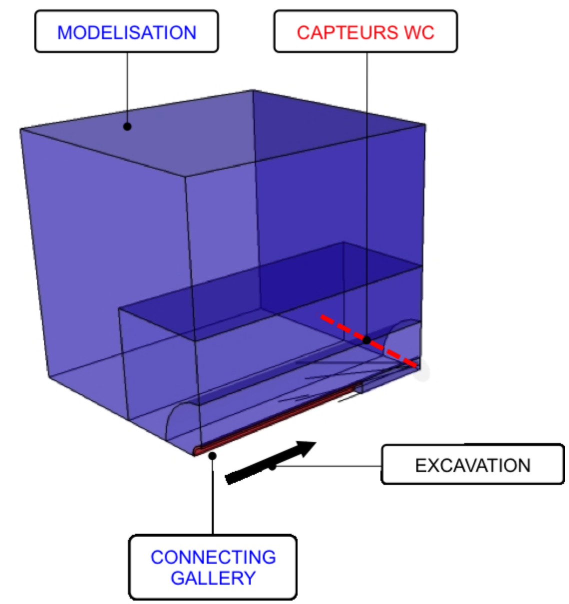
Modelling

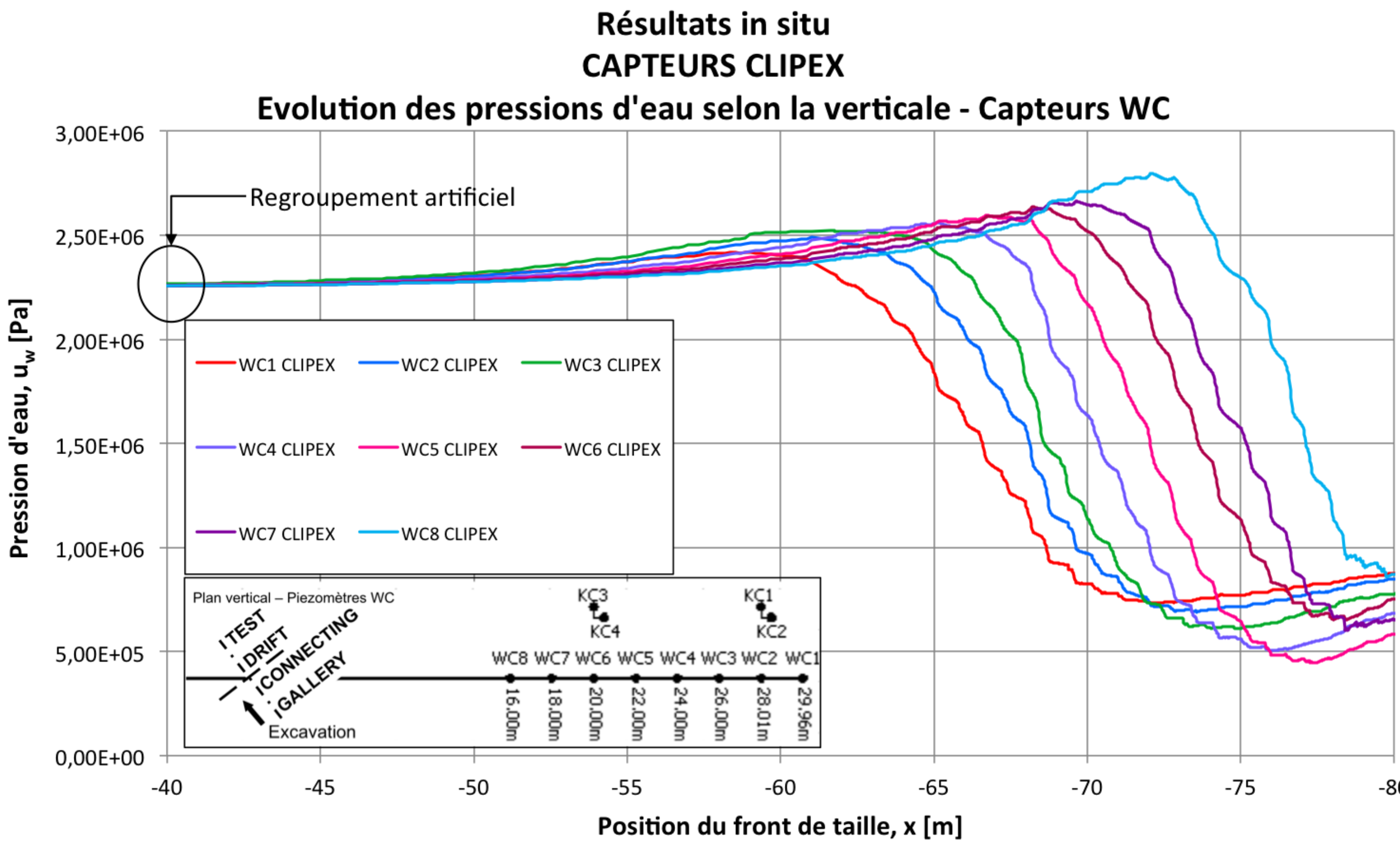


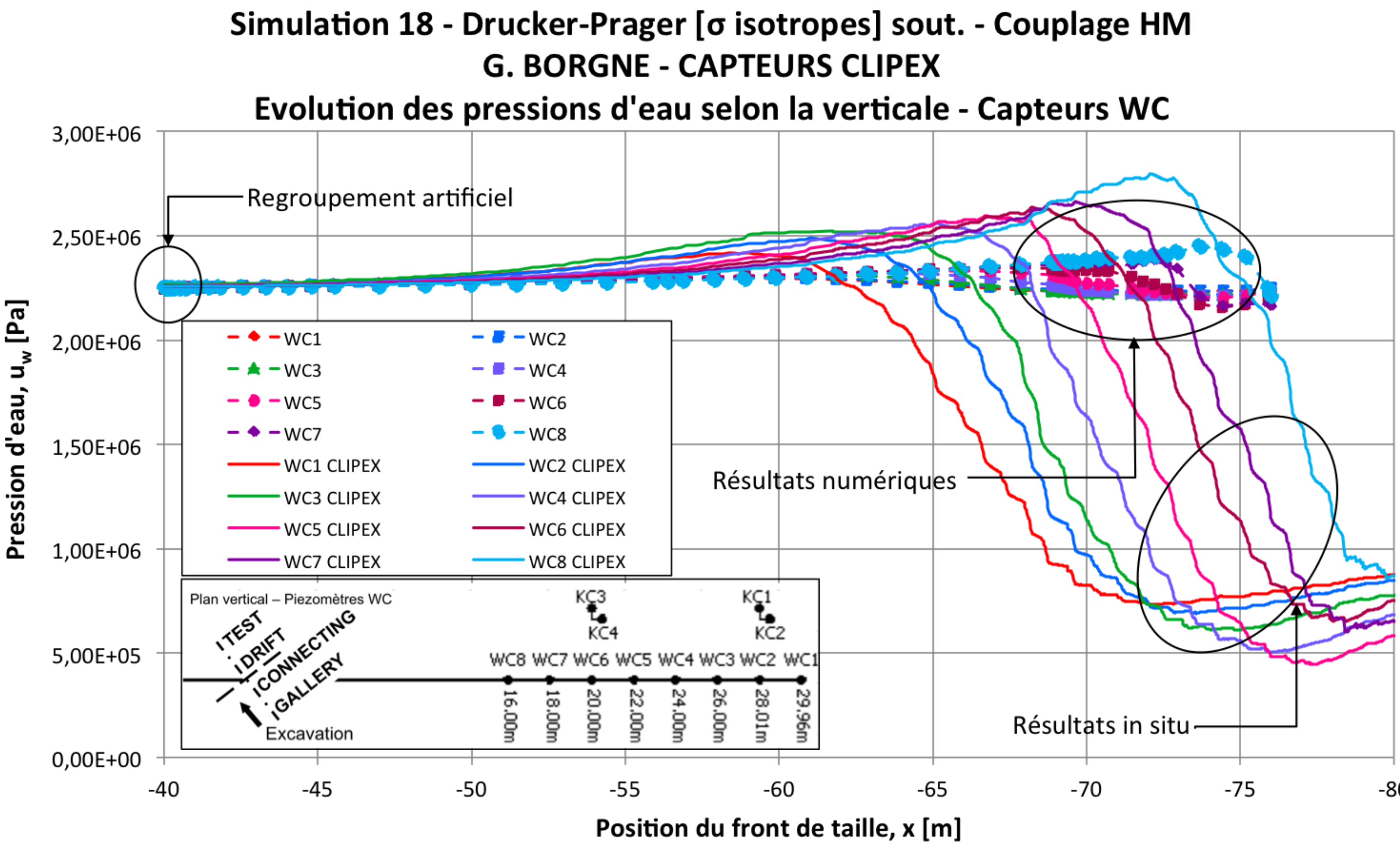
CLIPEX in situ sensors location

Série WC - Plan vertical
Coupe longitudinale






Résultats in situ
CAPTEURS CLIPEX
Evolution des pressions d'eau selon la verticale - Capteurs WC
Regroupement artificiel
Pression d'eau, u_w [Pa]
Position du front de taille, x [m]
WC1 CLIPEX
WC2 CLIPEX
WC3 CLIPEX
WC4 CLIPEX
WC5 CLIPEX
WC6 CLIPEX
WC7 CLIPEX
WC8 CLIPEX
Plan vertical – Piezomètres WC
TEST DRIFT
CONNECTING GALLERY
Excavation
KC3 KC4 KC1 KC2
WC8 WC7 WC6 WC5 WC4 WC3 WC2 WC1
16.00m 18.00m 20.00m 22.00m 24.00m 26.00m 28.01m 29.96m
3,00E+06
2,50E+06
2,00E+06
1,50E+06
1,00E+06
5,00E+05
0,00E+00
-40 -45 -50 -55 -60 -65 -70 -75 -80


Simulation 18 - Drucker-Prager [σ isotropes] sout. - Couplage HM
G. BORGNE - CAPTEURS CLIPEX
Evolution des pressions d'eau selon la verticale - Capteurs WC
Regroupement artificiel
Résultats numériques
Résultats in situ
Pression d'eau, u_w [Pa]
Position du front de taille, x [m]
3,00E+06
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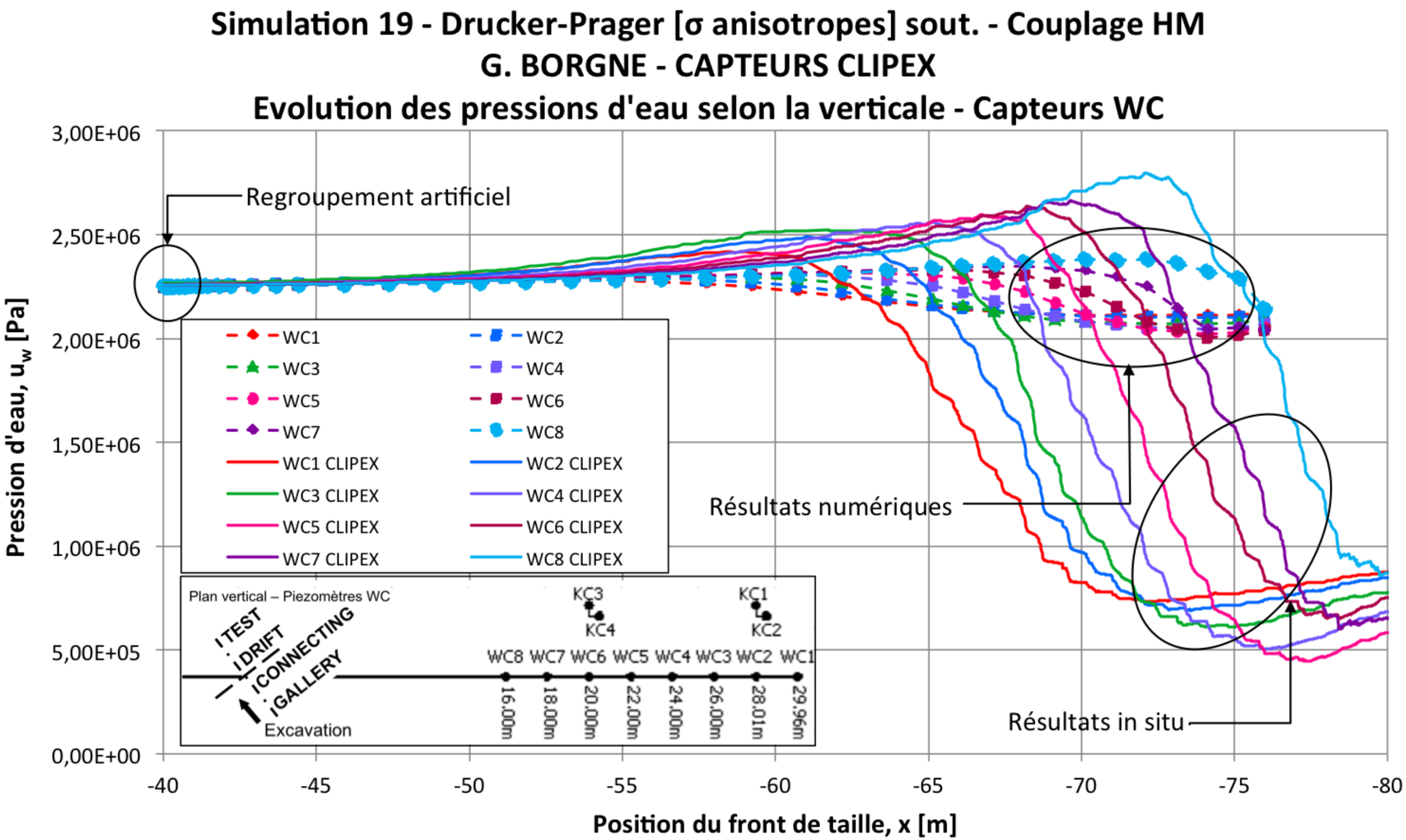
Simulation 19 - Drucker-Prager [σ anisotropes] sout. - Couplage HM
G. BORGNE - CAPTEURS CLIPEX
Evolution des pressions d'eau selon la verticale - Capteurs WC
Pression d'eau, u_w [Pa]
Position du front de taille, x [m]
Regroupement artificiel
Résultats numériques
Résultats in situ
WC1
WC2
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WC7
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Plan vertical – Piezomètres WC
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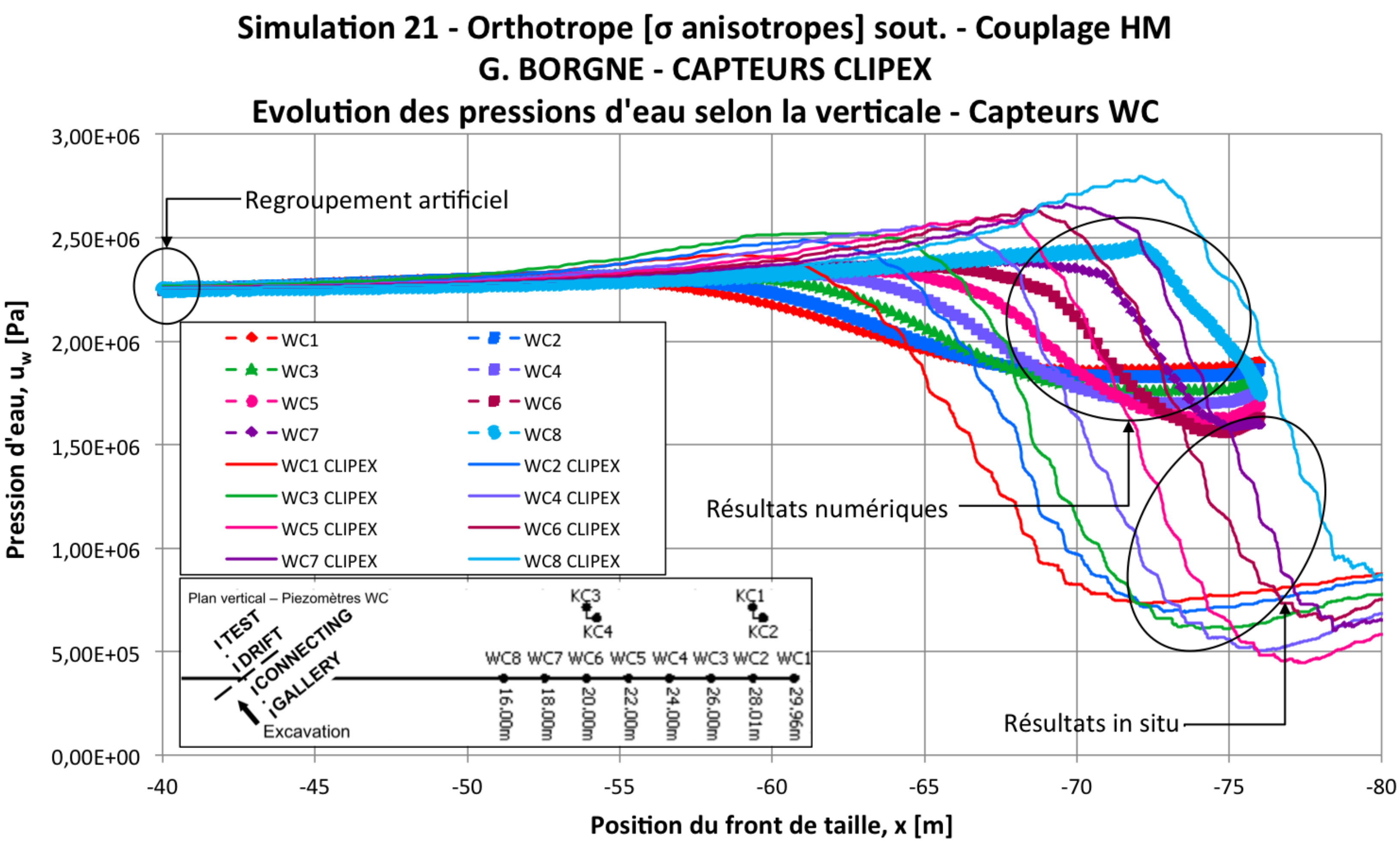
Simulation 21 - Orthotrope [σ anisotropes] sout. - Couplage HM
G. BORGNE - CAPTEURS CLIPEX
Evolution des pressions d'eau selon la verticale - Capteurs WC
Pression d'eau, u_w [Pa]
Position du front de taille, x [m]
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Conclusion

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Importance of stress anisotropy

Importance of material anisotropy

Perspectives

Study of the anisotropy of the permeability

Influence of geotechnical properties

Influence of the fracturation on the permeability

Integration of the drainage at the gallery wall

Main conclusion

Experimental studies

Good agreement of the measured water retention curve with data from the literature

Material anisotropy

Numerical studies

3D study of the hydro-mechanical coupling in Boom Clay

Infuence of material (and stress) anisotropy

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