Imperial College London

Bentonite Mechanical Evolution

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BEACON
Bentonite Mechanical Evolution

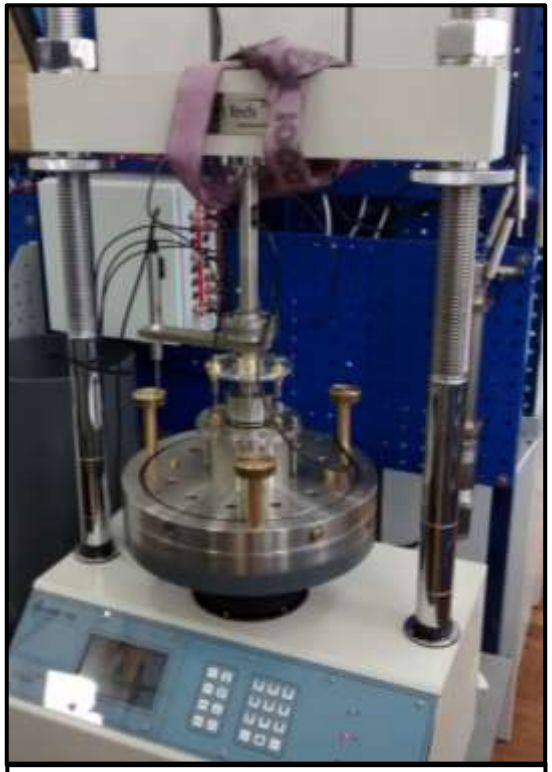
Outline

- Introduction of bentonite-related research at Imperial College (IC)
- Constitutive modelling: IC’s current capabilities

Introduction

- Current bentonite-related research at Imperial College
  - Experimental: bespoke laboratory facilities

Desiccator with Relative Humidity (RH) suction control



Temperature and suction controlled oedometer

Temperature and suction controlled triaxial cell

Ridley (1992); Colmenares (1997); Melgarejo (1994); Dineen (1997); Cunningham (2000); Monroy (2007); Mantikos (since 2014); Kirkham (since 2016)

Introduction

- Current bentonite-related research at Imperial College
  - Numerical: bespoke FE code ICFEP (Potts & Zdravkovic, 1999, 2001)

    - fully THM coupled for saturated and unsaturated soils
    - constitutive framework: expanded BBM & BExM
    - suction- and void ratio- dependent 3D SWR model
    - suction-, void ratio- and degree of saturation- dependent permeability model
    - boundary conditions:
      - infiltration
      - precipitation
      - heat flux
      - convective heat loss
      - prescribed temperature / pore pressure
      - excavation
      - construction and compaction

Smith (2003); Georgiadis (2003); Tsiampousi (2013); Cui (2015); Gawecka (2017)
Ghiadistri (since 2015)

BEACON – constitutive modelling

- ICL's modelling capability for unsaturated soils
  - modified BBM (Georgiadis et al., 2005; Tsiampousi et al., 2013, 2016)

  - two independent stress variables:

    matric suction: $s = u_a - u_w$

    net stress: $\bar{\sigma} = \sigma - u_a$

  - introduce equivalent suction:

    $s_{eq} = s - s_{air}$

    and equivalent stress:

    $\hat{\sigma} = \bar{\sigma} + s_{air}$

    → Capable of automatic switching from saturated to unsaturated conditions and vice versa

BEACON – constitutive modelling

- ICL's modelling capability for unsaturated soils
  - modified BBM (Georgiadis et al., 2005; Tsiampousi et al., 2013, 2016)
    - application: moderately expansive soils

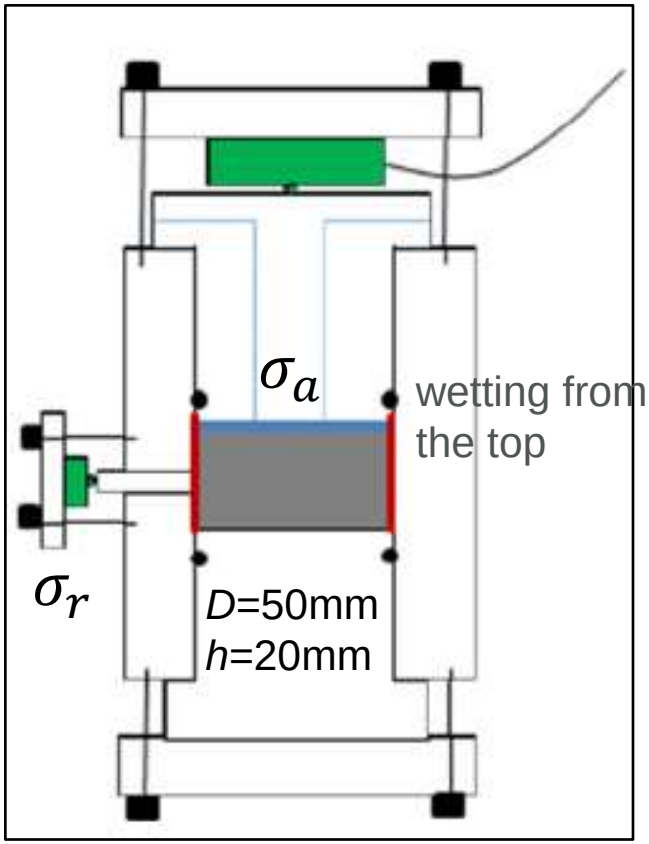
soil-plant-atmosphere interaction in infrastructure embankments, natural and cut slopes

embankment:
compacted London clay

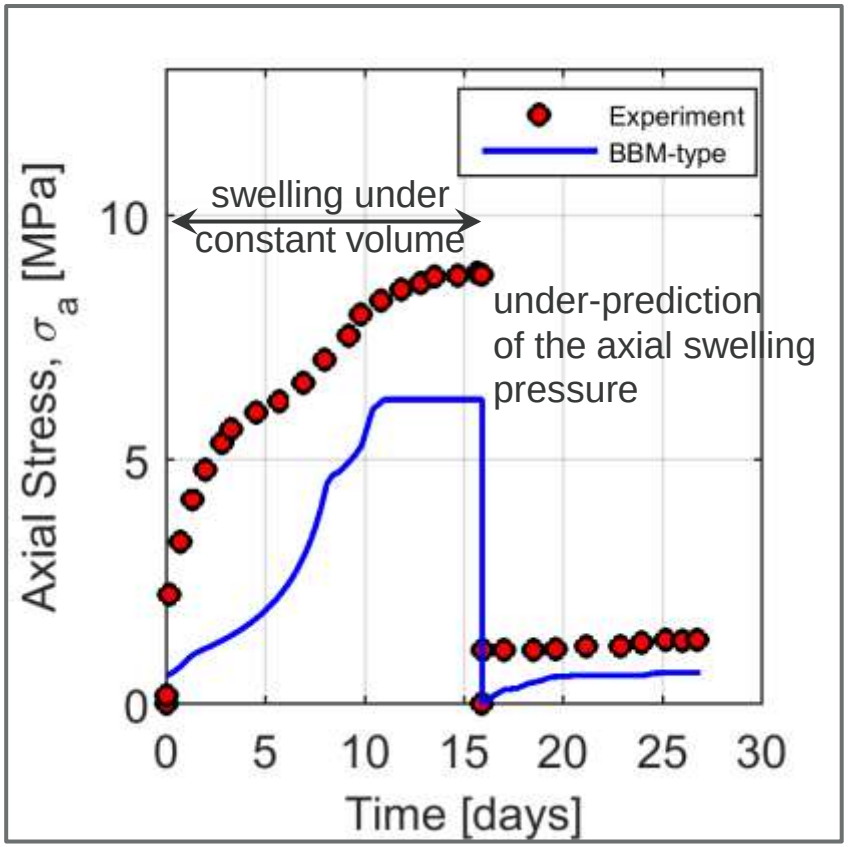
BEACON – constitutive modelling

- ICL's modelling capability for bentonite
  - modified BBM (PhD of Ghiadistri, since 2015; funded by RWM / AMEC FW)

- application: MX-80 *axial* swelling test by Dueck et al. (2011, 2014) (EBS Task Force on bentonite homogenisation)



Experimental set up



Evolution of σ_a with time

BEACON – constitutive modelling

- ICL's modelling capability for bentonite
  - modified BExM (PhD of Ghiadistri, since 2015; funded by RWM / AMEC FW)

model with a double-porosity structure

MACRO structure
unsaturated
BBM
e_M, K_M

MICRO structure
saturated, elastic, volumetric
BExM
e_m, K_m

matric suction: $s = u_a - u_w$

net stress: $\bar{\sigma} = \sigma - u_a$

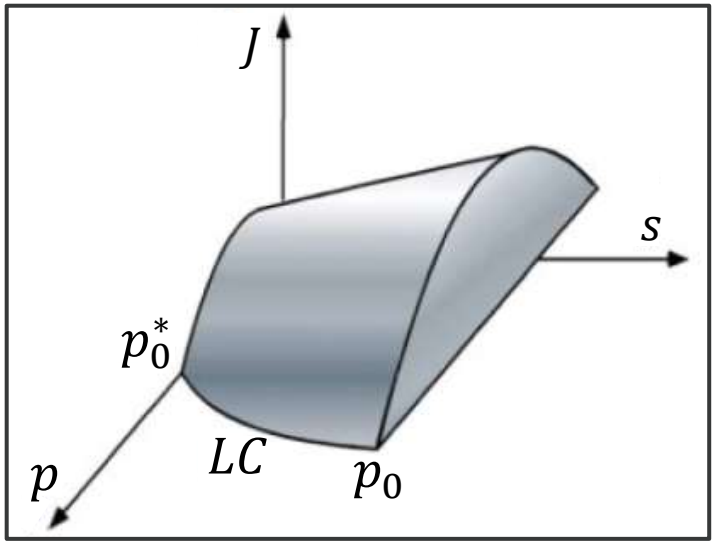
effective stress: $\sigma' = \sigma + s$

1. microstructure is capable of producing plasticity (β-mechanism):

$$\Delta\varepsilon^p_{vol,M,\beta} = f \cdot \Delta\varepsilon^e_{vol,m}$$

$$\Delta\varepsilon^p_{vol} = \Delta\varepsilon^p_{vol,M,LC} + \Delta\varepsilon^p_{vol,M,\beta}$$

$$\Delta p_0^* = p_0^* \frac{\nu}{\lambda(0) - \kappa} \Delta\varepsilon^p_{vol}$$ hardening law



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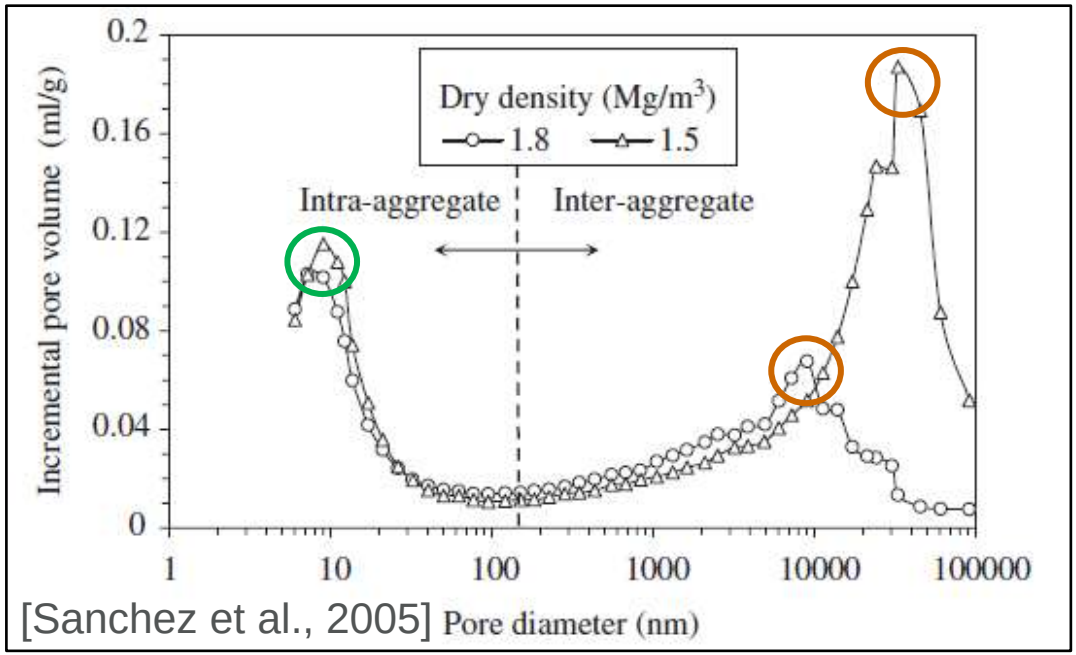
2. void factor:

$$VF = \frac{e_m}{e_{tot}} = \frac{volume\ of\ micropore}{volume\ of\ pores}$$

estimate from MIP tests ?



[Sanchez et al., 2005]

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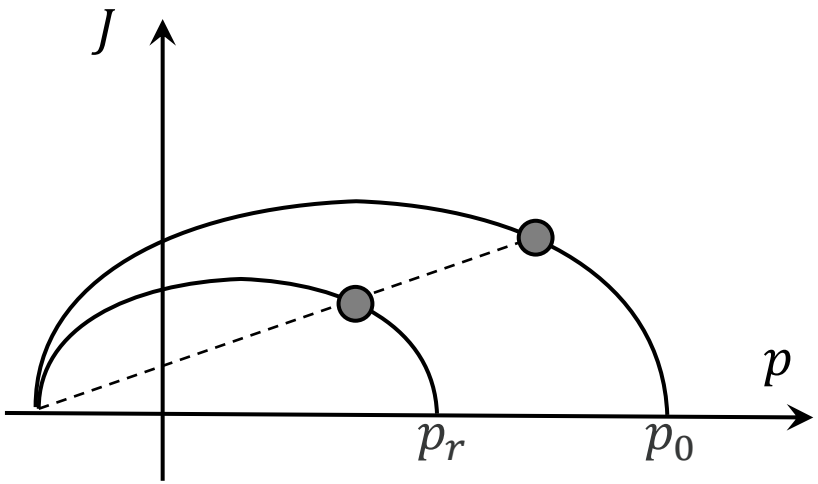
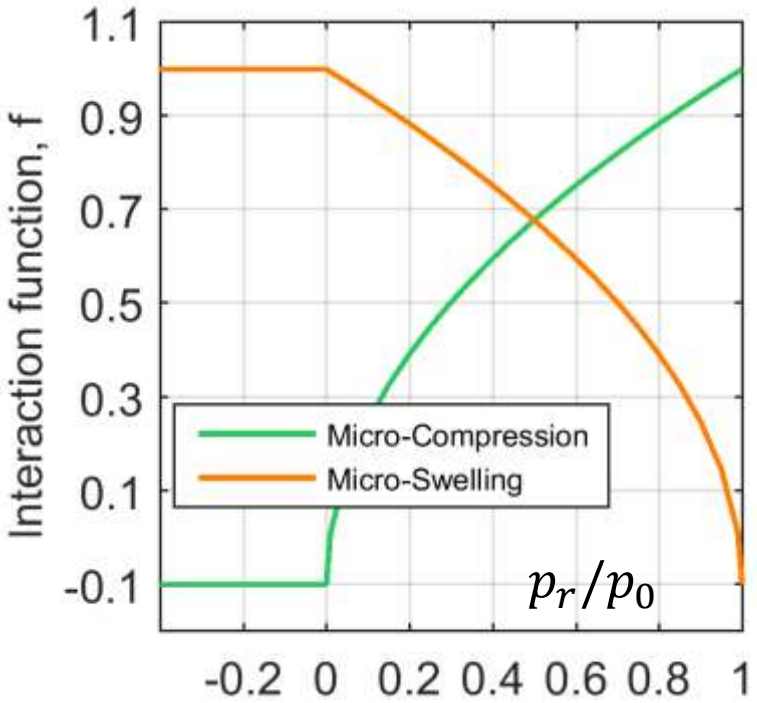
3. degree of openness of the structure

$$\Delta\varepsilon^{p}_{vol,M,\beta} = f_\beta \cdot \Delta\varepsilon^{e}_{vol,m}$$





BEACON – constitutive modelling

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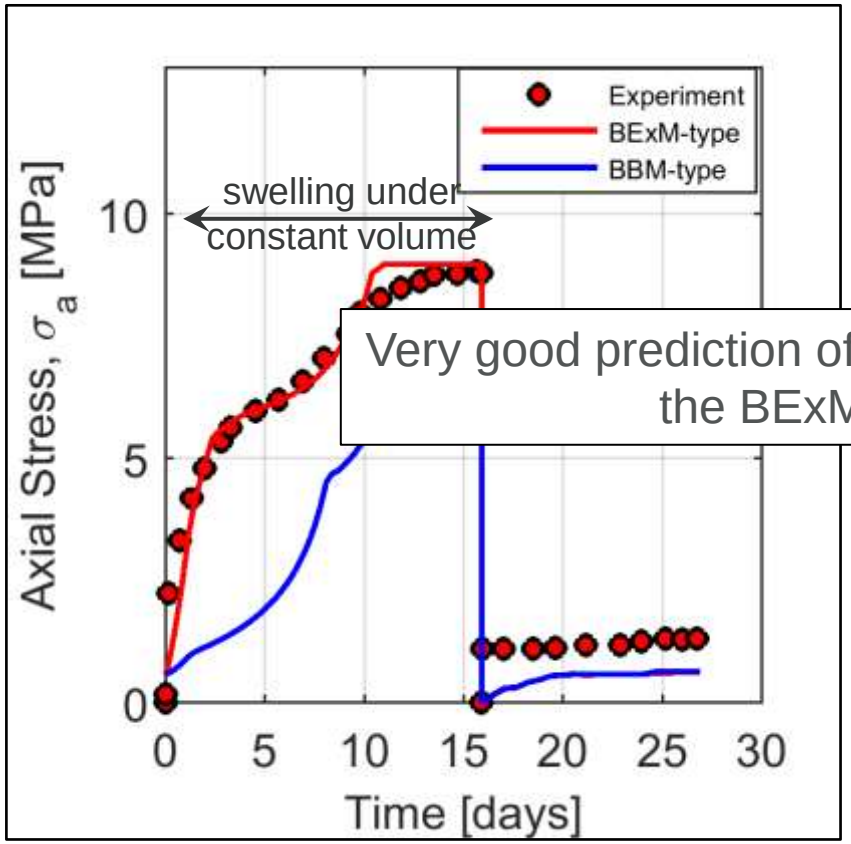
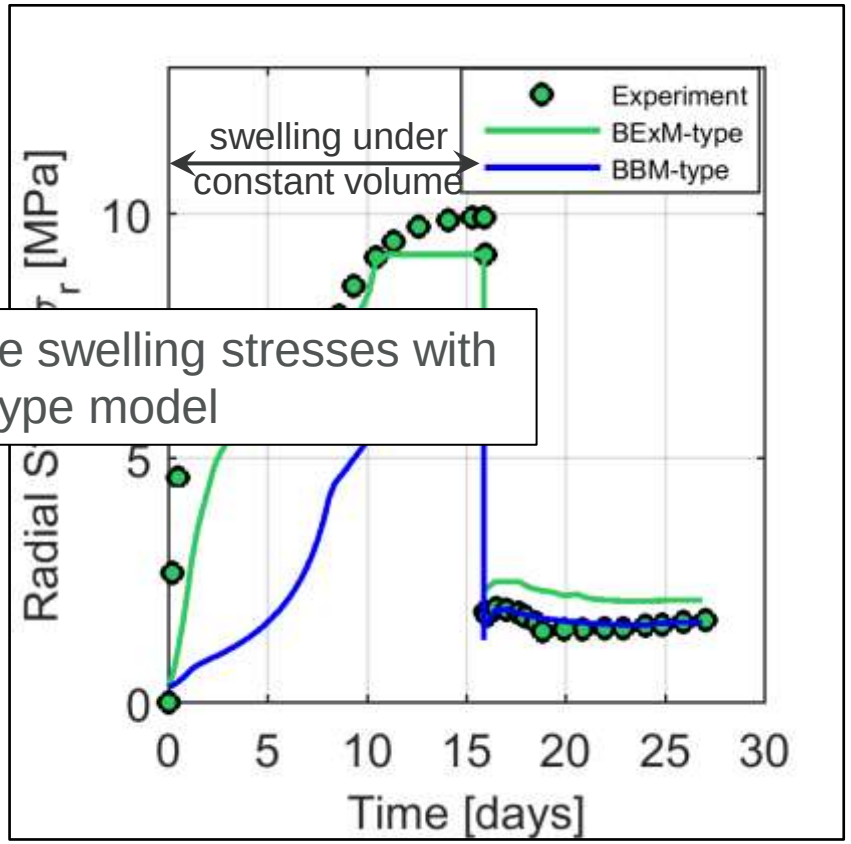
- application: MX-80 *axial* swelling test by Dueck et al. (2011, 2014) (EBS Task Force on bentonite homogenisation)



Evolution of σ_a with time



Evolution of σ_r with time

Very good prediction of the swelling stresses with the BExM- type model

BEACON – constitutive modelling

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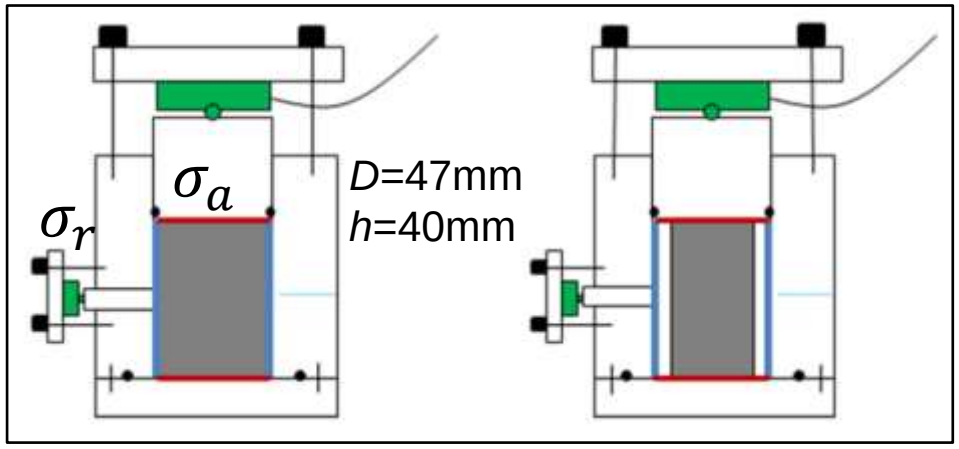
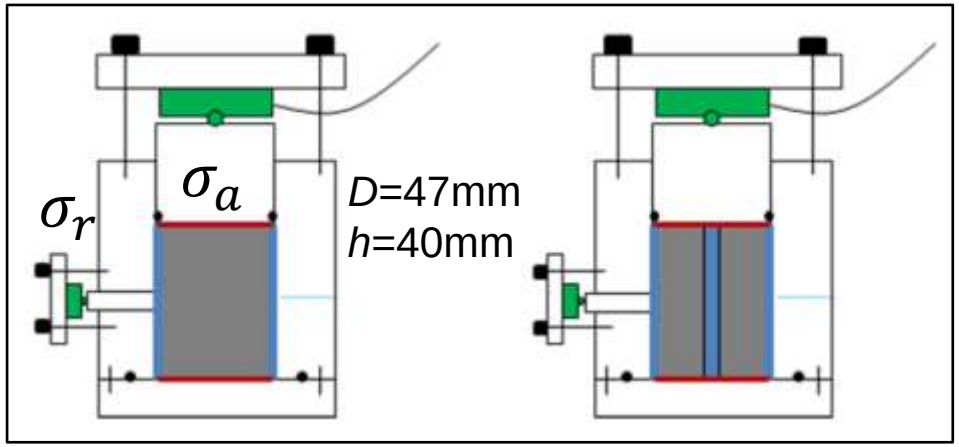
- application: MX-80 *radial* swelling tests by Dueck et al. (2011, 2014) (EBS Task Force on bentonite homogenisation)



wetting from the sides and constant volume swelling

followed by

outward radial swelling



described as two identical samples; the same initial suction (47 MPa) and dry density (1.66 Mg/cm^3)

wetting from the sides and constant volume swelling

followed by

inward radial swelling

BEACON – constitutive modelling

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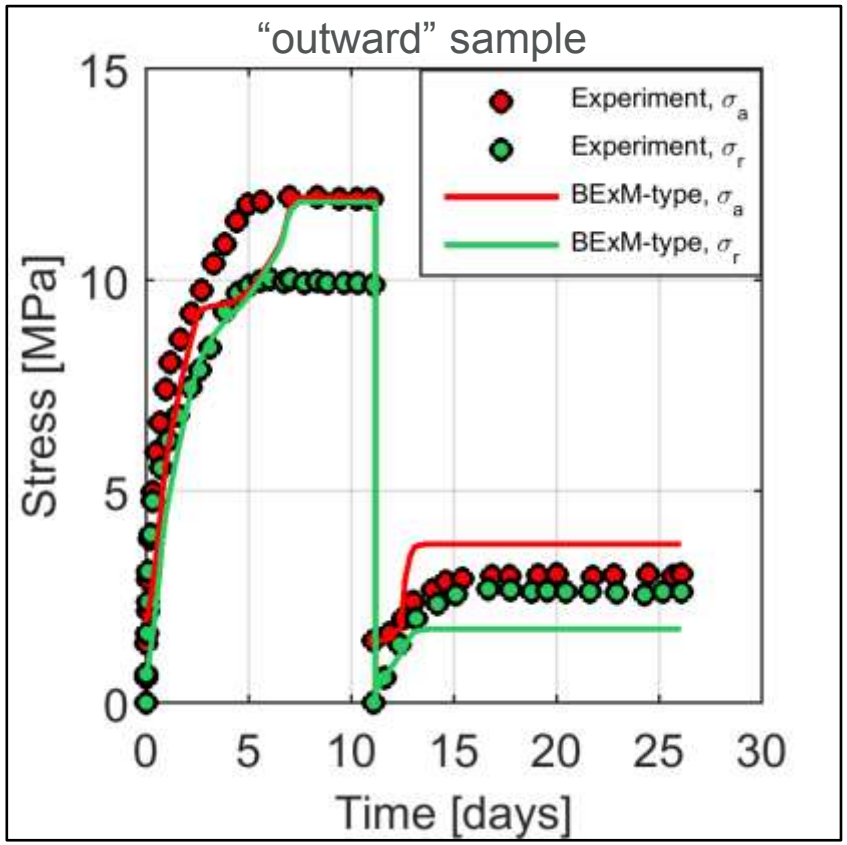
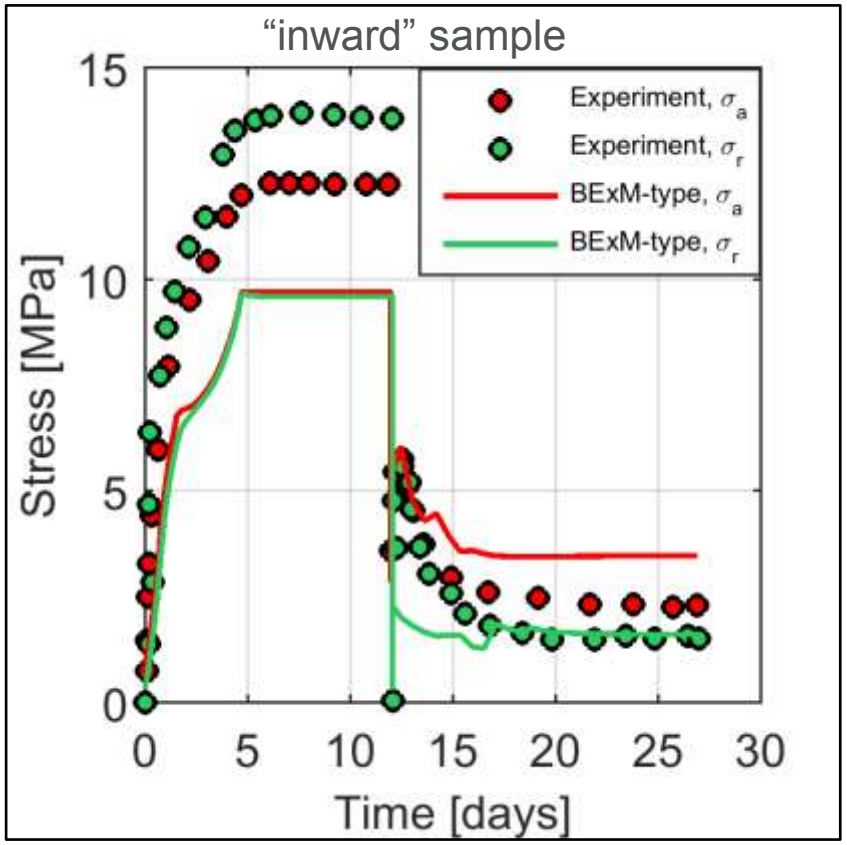


Evolution of swelling pressures



Evolution of swelling pressures

BEACON – constitutive modelling

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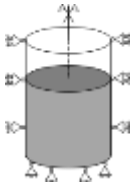
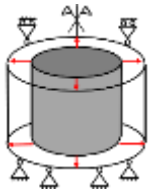
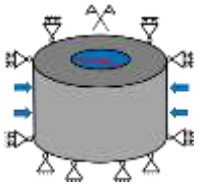
Summary of *constant volume* swelling pressures

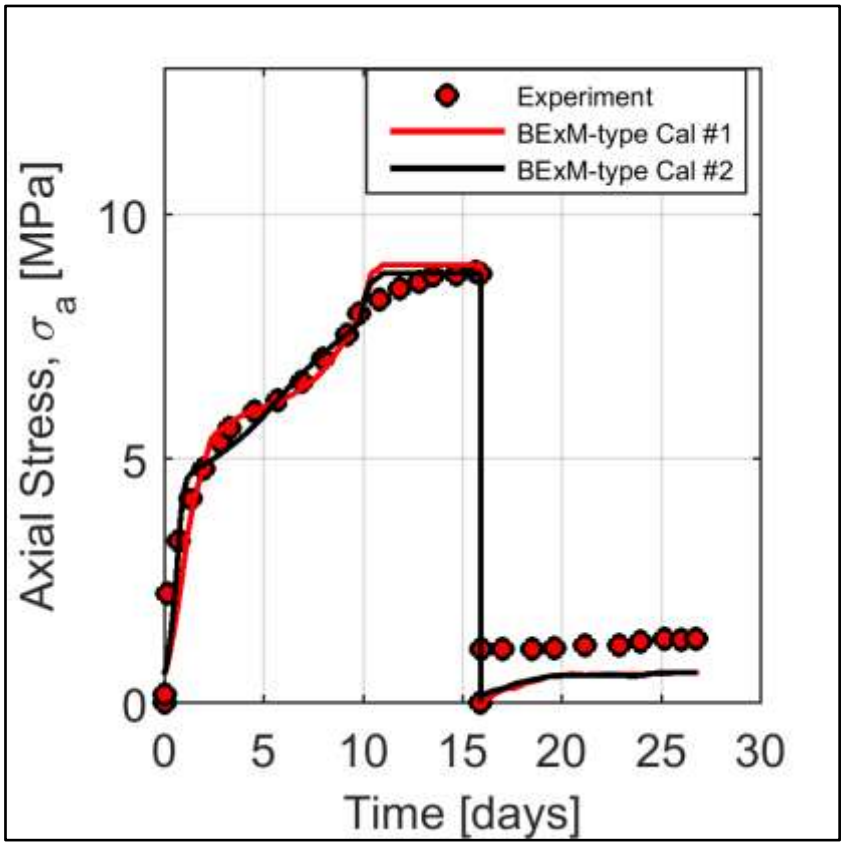
	 *Axial Swelling*	 *Radial Outward Swelling*	 *Radial Inward Swelling*
Axial pressure	$9\ MPa$ **$9\ MPa$**	$12\ MPa$ **$11\ MPa$**	$12\ MPa$ **$10\ MPa$**
Radial pressure	$10\ MPa$ **$9\ MPa$**	$10\ MPa$ **$11\ MPa$**	$14\ MPa$ **$10\ MPa$**
Initial stress state	$\sigma_a = 0.6\ MPa$ $\sigma_r = 0.3\ MPa$	$\sigma_a = 1.9\ MPa$ $\sigma_r = 0.6\ MPa$	$\sigma_a = 0.9\ MPa$ $\sigma_r = 0.3\ MPa$

Experimental uncertainties: - sample preparation, or
- experimental procedure, or …

BEACON – constitutive modelling

- ICL's modelling capability for bentonite
  - modified BExM (PhD of Ghiadistri, since 2015; funded by RWM / AMEC FW)

- application: MX-80 *axial swelling* tests by Dueck et al. (2011, 2014) (different BExM calibration)



Evolution of σ_a with time

Equally good predictions with both calibrations

Final remarks

- Current observations
  - additional fundamental experimental evidence for a better certainty in calibrating both the MACRO and MICRO contributions
  - comprehensive details of experimental procedures for existing experiments (e.g. sample preparation, initial stresses)
- Contribution to BEACON
  - further application & development of the current constitutive model (WP3 and WP5)
  - compilation of experimental evidence we have used to date as contribution to WP2