Micromechanical insights into the behaviour of unsaturated granular materials

experiments and modelling

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Modern Trends in Geomechanics 4
Assisi, 16-18 May, 2016

Wetting-induced collapse phenomenon

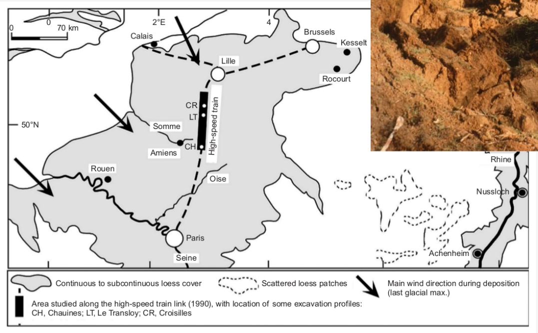
(courtesy: E. Alonso)

A challenging issue for soil mechanics and geotechnical engineering

- challenges the definition of a proper effective stress, extending Terzaghi's stress for saturated soils
- unsaturated states are (usually) disregarded in geotechnical design

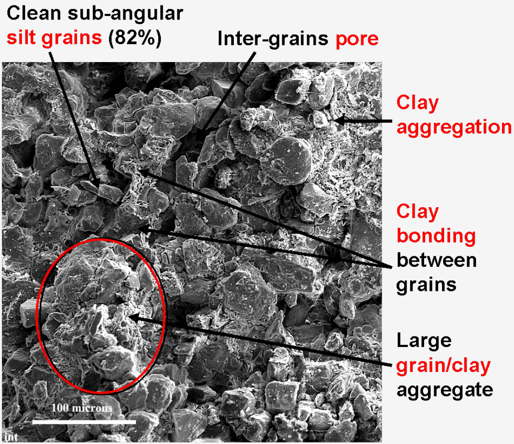
Behaviour of an unsaturated intact loess

- PhD: José Muñoz-Castelblanco (Muñoz-Castelblanco et al. 2011, 2012a,b,c)
- Colleagues: Pierre Delage & Yu-Jun Cui



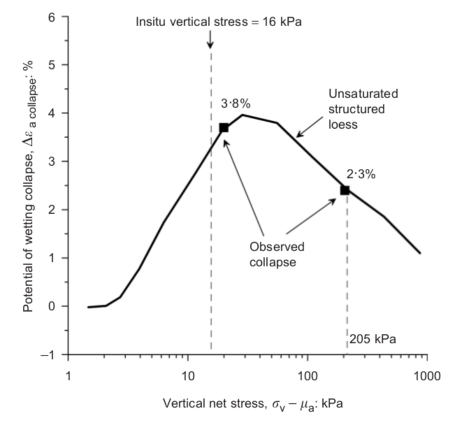
Disorders area and collapse of shallow layers.

Bapaume Loess (aeolian silt, Northern France)



SEM micrograph of Bapaume loess.

Bapaume Loess – hydro-mechanical behaviour



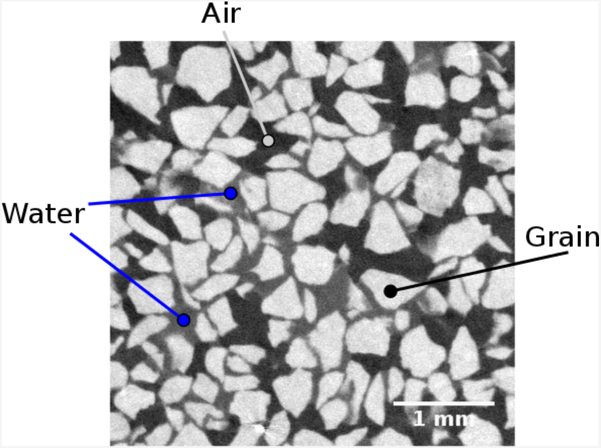
Potential of collapse due to wetting.

$\hookrightarrow$ what about mechanisms at the microscale?

Sandcastles

Simply (?) wet sand (Sagrada Familia ©SetosPuppy).

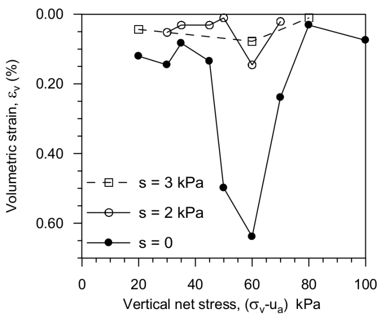
Sandcastles



Hostun sand (Bruchon, 2014).

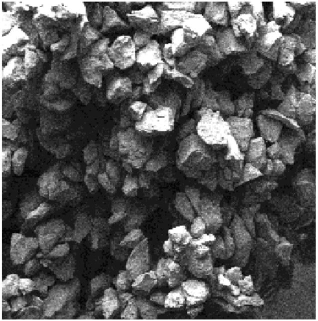
Capillary collapse of sand: macro- vs meso-scale analysis

- PhD: Jean-François Bruchon (Bruchon et al., 2013a,b)
- Colleagues: Michel Bornert, Pierre Delage, Nicolas Lenoir, Matthieu Vandamme



Castelldefels sand

(Alonso & Romero, 2003)



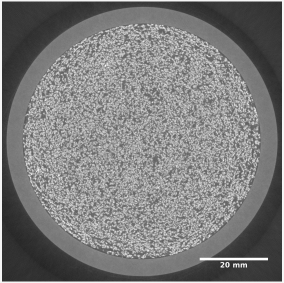
SEM image of Hostun sand

(moist damping: Benhamed et al., 2004)

- gain insight into mesoscale mechanisms leading to capillary collapse

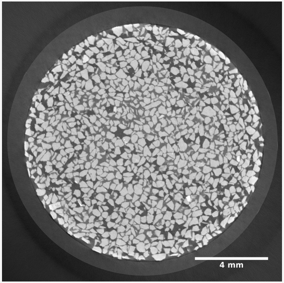
X-ray computed tomography

a matter of scale. . . and choice!



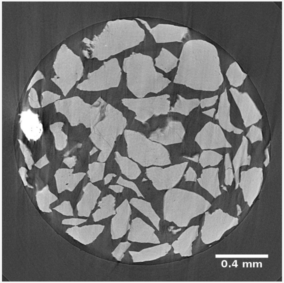
(a) D = 70 mm,

voxel = 50^3 μm



(b) D = 13 mm,

voxel = 10^3 μm



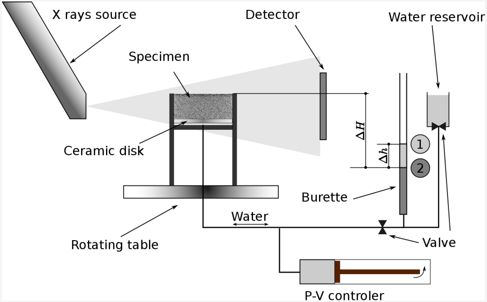
(c) D = 1.9 mm,

voxel = 2.5^3 μm

Criterion	a	b	c
Measure of deformation (ε)	+1	+1	-1
Phase separation (w)	-1	0	+1
Representativeness of macro. behaviour (REV)	+1	0	-1
Specimen preparation	+1	-1	-1
Loading application	+1	-1	-1

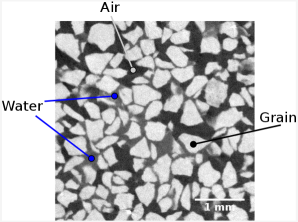
Experimental setup and material

loose sand specimen and capillary pressure control



Hostun sand (250–500 μm):

- "wet pluviation"
- water content: $w = 7\%$ ($S_w = 15\%$)
- porosity: $n = 0.56$



X-ray computed tomography

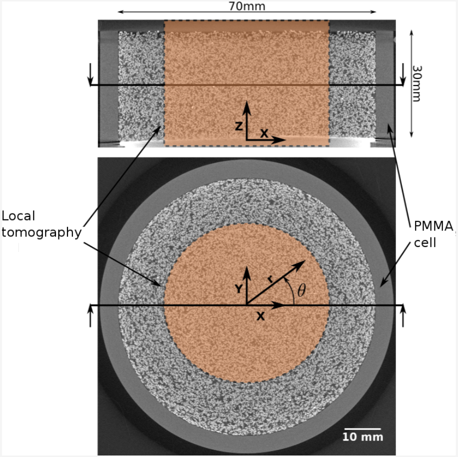
our strategy. . .

2 tomographies at 2 scales:

- global tomography ($50\ \mu$m voxel size)
- local tomography ($25\ \mu$m voxel size)

Image treatment and analyses:

- field measures: ε, w
- microstructure: homogeneity, phases characteristic size

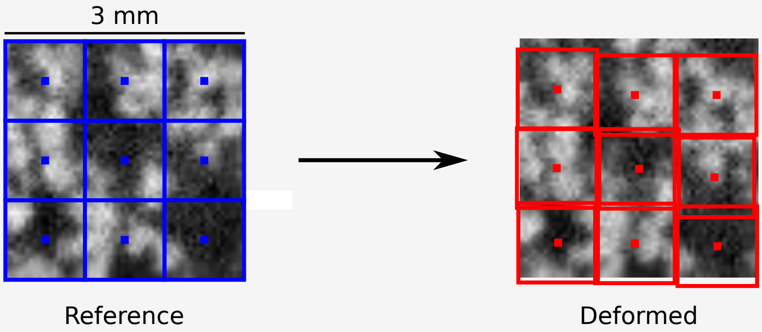


Global tomography

Field measurements: ε

Volumetric digital image correlation (V-DIC) :

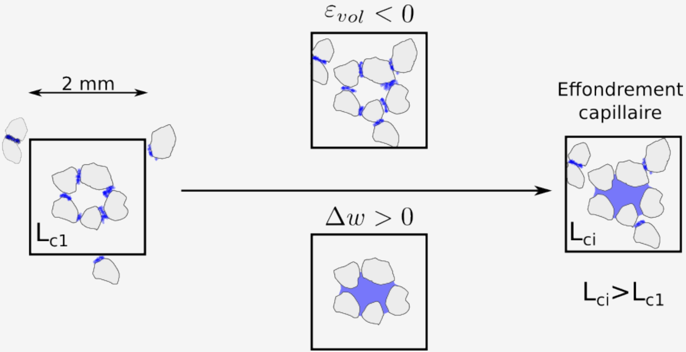
1. get displacement field from correlation "windows"
2. derive strains (8 node-elements centered on correlation windows) $\rightarrow \varepsilon$



(1) CMV 3D (in-house software); (2) Imagej

Field measurement (ROI): w

Principle: using relative variation of grey levels knowing ε_{vol}



$$\frac{L_{ci} - L_{c1}}{L_{c1}} = \alpha \frac{\varepsilon_{vol}}{\varepsilon_{vol} + 1} + \beta \frac{\Delta w_c}{\varepsilon_{vol} + 1}$$

$\alpha < 0$ and $\beta > 0$ function of L, G_s, w_1 et n_1

X-ray computed tomography

2 regions of analysis (avoiding artefacts)

- ROI: region of interest, global tomography cylinder: H = 19 mm, D = 70 mm
- VS: segmented volume, local tomography cube: C = 18.7 mm

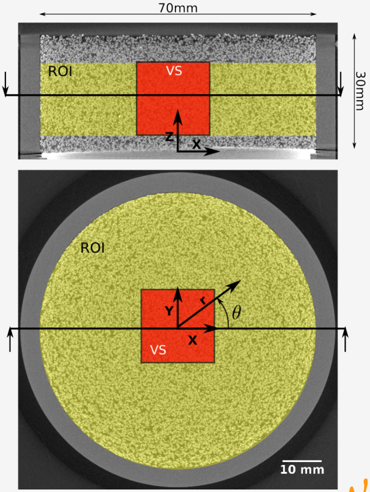
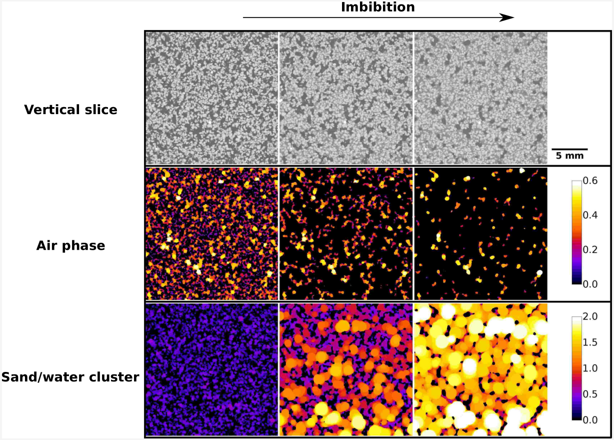


Image treatment and analysis (VS)

Matheron's granulometry (largest inscribed spheres) + DIC

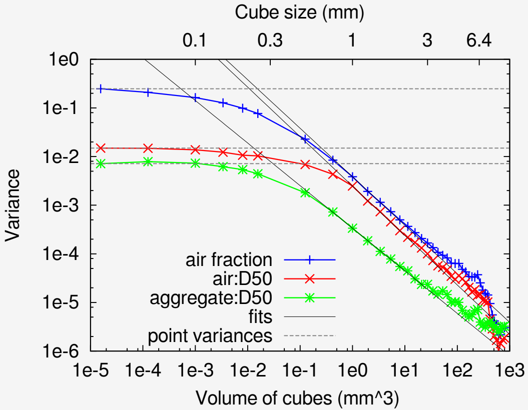
(. . . after filter application and image segmentation. . .)



(colour scale: spheres diameter)

Caméléon-Population software, O. Cugnon de Sévricourt & V. Tariel

Defining a RVE? I

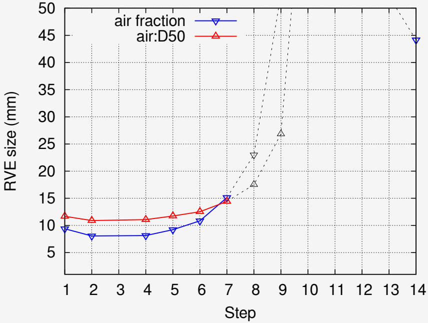


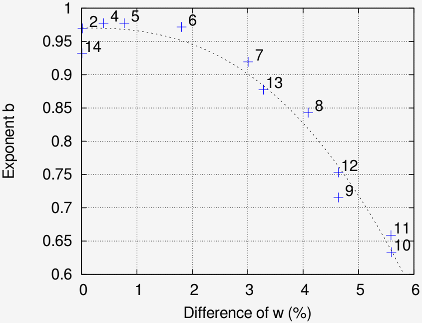
$$f(V) = \frac{A\,\sigma^2}{V^b}$$

A: integral range (variation scale)
$b \approx 1$: homogeneous (Matheron's criterion)

Effect of cube size on the variance of air fraction and D_{50} (initial state).

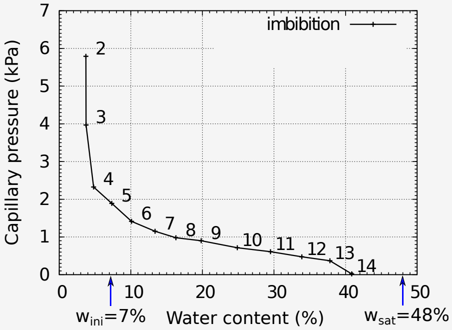
Defining a RVE? II



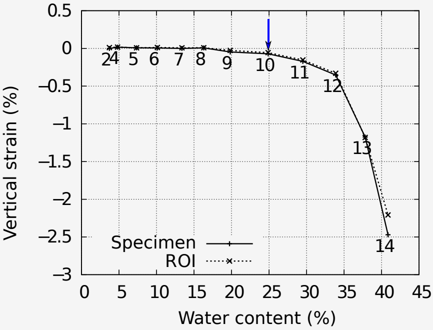


Evolution of RVE size of air fraction and of median diameter of air.

Collapse response - macroscale



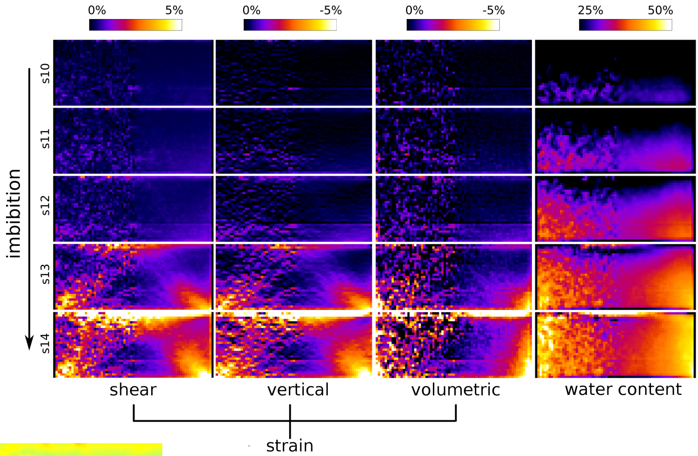
Capillary curve

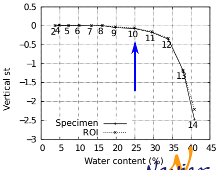


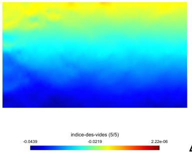
Collapse curve

- step 1: $w = 7\%$, $p_c = ?$
- step 1→2: drainage
- step 2→14: imbibition
- "critical" water content: 25%

Heterogeneity?

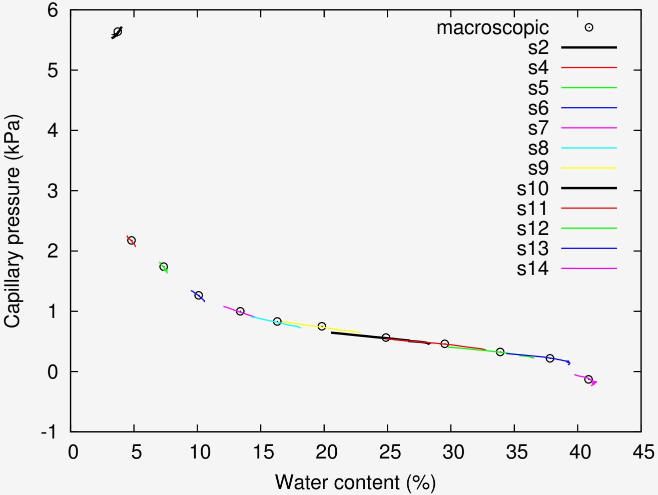






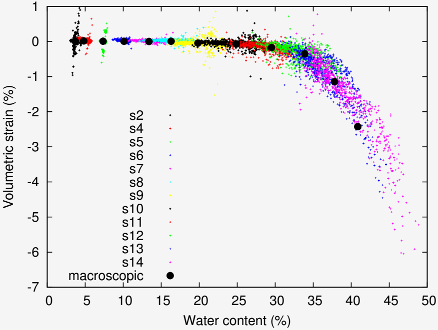
Δe (FEM, unsat. MCC)

Macro- and mesoscopic scales: water retention curve

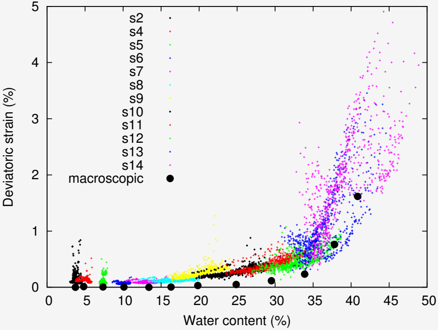


Capillary curve (mesoscale: average by layer)

Macro- and mesoscopic scales: strains

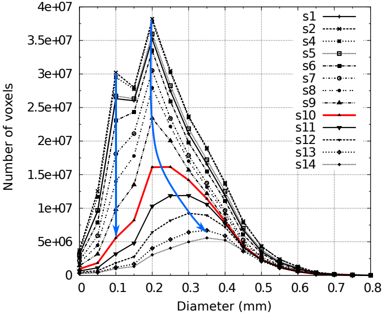


Volumetric strain (mesoscale: θ-average)

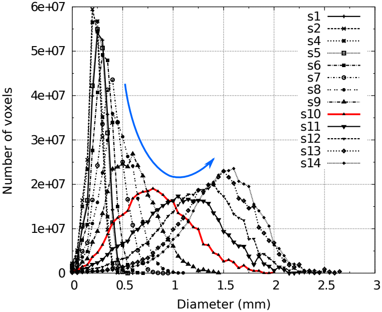


Deviatoric strain (mesoscale: θ-average)

Phases size evolution during imbibition

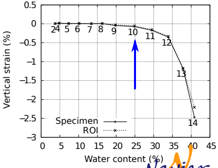


Air phase



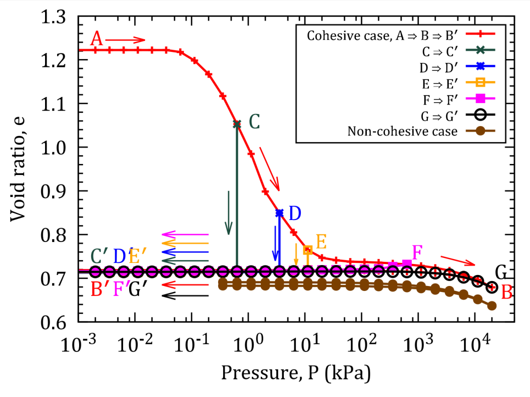
Aggregate phase

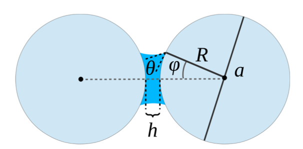
- Collapse is visible when water starts to fill macro-pores (inter-aggregates) and merging aggregates



Modelling (ongoing work)

- PhD: V.D. Than (Than et al. 2016)
- Colleagues: Anh-Minh Tang, Jean-Noël Roux





Isotropic compression and wetting of unsaturated sand

Concluding remarks and perspectives

- X-ray CT investigation of unsaturated sand subjected to wetting
- Specimen preparation induces a double porosity
- Double porosity sctructure plays a key role in capillary induced collapse
- Local (mesoscale) and macroscopic responses are compatible

- Experiments with better resolution (smaller specimens) & DEM (PhD Than)
- Multiscale numerical modelling
  (Ioannis Stefanou, Patrick Dangla)

http://biot2017.sciencesconf.org/

References

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