Analysis of unsaturated properties of a sandy soil using X-Ray CT

E. Shiota[a], L. Oxarango[b*], L. Chang[c], P. Delmas[c], T. Mukunoki[a]

[a]X-earth Center, University of Kumamoto, Japan
[b]LTHE, Université Grenoble Alpes, France
[c]Department of Computer Science, The University of Auckland, New Zeland
**Corresponding author, laurent.oxarango@ujf-grenoble.fr*

Keywords : unsaturated properties, Segmentation, X-ray CT

Abstract

The objective of this study is to explore the capability of X-ray Computed Tomography (µX-ray CT) to characterize the unsaturated properties of a sandy soil (i.e. Toyoura sand). A classical hanging column water retention test is performed using a custom centimetric cell. At each suction step, once the capillary/gravity equilibrium is reached, the sample is analyzed using a µX-ray CT scanner. The resulting 3D image of the sample (15mm*15mm*15mm) is acquired with a voxel size of 9 µm. A specific segmentation algorithm presenting similarities with the approach proposed in [1] has been implemented to separate the solid, liquid and gas phase (figure 1).

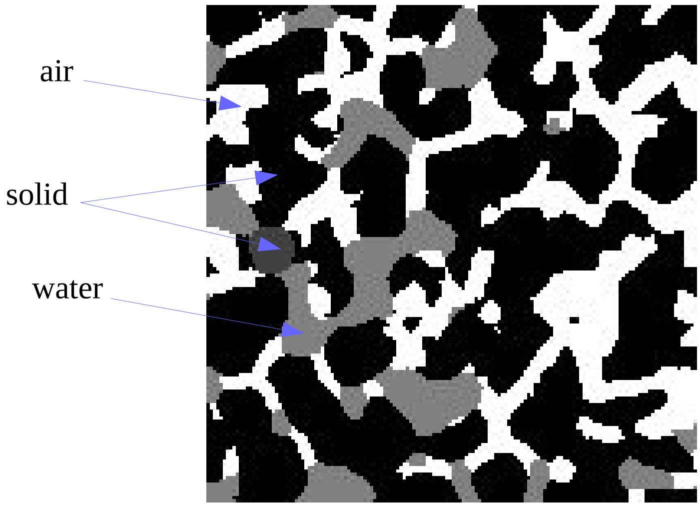

Figure 1: Example of 3 phase segmentation on a sub-sample

The Local Adaptive Kriging algorithm is a two steps segmentation approaches: (i) a set of gaussians is fitted to the image histogram using the Expectation-Maximization (EM) algorithm, (ii) a refinement step where the pixels belonging to more than one gaussian are sorted based on the distribution of grey levels in their neighborhood using a kriging algorithm based on the pixel-distance.
The resulting segmented images are then analyzed in order to estimate the volumetric moisture content and the specific surfaces between phases. A methodology based on stochastic sub-sampling is used to select the minimum

Representative Elementary Volume (REV) as suggested in [2] and [3]. A satisfactory agreement is obtained with the macroscopic water balance on the tested sample (Figure 2a). The water distribution is analyzed with respect to the pore diameter and the meniscus size and shape are extracted providing an original insight of capillary effects in a real 3D porous material.

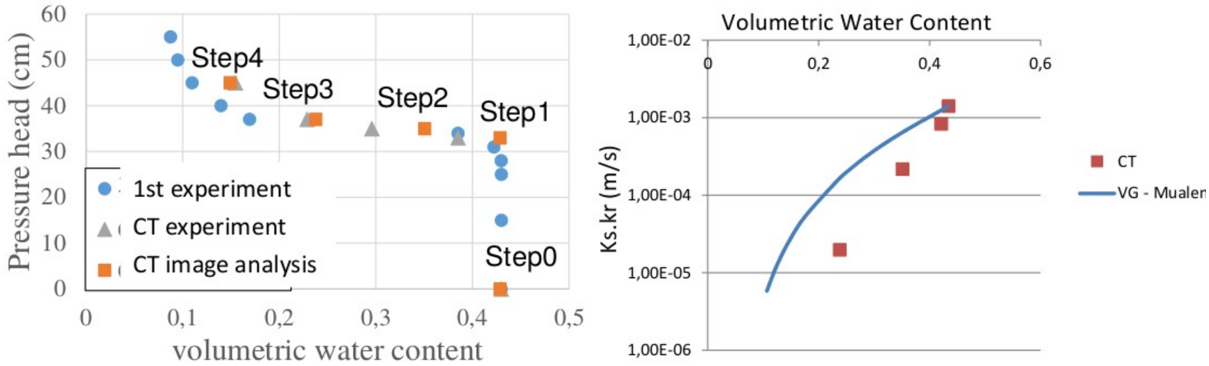

Figure 2: a. Retention Curve, b. Relative Permeability Curve

In a second part, the water flow at the pore scale is simulated using the Lattice Boltzmann Method (LBM) [4] in order to estimate the relative permeability for each water content. These simulations are performed in the water phase only thus neglecting the effect of the pressure gradient and gas/liquid interfaces. The obtained relative permeability curve presents a reasonable agreement with the classical Van Genuchten-Mualem function (Figure 2b). However, a stiffer decrease of the permeability with decreasing volumetric water content is observed.

These results highlight the capability of µX-ray CT to study multiphase phenomena in porous media

Acknowledgment

This study is part of the H2020 Rise Project PROTINUS.

References

[1] Hashemi, M.A., Khaddour, G., François, B., Massart, T.J., Salager, S., A tomographic imagery segmentation methodology for three-phase geomaterials based on simultaneous region growing, *Acta Geotechnica*, 9, pp831–846 (2013).

[2] Zhang, D., Zhang, R., Chen, S., Soll, W.E., Pore scale study of flow in porous media: scale dependency, REV and statistical REV, *Geophyscal Research Letter*, 27, pp. 1195–1198 (2000).

[3] Rolland du Roscoat, S., Decain, M., Thibault, X., Geindreau, C., Bloch J.F., Estimation of microstructural properties from synchrotron X-ray microtomography and determination of the REV in paper materials. *Acta Materialia*, 55 (8), pp 2841–2850 (2007).

[4] He, X., Luo, L.S.: Lattice Boltzmann model for the incompressible Navier–Stokes equation. J. Stat. Phys. 88(3–4), 927–944 (1997)