Modeling the Evolution of Soil Hydraulic Properties during Consolidation Process Under Saturated Conditions.

Yann Periard (1) and Silvio José Gumiere (1)

yann.periard-larrivee.1@ulaval.ca

(1) Université Laval, Faculté des sciences de l'agriculture et de l'alimentation, Département des sols et de génie agroalimentaire, Québec, Canada ,

UNIVERSITÉ LAVAL

Session: Soil Hydrology - Patterns and Process Interactions in Space and Time: II

Poster Number 1424

Introduction

- Knowledge of soil hydraulic properties is fundamental
- Soil is deformable
- Intense agricultural systems
- Subject to external stress
- Machinery traffic and flooding
- Changes in volumetric strain and consequently, alteration of soil hydraulic properties
- Advances in the field of tomography imagery allow for the characterization of a number of soil hydraulic properties (Wildenschilds and Sheppard, 2013)

Objective

- The main objective of this study is to propose a numeric model to predict the evolution of soil hydraulic properties during the consolidation process under saturated conditions.

Materials & Methods

Experimental set up

- Cylinder of 56 cm of length and 15 cm of diameter.
- Unconsolidated Ottawa sand
- Outflow measurement with absolute pressure transducer (Hobo U20 Water Level Logger, ONSET, Bourne, MA, USA)
- Constant pressure head of 25 kPa at the inlet
- Constant pressure head of 0 kPa at the inlet

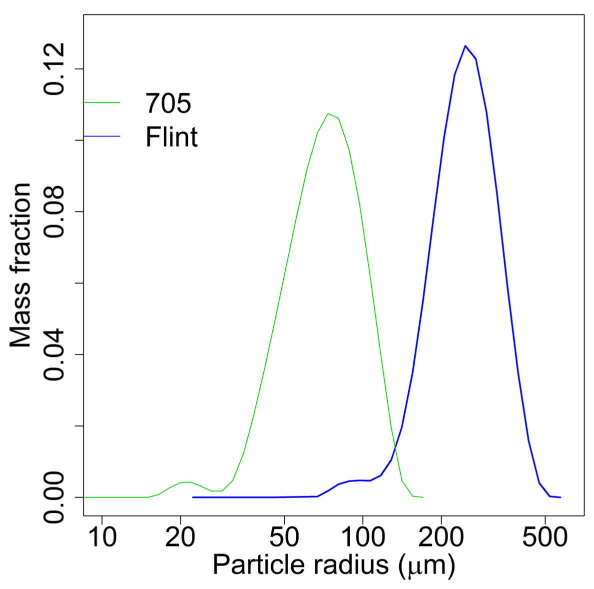


Figure 1. Particle size distribution

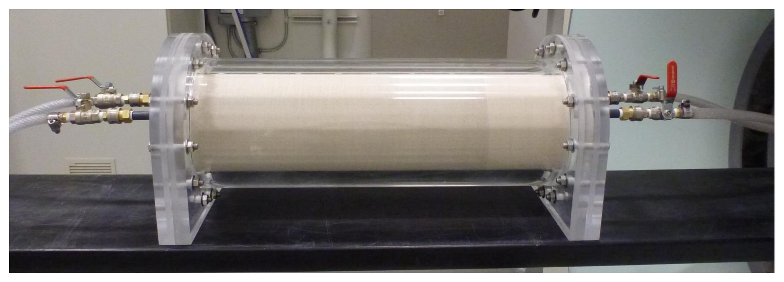


Figure 2. Soil cylinder

Materials & methods

Tomographic analysis

- The study was realised at the *Laboratoire Multidisplinaire de Scanographie du Québec de l'INRS.*
- Medical CT scan of type Somatum Volume Access (Siemens, Oakville, ON, CA).
- Energy levels:140, 120, 100 et 80 keV
- Voxel resolution : 0.1x0.1x0.6 mm

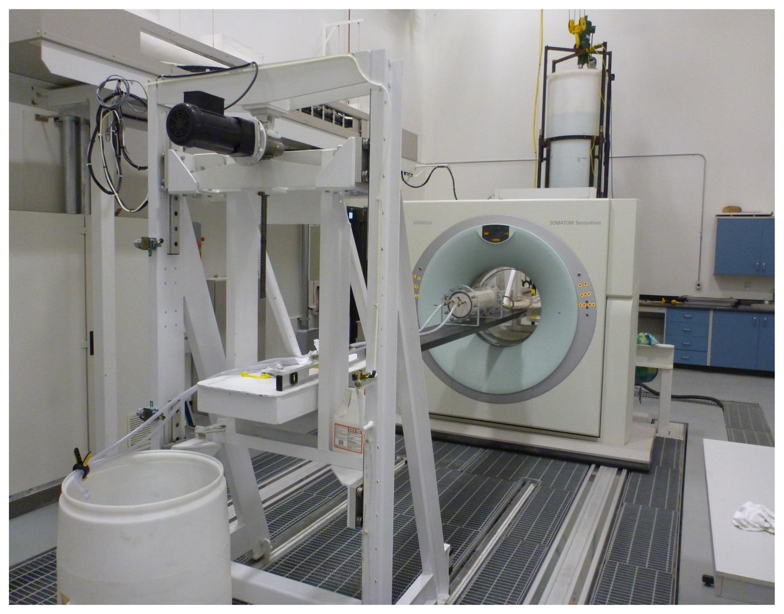


Figure 3 Medical CT scan and experimental setup

Determination of the porosity

Lambert-Beer law

$$I = I_0 \exp(-\mu x) \qquad HU = 1000(\mu - \mu_w)/(\mu_w - \mu_a)$$

$$\phi = \frac{Hu_{quartz} - Hu}{Hu_{quartz} - Hu_{air}}$$

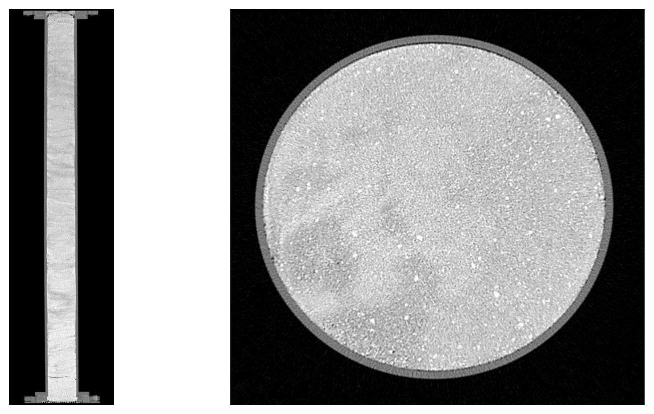


Figure 4. Vertical and horizontal slices

Model of consolidation (Poroelastic model)

Poroelastic models describe the interaction between fluids and porous media deformation. The fluids in the soil may absorb stress, which results in fluid pressure or equally hydraulic head.

Fluid flow through porous media:

The Darcy Law was used to estimate the flow in the poroelastic model within the pressure head formulation

$$\rho_f S_\alpha \frac{\partial H}{\partial t} + \nabla \cdot \rho_f[-K\nabla H] = -\rho_f \alpha_B \frac{\partial}{\partial t}\varepsilon_{vol}$$

where ρf is the fluid density, H is the pressure head (m), K is the hydraulic conductivity (m/s), ε_{vol} is the volumetric strain of the porous matrix, and α_B is the Biot-Willis coefficient .

Porous media deformation:

The governing equation for the poroelastic material model is:

$$-\nabla \cdot \sigma = \rho \mathbf{g}$$

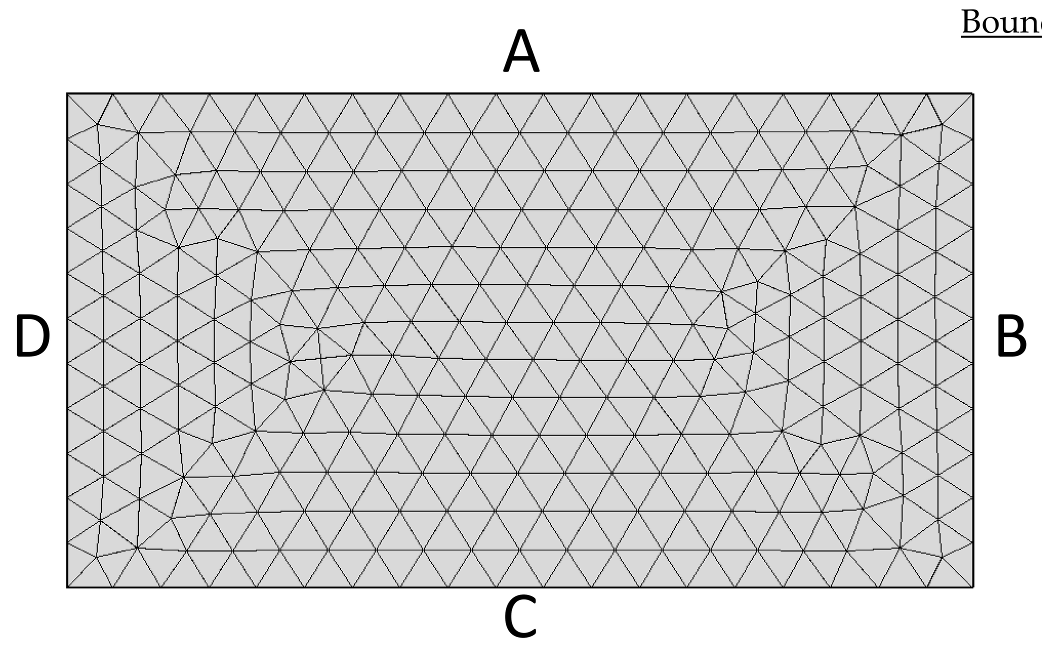
where, σ is the total stress tensor, ρ is the total density, and g is acceleration of gravity. For an isotropic porous material under plane strain conditions, the model simplifies to :

$$\begin{bmatrix}\sigma_{xx}\\ \sigma_{yy}\\ \sigma_{xy}\end{bmatrix} = \frac{E}{(1+\nu)(1-2\nu)}\begin{bmatrix}1-\nu & \nu & 0\\ \nu & 1-\nu & 0\\ 0 & 0 & 1-2\nu\end{bmatrix}\begin{bmatrix}\varepsilon_{xx}\\ \varepsilon_{yy}\\ \varepsilon_{xy}\end{bmatrix} - \begin{bmatrix}\alpha_B p & 0 & 0\\ 0 & \alpha_B p & 0\\ 0 & 0 & \alpha_B p\end{bmatrix}$$

where, E is Young's modulus (Pa), ν Poison's ratio and $\varepsilon_{i,j}$ deformation calculated by:

$$\varepsilon_{xx} = \frac{\partial u}{\partial x} \quad \varepsilon_{yy} = \frac{\partial v}{\partial y} \quad \varepsilon_{xy} = \frac{1}{2}\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right) \quad \varepsilon_{xy} = \varepsilon_{yx} \quad \varepsilon_{xz} = \varepsilon_{yz} = \varepsilon_{yz} = 0$$

Simulation conditions



Boundary conditions :

Fluid flow through porous media:

A. no flow
B. H=0 m
C. no flow
D. H=1m

Porous media deformation:

A. roller
B. fixed constraint
C. roller
D. Free

Figure 5. Boundary conditions

Results

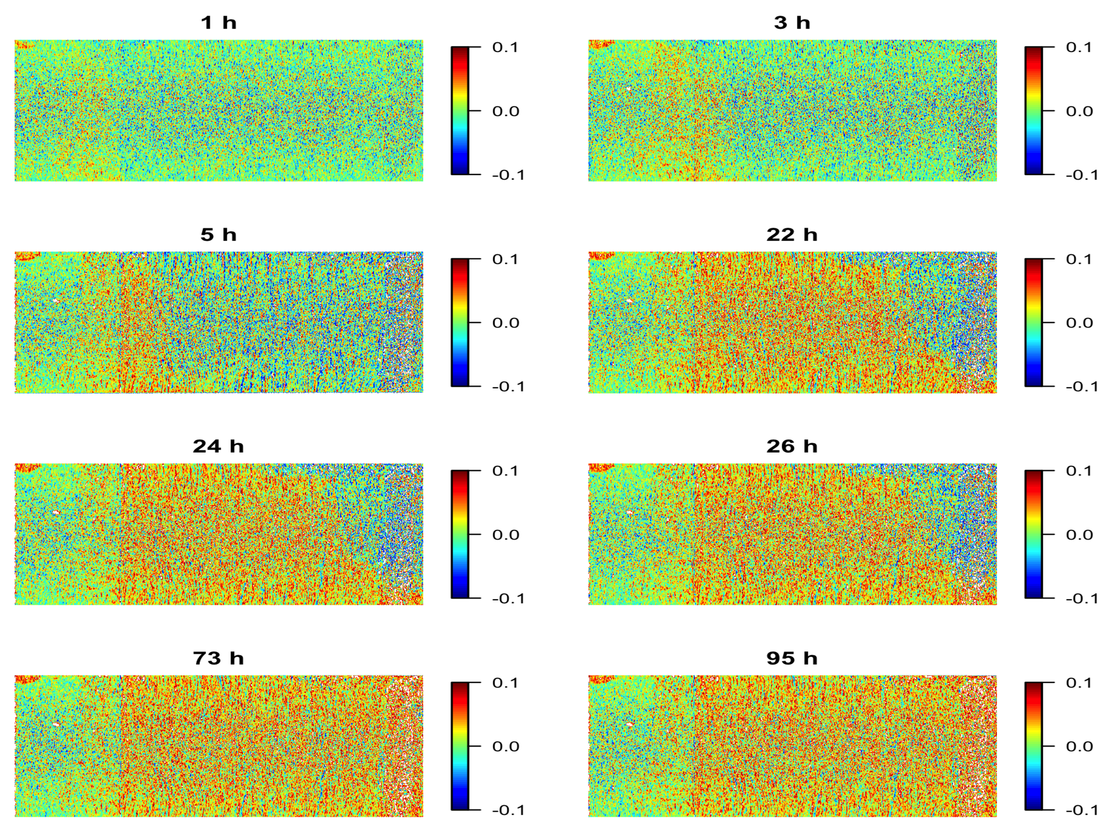


Figure 6. Radial plane of spatial variability of displacement (cm) calculated with the measurement of the density with medical Ct scan.

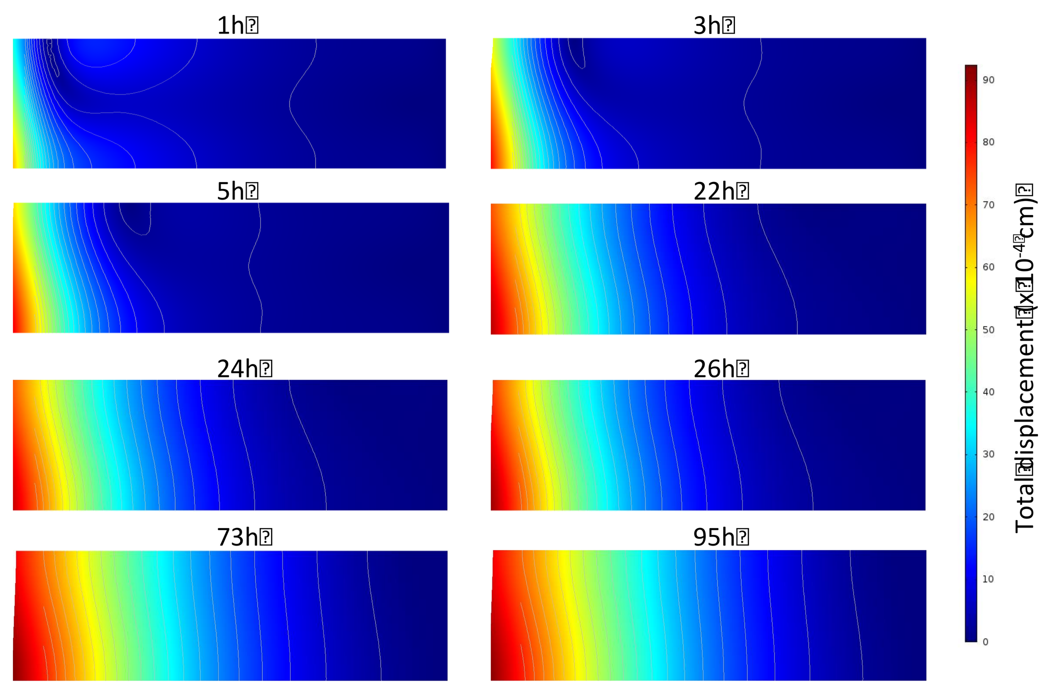


Figure 7. Radial plane of spatial variability of displacement simulated with the model.

Conclusion

- CT-Scans appear to be very useful in understanding the consolidation processes occurring un soils under drainage conditions;
- The simulated displacement within the model agrees very well with the measured displacement.

Acknowledgements

NSERC CRSNG · Fonds de recherche sur la nature et les technologies Québec · ATOKA · UNIVERSITÉ LAVAL · Fruit d'Or · HORTAU

References

Wildenschild, D. and A.P. Sheppard. 2013. X-ray imaging and analysis techniques for quantifying pore-scale structure and processes in subsurface porous medium systems. Advances in Water Resources 51: 217-246. doi:http://dx.doi.org/10.1016/j.advwatres.2012.07.018