Studying the effect of desiccation cracking on the hydraulic behavior of a Luvisol-From an experimental and numerical approach

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Introduction

Cracking due to desiccation on soil surface is a common phenomenon and related to the interaction between soil and atmosphere. Indeed, during dry seasons, high evaporation of pore water near the soil surface leads to a more significant soil suction in that region. The suction results in compressive stresses on the soil structure and produces shrinkage including cracking. As the crack network forms, the natural soil structure is strongly modified, which influences the soil's hydraulic behavior directly and provides preferential flow pathways for soil-water transport.

The work aims to study the formation of cracks during evaporation process of a *Luvisol* and evaluate how cracking affects the soil hydraulic conductivity. Laboratory experiments were firstly performed to investigate the initiation and propagation of cracks on soil surface. Through the tests, the hydraulic properties and the drying kinetics of soil samples were also determined. Finally, numerical simulations were carried out to emphasize the effect of desiccation cracking on the moisture transport mechanisms in soil samples.

Material and method

The soil used in the experiment is classified as a *Cutanic Luvisol*. Undisturbed soil samples were taken from the field named "Bordia", located in Gembloux, Belgium. Drying tests were performed by means of HYPROP which is an accurate instrument for an evaporation method (Peters and Durner, 2008). In this technique, saturated soil sample is placed on the device and both are weighed on a precision balance. The soil surface then is exposed to a free evaporation under atmospheric conditions. To increase the rate of evaporation, a heat-lamp-bulb is placed one meter above the soil surface. The variation in hydraulic head inside the soil sample is assessed by two tensiometers placed at different height while the change in water content is determined by the weight changes of the sample. Both data are recorded during the tests and they are used to determine hydraulic properties of the soil sample. The drying kinetics of soil sample can also be characterized by representing the drying curves in different ways: drying rate versus time or, drying rate versus averaged moisture content, in which the drying rate, $q = -\frac{dm}{dt}$, is calculated on the basis of the weight changes. Along with these measurements, a camera is positioned above the soil sample to capture images every 30 minutes as to assess how cracks initiate and evolve on the soil surface.

A numerical modelling of soil evaporation process based on a thermo-hydro-mechanical framework was conducted in order to understand the impact of cracks on the soil hydraulic behavior. All the constitutive models have been implemented in the finite element code LAGAMINE developed by the University of Liège. Briefly, the drying kinetics is modelled using the boundary layer model (Gerard et al., 2010), assuming that the vapor and heat transfer take place in a boundary layer at the surface of the porous medium. The embedded fracture model is chosen to represent the development of the fractures in porous medium in which fracture opening is activated by a threshold strain parameter (Olivella and Alonso, 2008).

Results and discussion

We investigated the formation of desiccation cracks in parallel with the evolution of the soil moisture content. The results of the experiment show that there were three periods of drying soil occurring in varying atmospheric conditions (relative humidity and temperature). The first period was characterized by a high and constant drying rate (CRP), $q \approx 3.5 \times 10^{-7}\ \mathrm{kg.s^{-1}}$. Cracks were formed at the end of this period as the most shrinkage occurred and the drying stresses rose to a maximum value. Several cracks in the range of $0.5 - 2$ mm wide were observed. It should be noted that undisturbed soil samples had some pre-existing cracks in soil matrix. The second period (FRP) was considered to begin when the drying rate declined. During this period, the soil surface experienced a rapid drying. Transitions between periods CRP and FRP was characterized by a "critical-moisture content", $\overline{w}_{cr} = 0.2 - 0.25$. The third period was distinguished by a low, relatively constant drying rate. No more cracks developed in this period.

2D-axisymetric modelling of cylindrical samples were performed. The numerical results for mass loss, drying rate and drying curve showed a good fit with the experimental ones. An increase in intrinsic permeability up to one order was observed in the fracture zones. This caused a quicker drying of soil samples during the period FRP. On the moisture transport mechanisms, Darcy's flow increased in the fracture zones as preferential flows developed while vapor diffusion showed only a slight modification.

Conclusion

In this work, we have suggested using HYPROP device to investigate soil behavior associated with cracks formation during drying process caused by evaporation. We have validated the capacity of the numerical model to reproduce the drying tests conducted. Our results also have suggested that using a simple concept of cracking development, a continuum model is capable of modelling preferential flows developed in a fractured porous medium such as agricultural soil.

References

Peters, A., Durner, W., 2008. Simplified evaporation method for determining soil hydraulic properties. *J. Hydrol.*, 356 (1–2), 147–162.

Gerard, P., Léonard, A., Masekanya, J. P., Charlier, R., Collin, F., 2010. Study of the soil–atmosphere moisture exchanges through convective drying tests in non-isothermal conditions. *Int. J. Numer. Anal. Meth. Geomech.*, 34(12), 1297-1320.

Olivella, S., Alonso, E. E., 2008. Gas flow through clay barriers. *Géotechnique*, 58(3), 157-176.