X International Conference on Computational Plasticity
COMPLAS X
E. Oñate and D. R. J. Owen (Eds)

INFLUENCE OF CRACKING IN THE DESICCATION PROCESS OF CLAY SOILS

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Key words: desiccation; curling; state surfaces; fracture mechanics; boundary value problems.

Summary:
It is well known that clayey soils undergoing desiccation tend to shrink and eventually crack. Analysis of the behaviour and influence of cracks in these types of soils is very important in several engineering fields such as mine tailing dams, long-term radioactive waste storage, impervious core of earth dams, and in any situation where clay is used as a barrier to fluid flow. Loss of humidity and cracking changes the permeability of such barriers that may no longer work properly and pose potentially high risks to property and lives.

This paper presents an analysis of cracking during drying of soils using a computer code developed within the framework of the finite element and finite differences methods. A study of the influence of crack initiation and propagation in the desiccation process is also undertaken, with a comparative analysis of the phenomenon both with and without crack generation that allows some preliminary conclusions about the desiccation problem.

The computer code has been implemented within the MatLab environment. The formulation is based on the principles of the unsaturated soil mechanics and the mechanics of a continuum medium. The partial differential equations that govern the problem are solved using the finite element (Galerkin) method in space and the finite differences method, using the Crank-Nicholson scheme, in time. Further developments of the code will include fracture mechanics principles to simulate crack propagation.

1 INTRODUCTION

We present a coupled hydro-mechanical numerical model based on continuum mechanics and unsaturated soil mechanics (Levatti et al. 2009) that is able to reproduce shrinkage with imposed cracks in desiccation processes in clayey soils. Boundary conditions are determinant for predicting the strain behaviour of soils during desiccation. The constitutive relation is based on the concept of state surface. An explicit scheme is used to solve the equations. The results provide fundamental insights into the problem of crack formation and propagation in soils.

2 HYDRO-MECHANICAL MODEL

Two state stress variables are adopted in this model: the total stress $\boldsymbol{\sigma}$ and the negative pore water pressure p. Under the assumptions of small-strain theory, isothermal equilibrium and negligible inertial forces, we obtain the following balance equations: first, the linear momentum balance equation for a two-phase medium, where ρ is the density, and $\mathbf{g}$ is the gravity vector:

$$\nabla \cdot \boldsymbol{\sigma} + \rho \mathbf{g} = 0 \tag{1}$$

Second, the water mass balance equation, where ρ^w is the water density, $\mathbf{q}$ is Darcy's velocity, n the porosity and S_r the degree of saturation:

$$\nabla \cdot (\rho^w \mathbf{q}) + \frac{\partial}{\partial t}(\rho^w n S_r) = 0 \tag{2}$$

We can summarize the coupled problem through the next system of differential equations:

$$\begin{cases} \mathbf{K}\dfrac{\partial \overline{\mathbf{u}}}{\partial t} + \mathbf{Q}\dfrac{\partial \overline{\mathbf{p}}}{\partial t} - \mathbf{f}^u = \mathbf{0} \\ \mathbf{P}\dfrac{\partial \overline{\mathbf{u}}}{\partial t} + \mathbf{S}\dfrac{\partial \overline{\mathbf{p}}}{\partial t} + \mathbf{H}\overline{\mathbf{p}} - \mathbf{f}^p = \mathbf{0} \end{cases} \tag{3}$$

where $\overline{\mathbf{u}}$ and $\overline{\mathbf{p}}$ are, respectively, the nodal displacements and the nodal pore pressure vectors; **K**, **S**, **H** are the stiffness, compressibility and permeability matrices respectively and **Q**, **P** are coupling matrices; $\mathbf{f}^u$, $\mathbf{f}^p$ are the nodal force and nodal flow vectors respectively; all resulting from the FEM approach.

3 UNSATURATED SOIL MECHANICS CONCEPTS

For the hydro-mechanical formulation two constitutive models are needed. The mechanical constitutive model, Eq. (4), is written in terms of state surfaces (Alonso et al. 1990; Lloret and

Alonso 1985; Matyas and Radhakrishna 1968) whereas for the hydraulic constitutive model, including unsaturated flow, Eq. (5), Darcy's law is used. The models can be written as follows:

$$\varepsilon_v = n = -\frac{\Delta e}{1+e_0};\ \Delta e = a_1 \Delta \ln(\sigma_m + a_4) + a_2 \Delta \ln\left(\frac{p+p_{ref}}{p_{ref}}\right) + a_3 \Delta\left[\ln(\sigma_m + a_4)\ln\left(\frac{p+p_{ref}}{p_{ref}}\right)\right] \quad (4)$$

$$\mathbf{q} = -\mathbf{K}(S_r)\cdot(\nabla p - \rho^w \mathbf{g}) \quad (5)$$

where ε_v is the volumetric strain; σ_m is the mean stress; e and e_0 are the current and initial void ratios; a_1, a_2, a_3, a_4 are state surface constants; p is the negative pore water pressure; and p_{ref} is a reference pressure.

Furthermore, we need to express the relation between suction and degree of saturation. For the purpose of this paper the following relation (van Genuchten 1980) has been chosen:

$$S_r = \left[1 + \left(\frac{p}{P_0 f_n}\right)^{\frac{1}{1-\lambda}}\right]^{-\lambda} \quad (6)$$

where S_r is the degree of saturation, λ is a material parameter, P_0 is the air entry value at the reference porosity n_0 and f_n is a function of porosity and material parameters.

4 RESULTS AND CONCLUSIONS

Two simulations of rectangular samples of the same size (40×20 cm) with different size of initial crack are presented in this paper. A pressure of -60 MPa at the top of the sample and on the boundary crack was imposed during a 40-day simulation. The boundary conditions imposed on the lateral sides consisted on a restriction of horizontal displacement plus restriction of the horizontal and vertical displacement in nodes at 0 heights.

Figure 1 depicts two numerical results from the two samples with the boundary and pressure conditions cited above. The figure clearly shows the influence of the centre crack size. With bigger cracks the process reaches the stable condition in less time. In the first simulation, Figures 1a,c,e the stable condition is not reached after the 40-day simulation. However in the second case, Figures 1b,d,f, stabilization is reached after 20 days of simulation. Figures 1a,b show the evolution of pressure with time at the reference point; Figures 1c,d show the final pressure field and Figures 1e,f show the horizontal stress field.

Cracking processes change pressure and boundary conditions during desiccation and have a strong influence on the behaviour of the drying soils. It is necessary to control these changes to simulate properly this kind of phenomenon.

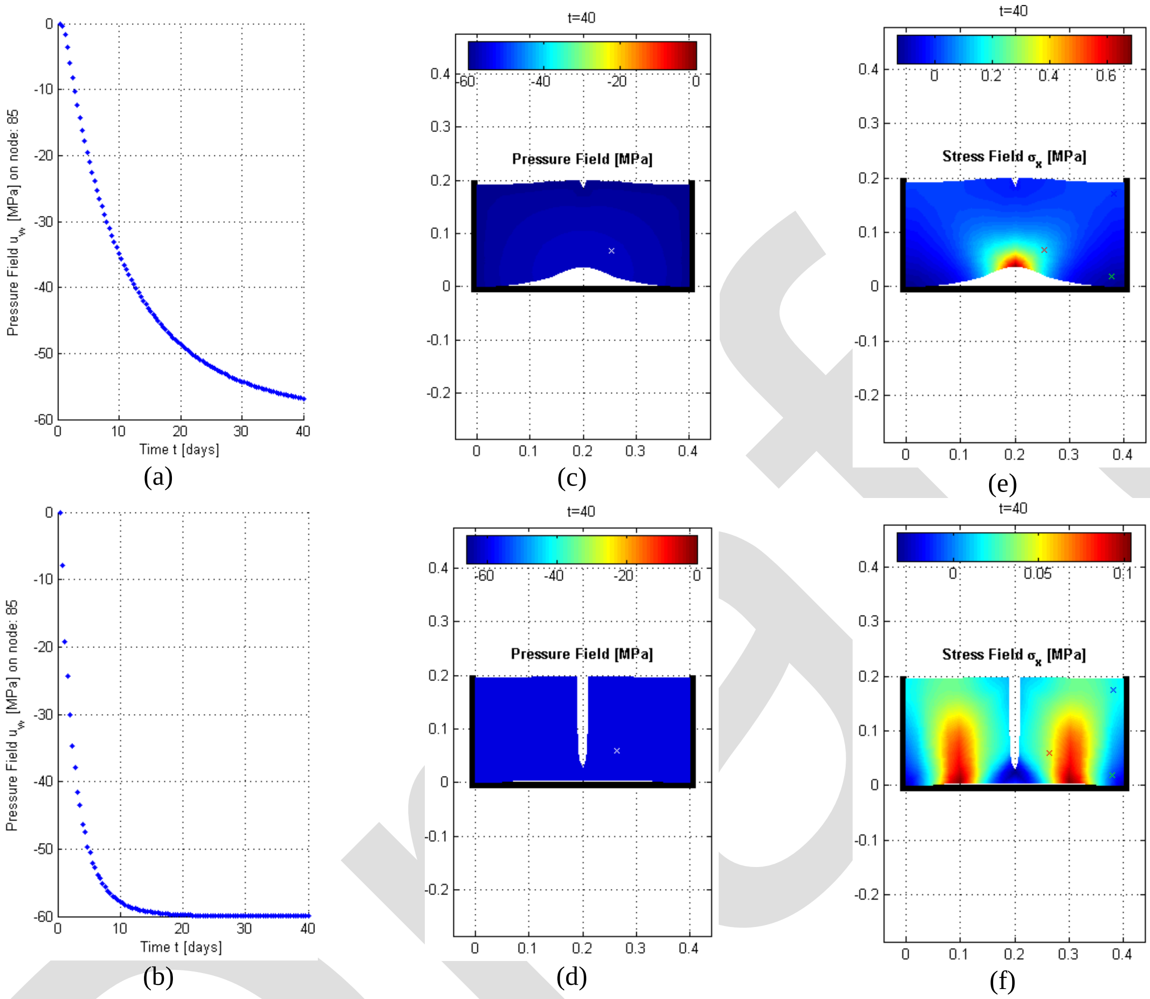

Figure 1.- (a) and (b) pressure evolution with time at the white point; (c) and (d) final pressure field; (e) and (f) final stress field.

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