V International Conference on Computational Methods for Coupled Problems in Science and Engineering
COUPLED PROBLEMS 2013
S. Idelsohn, M. Papadrakakis and B. Schrefler (Eds)

INFLUENCE OF CRACKS ON THE SOIL-ATMOSPHERE INTERACTION: NUMERICAL COUPLED MODEL OF THERMO- ATMOSPHERE-POROUS MEDIA

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Key words: Clay, cracks, soil-atmosphere interaction, evaporation, finite element model

Abstract. Soil shrinks as it desiccates, and the magnitude of shrinkage can be large for clayey soils. The drying of soil leads to cracks formation, causing high suctions to develop within. Cracks expose the deep soil and more evaporation can be expected in dry periods. To illustrate the effect of cracking, a numerical model of soil-atmosphere interaction has been developed taking into account the thermo-fluid coupling of an unsaturated clay soil. The model is used to simulate the evolution of evaporation during the drying process. The main results show a significant influence of the presence of cracks on the evaporation. This study also offers a simple method for taking into account the presence of cracks in the soil-atmosphere exchange.

1 INTRODUCTION

Desiccation cracking is a common phenomenon in clay materials. Since superficial soils are directly exposed to seasonal changes in climate, desiccation cracks develop at the surface of soils as they dry and shrink.

Cracks induce changes in soil surface patterns and can greatly modify their hydraulic properties. Moreover, shrinkage cracks create in soil zones of weakness affecting the stability of buildings and structures that are constructed on clayey soils.

Many attempts have been made to follow the initiation of cracks and to describe the cracking process. Most of these studies are based on field and laboratory experiments [1- 9].

In view of modeling the cracking process, there is very little literature on the impact of cracks on evaporation from soil surface and on suction development [10-12].

In this study, a numerical model is developed to investigate the effect of cracks on evaporation evolution from a soil surface exposed to dry conditions.

Then a simplified approach able to reproduce the impact of cracks on the soil behaviour is presented and discussed.

2 NUMERICAL MODEL

The theory is based on the principles of Darcy's law and Fick's law to describe the flow of liquid water and water vapor in the saturated - unsaturated soil below the surface.
Penman-Wilson (1948) [13] method for evaporation is used to predict evaporation from the soil surface, as follows:

$$E_{vap} = \frac{\Delta R_n / L_V + \eta E_a}{\Delta + \frac{1}{\varphi_s}} \tag{1}$$

$$E_a = 0.35(1 + 0.15U_a)(\frac{1}{\varphi_a} - \frac{1}{\varphi_s})P_a \tag{2}$$

Δ is the slope of the saturation vapor pressure versus temperature curve at the mean temperature of the air, R_n is the net radiation at the soil surface, L_V is the latent heat to vapor, η is the psychrometric constant, U_a is the wind speed, P_a is the vapor pressure in the air above the evaporation surface; φ_a and φ_s designate the relative humidity in the air and at the soil surface, respectively.
Permeability is calculated using (Fredlund et al. 1994; Leong and Rahardjo 1997) formulation [14,15] and Wilson's equation (1990) [16] was used to estimate the temperature at the surface of soil. For water retention curve, the Van Genuchten equation (1980) [17] is used and Van de Griend and O'Neill (1986) [18] equation is used to compute the thermal conductivity.

2.1 Model description

A conceptual model is developed that quantitatively describes the soil-atmosphere interaction for a clayey soil undergoing desiccation. Figure 1 shows finite element mesh and the domain boundary used in numerical analysis.
The model was 1 m deep, modeling the entire depth of soil and 20cm wide , half of the physical length because of the symmetry.
Mesh element sizes were reduced near the soil surface to increase model accuracy. To create a domain 1m deep by 20 cm wide, 21 rows and 20 columns, 800 elements were built.
The numerical model was used to simulate the results of 30 days evaporation for a clayey soil undergoing desiccation.

2.2 Boundary & Initial conditions

2.2.1 Initial Conditions

The same initial conditions were used in all simulations:
- Soil initially saturated given by: $\Psi=0$ for t = t0 and
- Surface temperature set at 20°C for t = t0

2.2.2 Boundary Conditions

Flow was allowed only from the upper surface to simulate the evaporation and thermal flux. Outward flux was not allowed at the right, left and lower boundaries (Figure 1).
For the sake of simplicity and to represent the drying environment, weather parameters was set constant for all the period of simulations with a temperature set at 20°C, relative humidity at 60%, solar radiation at 800 w/m^2 and air velocity set equal to 60 Km/h.

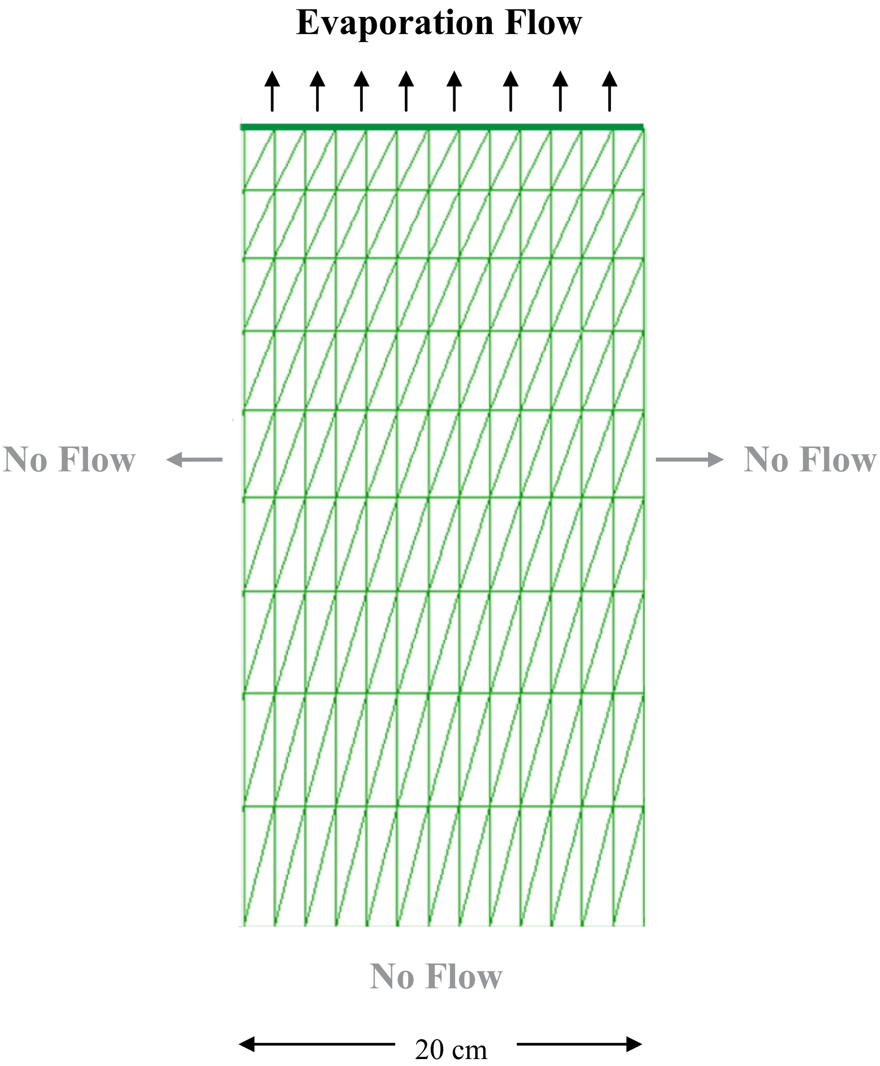

Figure 1: Geometry and boundary conditions used in case of intact soil

2.3 Soil properties

The model requires several input parameters specific to the soil undergoing desiccation. Hydraulic conductivity and water retention characteristics are needed to predict the evolution of the suction profile with time, relative humidity of the air and at the surface are needed to evaluate evaporation from soil surface.

3 RESULTS OF THE NUMERICAL SIMULATIONS

Results of the evaporation from the interface soil-atmosphere for intact and cracked cases are shown in the following sections.

3.1 Case 1: Intact soil

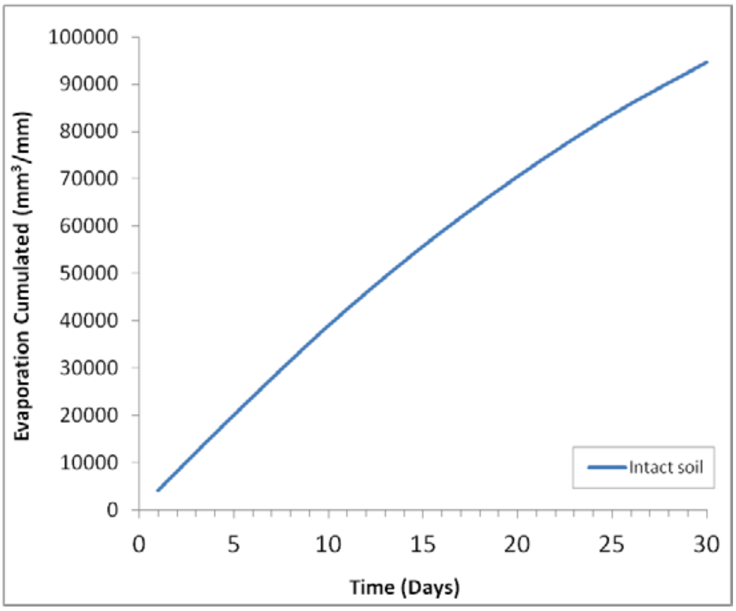

Figure 2: Cumulated evaporation flux for an intact soil surface

Figure 2 presents the cumulated evaporation flux for the 30 days. Evaporation shows a value of 400 mm/day at the end of the first day then increased almost linearly with time and attains a value of 9500 mm/day after 30 days.

Because soil is exposed to drying conditions, loss of water starts since the first day of simulations and continues; which, in turn, promote the evaporation process and increases the evaporation rate along the 30 days.

3.2 Case 2: Cracked soil

The purpose of this section is to show the impact of soil cracks on evaporation from soil surface. To that purpose, a crack of 5cm depth and 1cm width was incorporated into the model described above.

The geometry of the cracked model and the boundary conditions are shown in Figure 3.

We suppose that a crack occurs every 40cm at soil surface. And, since only half of the model is analyzed, the width of the model was then equal to 20cm with a depth of 1 m. The rightmost column represented the crack, with a new vertical front of 5cm.

To increase model accuracy, mesh element sizes were reduced near the crack and soil surface. Row widths away from the crack increased from 1.0 to 10 cm (Figure 3).

In the case of cracked soil, evaporation occurs from both surface and crack front. Then in the boundary conditions, the crack front is subjected too to atmosphere conditions.

Simulations were conducted in the same manner of the intact soil using the same soil properties, same initial conditions and same weathers parameters.

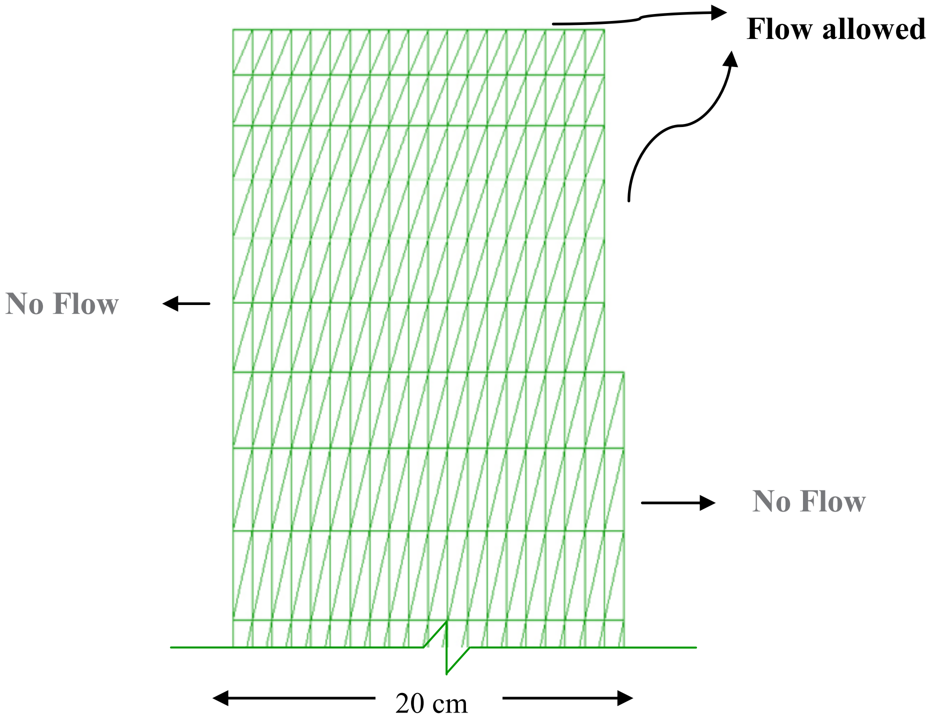

Figure 3: Geometry and boundary conditions of FEM used in the simulations of cracked soil

4 RESULTS COMPARISON: CRACKED/INTACT SOIL SURFACE

To show the influence of crack on the evaporation, the results from intact and cracked models are combined and compared in Figure 4.

It can be seen that the addition of the crack increased the evaporation from the first day and for the whole days of the simulations.

Crack was found to increase evaporation by 17% and 10% after 15 days and 30 days respectively.

The presence of crack exposes the deep soil and more evaporation can be expected in dry periods since the evaporation surface is increased. Cracks provide an excess of water loss mainly due to an increase in the hydraulic conductivity resulting in a higher evaporation rate.

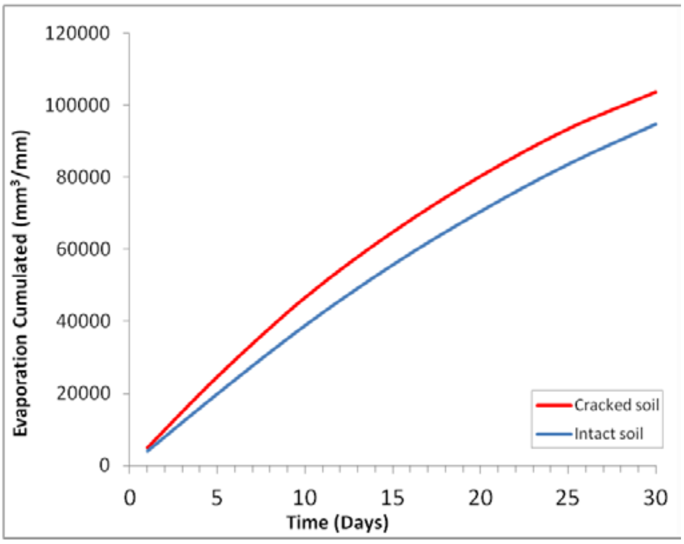

Figure 4: Evaporation pattern from intact and cracked surface

5 A simplified approach for cracked model

In this approach, a new finite element constitutive model, where we propose a new tool for modelling cracks in a simplified way is developed and discussed.

It was found from the previous study in this paper that, the surface of evaporation is the key parameter that controls the changes in the evaporation evolution and the cracking process. Hence, we suggest that, for a cracked soil, the water evaporates from a fictive length Leff with the same boundary conditions as the intact soil surface.

As the length Leff is larger than L intact soil and in order to reproduce the effect of cracks, Leff was estimated to be equal to Lintact soil multiplied by a parameter λ.

Numerical modelling to demonstrate the validity of the new methodology described herein was carried out. The results of the homogenized method subjected to desiccation conditions were compared to the previous model. The same soil model of 1m x 20 cm with a crack of (1cm x 5cm) is considered which corresponds to $\lambda = 1.25$ in the proposed model.

5.1 Validation of the proposed model

The results of non-cumulative evaporation using both models are shown in figure 5.

The graph show that the results from both approaches are very similar and that for all days of simulations.

The proposed approach was shown as an effective tool for modeling the effect of crack on soil performance especially when the geometry of the sample is difficult to reproduce.

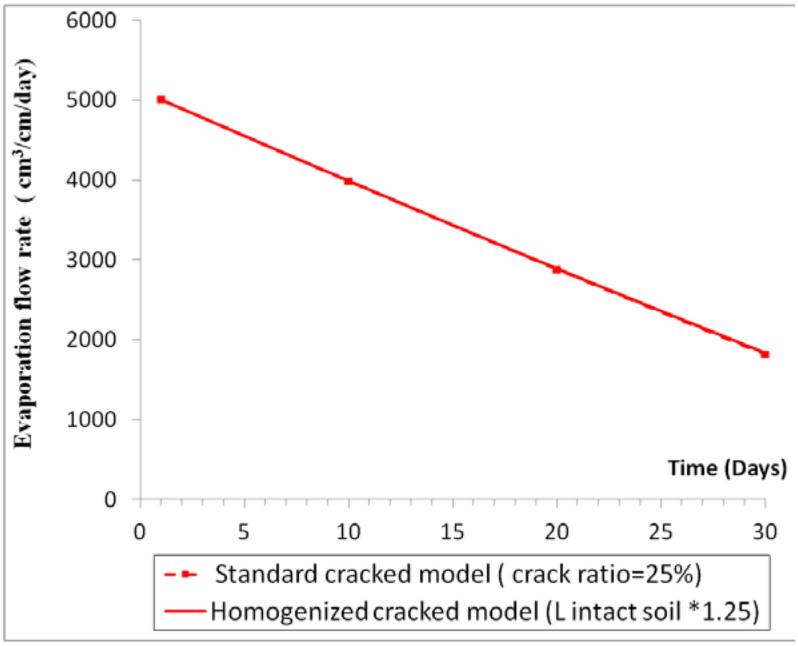

Figure 5: Evaporation flow pattern from both approaches

6 CONCLUSION

Desiccation cracking is a common phenomenon in clay materials, which can significantly affect the performance of soil. -In this study, the effect of soil cracks on evaporation was investigated. Two cases were studied: intact case and cracked case. Two finite element models for intact and cracked surface were created and evaporation was simulated using a multiphase numeric simulator. The model quantified the contribution of soil cracks on evaporation rates for a simulation of 30 days. Results were then compared with those of an intact soil. They show the important contribution of cracks in evaporation flux. In cracked soil, further loss of moisture from soil occurs as direct evaporation from the fronts of crack. Actually, the simulations that don't consider the presence of crack could severely underestimated evaporation flow.

A new approach to reproduce the impact of cracks on the soil behaviour in a simplified method was presented. Results from both models were shown and discussed; Remarkable agreement can be seen between the two models. The proposed model was shown to be able to reproduce the cracked soil behavior very well.

In further study, cracks should be taken in consideration when modelling soil-atmosphere interaction in dry periods.

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