SOIL DESICCATION CRACKING

DAVID A. ENCALADA*

*Universidad Politécnica de Cataluña
Campus Norte UPC, 08034 Barcelona, Spain
e-mail: david.encalada@estudiant.upc.edu

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Abstract. Environmental actions cause soil deterioration and affect infrastructure provoking economical damage. Desiccation cracking occurs due to water loss that causes shrinkage. Evaporation is the principal cause of water loss from the soil to the atmosphere. Digital image analysis is powerful tool to evaluate geometrical characteristics of crack pattern and cracking evolution. The geometrical properties of cracking may be used to compare with numerical simulations. There are several numerical approaches and strategies to simulate soil cracking. It is important to investigate the strength and weakness of different numerical methods to agree how to properly simulate cracking. In essence this document provides a general overview of water loss in soils, desiccation cracking and numerical approaches to simulate cracking.

1 INTRODUCTION

Soil surface interchanges moisture with the atmosphere. As this process takes place, drying/wetting cycles subject the soil mass to volume changes, also known as shrinkage and swelling. Shrinkage causes surface cracking. Swelling can close the cracks again. This process results in physical degradation or deterioration of soils due to environmental actions. The Figure 1 shows the soil-atmosphere interactions and the effect on pore water distribution. Evaporation reduces the water content at surface and upwards flux induces negative pore water pressure. Cracks initiate once internal tensile tresses exceed the soil tensile strength.

Cracking of soils results in the reduction of the overall strength due to creates zones of weakness. Another effect of desiccation cracks is the influences over the hydraulic properties of the ground. Cracks in the soil mass increases the infiltration rate and the permeability. During a rainfall, the rapid infiltration through the cracks can lead to elevate the pore water pressure and reduce the soil shear strength.

Desiccation cracking affects infrastructure resulting in economical damage. Desiccation cracks can have an important effect in slope stability. Figure 1 shows a shallow landslide

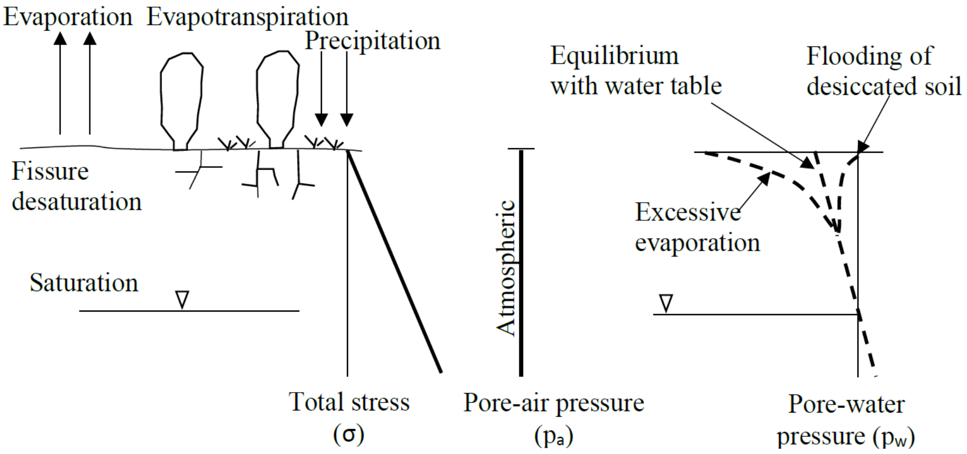


Figure 1: Total stress, pore-air pressure, and pore-water pressure distributions in unsaturated soil [4].

probably caused by soil desiccation cracks and seasonal fluctuations in water content [1]. Desiccation cracking have a significant impact on embankments [2, 3] and dams constructed from clay fills, and liners and covers for containment of solid or liquid wastes.

The water loss in soils by evaporation has been studied by agronomist, soil scientist and hydrologist, however, geotechnical engineers have paid less attention to this phenomena.

Soil cracking desiccation is a complex coupled thermo-hydro-mechanic process. However, the advances in computational procedures and numerical methods permits simulation of cracking formation and propagation during desiccation. It is important to know the advantages and drawbacks of each numerical method.

2 SOIL WATER EVAPORATION

Evaporation results in the water loss from the soil surface to the atmosphere. This phenomenon in a porous media involves the transfer of mass and energy including phase change, vapour difussion and liquid flow [5]. The evaporation rate depends on environmental conditions as temperature, relative humidity, wind speed and radiation, and intrinsic and transport soil properties as permeability, thermal conductivity and vapour diffusion.

Three stages occur that depend on the water content available as Figure 3a shows. Other investigations also recognise three stages, the stage 2 is known as a transition, as presents Figure 7b. The drying stages are:

1. Stage 1 or constant rate: External conditions control this stage [6, 5]. However, the soil properties control the duration of this stage [5]. Stage 1 happens at the beginning of evaporation when the soil wet and the supply of water to the surface is constant.

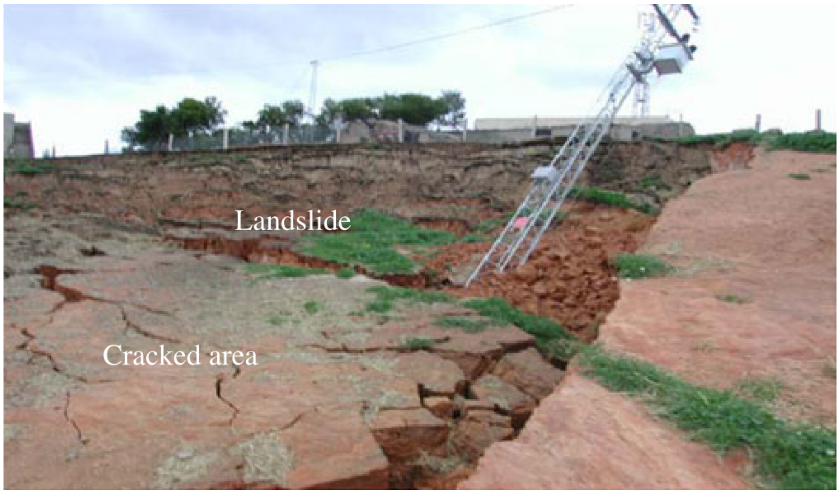


Figure 2: Damage of structures induce by desiccation cracks [1].

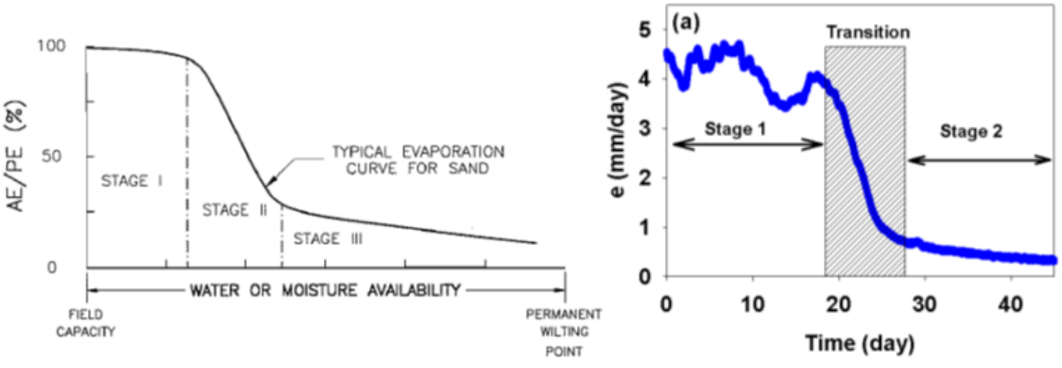
2. Stage 2 or falling: This stage starts when the liquid phase becomes discontinuous [7]. Hydraulic soil properties controls this stage [5].
3. Stage 3 or slow rate: When the surface is desiccated the water supply stops. The evaporation occurs below the surface, and the vapour is transported by diffusion through the dry surface. Diffusion dominates the evaporation rate in this stage [8, 7].

When the climate conditions are not steady, the drying curve can change. Others modifications in the curve are the effect in saline soils [9] and the effect of wind on the surface [10]. Wind on the surface produces a high evaporative demand that causes decreasing evaporation rate in the stage 1.

Soil water evaporation involves two domains. The atmosphere or free flux of air compound by gas phase. The other domain is the multiphase porous media. Usually, transport of water is modelled considering one domain (porous media) with a boundary condition at top. This single domain concept can use single liquid phase [11] or gas and liquid phases [12]. The most advanced model considers two domains concept [13]. However, it was developed to solve the hydro-thermal problem and not includes mechanical coupling.

3 CRACK PATTERN

Crack pattern is random in nature. Crack initiation is consequence of both flaws and stress concentration in the soil mass. In practice heterogeneities are random and difficult to predict. However, in some cases cracks can be predicted as they depend on the stress and strain field [14]. The water loss in soil mass causes negative water pressures (sution) to develop in the soil. Soil is compressed in all direction when suctions appers [14]. If the soil displacements are constrained the tensile stresses can reach the tensile strength and cause



(a) (b)

Figure 3: Evaporation stages in soils (a) Relation between actual evaporation and potential evaporation (AE/PE) [15]. (b) Stages of evaporation rate [7].

crack initiation. Tensile strength of soils depends on the water content. The desiccation cracks appear when the soil is almost saturated due to the low tensile strength at high moisture content [1]. This may explain that slurry clays cracks more than compacted clayey soil because soil gain tensile strength during compaction.

The study of geometrical structure of cracking pattern is important to understand the response to wetting and drying [16]. Cracks geometry and structure govern the hydraulic properties. Connectivity and continuity of crack networks relate the efficient of water infiltration and transport of solutes. Crack pattern also can indicate the conditions ,as the drying direction, and the homogeneity of the ground.

Crack network is generally highly irregular and difficult to measure with conventional and manual techniques. Today image analysis is a efficient and flexible tool to evaluate cracks pattern and morphology (see Figure 4). Some indicators like Crack Intensity Factor (CIF)[17] have been wisely employed in the past years. The principal geometrical properties of crack pattern determined by image processing are [18]:

1. Number of nodes (Figure 4a) per unit area and number of crack segments per unit area.

2. Number of cells per unit area and average area of cells (Figure 4b).

3. Average width and length of cracks (Figure 4c) and crack length per unit area or crack density.

4. Crack intensity factor (CIF) which is the ratio between the crack area and the total surface area. This is an indicator of the extent of superficial cracking.

(a) (b) (c)

Figure 4: Digital image of desiccated soil (a) Instersctions of cracks. (b) Area of cell. (c) Witdh and leght of crack.

4 NUMERICAL MODELLING

The numerical modelling of desiccation cracking has progressed during the last few decades. Generally, numerical modelling is classified in two categories, that is continuum and discontinuum numerical aproaches. Discontinuum approach is based on the discrete element method (DEM) which track the motion of large number of grains. This method simulates granular materials; however, using inter-particle contact law [19]. This approach seems to be a promising to model desiccation cracking; nevertheless, it is unable to predict multi-physical processes as evaporation and heat and mass transport.

Another to simulate cracking is using continuum approach. The most common similations are based on finite element method (FEM)[1, 20] and finite difference method (FDM)[21, 22]. The principal drawback of FEM and FDM is the difficulty to model crack initiation and propagation. One of the strategies to simulate cracking with continuum approach involves to employ interfaces. Usually vertical interfaces are located at potential cracks as shows Figure 5. Nevertheless, interface elements increase the computational cost. Other strategy is the use of dynamic evaporative boundary condition (see Figure 5). As cracks develop, the area exposed increases associated with the crack walls. Dynamic evoporative boundary captures the transient nature of exposed surface. However, crack walls are protected from atmospheric turbulence taking place a lower vapour gradient [22] and this probably is the reason that some investigations [20] do not include dynamic evaporative boundaries.

A different continuum approach is meshfree methods like smoothed particle hydrodynamics (SPH) method. In the SPH method the continuum equations are solve at material points. Bui et al. [23] use SPH to simulate desiccation cracks in soil and employ a simple

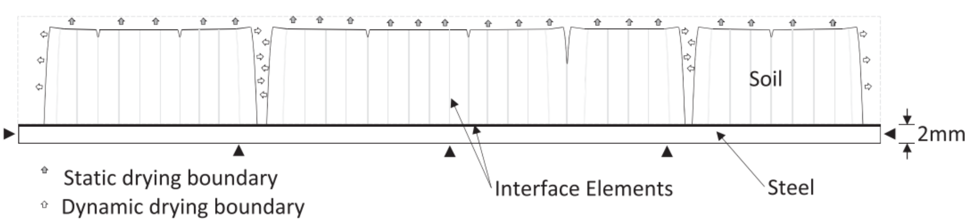


Figure 5: Total stress, pore-air pressure, and pore-water pressure distributions in unsaturated soil [22].

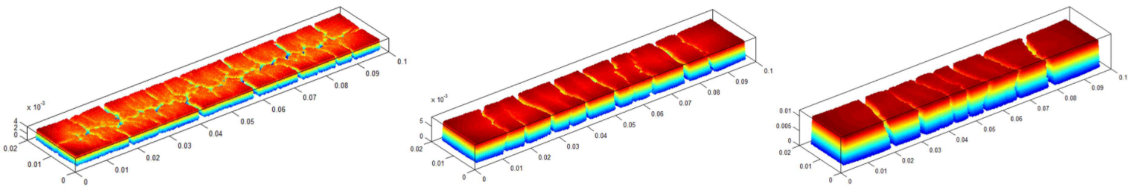


Figure 6: Cracking modeling using mesh-free SPH method [23].

damage constitutive model. One advantage of SPH method is that no requires interface elements to simulate cracking reducing the computational cost. The simulations with SPH method showed good qualitative reproduction of experimental observations as shows Figure 6. However, the study needs a quantity comparison of geometrical properties with the experiments. The SPH method is promising and need further progress in constitutive models and algorithm [23].

5 CONCLUSIONS AND FUTURE WORK

5.1 CONCLUSIONS

Evaporation is the principal cause of water loss. Geotechnical engineering have paid less attention to this phenomenon. This may be one of the reason for the lack evaporation models in water transport that incorporate mechanical coupling.

Image analysis has become an important tool to evaluate cracking desiccation in the few last years. Experimental cracking evolution and crack geometrical structure is useful to compare with numerical models.

Crack pattern is indicator of constraint and drying conditions that the soil is subjected. Boundary conditions are important to characterize cracking initiation trough numerical modelling.

There is not a consensus on how to carry on desiccation cracking simulations in soils due to its complexity. The SPH method is a promising alternative to FEM and FDM.

5.2 FUTURE WORK

Incorporate mechanical coupling to two domain approach.

Digital image evaluates the soil surface. Future investigations need to incorporate additional tools to digital image to evaluate depth cracking.

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