The paper was published in the proceedings of the 11th Australia New Zealand Conference on Geomechanics and was edited by Prof. Guillermo Narsilio, Prof. Arul Arulrajah and Prof. Jayantha Kodikara. The conference was held in Melbourne, Australia, 15-18 July 2012.

Evaporation in soils: Electrical conductance and optical observation

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ABSTRACT

The evaporation in soils naturally occurs and its characteristics have significant implications on geotechnical issues in unsaturated soils and relevant geostructures, fluid flows in hydrology, and agricultures. In particular, the existence of wetting front and the unsaturated zone plays an important role in slope stability in soils. This study examines the evolution of evaporation zone using optical observation in conjunction with the measurement of electrical resistance. The saturated sands in a transparent chamber that is placed on the balance are subjected to drying. The front view of drying phenomena is captured and the electrical resistance is obtained along the height using two electrodes system with time. Results show that the wetting front identified in the images does not necessarily coincide with the low value of electrical conductance, highlighting the presence of unsaturated regions and significance of long range connectivity of water phase that determine the conductance values.

Keywords: evaporation, electrical conductance, images, unsaturated zone, wetting front

1 INTRODUCTION

The water content is important because it determines the degree of saturation and the hydraulic conductivity of soils. Evaporation of water from soils and other processes control the amount of free water present in soils. Especially, evaporation from soils is an important phenomenon due to the fact that is affecting the soils environmental conditions, biological exchanges and engineering applications. An exact and scientific knowledge of the rate of evaporation at the interface between soils and atmosphere is required to assess the water content of the soils cover during drying periods (Yanful and Choo 1997). Since the rate of evaporation varies with soil type and climatic or environmental conditions, it is important to know this quantity and its impact on the soils. Several authors have shown that the mode of mass transfer to an evaporating surface is an important factor shaping evaporation patterns from porous media (Peck et al. 1971, Schlunder 1988, Van Brakel 1980). However, this quantity of evaporative loss of water is not easily measured and is usually estimated from the potential evaporation. The term potential evaporation is introduced as a climatic index (Thornthwaite 1948). Such methods of evaluating evaporation are appropriate for open water or fully saturated soil surfaces only(Wilson et al. 1994). The evaporation rates during early stages are limited rather by atmospheric condition and typically high and relatively constant due to liquid flow supplied through hydraulic pathways connecting the receding drying front and the evaporating surface (Shokri et al. 2008). This study presents the experimental observation using optical images and corresponding measurement of electrical conductance with time.

2 EXPERIMENTAL STUDY

The cell whose size is 150 mm * 20 mm * 220 mm (width * depth * height) made of transparent acrylic box is equipped with 10 electrodes at each side. The Ottawa 20-30 sands are placed with the cell by water pluviation to achieve 100% saturation. The initial void ratio of sample is 0.367. The cell is set on the scale to measure the weight, which is converted to the degree of saturation with time.

2.1 Electrical conductance measurement

The electrical conductance data are measured every 1 second. Total 20 data points are obtained from each electrode and 580 seconds pass after the measurements of 10 electrodes data. Thus, one stage of measurement lasts 780 seconds and the spacing between each electrode is 20 mm. The sequential data acquisition is controlled by Matrix Switch Board (PXI-2503, National Instruments) on the Data Acquisition Module (PXIe-8133, National Instruments). Electrodes are wired to the Matrix Switch Board which is connected with LCR Meter (LCR-819, GW-InStek). The measured electrical resistance values with time are saved for the analysis. The total weight of the cell is monitored every 1 second to compute the change of degree of saturation.

2.2 Optical observation

The 2-dimensional images of the acrylic box containing the sample are captured every 10 minutes. The digital camera (Powershot G9, Canon) is set by time interval shooting mode and also connected to Data Acquisition Module to save successive images. To minimize the illumination effect from the changes of light condition, the entire system is placed within the isolated space where all light is blocked. Figure 1 shows the experimental configuration

(a) The system of the evaporation test (b) The schematic diagram of the test

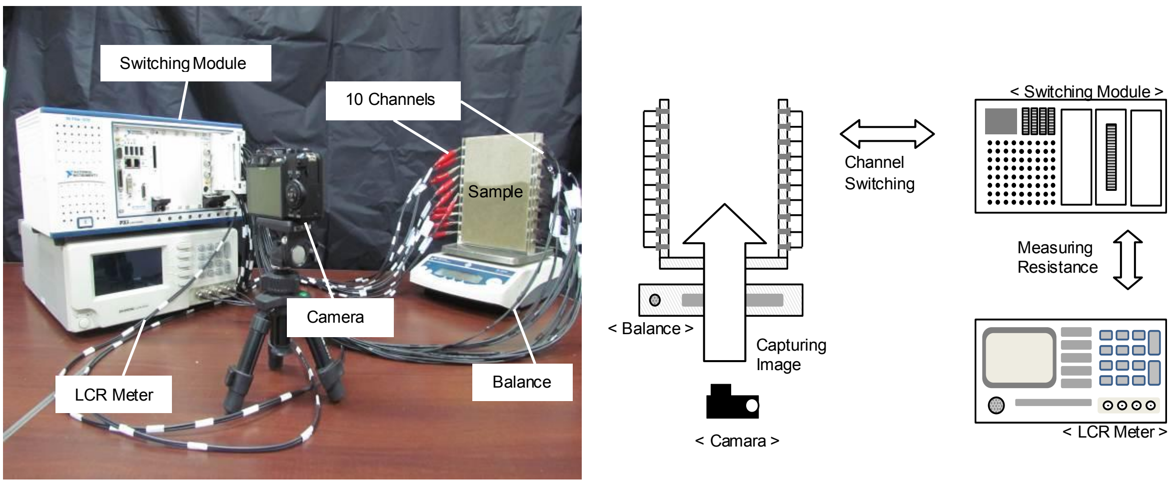

Figure 1. Experimental configuration

During the evaporation, the temperature remains from 30-35 degree.

3 RESULTS

3.1 Degree of saturation with time

Figure 2 shows that the degree of saturation of sample which is initially fully saturated is converted from the total weight and tends to decrease with time. The degree of saturation is used as an indicator for identifying varying the evaporation rates of sample though the soils are partially saturated. The evaporation rates of sample are quite constant (e.g., linear decrease of degree of saturation) followed by slower rate after ~ 150,000 seconds. Note that this time corresponds to ~ 1/3 of evaporation in height (e.g., ~ 70 in depth of the surface). The evaporation is mainly controlled by the temperature and relative humidity in general. Yet, the bi-linear decrement of degree of saturation with time is pronounced presumably because of the capillary effect. At early stage, the evaporation rates are relatively high and the loss of evaporative water is activated easily due to the capillary flow from drying front to evaporating surface. The following reduction of the evaporation rates is attributed to that the vertical capillary forces between the sand particles are no longer able to support evaporation of water enough as the drying front advances along the height.

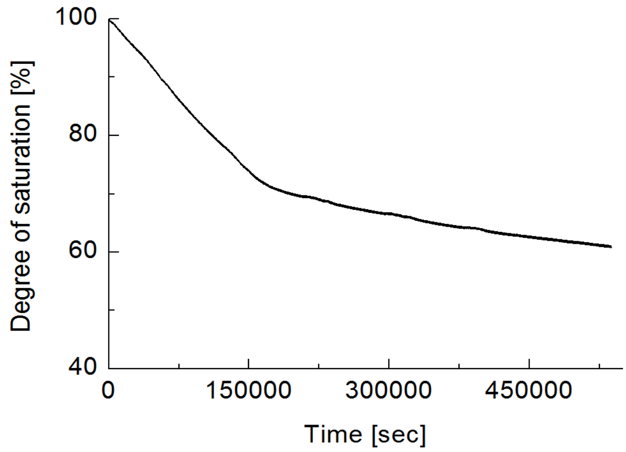

Figure 2. Degree of saturation with time

3.2 Electrical conductance and optical images

The electrical conductance and optical images during evaporation are shown in Figure 3. The measured electrical resistance is converted to the conductance to highlight the initial values. Note the y-axis in Figure 3 is in logarithmic scale. The values of the electrical conductance decrease with time and tend to converge to the asymptotic value of conductance, regardless of the channel height. The time when the reduction of the electrical conductance begins increases as the height of the channel decreases. Data in Ch1 follows the exponential decay as it is directly exposed to the atmosphere. Yet, the following channel data follows the discrete decrement followed by the constant and high value of conductance. As soon as the partially wetting zone passes the given electrode, the conductance value sharply drops (i.e., channel 1 at $t=0.25\cdot10^5$ s) whereas the decreasing rate is not necessarily consistent. The visual observation hints the location of wetting front coincides with the measurement plane (i.e., channel 4 at $t=1.75\cdot10^5$ s), the conductance does not drop much. It is attributed to the averaging effect of conductance measurement and long range connectivity of water phase. For a given measurement plane, the conductance drops a nominal value when the water phase from one electrode to another loses its connectivity through the pore space. Thus, the degree of saturation does not necessarily have to be close to zero to have a low conductance. It highlights that the identification of wetting front and the range of unsaturated zone requires careful analyses. Furthermore, the discrete drop of conductance supports the long range connectivity assuming that the changes in degree of saturation should not be discrete in nature. Also, the natural soil has a negative capillary pressure so that there should be a certain range of partially wetting zone, which is hard to be identified due to the long range connectivity mechanism. The wetting front does not evolve horizontally due to the varying capillary force.

Figure 4 shows that the time when the drying front advances during evaporation dramatically increases with depth. Note that the time for each channel is selected when the electrical conductance begins to drop followed by constant values. It is suggested that this may be attributed to the experimental configuration where the space is closed not to fully allow the ventilation, which may causes the high value of humidity whereas the nonlinear evolution of evaporation rates seems acceptable as the evaporation path becomes complicated throughout the network of pore space.

The Evolution of electrical conductance with time along the height is illustrated in Figure 5. The x-axis denotes the duration in time and y-axis indicates the measurement height. The drying region is expressed by blue colour where the low value of conductance is manifest. The transitional region between drying zone and wetting zone should exist where the identification of unsaturated zone is not clearly captured due to the above stated mechanism of long range connectivity. Assuming that the contact angle is ~ 10 degrees and average pore diameter is 1/6 of mean diameter (D_{50}=0.5mm), the height of capillary rise is approximately 35 mm. That is, the height of partially wetting zone should be at least 1.5 times of electrode spacing whereas the conductance measurement does not indicate the gradual transition covering this range.

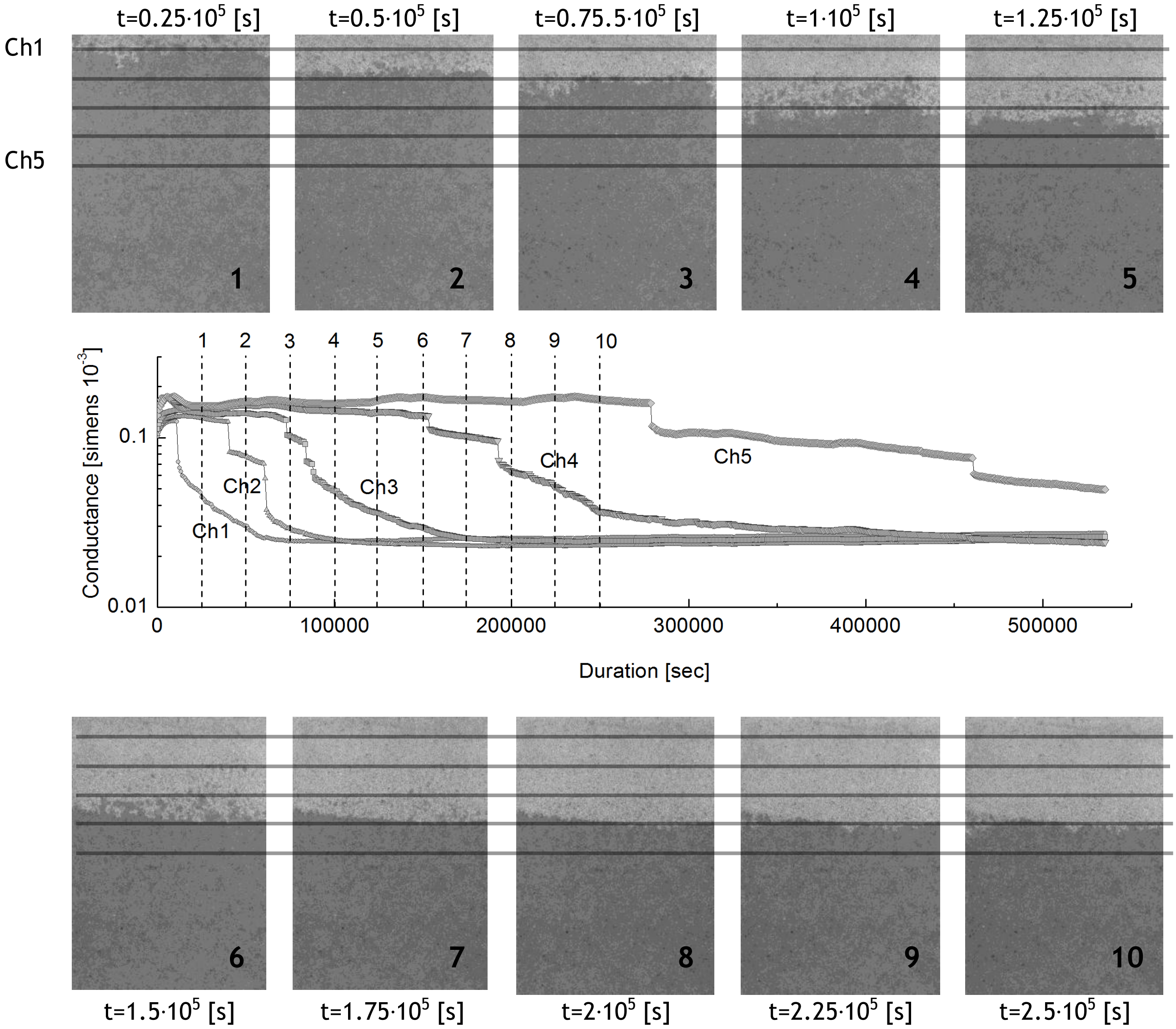

Figure 3. Electrical conductance and optical images during evaporation

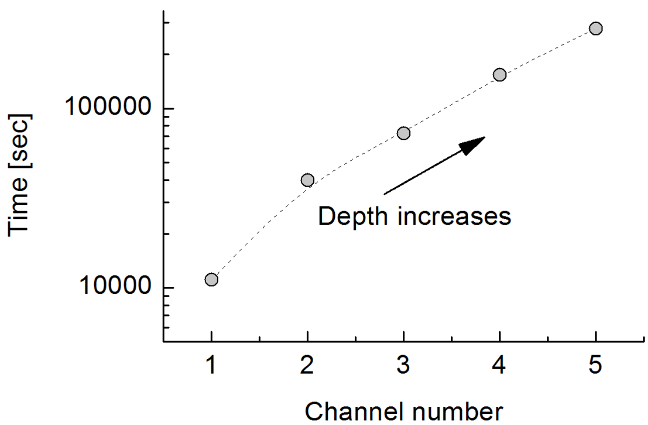

Figure 4. Conductance decrement time with channel

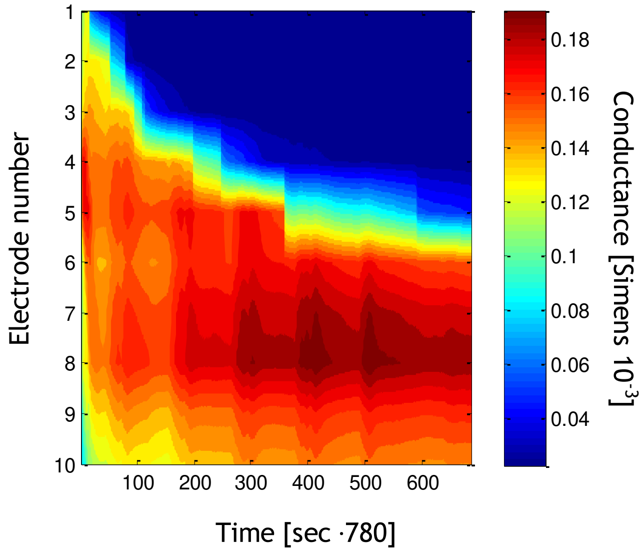

Figure 5. Evolution of electrical conductance with time along the height

4 CONCLUSIONS

The image acquisition and measurement of electrical conductance during evaporation in soils with time are experimentally explored. The evolution of evaporation rates identifies two stages; 1) early stage: The evaporation rates are relatively high and constant. Evaporation of water is activated easily due to being supported by capillary flow, and 2) second stage: The reduction of the evaporation rates is caused that the vertical capillary forces are not enough to support evaporation of water as the drying front advances. The conductance measurement follows the discontinuous lines along the depth due to the long range connectivity. It implies that the degree of saturation for a given measurement plane is not necessarily represented by the conductance. The existence of partially wetting zone between wetting and drying regions makes the interpretation of conductance results challenging whereas the identification of this zone is critical to further examine the geotechnical stability because it often triggers the failure. The wetting front appears undulated due to the varying capillary pressure, which in turn requires the 2D analysis as shown in this study rather than 1D approach. The interpretation of conductance results requires careful considerations because the wetting and drying front identified by visual observation does not fully coincide with the nominal value of conductance. In other words, soils can exist as partially saturated above the measurement plane where the conductance sharply drops.

5 ACKNOWLEDGEMENTS

This research is supported by the basic science research program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (No. 2011-0005593 and No. 2011-0022883).

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