

3 DIMENSION REAL TIME IMAGES OF RAINFALL INFILTRATION INTO UNSATURATED SOIL SLOPE

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ABSTRACT: Failure of soil slope is mainly due to infiltration of rainfall. The complexity of rainwater path infiltrate soil slope can be predicted using commercial software, and volumetric moisture content at the infiltrated slope area can be measured by Time-Domain-Reflectometry (TDR). Prediction of rainwater path is based on parameters obtained by laboratory works, and volumetric water content using TDR can only available at the point of insertion. In this research, an innovative method called Electrical Capacitance Volume Tomography (ECVT) was used in geotechnical engineering application in determining the real-time imaging of rainwater infiltration into unsaturated soil slope. This method also achieves permittivity value through the experiments and converted to volumetric water content using equation. A soil sample obtained from slope failure around National Defense University of Malaysia (NDUM) campus during monsoon season was used in the research. The results revealed real-time 3 dimensions (3-D) images of rainwater infiltrated into soil slope were produced through image reconstruction method of ECVT. Volumetric water content was also achieved using permittivity value attained by ECVT result. Images which permittivity indicated the infiltration of rainwater through soil slope were clearly shown in the results. This innovative technology is expected to improve the understanding of soil slope behavior especially in for rainfall infiltration that relates to soil stability.

Keywords: Rainfall, Infiltration, Soil slope, ECVT.

1. INTRODUCTION

Slope instability in a tropical country such as Malaysia, normally triggered by the high seasonal rainfall event. [1], [2], [8]. This main reason is also caused by other activities such as construction development of hillside, and geological factors. As rainfall event started and for sometimes, infiltrate into unsaturated soil slope, and increase the negative pore pressure above groundwater table and moisture content. In the monsoon season, soil slope will vigorously subject to high intensity and long duration of rainfall, and this cause rainfall-induced slope failure. [6].

The complexity of rainfall infiltration event into soil slope is due to non-linear of soil water characteristic and soil permeability [12]. The study of main parameters such as initial moisture content, soil water retention ability, soil porosity and others is vital for the understanding of soil behavior when subjected to various rainfall intensity and duration [3], [5].

Current studies on the rainfall-induced involve laboratory work such as using soil slope flume equipped with apparatus to measure the parameters. The images of rainfall infiltration showing the real-time infiltration are not available since all simulations were done by software. The prediction of soil moisture content was determined by

laboratory works and previous data to simulate rainfall infiltration into soil slope event.

This study is to introduce ECVT as an innovative technology used in geotechnical engineering research. ECVT is 3-dimensional real-time imaging system considered as “the most promising technique for dynamic flow imaging, which has a relatively high temporal resolution, up to few milliseconds, with a reliable spatial resolution [4].

The use of tomography technique is widely known for medical field purposes such as Magnetic resonance imaging (MRI), X-ray microtomography, Optical tomography, resistive tomography, Acoustic tomography, Positron-emission tomography (PET), Capacitance tomography, and others [11].

The principle of ECVT is based on forward and inverse problem electrical properties measurement [10].

Collection of capacitance data from electrodes to the data acquisition system is a forward problem, which the electrodes act as sensors are located at the perimeter of ECVT wall vessel. Next, the inverse problem will retrieve the capacitance data. Consequently, reconstructing the images is obtained through the measured data capacitance.

Earlier studies using ECVT are including gas distributor of the single gas distributor of paraffin

liquid, air, and glass beads as flow media [9] to ensure the moving object is detected by ECVT sensors and produce real-time images. Research by [7] shows the successfully capturing water seeping in each layer and producing 3D real images using ECVT.

As mentioned earlier, rainfall-induced soil slope failure mechanism was complex and obtaining related parameters and images in this area currently were using previous laboratory studies and prediction were attained from software.

Therefore, the objective of this study is to capture 3 dimensions real-time imaging along the experiment, and the capacitance data is then converted to evaluate volumetric water content for soil slope sample. Other than that the effect of rainfall intensity and duration to the image developed by ECVT and volumetric moisture content is also captured during the infiltration process.

2. MATERIALS AND METHOD

Samples for the purpose of the experiment were obtained from a site (Cadet Mess) around NDUM campus. These two sites experienced soil slope failure during monsoon season as high intensity and long duration of rainfall.

2.1 Basic Soil Properties

Basic soil properties were obtained from the laboratory for moisture content, porosity, bulk density and soil classification.

2.2 Experiment Set Up

The experiments were conducted in the laboratory using flume apparatus and other apparatus were attached such as water supply system, tilted flume with ECVT sensors and water effluent system.

2.2.1 Water Supply system

Water pump to simulate rainfall were used in this experiment. Water flow regulator to simulate rainfall is manufactured by Cole-Parmer, model 07554-80 Masterflex L/S economy with the variable-speed console and the speed varies from 1 to 10.

2.2.2 Tilted Flume Apparatus

Tilted flume as soil slope model was used and ECVT sensors system was attached to it. ECVT system is including the 32 channel sensors and

results were obtained through data requisition system (DAS) by personal computers.

Through laboratory experiment, DAS will capture the real-time images using MATLAB software. Schematic diagram of tilted flume apparatus using ECVT system and sizes is shown in Fig 1 (a) and (b) respectively.

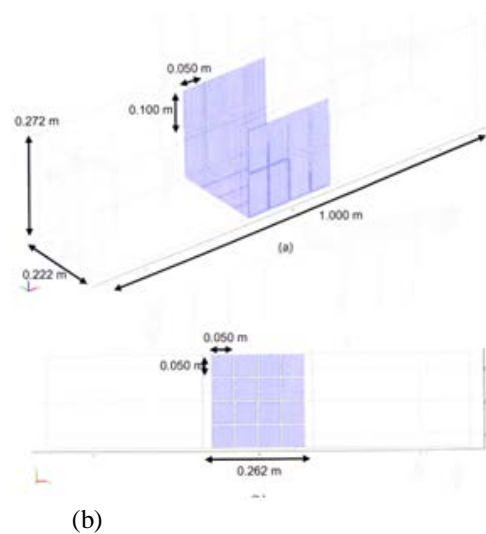
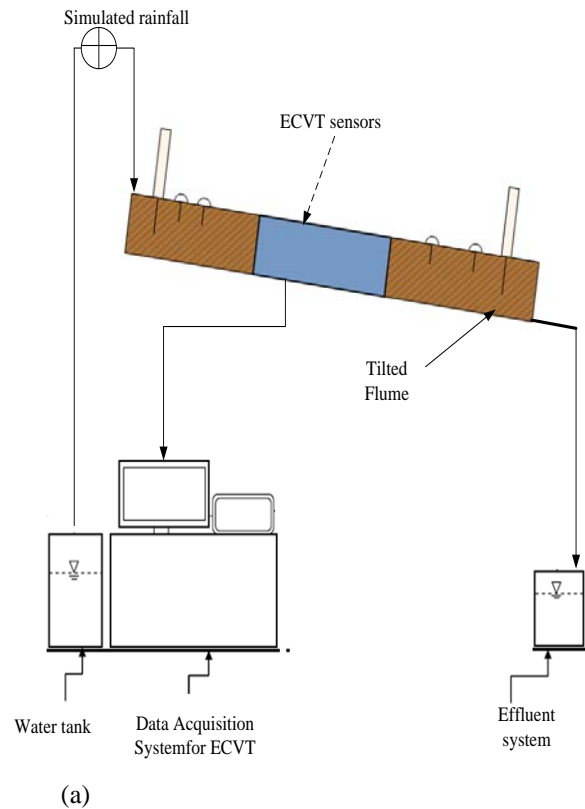


Figure 1: Schematic diagram of (a) tilted flume apparatus using ECVT system (b) sensors and sizes.

2.2.3 Experiment Schedule

Rainfall infiltration tests were conducted with the intensity of 0.2 mL/s flow rate, and duration of 30 and 60 minutes for all three samples. Schedule of experiments is shown in Table 1.

2.2.4 Images Reconstruction

In this research, 3 D real-time images were obtained through images reconstruction after experiments were done using MATLAB software. The different script to run the software was used and all saved file will be retrieved and went through the process.

Table 1: Experiments schedule

Soil Sample	Experiment no	Rainfall duration (second)	Drying duration (second)
CADET MESS	Calibration		300
	(Air)		
	Calibration (Soil)		300
	1	1800	1800
	2	5400	5400

2.2.5 Permittivity and Volumetric Moisture Content

Other than real-time images, permittivity and volumetric water content were also obtained in this study. Permittivity data were retrieved from the data and converted to determine volumetric water content proposed by [7]. It is noted that the relative permittivity for air, water, residual soil, and saturated soil are 1, 80, 2-4, and 23-28 respectively. The equation is as follows:

Normalized permittivity,

$$\epsilon_N = \frac{\epsilon - \epsilon_{res}}{\epsilon_{sat} - \epsilon_{res}} \quad (1)$$

Volumetric water content,

$$\theta = \eta \left(\frac{\epsilon - \epsilon_{res}}{\epsilon_{sat} - \epsilon_{res}} \right)^{0.5} \quad (2)$$

where ϵ_N , ϵ , ϵ_{res} , and ϵ_{sat} are normalized, relative, residual, saturated permittivity respectively, and η is the porosity.

3. RESULT AND DISCUSSION

3.1 ECVT 3 D Images

3 D real-time images for all samples were obtained as in Table 3. Selection of images was done through observation to present the significant changes to the images.

The result for the real-time images shows the detection of rainfall infiltration into the soil but there are many images need to be selected in order to show the changes.

In this experiment, there are 1800 and 5400 images for experiment 1 and 2 respectively. It is noted that x frame in this experiment refers to real-time images at the x second.

Results shown in Table 3 shows the 3 D Images of the sample for axis XY, YZ and XZ for slices of 1, 9, 17, and 25, at frame 1, 1000, 3000, and 5000. Each frame has 32 slice images (for 32 channel sensors). Images show the variation of color indication for permittivity from dark blue (lowest permittivity value), light blue, yellow, orange to red (highest permittivity value).

The results show that water infiltration is clearly indicated through the images but the only small variation is shown. This is believed due to the lower intensity and short duration rainfall applied during the experiment.

3.2 Permittivity and Volumetric Moisture Content (ECVT)

After images were obtained, the permittivity data were retrieved and converted to volumetric water content. A sample of average permittivity data and volumetric moisture content is shown in Figure 2 (a) and (b) for the frame of 5000 respectively.

The result of permittivity in Figure 2(a) indicated that the average volumetric moisture content of all frames during the experiment. The changes and increasing of permittivity during shows that the increase of moisture content throughout the experiment.

This result is shown by a sample value shown in Figure 2(b) which all 32 slices. The success of using equation by [7] is observed in this experiment.

4. CONCLUSION

This research study is regarding the using of ECVT system to detect rainfall infiltration into soil slope. Through previous studies in the

geotechnical engineering field, moisture content can be obtained through this system but only small-scale experiments were done. This experiment using indicated rainfall intensity and duration of wetting (rainfall) and drying (after rainfall) clearly shown the images of rainfall infiltration. The result of permittivity values also shown the changes of volumetric moisture content and proved that ECVT is appropriate to use to observe and study in soil slope rainfall infiltration. On the other hand, the small variation and changes in the 3D images indicate that the rainfall intensity may be too small. Therefore the author would like to suggest further experiments with higher rainfall intensity and longer rainfall duration for future.

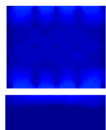
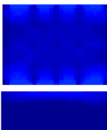
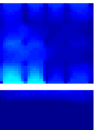
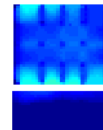
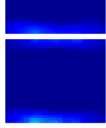


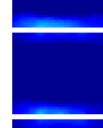
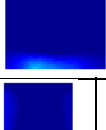
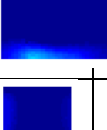
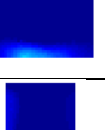
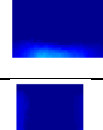
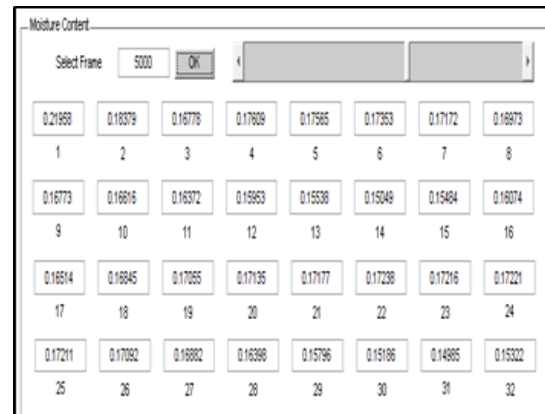
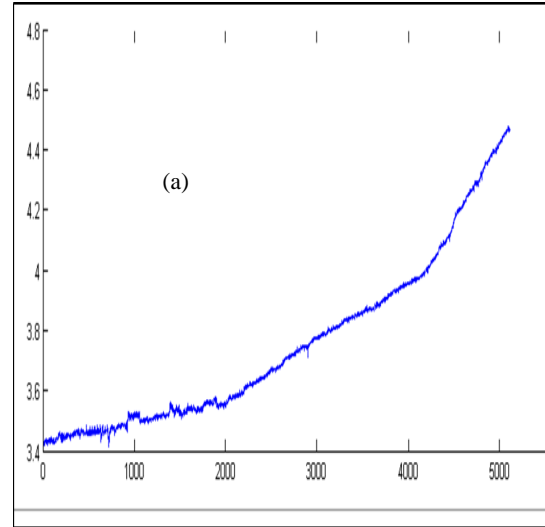
Frame	1	1000	3000	5000
XY AXIS				
YZ AXIS				
XZ AXIS				

Table 3: 3 D Images of the sample for axis XY, YZ and XZ for slices (a) 1 (b) 9 (c) 17 and (d) 25.



(b)

Figure 2: (a) Graph of average permittivity value and (b) average moisture content for each slice for frame 500.

5. ACKNOWLEDGEMENTS

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