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LABORATORY INVESTIGATION OF DRAINAGE CELL AS TRANSPORT LAYER IN RESIDUAL SOILS

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Abstract

Transport layer or unsaturated drainage layer is an alternative measure often employed to improve the performance of a capillary barrier system. A capillary barrier is an earthen cover used to prevent rainfall-induced slope failure. In this study, potential of using drainage cell system as transport layer is exploited using laboratory experimental methods. The drainage cell was sandwiched between grade V and grade VI soils in a two-dimensional laboratory slope model to act as transport layer. Coarse particles of gravel were compacted within the drainage cell to facilitate capillary break development at the interface. Each of grade V and grade VI soil was mixed with water content identical to residual water content determined from the soil water characteristic curves (SWCC) of each soil to enable simulation of their initial condition. Both soils are then compacted in the slope model to their dry densities. The whole set up was subjected to three rainfall intensities of 1.0586 x 10^{-5} m/s, 1.2014 x 10^{-6} m/s and 3.7337 x 10^{-7} m/s for 2 hour, 24 hour and 7 day, respectively. These rainfall intensities were determined from Intensity-Duration-Frequency (IDF) curve and were applied through a rainfall simulator which is part of the laboratory set up. The results shows that the transport layer formed with drainage cell was capable of producing capillary break and impedes percolation of the infiltrating water into the lower grade V soil layer. The accumulated water was later drained laterally above the interface of grade VI soil and drainage cell transport layer towards the toe of the slope model. In an event that the infiltrating water percolates the drainage cell transport layer due to longer rainfall duration, the drainage cell provides a definite direction through which the infiltrating water flow and diverted laterally. It was found that the modified capillary barrier with drainage cell transport layer performed much better than the conventional capillary barrier system.

Keywords: Drainage cell, transport layer, capillary barrier, residual soil

1.0 INTRODUCTION

Rainfall-induced landslide is a persistent natural disaster that occurs frequently in residual soil slope mainly due to intense or prolonged rainfall events [1-3]. Gavin and Xue [4] have shown that these types failure usually occurs during or shortly after rainfall event. The infiltrating water increases the pore water pressure thereby reducing matric suction from the unsaturated residual soil which invariably reduces the additional shear strength provided by the matric suction along the potential slip surface and trigger rainfall-induced slope failure in the unsaturated residual soil slope.

A capillary barrier system is used as preventive measure to minimize infiltration of rainwater into unsaturated residual soil [2, 5-7]. It is a system of soil consisting of fine-grained soil layer overlying a coarse-grained soil layer [8-10]. The variation in the soil particles between the two soil layers produce a contrast in hydraulic properties which forms a hydraulic impedance that limits downward movement of infiltrating water [11]. Hence, the infiltrated water into the system is stored in the fine-grained soil layer by capillary forces and is ultimately removed by evaporation, evapotranspiration, breakthrough or by lateral drainage through the soil slope [12]. The infiltrated water can only percolates the lower coarse-grained soil layer when the matric suction at the surface of the coarser soil layer decreases to a value close to its water entry value determined from SWCC [12].

The major setback of using capillary barrier system, especially the natural one to avert rainfall infiltration into unsaturated residual soil slope is the breakthrough occurrence (i.e. percolation of water into the lower coarse-grained soil layer) particularly during monsoon season. During monsoon season, the amount of infiltrating water is often greater than the storage capacity of the upper fine-grained soil layer and can results in breakthrough occurrence.

Therefore, the primary objective of this paper is to harness the possibility of using a transport layer to improve the performance of a capillary barrier system by diverting the infiltrating water to prevent breakthrough occurrence. The study was conducted with laboratory slope model. The natural capillary barrier effect that exist in tropical residual soil mantle due to weathering process was simulated in the laboratory and a transport layer formed with drainage cell system was used to divert the infiltrating water towards the toe of the slope model. The complete set up was subjected to three rainfall patterns and the variation of pore water pressure at the interface of the slope model due to each rainfall pattern were used and explained the effectiveness of the transport layer.

2.0 MATERIAL AND METHODS

The methodology used in this study is divided into two phases. In the first phase of the work, preliminary laboratory testing were performed and determined the relevant soil properties, while the second phase involved the laboratory modelling of the transport layer using a laboratory slope model.

Two types of soils (i.e. grade V and grade VI soils) are used in this study. These soils are collected from a particular slope located in Universiti Teknologi Malaysia, Johor Bahru campus. The relevant soil properties determined in the preliminary testing include the particle size distribution, atterberg limits and specific gravity of the soils. These tests were conducted based on the procedure outlined in BS 1337: part 2: 1990 [13]. Based on these tests the grade V and grade VI soils are classified as silty gravel and sandy silt, respectively. The saturated coefficients of permeability (k_{sat}) of the soils were determined using constant head and falling head methods. The constant head test was performed in accordance with the procedure described in BS 1337: part 5: 1990 [12] while the falling head test was performed using procedure outlined by Head and Epps [14]. The pressure plate test was also performed and determined the SWCCs of the soils using prescribed method in ASTM: D6836:2008 [15]. Using the determined SWCCs and k_{sat}, the unsaturated coefficient of permeability of the soils were predicted using van Genutchen method [16]. Using the hydraulic conductivity curves the breakthrough suction was determined as matric suction where the hydraulic conductivity of the soils intersects [5, 8, 17]. The values of these breakthrough suctions are 5 kPa and 1.5 kPa for sandy silt and silty gravel and sandy silt and transport layer, respectively. The particle size distribution curve, SWCC and hydraulic conductivity functions are presented in Figures 1, 2 and 3, respectively, while the summary of the test results are presented in Table 1.

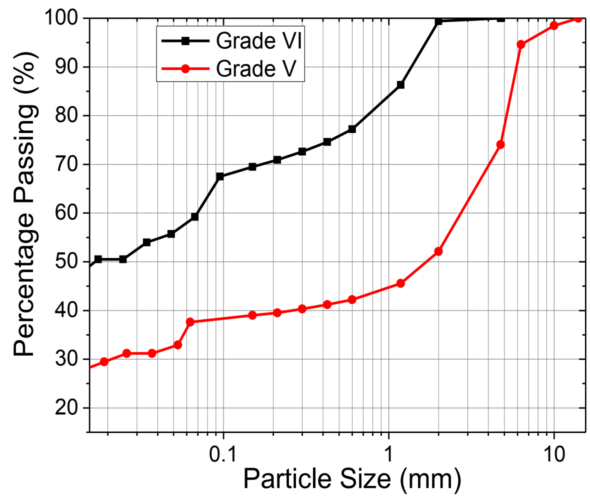

Figure 1 Particle Size Distribution Curves of the soil

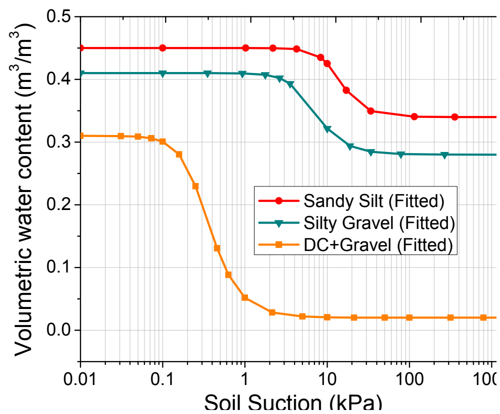

Figure 2 Soil Water Characteristic Curves

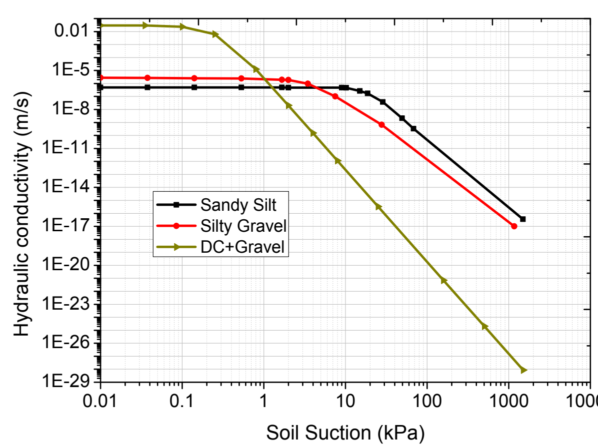

Figure 3 Hydraulic conductivity functions

Table 1 Summary of the soil properties

Property	Sandy silt	Silty gravel
Moisture content (%)	28	26
Liquid limit (%)	78	65
Plastic limit (%)	35	46
Specific gravity	2.64	2.66
Coefficient of permeability, k_{sat} (m/s)	5.89×10^{-7}	1.24×10^{-6}
Dry density, ρ_d (Mg/m^3)	1.38	1.26

The second phase of the methodology involved the laboratory experiment using laboratory slope model. The two dimensional laboratory slope model is of 2.0 m length, 1.10 m height and 0.10 m width and is inclined at an angle of 18° to the horizontal floor. The slope model was made from acrylic sheets and steel frames. Several holes were perforated at one side of the acrylic sheet for the installation of tensiometers. Figure 4 shows a schematic diagram of the slope model.

The soil samples were mixed with their respective residual water content to achieve target matric suction in the soils. The prepared samples were spread in the slope model and compacted to their dry densities in layers. A 300 mm layer of grade V soil was placed as bottom layer then a drainage cell (shown in Figure 5) is placed as the transport layer with gravel particles compacted inside its holes. Finally, a 300 mm layer of grade VI residual soil was placed above the transport layer. Series of tensiometers were installed in the slope model to measure soil suction while the test is performed. These tensiometers are connected to a data logger for continuous recording of the soil suction data as the test progress. The whole set up was subjected to three rainfall patterns through a rainfall simulator which is part of the laboratory set up. The rainfall intensities were determined from IDF curve of Johor Bahru, Malaysia which is shown in Figure 6.

The described procedure for preparing the soil samples was repeated for each of the three rainfall intensities and a total of six experiments were conducted. In the first three series of experiments; no transport layer was considered and they served as control for comparison purposes, while a drainage cell transport layer was considered in the remaining three experiments.

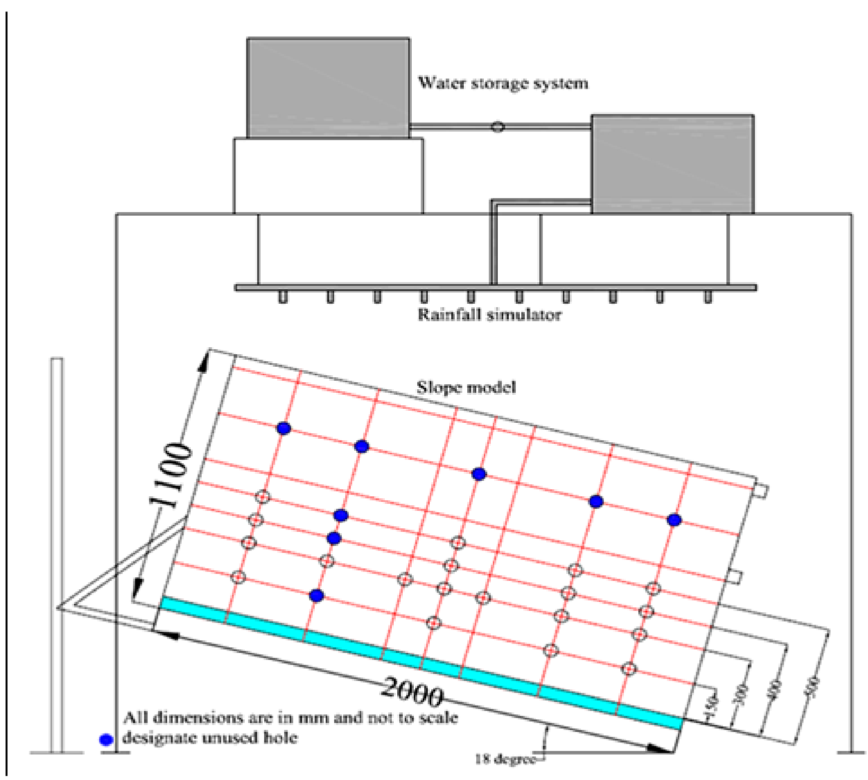

Figure 4 Laboratory testing set up

Figure 5 Drainage cell

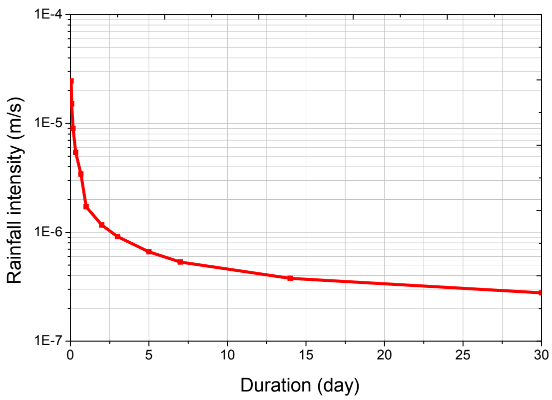

Figure 6 Intensity-Duration-Frequency (IDF) curve of Johor Bahru, Malaysia drainage cell

3.0 RESULTS AND DISCUSSION

Although the simulated rainfall was distributed throughout the length of the slope model by the rainfall simulator, but the infiltrated water flow from the crest towards the toe of the slope model due to sloping effect. Therefore it is obvious to have more water accumulated toward the toe of the slope model compared to the crest and middle points. £the crest of the slope experienced less water content because of drainage. Previous studies by Kassim [18] have shown that tensiometers placed at the middle of the laboratory slope model gives better results for comparison purposes than other tensiometers placed at the crest and toe of the slope model. Therefore, the suction recorded at the middle of the slope model, were used for the first set of results as presented in Figures 7 and 8. Whereas the results presented in Figures 9 and 10 are for suction variation with distance recorded at all the points along the interface.

The variations of the soil suction at the interface of the two soil layers without transport layer and with the drainage cell transport layer are presented in Figures 7 and 8, respectively. In Figure 7 where there is no transport layer breakthrough occurred due to all the three rainfall patterns. However, the period at which breakthrough occurred depends on the rainfall intensity and duration. For the 2-hour rainfall intensity (Fig 7a) the soil suction decreases from the initial value of 30 kPa at the beginning of the rainfall infiltration and reaches the breakthrough suction at the end of 2 hour rainfall duration. In this case the monitoring was performed for another 2 hours after the rainfall have stopped, as shown in this Figure the suction was maintained at breakthrough suction for over 40 minutes before it decreases below the breakthrough suction. In comparison to a system with drainage cell transport layer (Figure 8a), the soil suction was maintained as 30 kPa throughout the rainfall duration. In general, for 2-hour rainfall pattern, there was instantaneous downward movement of the infiltrating water until it reaches the interface in a system without transport layer. This infiltrating water dissociates the capillary forces in the sandy silt soil layer and also removed the capillary break at the interface and percolates the silty gravel layer. However, inclusion of drainage cell transport layer resulted in variation of the soil hydraulic properties which impede downward movement of the infiltrating water to the silty gravel layer, and hence, it flows laterally above the interface and accumulates towards the toe of the slope model.

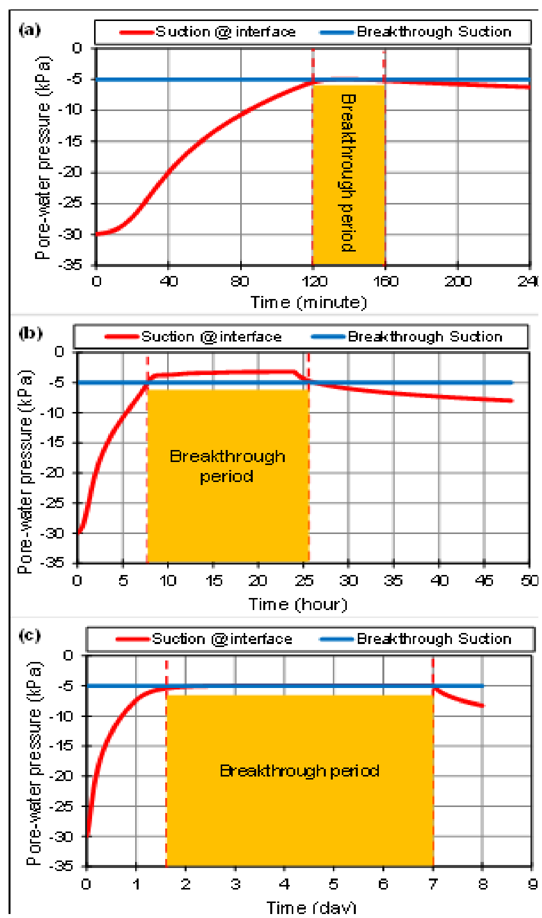

Figure 7 Suction variation at interface without transport layer (a) 2-hr (b) 24-hr & (c) 7-day rainfall patterns

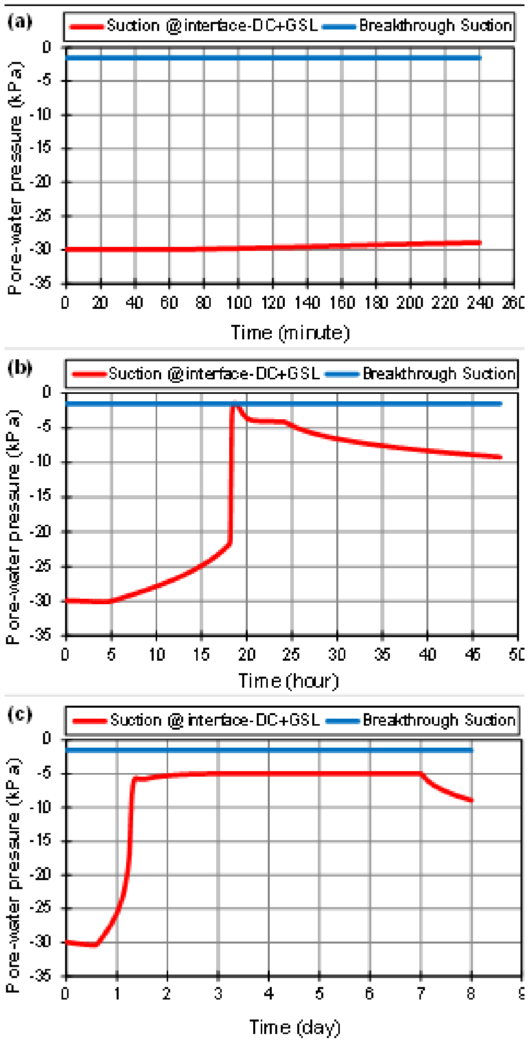

Figure 8 Suction variation at interface with transport layer (a) 2-hr (b) 24-hr & (c) 7-day rainfall patterns

For the 24-hour rainfall intensity, the soil suction decreases instantaneously from the initial soil suction of 30 kPa until it reaches the breakthrough suction of 5 kPa at about 7.5 hours when no transport layer is considered (Figure 7b). The soil suction at the interface decreases below the breakthrough suction until the end of the rainfall duration. This implies that the infiltrating water removed the capillary forces in the sandy silt soil layer and percolates the silty gravel layer. However, in Figure 8b (i.e. with drainage cell transport layer), the infiltrating water was diverted laterally above the interface for 18 hours. However, due to continuous accumulation of the diverted water which increases the volumetric water content at the interface a temporary percolation of the infiltrating water occurred, although it ceases immediately before the rainfall duration elapsed.

For the 7-day rainfall intensity, the infiltrating water moves downward quickly and reaches the breakthrough suction in the system without transport layer (Figure 7c). However, in the system with drainage cell transport layer (Figure 8c) the infiltrating water was diverted laterally above the interface before it flows through the transport layer towards the toe of the slope model due to the longer duration of the rainfall event.

The variations of soil suction with distance along the interface without transport layer and with drainage cell transport layer are shown in Figures 9 and 10, respectively. The suction variation at the interface due to 2-hour rainfall without transport layer is shown in Figure 9a, the soil suction at the interface decreases with time and reaches the breakthrough suction of 5 kPa towards the end of the 2-hour rainfall intensity. However, when the transport layer was considered (Figure 10a), the suction was maintained as 23 kPa which indicates that the infiltrating water was diverted laterally above the interface and does not penetrates into the lower silty gravel layer.

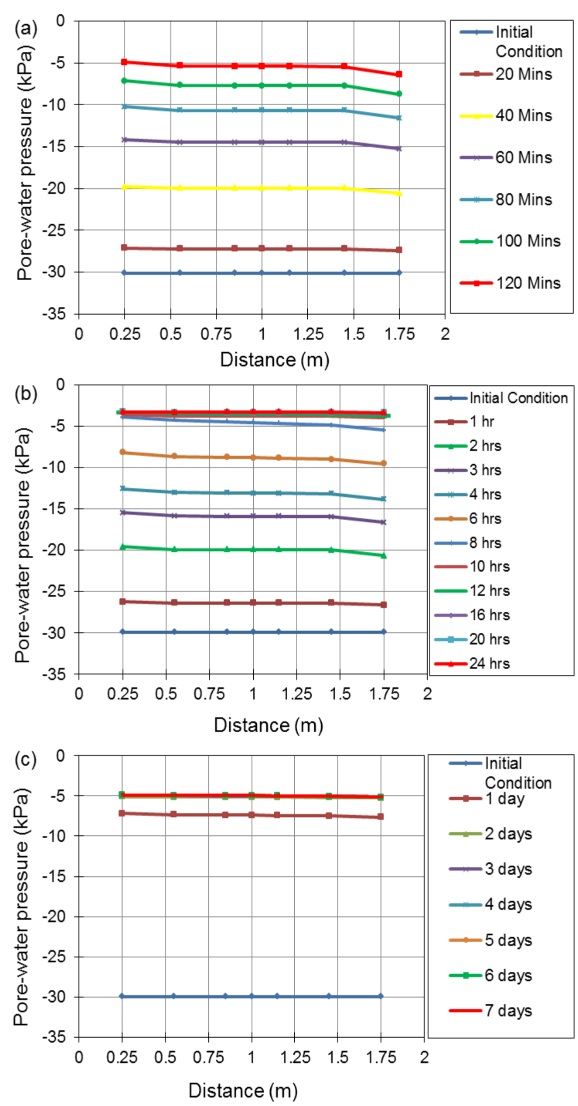

Figure 9 Suction variation with distance along the interface without transport layer (a) 2-hr (b) 24-hr & (c) 7-day rainfall patterns

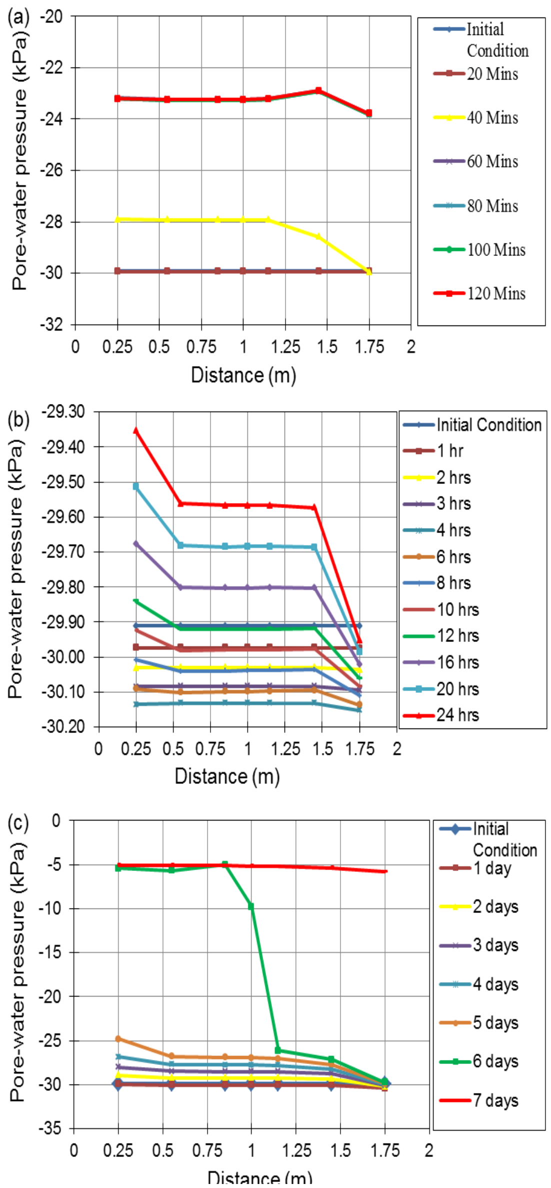

Figure 10 Suction variation with distance along the interface with transport layer (a) 2-hr (b) 24-hr & (c) 7-day rainfall patterns

Similarly, for the 24-hour rainfall intensity, the suction at the interface reaches the breakthrough suction after 8 hours of rainfall infiltration when no transport layer was considered (Figure 9b), but with drainage cell transport layer, the infiltrating water was successfully diverted above the interface and the minimum suction recorded at the end of the rainfall infiltration is 29.35 kPa (Figure 10b) which shows that there is no percolation of the infiltrating water in to the lower silty gravel layer.

In the case of the 7-day rainfall pattern, the soil suction decreases from the initial condition and reaches the breakthrough suction after 1 day of rainfall infiltration (Figure 8c). Although breakthrough have occurred at the middle and toe of the slope model even when the transport layer was considered due to this rainfall intensity, but the suction at the interface was maintained until the 6th day (Figure 9c) before it decreases to breakthrough suction. This may be attributed to the accumulation of the infiltrating water at the toe of the slope model which may spills towards the middle due to longer duration of the rainfall intensity.

4.0 CONCLUSION

The potential of using drainage cell as transport layer in a capillary barrier is investigated in this study. The capillary barrier was constructed with soil of grade V and grade VI according to weathering profile. A laboratory approach using 2-D laboratory slope model was followed. From the results obtained the following conclusion can be drawn from the study

(a) The used of drainage cell as transport layer modified the unsaturated hydraulic properties of the soil arrangements and impedes breakthrough occurrence.
(b) The drainage cell system facilitates capillary break development at the interface and results in lateral movement of the infiltrating water above the interface.
(c) Apart from lateral movement of the infiltrating water above the interface it similarly flows through the transport layer due increase in volumetric water content with time especially for longer duration rainfall events.

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