Laboratory Investigation of Drainage Cell as Transport Layer in Residual Soils

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Abstract

The results of laboratory investigation of transport layer using drainage cell system are presented in this paper. The drainage cell was sandwiched between grade V and grade VI residual soil in a two-dimensional laboratory slope model. Coarse particles of gravel were compacted inside the holes of the drainage cell to facilitate capillary break development and modify hydraulic properties between the soil layers. The grades V and VI residual soils were compacted in the slope model to their dry densities. The whole set up was subjected to three rainfall patterns 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 applied through a rainfall simulator which is part of the laboratory set up. The results show that inclusion of drainage cell in between the two soil layers impedes percolation of the infiltrating water into the lower grade V residual soil layer and facilitates lateral movement of the infiltrating water along the grade VI and transport layer interface towards the toe of the slope model. Similarly, it provides a definite direction through which the infiltrating water can further flow and diverted laterally in case it percolates the drainage cell due to prolonged rainfall pattern.

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

1 Introduction

Rainfall-induced landslide is a persistent natural disaster that occurs frequently in residual soil slope mainly due to frequent and prolonged rainfall events [1-2]. Gavin and Xue [3] 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 matric suction along the potential slip surface in the unsaturated residual soil slope.

A capillary barrier system is used as preventive measure to minimize infiltration of rainwater into unsaturated residual soil. It is a system of soil consisting of fine-grained soil layer overlying a coarse-grained soil layer [4-6] and the variation in the soil particles between the two soil layers produce a contrast in hydraulic properties which forms hydraulic impedance that limits downward movement of the infiltrating water [7]. Hence, the infiltrating water is stored in the fine-grained soil layer by capillary forces and is ultimately removed by evaporation, evapotranspiration or lateral drainage through the soil slope [8]. This infiltrating water will only enters the coarse-grained soil layer when the matric suction at the surface of the coarser soil layer decreases to a value close to the soil's water entry value determine from the soil water characteristics curve [8].

The major setback of using capillary barrier to avert rainfall infiltration into unsaturated residual soil slope is the breakthrough occurrence especially during monsoon season. Therefore, the primary purpose of this paper is to harness the possibility of using a transport layer to divert the infiltrating water to avert breakthrough occurrence. The study is conducted using laboratory slope model. The natural capillary barrier that exist in a tropical residual soil due to weathering processes is simulated in the laboratory and a transport layer form with drainage cell system is used to divert the infiltrating water towards the toe of the slope model. The complete set up is 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 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 determine relevant soil properties, while second phase involved the laboratory modelling of the transport layer using a laboratory slope model.

Two types of residual soils (i.e. grade V and grade VI) are used in this study. These soils are classified as silty gravel and sandy silt, respectively. The relevant soil properties determined in the preliminary testing include the particle size distribution, the atterberg limits and the specific gravity of the materials. These tests were conducted based on the procedure outlined in BS 1337: 1990 part 2 [9]. The saturated coefficients of permeability (k_{sat}) and the dry densities of the soil samples were also determined. The results of these tests are tabulated in Table 1 while the particle size distribution curve is shown in Figure 1.

In the second phase of the work, a two dimensional laboratory slope model of 2000 mm in length, 1100 mm in height and 100 mm in width was used. The slope model was made from acrylic sheets and steel frames. Several holes were perforated at strategic points in one side of the acrylic sheet for the installation of tensiometers. Figure 2 shows a schematic diagram of the slope model. The soil samples were mixed with their respective residual water content to achieve target matric suctions in the soils. The prepared samples were spread in the slope model and compacted to their dry densities. A 300 mm layer of grade V residual soil was placed as the bottom layer then a drainage cell (Figure 3) is placed as the transport layer with gravel particles compacted in the holes. Finally, a 300 mm layer of grade VI was placed above the transport layer. However, it's worth knowing that a particular set up does not contained a drainage cell and served as control. Series of tensiometers were installed in the slope model to measure the soil suction while the test is performed. These tensiometers are connected to a data logger for continuous recording of the 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.

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 (m/s)	5.89×10^{-7}	1.24×10^{-6}
Dry density, ρ_d (Mg/m^3)	1.38	1.26

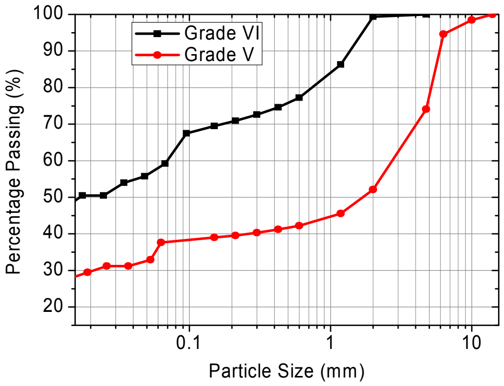

Figure 1. Particle Size Distribution Curves

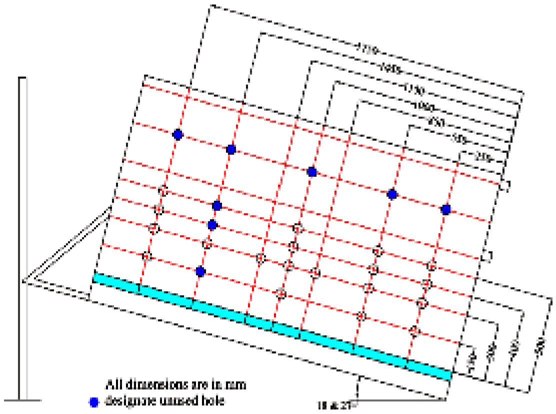

Figure 2. Laboratory slope model

Figure 3. Drainage cell

3 Results and Discussion

The variations of soil suction along the interface of the two soil layers without transport layer and with the drainage cell transport layer are presented in Figures 4 and 5, respectively. In Figure 4 where there is no transport layer breakthrough occurred due to all the three rainfall patterns. However, the period at which the breakthrough occurred depends on the rainfall intensity and duration. For the 2-hour rainfall pattern (Fig 4a) the soil suction decreases from the initial soil suction 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 Fig the suction was maintained at breakthrough suction for 40 minutes before it decreases below the breakthrough suction. In comparison to a system with drainage cell transport layer (Fig 5a), 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 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.

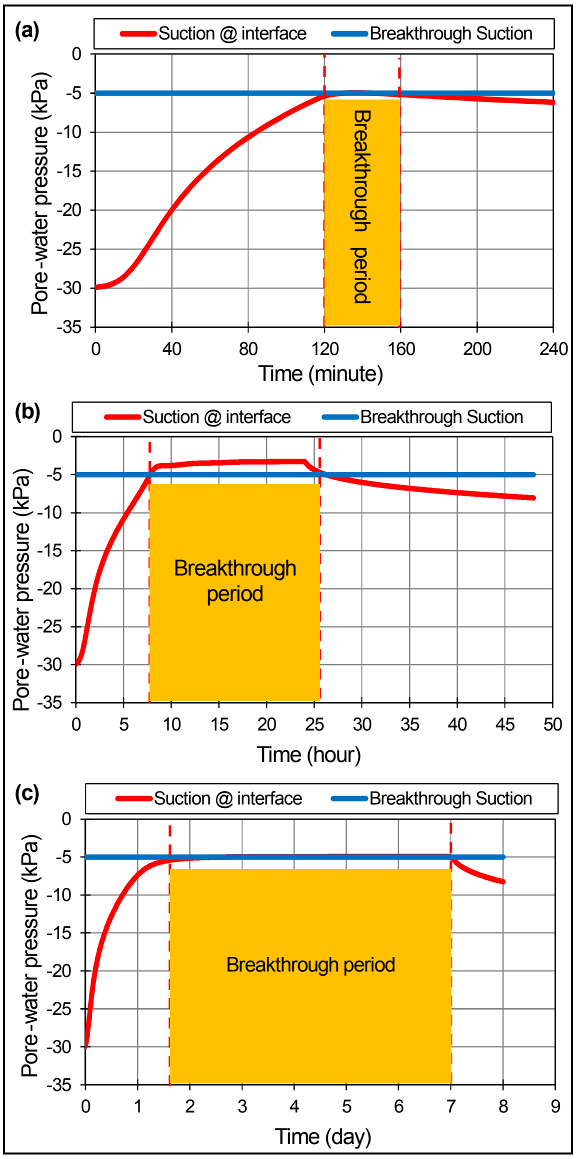

Figure 4. Suction variation at interface without transport layer (a) 2-hr (b) 24-hr & (c) 7-day rainfall patterns

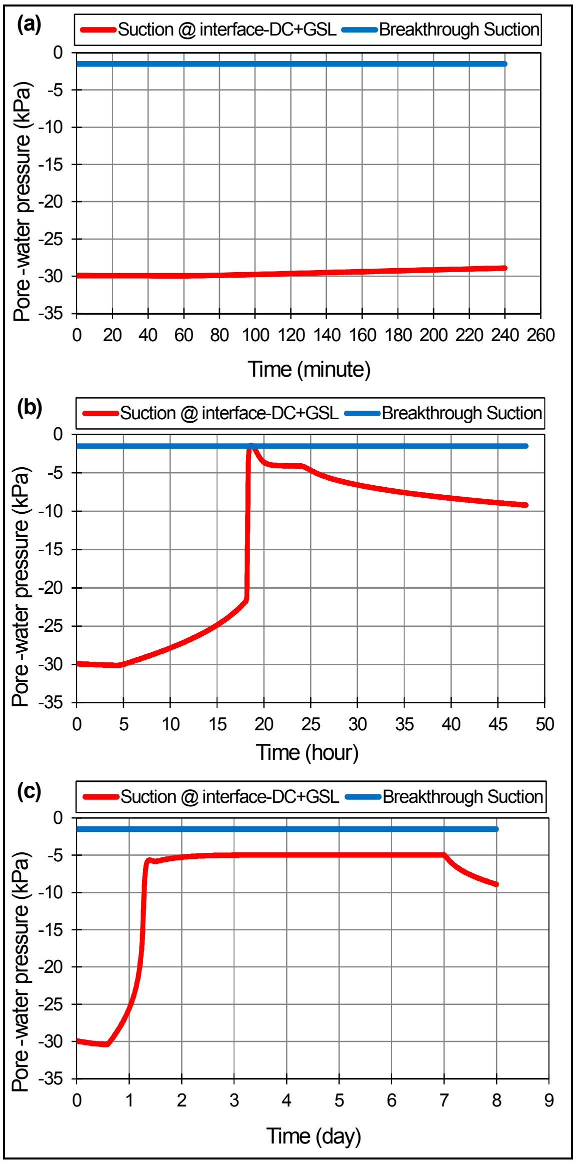

Figure 5. Suction variation at interface with transport layer (a) 2-hr (b) 24-hr & (c) 7-day rainfall patterns

For 24-hour rainfall pattern, the negative pore water pressure decreases instantaneously from the initial soil suction of 30 kPa until it reaches the breakthrough suction of 5 kPa at about 7.5 hours (Fig 4b). The soil suction at the interface decreases below the breakthrough suction until the end of the rainfall infiltration. This implies that the infiltrating water removed the capillary forces in the sandy silt soil layer and percolates the silty gravel layer. However, in Fig 5b (i.e. with transport layer), the infiltrating water was diverted laterally above the interface for 18 hours. Continuous accumulation of the diverted water increases the volumetric water content at the interface which causes a temporary percolation of the infiltrating water which ceases immediately.

For the 7-day rainfall pattern, the infiltrating water moves downward quickly and reaches the breakthrough suction (Fig 4c). However, in a system with drainage cell transport layer (Fig 5c) it was diverted laterally above the interface before it flows through the transport layer towards the toe of the slope model.

4 Conclusion

The results of laboratory investigation of drainage cell as transport layer in a two-layered residual soil slope are presented in this paper. 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 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 the volumetric water content with time.

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