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COMMON GROUND 07

Capillary barrier as slope cover

Harianto Rahardjo, Henry Krisdani, Leong Eng-Choon
School of Civil and Environmental Engineering, Nanyang Technological University, Singapore
Ng Yew Song, Foo Moo Din, Wang Chien Looi
Building Technology Department, Housing and Development Board, Singapore

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ABSTRACT

This paper presents the trial application of capillary barrier system as a slope cover to prevent rainfall-induced slope failures. The capillary barrier system was constructed on a slope which experienced a shallow slip. Generally, capillary barrier system is constructed on a relatively flat soil surface in arid or semi-arid regions. However, in this study, the capillary barrier system was constructed on a slope in tropical region with high rainfall intensities. Capillary barrier system is constructed using a fine-grained soil layer overlying a coarse-grained soil layer. In this study, the capillary barrier system was constructed using fine sand as the fine-grained layer and a geosynthetic material as the coarse-grained layer. The geosynthetic material used was a geocomposite which consists of a drainage mat sandwiched between two layers of filter geotextile. The fine sand layer was contained using geocell and placed above the geosynthetic material. Top soil was placed above the fine sand layer and grass was grown on the surface. The repaired slope was then instrumented using tensiometers to measure the negative pore-water pressure. The tensiometers were installed at different depths from 0.15 m to 2.10 m below the slope surface. The original slope adjacent to the repaired slope was also instrumented using tensiometers to investigate the performance of the capillary barrier system for maintaining negative pore-water pressures in the slope. The measurement results indicated that the capillary barrier system was able to reduce rainwater infiltration into the slope and maintain negative pore-water pressures in the soil down to a deeper depth from the ground surface.

1 INTRODUCTION

Slope failures frequently occur in residual soil slopes in tropical regions. The main cause of slope failure in residual soil slopes has been attributed to rainfall infiltration (Brand, 1984). Previous research works indicated that infiltration has a significant effect in reducing matric suction and consequently shear strength of residual soil slopes (Rahardjo et al., 2005, Zhang et. al., 2000; Gasmo et al., 2000). One of the possible preventive measures for the rainfall-induced slope failure is by minimizing water infiltration into the soil slopes. Previous research works indicated that capillary barrier system could be used as a soil cover system to minimize rainfall infiltration (Tami et al., 2004; Khire et al., 2000; Morris and Stormont, 1997; Stormont, 1997). Field capillary barriers as soil cover for landfills and waste containment purposes under relatively flat soil surfaces have been studied extensively (Stormont, 1997; Khire et al., 1999; Yanful et al. 1999). However, sloping capillary barriers, especially for slope stabilization purposes have not been fully studied. In this study, a capillary barrier was constructed in the field to investigate its potential use as a soil cover for slope stabilization purposes against rainfall-induced slope failure.

A capillary barrier is a soil cover employing a fine-grained soil layer overlying a coarse-grained soil layer. The principle of capillary barrier is based on the contrast in the unsaturated hydraulic properties (soil-water characteristic curves and permeability functions) of the materials. Under unsaturated conditions, the coefficient of permeability of the coarse-grained layer is much lower than that of the fine-grained layer. Therefore, under this condition, water will not flow into the coarse-grained layer. Water will be stored or diverted laterally through the fine-grained layer. Other than using soils as the material, several studies had been conducted to incorporate geosynthetic as a material of capillary barrier system (CBS). Stormont (1998) studied the application of Geocomposite Capillary Barrier Drain (GCBD) system as a drainage system on a pavement design. The GCBD system consisted of three layers that are, from top to bottom: a transport layer, a capillary barrier layer, and a separator layer. Non-woven geotextile was used as a transport layer and as a separator layer, while a geonet with relatively large, open pores functions as a capillary break. Results of the study showed that commercially available geosynthetics, when combined in

GCBD system, could drain water laterally while the adjacent soil remained unsaturated. Krisdani et al. (2006) conducted a 1-D laboratory capillary barrier column test to investigate the infiltration characteristics and the storage of fine-grained layer and also to compare the performance of the capillary barrier models constructed using different materials (i.e., geosynthetic material and gravelly sand) as the coarse-grained layer. The results indicated that capillary barrier effect existed in both capillary barrier columns with geosynthetic material and gravelly sand as the coarse-grained layer. During the rainfall tests, the geosynthetic material was found to be more effective than the gravelly sand to be used as the coarse-grained layer in a capillary barrier system.

In this study, a capillary barrier using fine sand as the fine-grained layer and geosynthetic material as the coarse-grained layer was constructed on a cut slope which experienced a shallow slip. The slope was then monitored using tensiometers at several depths to study the performance of the capillary barrier system.

2 MATERIAL PROPERTIES

Based on the laboratory tests, the soil type of the slope is classified as a clay with high plasticity according to Unified Soil Classification System. Grain-size distribution of the soil is presented in Figure 1. The plasticity index and liquid limit of the soil are 32% and 58%, respectively. The fine-grained layer of the capillary barrier system constructed in this study is a fine sand. Grain-size distribution of the fine sand is also presented in Figure 1. The specific gravity of the fine sand is 2.59 and the saturated coefficient of permeability is 3×10^{-4} m/s. In the field capillary barrier system, the fine sand was placed loosely at a dry density of around 1.4 Mg/m^3. This dry density was also used for laboratory tests, including the constant head test to obtain the saturated coefficient of permeability and the Tempe cell test to obtain the drying soil-water characteristic curve (SWCC).

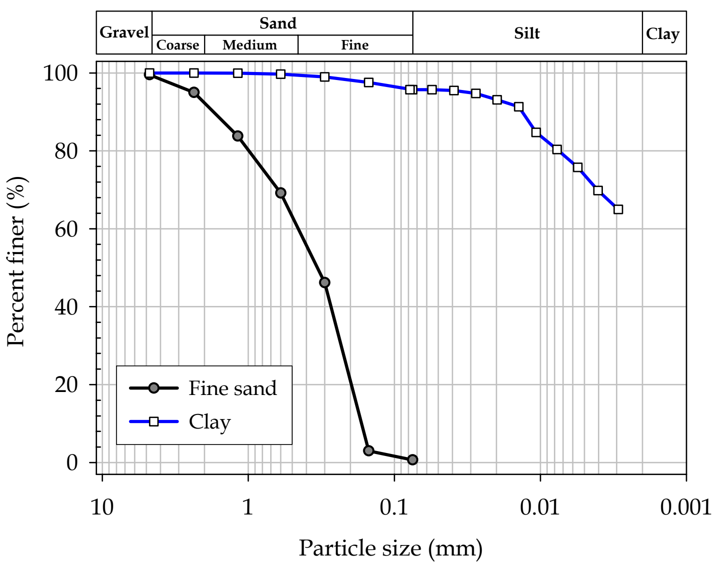


Figure 1: Grain-size distribution of the fine sand used as the fine-grained layer

Geotextile-water characteristic curve (GWCC) of the filter geotextile was also investigated. The GWCC was investigated using capillary rise principle. Geotextile specimen of 300 mm in length and 50 mm in width was used in the test. About 20 mm of the length was submerged in a water container and the remaining 280 mm was hung above the water level which was maintained constant during the test. To obtain the drying GWCC, the geotextile specimen was saturated prior to the test. After equilibrium condition was reached, the geotextile specimen was cut at every 5 mm and subsequently the cuttings were oven-dried to obtain the water contents. The GWCC was obtained by plotting the water contents of each specimen from different heights against the corresponding matric suctions, which were determined based on the height of the specimen above the water table. The experimental results of both fine sand and geotextile were then fitted using Fredlund & Xing (1994) equation with the correction factor, C(ψ), set to 1 as recommended by Leong and Rahardjo (1997). The experimental results and the fitted curves are presented in Figure 2.

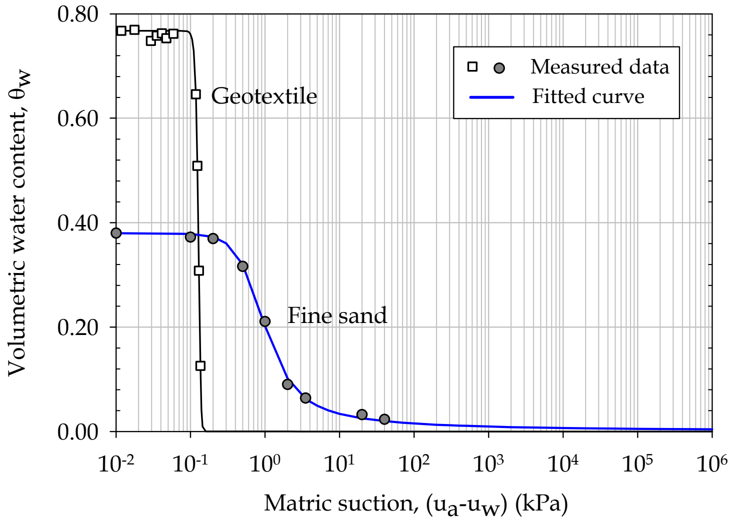


Figure 2: Drying water characteristic curves of the fine sand and the geotextile

3 FIELD INSTRUMENTATION

The capillary barrier system was constructed using a 0.1 m thick fine sand layer contained within a 0.2 m thick geocell and placed above the geosynthetic material. Top soil of 0.1 m thick was placed above the fine sand layer thus filling up the geocell and grass was grown on the surface. The slope was then instrumented with tensiometers at several depths (0.15, 0.30, 0.60, 1.20, and 2.10 m) to measure the negative pore-water pressure in the soil. Four rows of tensiometers were installed in the repaired slope and two rows of tensiometers were installed in the original slope adjacent to the repaired slope to investigate the performance of the capillary barrier system. Each tensiometer was equipped with Bourdon gauge to measure the negative pore-water pressure. The layout of the instrumentation is presented in Figure 3. Photograph of the instrumented slope and the tensiometer installed in the slope is presented in Figure 4.

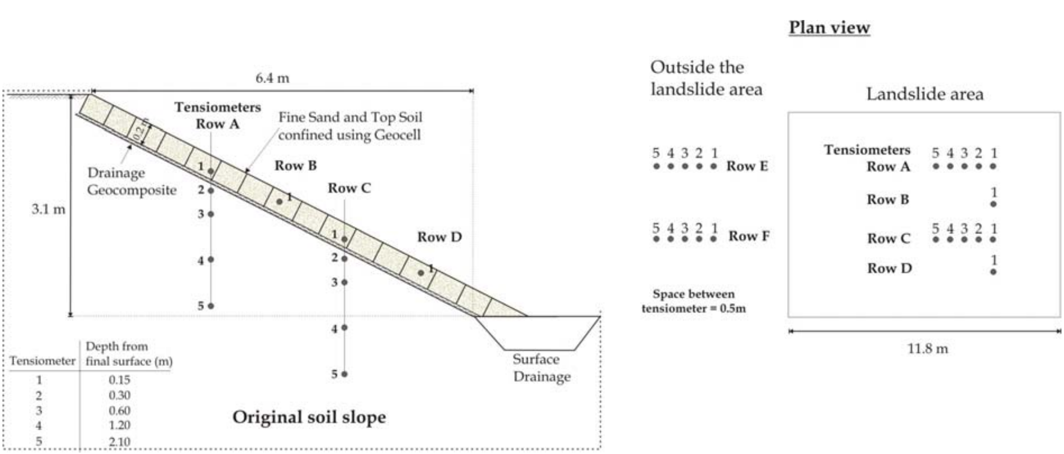


Figure 3: Layout of the slope instrumentation

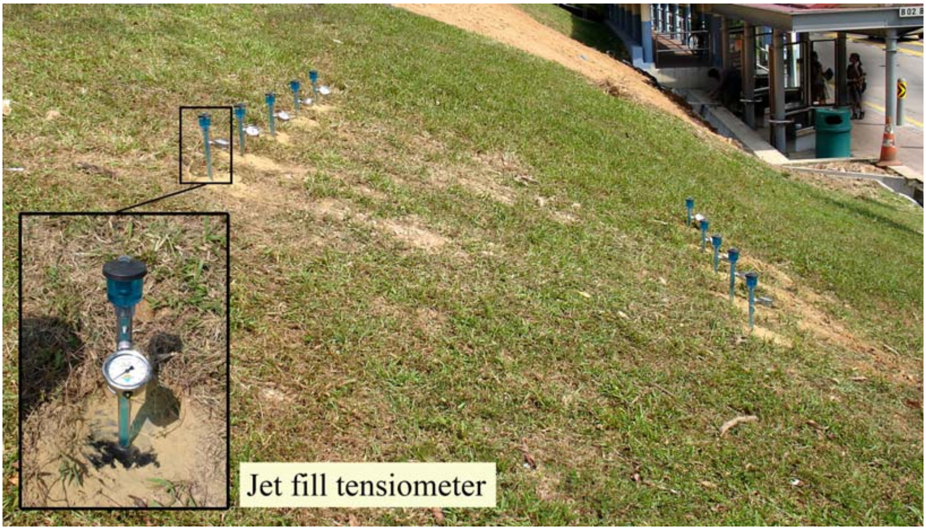
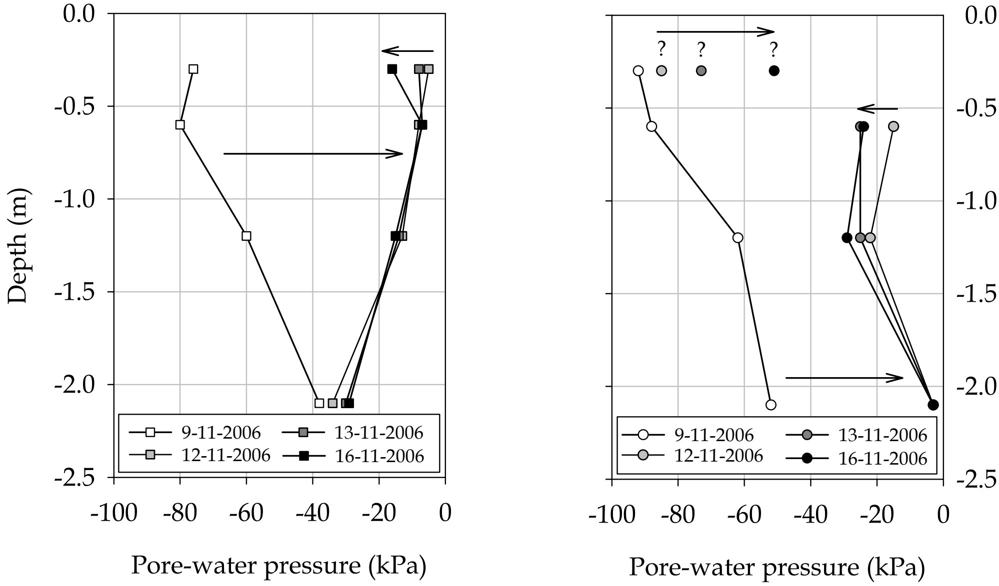


Figure 4: Instrumented slope

4 RESULTS AND DISCUSSION

The pore-water pressures measured by the tensiometers were recorded manually at least two times every week. Figure 5 shows the pore-water pressure profiles measured by tensiometers at Row A (crest of the slope with CBS) and Row E (crest of the slope without CBS) from 9 to 16 November 2006. Pore-water pressure measured by the top tensiometers (depth = 0.15 m) were not presented due to the highly variable measurement because of the poor contact between the tensiometer tip and the soil. It can be seen from Figure 5 that the pore-water pressure at the crest of the slope (Row A and Row E) can be as low as -80 to -90 kPa near the ground surface during dry period (as measured on 9 November 2006). The presence of negative pore-water pressure increases the shear strength of the soil so that the slopes are less susceptible to failure.

Daily rainfall data from a weather station near the location of the monitored slope is presented in Figure 6. Based on the rainfall data, several rainfall events occurred at the location of the slope from 9 to 11 November 2006. The pore-water pressure profile on 9 November 2006 presented in Figure 5 were recorded prior to the rainfall events, therefore they are still highly negative. The pore-water pressure increased significantly after the rainfall events as measured by the tensiometers on 12 November 2006. Nevertheless, the pore-water pressure remained negative in both slopes. Figure 5 indicates that the capillary barrier system does reduce the amount of rainwater infiltrating into a deeper depth. The pore-water pressure at the depth of 2.10 m on the slope protected by the capillary barrier remained low (-30 kPa), while on the slope without capillary barrier, the pore-water pressure at the depth of 2.10 m increased to almost zero. The pore-water pressure measured near the surface (0.30 m depth) of Row A (Figure 5.a) experienced a drying process from 12 November 2006 onwards. However, the pore-water pressure measured near the surface (0.30 m depth) of Row E (Figure 5.b) experienced a wetting process when there was no rainfall, indicating that the tensiometer at 0.30 m depth at Row E did not work properly during this period of time. This might be caused by cavitation of the tensiometer due to the pore-water pressure was highly negative (lower than -90 kPa) as measured on 9 November 2006.



(a) Row A (crest of the slope with CBS) (b) Row E (crest of the slope without CBS)

Figure 5: Pore-water pressure measured by tensiometers at (a) Row A and (b) Row E from 9 to 16 November 2006

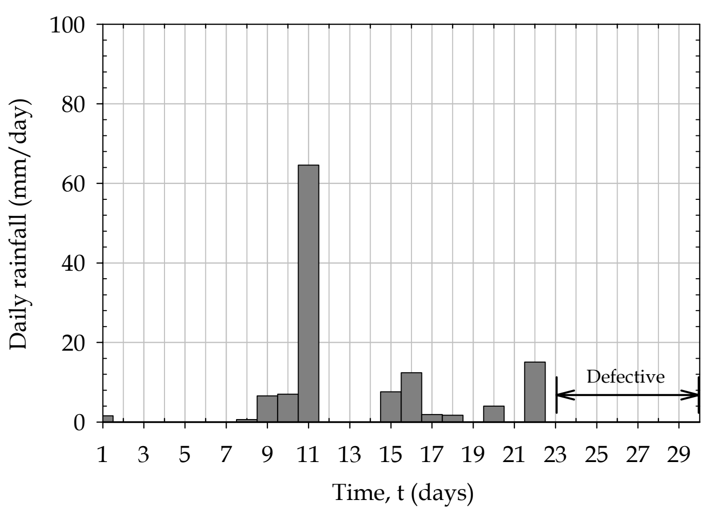


Figure 6: Daily rainfall data for November 2006 (National Environment Agency)

5 CONCLUSIONS

Based on the pore-water pressure data measured by the tensiometers, the capillary barrier system constructed in the repaired slope was able to reduce the amount of rainwater infiltrating into a deeper depth and therefore maintain the pore-water pressure in the slope to remain negative down to a deeper depth from the ground surface. The negative pore-water pressure is required to maintain the stability of the slope against rainfall-induced slope failure. Further measurements are still needed to better understand the performance of capillary barrier as slope cover.

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