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Impinging Flow Over Drainage Layers Including a Geocomposite

J.A. Kuhn[1], J. S. McCartney[2], and J. G. Zornberg[3]

[1]Civil Engineering Department, University of Texas at Austin, Austin, TX 78712; PH: (512) 232-3595, FAX: (512) 471-5631, email: jeffkuhn@mail.utexas.edu
[2]Civil Engineering Department, University of Texas at Austin, Austin, TX 78712; PH (512) 471-5631; FAX (512) 471-6548; email: jmccartney@mail.utexas.edu
[3]Civil Engineering Department, University of Texas at Austin, Austin, TX 78712; PH (512) 471-6548; FAX (512) 471-6548; email: zornberg@mail.utexas.edu

Abstract

The characteristics of the impinging flow over drainage layers that include a geocomposite are being investigated at the University of Texas at Austin. The focus of this study is on applications where a drainage system consists of geocomposite overlain by a sand layer. An experimental testing program is underway, which involves infiltration tests through a sand-geocomposite system constructed to quantify the impinging flow from the sand into the geocomposite drainage layer under unsaturated conditions.

Introduction

Geocomposite drainage layers are now commonly used as an alternative to conventional sand or gravel drains in landfills, roadways, and retaining walls. Geocomposite drainage layers with different configurations are being evaluated at The University of Texas at Austin to investigate the mechanisms of infiltration from a soil layer into an underlying geocomposite drainage layer. The specific focus is on applications where a drainage layer consists of a geocomposite overlain by a sand layer. The methodology for calculating the maximum liquid thickness in such drainage systems is provided by Giroud et al. (2004). This study attempts to quantify the vertical infiltration from the upper soil layer into the lower geocomposite layer when accounting for the unsaturated condition of the soil layer. Specifically, a series of infiltration tests are being conducted using various soil-geocomposite configurations. Instrumentation is used to continuously measure not only the flow, but also the soil water content profiles. This will allow assessment of the interaction between unsaturated soil and underlying geosynthetics, boundary conditions, and soil moisture storage capacity. This study will provide insight into the performance of geocomposites in contact with unsaturated soils when used as drainage layers, separation layers, protection layers, and hydraulic barriers.

Materials

A geocomposite drainage layer typically includes a geonet sandwiched between nonwoven geotextiles. The impinging flow across the geotextile and into the geonet is well defined if the overlying soil layer is saturated. However, a capillary break may develop at the soil-geocomposite interface if the overlying soil is under unsaturated conditions. This can lead to (1) build up of moisture at the interface between the soil and the geocomposite material and (2) in-plane drainage within the soil layer along the soil-geocomposite interface. Understanding of these mechanisms is relevant for quantification of the impinging flow used in the design of drainage layers, performance of systems used for quantifying percolation through landfill covers, and interpretation of information gathered from leak detection systems.

The hydraulic conductivity of the soil-geocomposite layered system is governed by the hydraulic conductivity of the material within the system with the lowest hydraulic conductivity. While the hydraulic conductivity of the sand and geocomposite materials is comparatively large under low suction (i.e. near saturation conditions), the hydraulic conductivity of the geocomposite interface may be less than that of the soil under high suction values. Consequently, moisture may accumulate at the interface when the soil is under unsaturated conditions.

The soil water characteristic curve (SWCC) is the relationship between the soil volumetric water content and the capillary pressure, or suction, and can influence significantly the interaction between the soil and the geocomposite under unsaturated conditions. The soil moisture characteristic curve of the sand used in this investigation was obtained using a pressure plate extractor. In the pressure plate, an initially saturated soil is placed on a saturated, fine-pored ceramic plate which only allows the passage of air, not water. Air pressure is then applied to the soil which induces water flow from the soil through the porous plate until the air pressure and soil suction (i.e. the forces of the menisci holding water within the soil) are in equilibrium. At this point, the soil specimen is removed and the water content is measured, defining one point on the SWCC. This process is repeated for various values of air pressure. The SWCC of the geotextile component of the geocomposite was also defined in this study using a pressure plate extractor using similar procedures as with the sand. In addition, a geotechnical centrifuge with a radius of 194 mm was used to define points under high suction values. The geotextile specimens tested in the centrifuge were first saturated, placed atop a porous platen, and then spun at a constant angular velocity in a centrifuge. The centrifugal force forces water out of the geotextile and subsequently through the porous platen where is collected in a reservoir. The change in weight is measured for each increase in angular velocity. The matric suction can be inferred from the angular velocity using a formula as follows (Hassler and Brunner , 1945):

$$\psi = \frac{\omega^2 r^2}{2g} \quad (1)$$

Where ψ is the material (soil or geotextile) suction, ω is the angular velocity, r is the radius of the centrifuge to the midpoint of the specimen (194 mm for the geotextile), and g is the acceleration due to gravity. It was assumed that the variation in centrifugal field over the specimen was minimal because the geotextile thickness (1.97 mm) was negligible compared to the radius. The degree of saturation was obtained by dividing the gravimetric moisture content by the saturated gravimetric moisture content.

The data points collected using this process can be represented by several functions. Table 1 summarizes the residual volumetric water content (θ_r), saturated volumetric water content (θ_s), van Genuchten empirical constant (α), van Genuchten dimensionless exponent (n), and saturated hydraulic conductivity (K_S). θ_s for the geocomposite was assumed to be 0.45, although the shape of the SWCC in terms of the degree of saturation was not particularly sensitive to this parameter. In this study, the van Genuchten model was used (van Genuchten 1980). The sand used within study was placed with a relative density (Dr) of 50%. Figure 1 shows the obtained SWCC for a sand-geocomposite interface and sand. The relationship between hydraulic conductivity and suction (referred here-in as the k-function) is obtained analytically using the same parameters defined for the SWCC as well as the saturated hydraulic conductivity, Ks. The saturated hydraulic conductivity of the geotextile component of the geocomposite was defined by multiplying its permittivity of 0.5 1/s by its thickness of 19.7 mm. Figure 2 shows the k-function curves for the geocomposite and sand used in this study.

A capillary break will occur at the interface between the two materials when the underlying geocomposite has a lower hydraulic conductivity than the sand for a given suction. For example, Figure 1 indicates that the degree of saturation of both the geocomposite and sand decrease markedly at a suction of 10 mm of water (the air entry suction). More significantly, Figure 2 indicates that the hydraulic conductivity of the geocomposite decreases to values below that of the sand at a suction of approximately 100 mm of water. That is, breakthrough would occur through this system at a suction of 100 mm of water, based on the information gathered from pressure plate extraction and centrifuge testing.

Table 1: van Genuchten Parameters for Soils and Geosynthetics

Material	θ_r (%)	θ_s (%)	α (mm^{-1})	n	k_s (mm/s)
Monterey sand (D_r = 50%)	0.013	0.40	0.010	3.000	1
Geocomposite	0.020	0.45	0.012	5.000	1.905

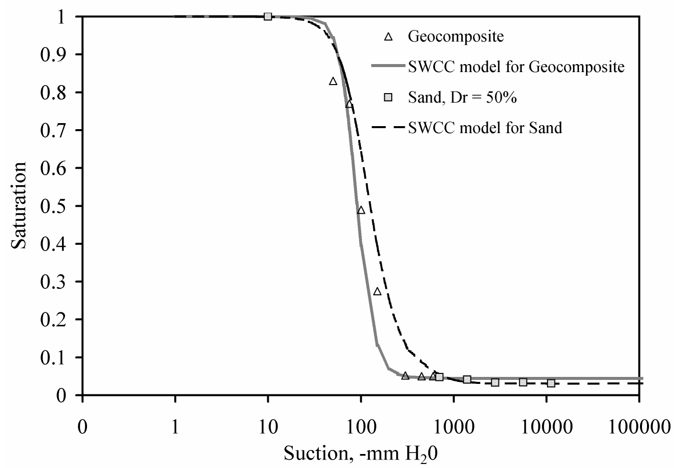

Figure 1. SWCC for geocomposite and sand.

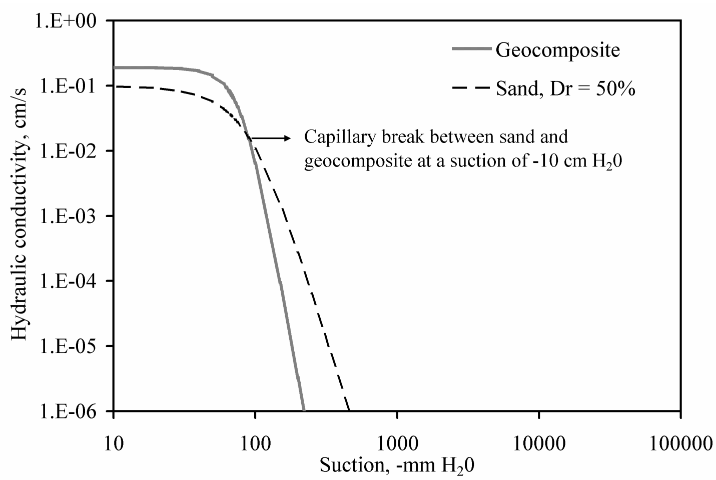

Figure 2. k-function for geocomposite and sand.

Experimental Testing Program

Infiltration tests are being conducted using several soil-geocomposite profiles in order to quantify the interaction between geocomposite drainage layers and soil under unsaturated conditions. Figure 3 shows a schematic of view of the infiltration test conducted as part of this research project.

Flow is applied in the vertical direction, although some preferential flow is expected to occur. Breakthrough within the profile is detected when water is collected in the underlying gravel support layer. Testing was also performed on a control profile consisting entirely of Monterey sand. Water content is being monitored throughout the vertical profile. Specifically, water content is measured directly using gravimetric sampling and indirectly using time domain reflectometry (TDR) technology. The monitoring layout is also shown in Figure 3.

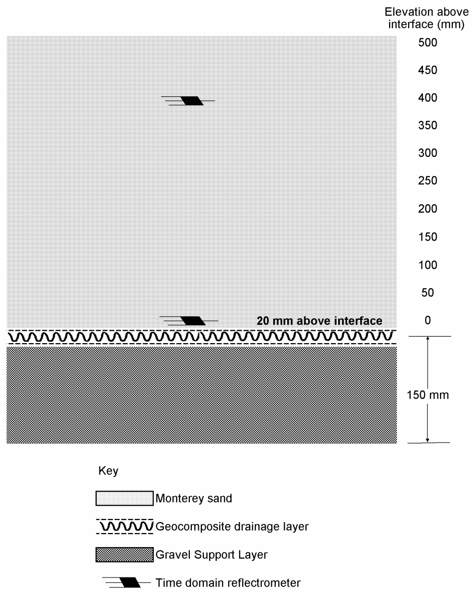

Figure 3. Schematic profile of infiltration test.

Preliminary results from a test conducted using a flow rate of 2.6 x 10 $^{-4}$ mm/s are discussed next. This flow rate is below the saturated hydraulic conductivity of the sand and of the geocomposite. Monitoring was continued until flow was observed to exit the bottom of the profile and reached steady-state flow conditions within the column.

The experimental testing program involves measuring the progress of the wetting front, the suction value at breakthrough, and the amount of water that accumulates above the capillary break. Development of a capillary break was evidenced when the wetting front reached the soil-geosynthetic interface. This was evidenced by a decrease in suction near the interface, and an accumulation of moisture in the overlying sand layer. When a critical suction was reached (which may possibly be a positive pressure), water broke through into the geocomposite drainage layer. The flow rate was observed to increase until a constant rate was established.

Figure 4 shows the changes in moisture content with time measured at 400 and 20 mm above the interface. The results indicate that breakthrough occurred through the sand-geocomposite profile approximately 2000 minutes after the application of the surface in-flow. TDR measurements indicated the progress of a wetting front and subsequent moisture accumulation over the geotextile due to the development of a capillary break. The TDR at 400 mm indicated the arrival of a wetting front at approximately 1250 minutes, while the TDR at 20 mm indicated the arrival of a wetting front at approximately 1500 minutes. The moisture content at 20 mm continues to increase until approximately the time at which breakthrough was observed after approximately 2000 minutes. The water content at the soil-geocomposite interface at the time of breakthrough was 27 % (S = 69%). As indicated by the SWCC in Figure 1, this water content corresponds to a suction of 95 mm of water. This is consistent with the prediction obtained from the k-function curves for the sand and geocomposite. Specifically, the results in Figure 2 indicate that the capillary break between sand and geocomposite should occur at a suction of approximately 100 mm water. Consequently, good agreement was obtained between the theoretical (k-function) and experimental (infiltration test) results for the suctions at the time of breakthrough.

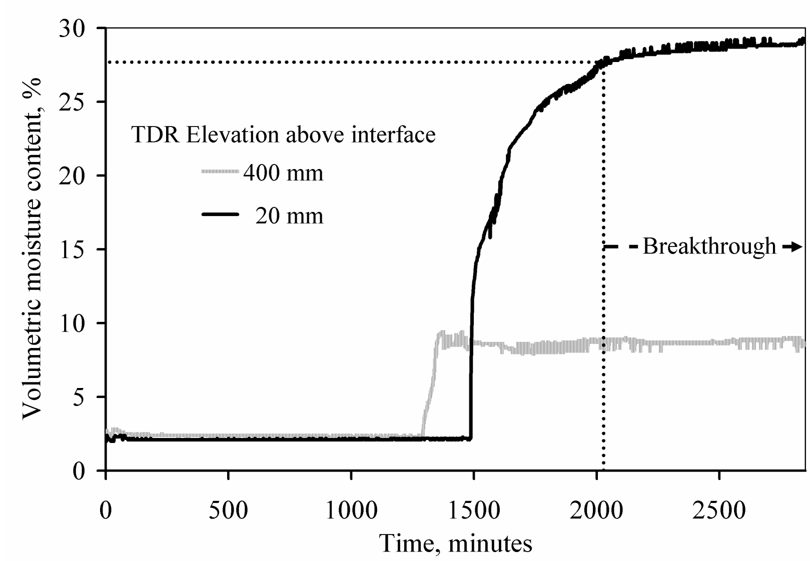

Figure 4. Volumetric water content for the sand – geocomposite profile.

Preliminary Conclusions and Path Forward

The performance of geocomposites in contact with unsaturated soils is being evaluated at The University of Texas. Preliminary conclusions obtained from an infiltration test involving a sand layer placed over a geocomposite drainage layer are as follows:

- A capillary break develops between the sand and the geocomposite under unsaturated conditions, as the hydraulic conductivity of the geocomposite is less than that of the overlying sand for high suction values.
- Upon breakthrough, steady-state flow was established through the sand and geocomposite layers.
- Good agreement was observed between the suction at breakthrough obtained experimentally from the infiltration tests and the theoretical k-function estimated using the water characteristic curves for the sand and geocomposite (defined using a pressure plate extractor and a geotechnical centrifuge).

Additional testing will focus on the time required to reestablish the capillary break once water flow is stopped. Further testing will also make use of different combinations of monitoring devices, including tipping bucket rain gauges to continuously monitor outflow and heat dissipation sensors to measure suctions. Additional testing is expected to identify the impact of the interaction between the unsaturated behavior of soils and geosynthetics on current design procedures for geosynthetic drainage layers.

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