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Geocomposite capillary barrier drain for unsaturated drainage of pavements

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ABSTRACT: The Geocomposite Capillary Barrier Drain (GCBD) is a new invention that drains water from overlying soil that is partially saturated and also stops the upward unsaturated water flow. We placed the GCBD between the base and the subgrade of a pavement test section, and it drained water from the base when the base was not saturated and prevented most infiltrating water from reaching the subgrade. The GCBD reduced the total amount of water and length of time that water persisted in the base and reduced the total amount of water in the subgrade compared to a section that contained only a separator. When placed in paved roads between the base and subgrade, the GCBD should 1) accelerate the drainage and drying of the base after infiltration, 2) protect the subgrade from wetting and 3) reduce the upward unsaturated flow of water into the base course.

1 INTRODUCTION

Draining water from geotechnical systems while the constituent soils are unsaturated—i.e., before positive pore water pressures develop—would provide great economic benefit. We developed the Geocomposite Capillary Barrier Drain (GCBD) to do this, and it drains water from soils at negative pore water pressures (Henry and Stormont, 2000). Results of a proof-of-concept study of the GCBD are reported here.

When water infiltrates fine soil and reaches a layer of larger-pored soil (a capillary barrier), it accumulates at the interface until the suction of the water reaches a threshold "entry suction" and enters the layer. If the large-pored layer is dipping, the water flows down dip. The hydraulic conductivity of the overlying soil increases as the water content increases, and thus lateral drainage is concentrated in the region just above the interface (Fig. 1a). Eventually the soil water suction reaches the entry suction of the underlying layer and water breaks through into the lower layer. The horizontal length along the interface that water is diverted before breakthrough is called the diversion length.

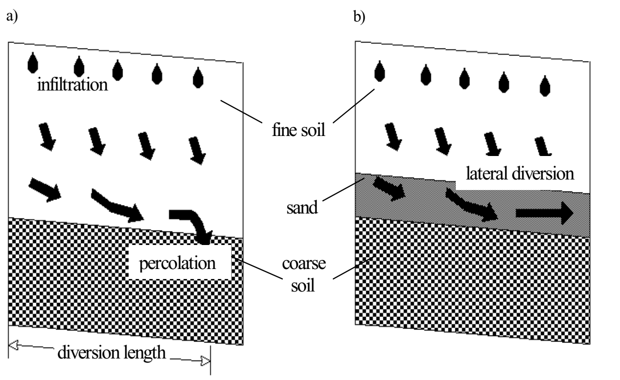

Figure 1. Lateral drainage in unsaturated soil with: a) a capillary barrier and b) a transport layer above a capillary barrier.

Placing a transport layer such as fine sand between the overlying soil and the capillary barrier significantly increases the amount and rate of water drained under such conditions (Figure 1b). The transport layer is conductive enough while partially saturated to laterally divert the downward-moving water, yet it remains unsaturated for a considerable diversion length and thereby preserves the capillary barrier. Experimental and numerical investigations indicate that unsaturated soil drainage using fine sand as the transport layer and gravel as the capillary barrier is effective (Stormont and Morris, 1997). A system fabricated from geosynthetics has a number of advantages compared to using gravel and fine sand: 1) the desired properties can be optimized and controlled, 2) drainage can be combined with reinforcement and separation, 3) the system will be thinner than soil layers, and 4) the materials are readily available and easy to place.

The GCBD comprises three layers that are, from top to bottom, a transport layer (geotextile), a capillary barrier (geonet), and a separator geotextile (Fig. 2). A geonet with relatively large, open pores is the capillary barrier—i.e., taking the place of the underlying coarse soil in the systems shown in Figure 1. The separator prevents underlying soil from intruding into the pore spaces of the capillary barrier. Although this geocomposite resembles a conventional geocomposite drain, the transport layer drains water under negative pressures.

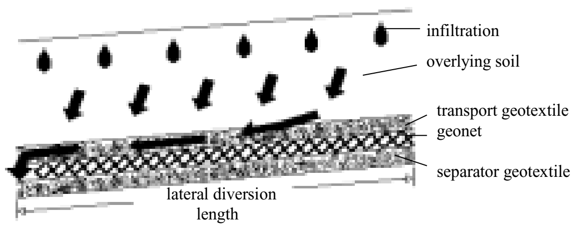

Figure 2. Geocomposite Capillary Barrier Drain (GCBD) with overlying soil.

2 EXPERIMENTAL PROGRAM

We conducted the GCBD proof-of-concept study in two phases. In Phase 1 we selected a prototype transport layer from among various textiles using capillary rise, moisture retention and in-plane transmissivity measurements (Stormont, et al., 2001). We then conducted a drainage test with the prototype transport layer by placing the GCBD between 100 mm of clayey sand and 150 mm of overlying silty gravel in a 3-m-long box tilted at a 2.5% slope. At a rate of long-term infiltration rate of 0.15 mm hr^{-1}, the transport layer drained all water from the overlying soil at suctions of 120 mm and greater (Stormont, et al., 2001). In Phase 2 we used large-scale pavement test sections to evaluate the drainage of a pavement with a GCBD and compare it with the drainage from a typical pavement. Highlights of those test results are reported here.

The prototype transport layer selected, referred to as TGLASS, is a woven, multifilament fiberglass textile with a mass per unit area of 2370 g m^{-2}, a thickness of 3.2 mm, and an O_{95} size of 0.075 mm. It is a specialty fabric for industrial insulation applications.

2.1 *Experimental set-up*

We constructed a large box for applying water to and measuring outflow from various layers in 1) a control pavement test section and 2) a pavement test section containing the GCBD. The box was filled with subgrade overlain by either a separator (control) or the GCBD that was, in turn, overlain by the base and then paved (Fig. 3). The base material used meets New Hampshire DOT specifications for a dense graded aggregate base. The box is tilted by 2% from south to north and from east to west. In addition to the tilt of the box, the soil layers were emplaced at a 2% grade from east to west. The box contains a 1.3-m-long lane of a 'paved road' from the centerline through the bottom of a ditch, and the pavement is 'cracked' containing a 2.5-mm-wide crack, 300 mm in length (Fig 4).

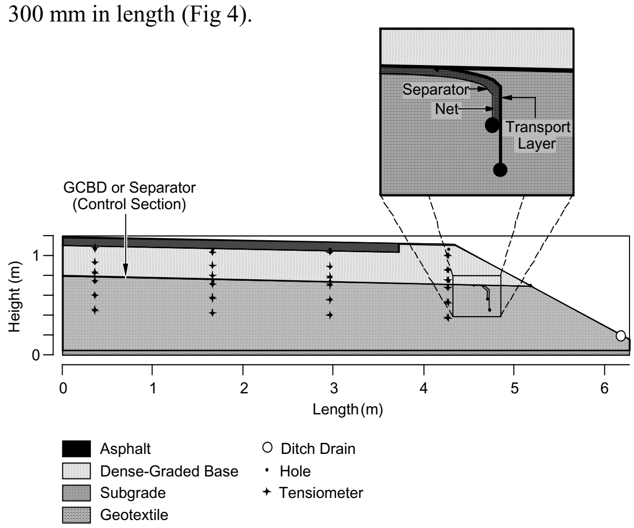

Figure 3. Cross-section of the GCBD test section showing detail of water collection system for the GCBD layers.

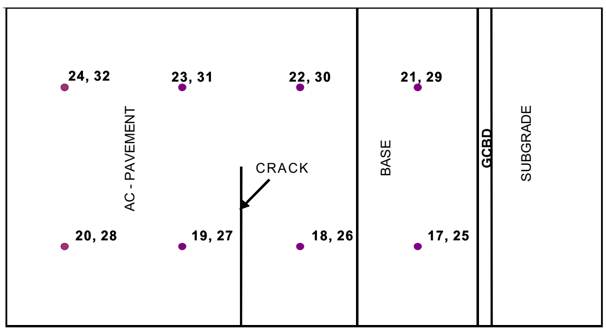

Figure 4. Plan view of test box. The numbers label the tensiometers that are located 25 mm below the base/ subgrade interface (17-24) and 13 mm above the interface (25-32). The box tilts down and to the right.

The control section comprised an average thickness of 0.71 m of subgrade, a geotextile separator, 0.3 m of base gravel and 50 mm of asphalt pavement. Fifty mm of gravel with a geotextile separator was placed under the subgrade to help insure uniform water distribution when a water table is present. The test section containing the GCBD is identical to the control section, except that the GCBD is located between the base and subgrade. Construction details can be found in Henry, et al. (accepted for publication). The control section was built first. When control tests were completed, the GCBD test section was constructed.

There are three layers of eight tensiometers in the subgrade and base, for a total of 48 tensiometers. They are located in vertical columns at increasing depths (Figs 3,4). The subgrade tensiometers are located 0.3 m from each edge of the box at depths of 330, 179 and 25 mm below the base/ subgrade interface. The tensiometers in the base layer were located at 13, 127 and 279 mm above the base/ subgrade interface. The lowest layer of tensiometers is labeled 1 through 8, tensiometers 9 through 16 identify the second layer and so forth for each layer (e.g., Fig. 4). Note that the westernmost tensiometers are located beneath the unpaved shoulder.

2.2 *Tests conducted*

We applied water, measured outflow and monitored soil moisture tension to compare the performance of the two configurations. The amount of water applied simulates typical storms that occur in the northeastern United States (Table 1). Tests 1, 3 and 4 were conducted on the control section, and the remaining tests were conducted on the GCBD test section. Test 1 was a very large storm and served to moisten the soil layers and place a 0.2 m-high water table into the test box. Tests 4 and 8 simulated a four-year design storm of 6 hours in northern New England, determined according to the Steel Formula (Lindeburg, 1998). Tests 3 and 9 approximated a 10-year design storm of 1 hour. Additional tests were conducted, but the results do not add significantly to the information provided here. For most tests, the water was applied by hand with a sprinkling can.

Table 1. Rates and amounts of water applied. The test surface area is 7.996 m^2.

Test	Intensity mm hr^{-1}	Duration Hr	Quantity of water m^3
1	11.1	6.0	0.532
4	1.6	5.4	0.070
8	1.6	6.0	0.076
3	9.5	1.0	0.076
9	9.5	1.0	0.076

3 RESULTS

3.1 *Six hour storm: Tests 4 and 8.*

The suction head measurements after the six-hour storm 25 mm below the separator and the GCBD are shown in Figures 5 and 6, respectively. (Figure 4 shows tensiometer locations.) In test 4, all suction heads below the interface decreased within one day of the test start, indicating that water infiltrated through the base and into the subgrade. There was also an area of ponding on the pavement just above tensiometers 19 and 20, and the lowest soil moisture tensions measured occurred below tensiometer 19—apparently receiving water from the crack in the pavement as well as from the ponded area.

In test 8, the suction heads below the GCBD remained approximately constant after the storm (e.g., tensiometers 19 and

26), except for the area beneath the unpaved shoulder, as indicated by tensiometers 17 and 21. After we stopped applying water, the transport layer drained at a greater rate than the ditch (Fig. 7). Tensiometers in the base indicated that the transport layer was draining water from the unsaturated soil (Fig. 8).

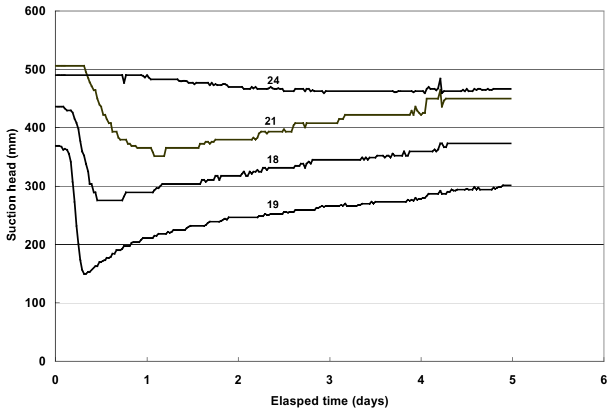

Figure 5. Suction heads in the subgrade, 25 mm below the separator in the control section for Test 4 (control section). Tensiometer 17 did not function properly for this test. Water was applied for 6 hours, for the first 0.25 days shown.

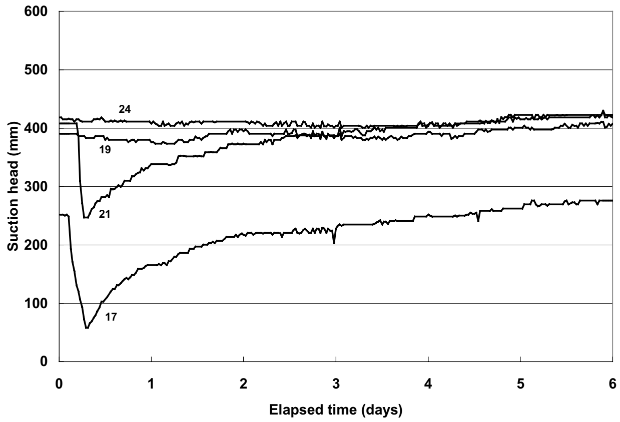

Figure 6. Suction heads in the subgrade, 25 mm below the GCBD for Test 8. Water was applied for 6 hours, for the first 0.25 days shown.

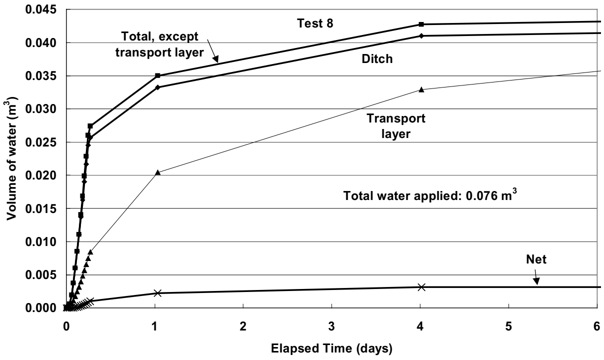

Figure 7. Outflow measured from Test 8.

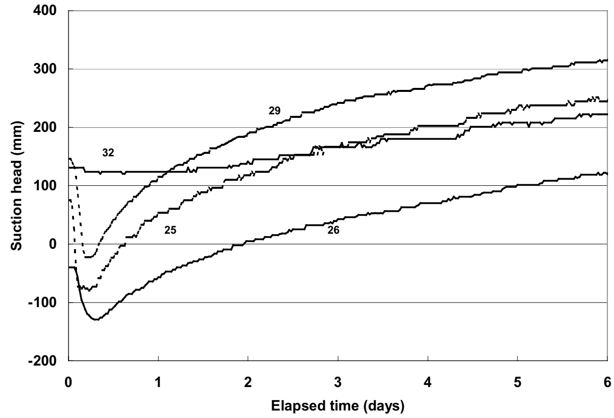

Figure 8. Soil suction heads in the base at 13 mm above GCBD for Test 8.

3.2 *One hour storm: Tests 3 and 9.*

There was considerable more runoff in the one-hour storm than in the six-hour storm, and less water infiltrated the base (Fig. 9). About 80% of the water applied ran off in test 9 vs. 60% in test 8.

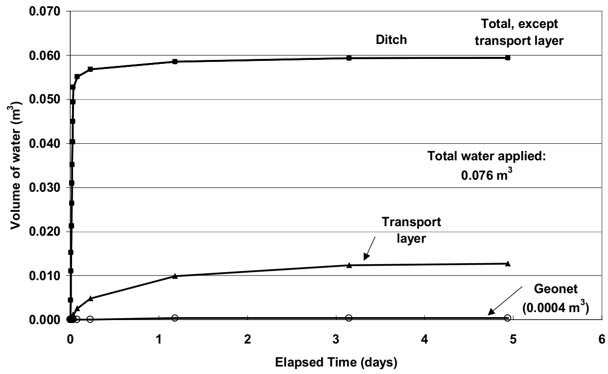

Figure 9. Outflow from Test 9.

The suction heads in the subgrade were similar at the beginning of tests 3 and 9. However, the subgrade of test 9 was completely protected from changes in moisture content due to this storm whereas the subgrade of test 3 was not (Figs. 10 and 11). On day 5 the transport layer was draining the base at suction heads ranging from 175 to 360 mm (Fig. 12).

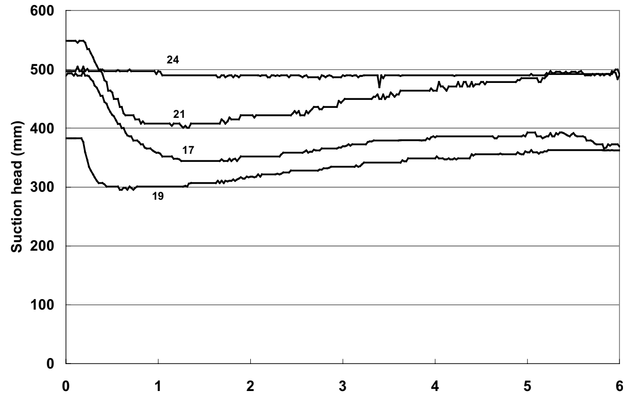

Figure 10. Suction heads in the subgrade, 25 mm below the separator in the control section for Test 3.

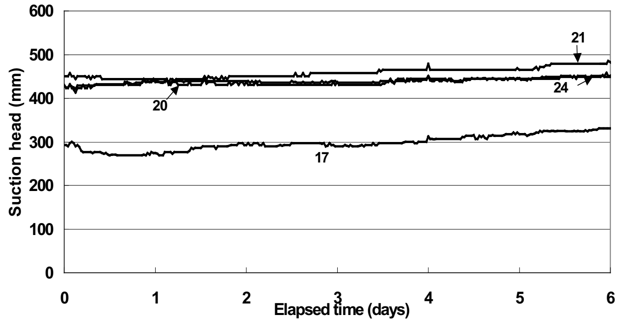

Figure 11. Suction heads in subgrade, 25 mm below the GCBD in Test 9.

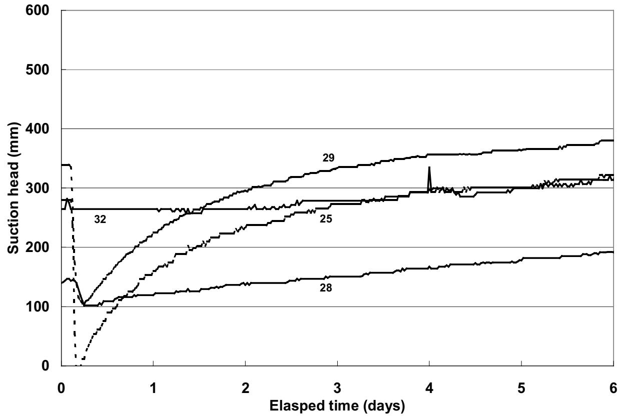

Figure 12. Suction heads in base, 13 mm above the GCBD in Test 9.

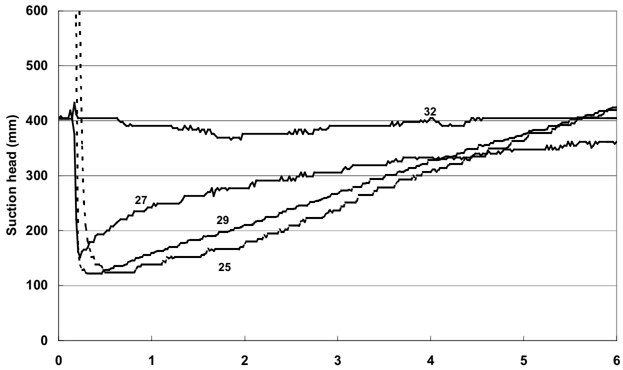

Figure 13. Suction heads in the base of test 3, 13 mm above the GCBD in Test 3.

Note that the GCBD protected the subgrade in test 9 after it had allowed some water to pass through in test 8. This means that once allowed to "dry," the GCBD also functioned well after water broke through it into the subgrade in test 8. The elapsed time between the starts of tests 8 and 9 was 8 days.

The decrease in moisture content of the base was accelerated in tests with the GCBD, as compared to the tests with the geotextile separator (e.g., Figs. 12, 13). This demonstrates that the GCBC removes water from the base at a significantly greater rate than when water is forced to drain by infiltration subgrade.

4 COMMENT

The principle factors in the performance of a GCBD are the properties of the transport layer. The TGLASS tested as a prototype transport layer is an off-the-shelf industrial insulation product and was not specifically developed to be transmissive to water at unsaturated conditions. Further, the TGLASS is relatively expensive compared to conventional geotextiles. Further development in conjunction with manufacturers will result in a more effective and less costly transport layer than our current prototype and hence will increase the potential applications of GCBD systems.

5 CONCLUSIONS

At infiltration rates that occur in the field and are of concern to transportation agencies, the GCBD drained water from the overlying base prior to fully saturated conditions, that is, under negative water pressures. Furthermore, the GCBD prevented the moistening of the subgrade at infiltration rates that approximate a 10-year, one-hour design storm. This suggests that we can design drainage for the ultimate purpose of extending pavement lifetime by 1) limiting the time that bases are saturated and 2) diverting large volumes of water to a drainage system before it reaches the subgrade.

In the specific GCBD that we tested, we drained water from overlying base soil when the water was subjected to 100 mm of suction head and greater. Furthermore, the GCBD recovered its function and protected the subgrade in a test following a test in which a small amount of water had broken through the GCBD into the subgrade.

The transport layer that we tested is a specialty fabric, and its cost is relatively great. We believe that a material explicitly designed and manufactured as a transport layer would be substantially less expensive.

6 REFERENCES

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7 ACKNOWLDEGMENTS

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