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Technical note

Laboratory tests to evaluate effectiveness of wicking geotextile in soil moisture reduction

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ABSTRACT

A new type of woven geotextile, referred to as wicking geotextile, was developed and introduced to the market. Since this wicking geotextile consists of wicking fibers, they can wick water out from unsaturated soils in a pavement structure thus resulting in an increase of soil resilient modulus and enhance performance of roadways. In this study, a physical model test was developed to evaluate the effectiveness of the wicking geotextile in soil moisture reduction for roadway applications. A test box with a dimension of 1041 mm in length, 686 mm in width, and 584 mm in height was used in this study. Two HDPE plastic panels were used to separate the box into two sections, one containing a dehumidifier and the other backfilled with soil. The dehumidifier was adopted to collect the water, which was wicked out from the soil by the wicking geotextile and evaporated into air. Test results show that (1) the wicking geotextile wicked water out from the soil even at the moisture content close to the optimum moisture content and (2) the comparison of soil moisture contents before and after rainfall demonstrated that the wicking geotextile maintained the soil moisture contents after rainfall close to those before rainfall and had an effective distance for the soil moisture reduction.

1. Introduction

Both woven and nonwoven geotextiles, are commonly used for reinforcement and/or drainage purposes in civil engineering practice. Researchers have investigated the behavior of geotextiles for hydraulically-related applications including (1) hydraulic properties and behavior of geotextiles included in different types of soils (Stormont et al., 1997, 2010; Ho, 2000; Iryo and Rowe, 2005; Bhattacherjee and Viswanadham, 2015); (2) design methods and criteria for geotextiles to meet drainage requirements (Holtz et al., 1997; Lee and Bourdeau, 2006); and (3) used as capillary barriers (McCartney and Zornberg, 2010; Zornberg et al., 2010). Most of the studies have been focused on the drainage of water through geotextiles under the influence of gravity. Geotextiles have been increasingly used for roadway drainage applications, which often have a transition from a large amount of water supply (especially after heavy rainfall) to a small amount of water supply (such as a long time after rainfall). Under the large amount of water supply, the soil is typically saturated or close to saturation. However, under a small amount of water supply, the soil is likely unsaturated. Conventional geotextiles are only effective when the soils are saturated with the help of gravity. However, conventional geotextiles cannot drain water out from unsaturated soils with the influence of gravity only (Iryo and Rowe, 2003). In addition, water ponding due to an uneven interface between base course and subgrade may reduce or result in no hydraulic gradient. Under this situation, water cannot be drained out from soil by a conventional geotextile. The drainage behavior of geotextiles under saturated conditions is different from that under unsaturated conditions. Iryo and Rowe (2003) pointed out that geotextiles could change from being permeable to impermeable only by a small change of suction.

A few studies have been done in the past decades on the behavior of geotextiles under unsaturated conditions. Bouazza et al. (2006) found that clogging of a nonwoven geotextile could affect its water drainage characteristic curves. As such, possible foundation distortion could be induced due to the accumulation of water above the geotextile. Stormont and Morris (2000) reported the potential for clogging of a geotextile due to the soil fines (<200 μm) sticking

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to the geotextile, which also reduced its hydraulic conductivity in an unsaturated condition. Bathurst et al. (2007) developed a one-dimensional (1-D) column apparatus to investigate the unsaturated-saturated response of a sand-geotextile system. They observed transient water ponding above the surface of the geotextile due to the accumulation of water under the initial unsaturated condition regardless of the subsequent saturated process. Hatami and Esmaili (2015) conducted small-scale pullout tests on geotextiles in soils with different moisture contents to investigate the influence of moisture content on the shear strength at the interface of soil and geotextile. Esmaili et al. (2014) proposed a moisture reduction factor to consider the effect of the moisture content of soil on the pullout resistance of a geotextile. Garcia et al. (2007) conducted laboratory tests to study the hydraulic behavior of permeable geosynthetics within unsaturated embankments subjected to rainfall infiltration. A series of tests in both laboratory and field have been conducted to investigate the performance of Geocomposite Capillary Barrier Drains (GCBD) in roadway applications (Stormont and Stockton, 2000; Henry and Stormont, 2002; Stormont and Ramos, 2004; Stormont et al., 2009; Stormont et al., 2010). The GCBD system consists of three layers from top to bottom: a transport layer (fiberglass or polypropylene geotextile); a capillary barrier (geonet); and a separator (geotextile). The transport layer transports water drained by gravity from a base course, the capillary layer stops water upward and downward, and the separator prevents the intrusion from subgrade to base course. Test results indicate GCBD is effective to limit the moisture change in the base course. However, a three-layer system may cause some difficulties in the construction in terms of the time of construction, the treatment of the overlap, and the cleanness of the layer interface.

A new type of woven geotextile, referred to as a wicking geotextile, has been developed by a geosynthetic manufacturer and introduced to the market, which combines functions of reinforcement, drainage, capillary action, and separation by a single layer of geotextile. This wicking geotextile is made of special hydrophilic and hygroscopic 4DG™ (DG = deep groove) fibers with multichannel cross sections. The diameters of the micro-channels vary from 5.7 microns to 47.8 microns (Han and Zhang, 2014). The multichannel cross section has a high shape factor (defined as the ratio of the area of the profile to the area of a circle having the same perimeter) and a number of channels per fiber, which enable the wicking geotextile to have capillary action and water transport in an unsaturated environment. The specific surface area of the wicking fiber is 3.65 m^2/g (Han and Zhang, 2014). The mechanism of removing water by the wicking geotextile can be considered as three stages: (1) water is sucked into the wicking geotextile by the capillary force generated by the wicking fibers embedded in the wicking geotextile; (2) water is transported along the wicking geotextile to the exposed portion by the suction difference between the exposed and the submerged (or buried) portions; and (3) water evaporates and/or drops from the exposed portion of the wicking geotextile. Zhang et al. (2014) reported a field test on the use of the wicking geotextile to mitigate frost boils in Alaskan roads. The field results showed a significant effect on moisture reduction in the roads and the prevention of the frost boils. Azevedo and Zornberg (2013) investigated the unsaturated properties of the wicking geotextile using a small soil column filtration test. They found that the wicking geotextile was more effective for lateral drainage than the conventional geotextile. Guo et al. (2016) investigated the maximum water removal rate of the wicking geotextile in water tanks under controlled temperature and relative humidity conditions. A concept of equivalent water evaporation length was proposed to quantify the water removal ability of the wicking geotextile in water. However, no study has been done so far to quantify the wicking ability of the wicking geotextile for roadway applications so that an appropriate design method can be developed.

In this study, a physical model test was developed to quantify the wicking ability of the wicking geotextile and to evaluate the effectiveness of the wicking geotextile in moisture reduction of a road section, which consisted of a base course over a subgrade. A dehumidifier was adopted to collect the water drained or wicked out from the soil by the wicking geotextile and evaporated into air. The effectiveness of the wicking geotextile was also evaluated with a rainfall of 38.1 mm/h (a typical rainfall magnitude in Kansas (Han, 2015)) for 40 min.

2. Test methodology

2.1. Test setup

Fig. 1 shows the schematic of the test setup. A plastic box with a dimension of 1041 mm in length, 686 mm in width, and 584 mm in height was purchased and used to build the test box. Two pieces of 13 mm thick HDPE plastic panels were used to separate the box into two partitions, one to be backfilled with soil and gravel, and the other to contain a dehumidifier to collect water removed from the soils by the wicking geotextile. A dehumidifier under normal operation generates heat, which can influence water evaporation. To minimize the temperature effect, the top of the partition containing the dehumidifier was open to release the heat generated from the dehumidifier. The temperature and the relative humidity inside the partition were monitored during the test, which ranged from 22 °C to 26 °C and 33%–50%, respectively. The temperature and the relative humidity in the room ranged from 21 °C to 25 °C (average 23 °C) and 27%–32% (average 30%), respectively. When the top of the dehumidifier section was open, the dehumidifier could collect the water from air. The dehumidifier was calibrated in air before construction of the road section inside the box and verified by a repeatability test. The capacity of the dehumidifier is 1.5 L/day. It works with a voltage of 115 V and a frequency of 60 Hz. A gasket at a height of 381 mm from the box bottom was attached at the interface between these two box panels. This gasket allowed the placement of the wicking geotextile and prevented any possible water leakage. The box separator was stabilized using a steel frame made of 25 mm wide square steel tubes, which was connected with the two sides of box walls.

2.2. Test material preparation

The subgrade material used in this study was an artificial mixture of Kansas River sand and kaolinite with a ratio of 3:1 by

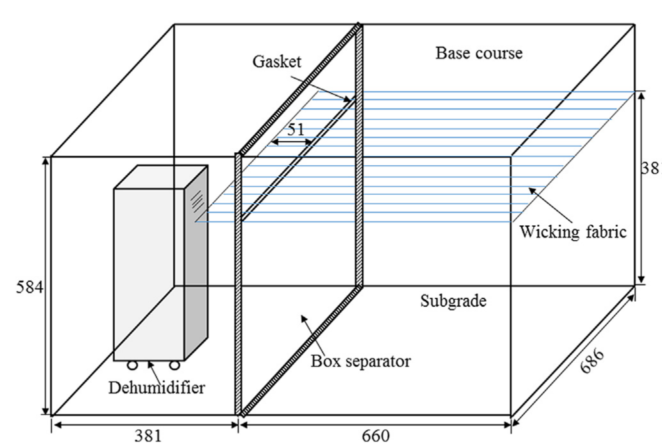

Fig. 1. Schematic of the test setup (unit: mm, not to scale).