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Effect of infiltration on the performance of an unsaturated geotextile-reinforced soil wall

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ABSTRACT

A full-scale geotextile-reinforced soil wall was built in order to assess the characteristics of water infiltration and its effect on the structure performance. Nonwoven geotextiles were selected as inclusions in order to provide not only reinforcement, but also internal drainage to the fine-grained soil used as backfill material. The structure was built in a laboratory setting, which facilitated implementation of a thorough instrumentation plan to measure volumetric water content changes of soil, suction, facing displacements and reinforcement strains. An irrigation system was used to simulate controlled rainfall events. The monitoring program allowed the evaluation of the advancement of infiltration and internal geosynthetic drainage. Evaluation of the effect of the hydraulic response on the overall performance of the structure included assessment of the development of capillary breaks at soil-geotextiles interfaces. Capillary breaks resulted in water storage above the geotextile reinforcements and led to retardation of the infiltration front in comparison to the infiltration that would occur without the presence of permeable reinforcements. After breakthrough, water was also found to migrate along the geotextiles, suggesting that the reinforcement layers ultimately provided in-plane drainage capacity. While generation of positive pore water pressures was not evidenced during the tests, the advancing infiltration front was found to affect the performance of the wall. Specifically, infiltration led to increasing reinforcement strains and facing displacements, as well as to the progressive loss of suction. While the accumulation of water due to the temporary capillary break also resulted in an increased backfill unit weight, its effect on deformation of the wall was not possible to be captured but it is intrinsic on the overall behavior observed in this study. Correlations between reinforcement strains/face displacement and the average of suction in the backfill soil, as measured by tensiometers in different locations within the backfill mass, point to the relevance of the suction as a representative indicator of the deformability of the geotextile-reinforced wall subjected to water infiltration. Reinforcement strains and face displacements were found to reduce more significantly with reduction of suction until a certain value of suction from which the rate of decreasing declines.

1. Introduction

Nonwoven geotextiles have often been reported to successfully reinforce fine-grained soils in earth retaining walls and embankments (Tatsuoka and Yamauchi, 1986; Gourc and Matichard, 1992; Mitchell and Zornberg, 1995; Wayne et al., 1996; Ehrlich et al., 1997; Benjamin et al., 2007; Portelinha et al., 2013, 2014). In particular, the use of nonwoven geotextiles has been reported to facilitate the use of on-site fine-grained backfill materials, resulting in important cost savings. This is because the use of nonwoven geotextiles as reinforcement layers is expected to allow internal drainage that, in turn, leads to improved stability by dissipating pore water pressures during construction or precipitation events.

In fact, a number of the reported studies have indicated an adequate performance of geotextile-structures constructed using poorly draining backfill, even when subjected to significant periods of rainfall events (Carvalho et al., 1986; Tatsuoka and Yamauchi, 1986; Mitchell and Zornberg, 1995; Wayne et al., 1996; Portelinha

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et al., 2013, 2014).

The effectiveness of in-plane drainage provided by permeable geosynthetic reinforcements (e.g., nonwoven geotextiles, geocomposites) has been previously evaluated and quantified using different approaches (e.g. pullout tests, full-scale models, small-scale models). The benefits of minimizing the generation of positive pore water pressures has been a common finding in these studies (Perrier et al., 1986; Ling et al., 1993; Mitchell and Zornberg, 1995; Kempton et al., 2000; Tan et al., 2001; Zornberg and Kang, 2005; Ghionna et al., 2010; Portelinha et al., 2013; Bhattacherjee and Viswanadham, 2015; Thuo et al., 2015). Some of these studies have concluded that internal drainage enhances internal stability by facilitating the development of conditions corresponding to a drained soil behavior (Yamanouchi et al., 1982; Tatsuoka and Yamauchi, 1986; Yunoki and Nagao, 1988; Zornberg and Mitchell, 1994; Bhattacherjee and Viswanadham, 2015).

Since the water pressures within an unsaturated soil mass are negative, their understanding requires evaluation of the unsaturated hydraulic and mechanical characteristics of geosynthetics, backfill, and interfaces (Iryo and Rowe, 2005; Bouazza et al., 2013; Thuo et al., 2015; Vahedifard et al., 2016). Zornberg et al. (2010) reports the development of capillary breaks when nonwoven geotextiles underlay unsaturated soils. This is because under unsaturated conditions the hydraulic conductivity of nonwoven geotextiles is typically lower than that of the overlying soil. This phenomenon results in additional storage of moisture at the soil-geosynthetic interface until the suction decreases below a value identified as the “breakthrough” suction. The capillary break effect has been observed to increase the water storage capacity of soils (Stormont et al., 1997; Khire et al., 2000; McCartney and Zornberg, 2010).

Iryo and Rowe (2005) conducted finite element simulations of the hydraulic behavior of permeable geosynthetics within unsaturated embankments subjected to infiltration. The study showed that nonwoven geotextiles would delay water infiltration in situations where the soil pore water pressures are negative, whereas they would enhance drainage in situations where the pore water pressures are positive. The authors also found that nonwoven geotextiles would only act as internal drains after a moisture threshold has been reached and that drainage could be improved by installing the reinforcement on an inclined grade. This study also reported that the contribution of nonwoven geotextiles to the stability of embankments constructed with fine-grained soils is less relevant as a drainage material than as a reinforcement material. In a similar finite element study, Bhattacherjee and Viswanadham (2015) reported that the use of a hybrid-geosynthetic layers (i.e., dual function material providing drainage and reinforcement) is effective for reduction in excess pore water pressure. Further, the global stability of a hybrid-geosynthetic-reinforced slope was found to increase considerably, while the deformation values were significantly lower for the reinforced slope as compared with that of the unreinforced slope.

Garcia et al. (2007) tested small-scale reinforced embankment models built using permeable geosynthetics (nonwoven geotextiles, woven/nonwoven geocomposites and strips of nonwoven geotextiles). The embankments were subjected to cycles of wetting and drying. Pore water pressures (negative and positive) and volumetric water content values were monitored. The results showed that geosynthetics embedded within the soil showed drainage capabilities only when the pore water pressures of the overlying soil reached values close to zero or became positive. Local failure during the wetting process was reported when positive pore water pressures were observed to develop above the soil-geosynthetic interface. In models where strips of nonwoven geotextiles were used, water did not accumulate over the soil-geotextile interface. Strips of geotextile were reported to prevent the development of capillary break and to allow drainage of water within the embankment.

Krisdani et al. (2010) built a small-scale slope model to simulate a sloping capillary break. The model involved a 0.20 m thick fine sand layer (as the fine-grained layer) and a nonwoven geotextile (as the coarse-grained layer). The objective was to investigate the development of capillary breaks and the efficiency of internal drainage layers. Rainfall events of different intensities and durations were applied over the model. The test results indicated that presence of the geosynthetic led to the development of a capillary break and prevented water infiltration into the underlying soil layer. Lateral diversion flow was found to develop along the fine-grained layer (fine sand), which was interpreted as an indication of the development of a capillary break during rainfall events.

Other relevant aspect to be assessed in unsaturated reinforced soil structures is the fact that suction might change when subject to infitration resulting in reduction on shear strength and shear modulus of soil. In the last decades, many studies have been dedicated to describe the effect of suction on the shear strength of soils (Bishop et al., 1960; Fredlund and Morgernstern, 1977; Fredlund et al., 1978; Karube, 1988; Toll, 1990; Wheeler and Sivakumar, 1992, Vanapalli et al., 1996; Khalali and Khabazz, 1998). Recently, studies have been conducted in order to describe the relationship between suction and shear modulus of soil (Cabarkapa et al., 1999; Mancuso et al., 2002; Ng and Yung, 2008; Ng and Xu, 2012). Generally, authors have reported that the shear modulus increases until a certain value of suction from which no significant increases in modulus is reached. The rate of increasing declines when the suction is higher than the air-entry value of the soil.

In summary, while previous studies on the infiltration into unsaturated geotextile-reinforced soil systems have used small-scale models or numerical simulations, no full-scale study has been reported so far on this relevant issue. In particular, only limited information is currently available on the effect of water infiltration on the overall performance of geosynthetic-reinforced walls. This includes the lack of the quantification of wall deformations that could be induced by wetting and development of capillaty breaks during infiltration. Accordingly, an important objective of this study is to evaluate the infiltration process into the unsaturated fill in a geotextile-reinforced wall and its effect on the structure mechanical response. This is achieved by monitoring the performance of a large-scale reinforced soil wall. The experimental program focuses specifically on the impact of infiltration into the backfill of a wall reinforced with nonwoven geotextiles. Reinforcement strains and face displacements are used as key aspects to quantify the wall performance.

2. Experimental program

The experimental program in this study involved monitoring the hydraulic and mechanical responses of a full-scale geotextile-reinforced wall subjected to infiltration. The model reported in this paper is part of a series of full-scale walls constructed in the Geosynthetics Laboratory of the Sao Carlos School of Engineering at the University of Sao Paulo, Brazil. The characteristics of the wall reported in this paper are discussed next.

2.1. Reinforced steel frame

A reinforced steel frame was used to house the series of full-scale reinforced soil wall structures, which were 1.8 m high and 1.55 m wide, with backfill soil extending to a distance of 1.8 m from the front edge of the box. The structure was founded on a rigid