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Experimental and numerical study of geosynthetic reinforced soil over a channel

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ABSTRACT

Geosynthetics have been commonly used as reinforcement layers to bridge over underground cavities, sinkholes, and trenches to support upper soil mass. In such applications, the geosynthetics, acting as tensioned membranes plus the effect of soil arching, maintain the stability and mitigate the subsidence of the overlying soil. This study, including a two-dimensional experimental testing and subsequent numerical simulations, investigates the subsidence of the soil mass and deformation of the geosynthetics over a roadway subdrain. The experimental study was performed in a fabricated container with 7 trapdoors (125 mm each) at the bottom. One of the trapdoors was lowered to mimic a trench for sub-drain. Cylindrical aluminum bars were used as "soil" in the experimental testing to imitate the two-dimensional (2D) situations. A layer of geotextile was placed underneath the "soil fill" to serve as the reinforcement. Following the experimental test, a numerical simulation was carried out, using Discrete Element Method, PFC^{2D}, to extend the scope of the experimental study. The results indicated that (1) the deformed shape of the geosynthetic layer is approximately parabolic, (2) the subsidence was decreased hyperbolically in the vertical direction and the lateral influence range appeared to be bounded by two lines inclined at ($45^\circ + \phi/2$), and (3) the friction angle showed significant influence on subsidence and tension in geosynthetic.

1. Introduction

Shallow underground cavities and channels are common in some areas, especially in the karst terrain and ground water active regions (Jennings, 1971; LeGrand, 1973). A cavity or channel forms when the subsurface soil/rock is dissolved, eroded, and transported. Also inappropriately graded retaining wall or embankment fill can lead to migration of material and eventually formation of cavities (Aubeny et al., 2013). Cavities and channels can cause a substantial surface subsidence or even collapse if not appropriately designed (Han et al., 2008). In recent years, due to the oil booming in south of the U.S., overweight trucks become frequent and damage pavement subdrains that are usually perforated PVC pipes across the pavement section to guide water out. The pipes are usually 50–125 mm in diameter, located in the subgrade soil and separated from the sub-base course layer by a layer of geotextile. The excessive load from overweight trucking crushes the pipe, leading to a channel underneath the pavement.

Such incidences are relevant to many completed studies on using geosynthetics to support soil mass over cavities or local soft zones, for example, the studies by Bonaparte and Berg (1987), Kinney and Connor (1987), Giroud et al. (1990), Chew et al. (2004), Han et al. (2008), Villard and Briancon (2008), Wang et al. (2009), Bhandari (2010), and van Eekelen et al. (2015). The outlined principle from these studies is the load transfer induced by soil arching and tensioned membrane (Marston, 1929; Terzaghi, 1936, 1943; Hewllet and Randolph, 1988; Delmas, 1979; Giroud et al., 1990). Based on different soil arching and tensioned membrane theories, a few design methods have been developed to design the earth structures using geosynthetic as reinforcement to bridge over incompetent soil or voids. These methods have shown discrepancy in terms of the load transfer ratio (the ratio of the reduced stress to the overburden stress) and tension in geosynthetics (Naughton and Kempton, 2005). More importantly, there is no method available to estimate the subsidence of the soil mass. Huang (2007) pointed out that the soil subsidence was very

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important and influenced the serviceability of the superstructure. The objective of this study is to investigate the subsidence of soil, the deformation of the geosynthetics, and the influence range due to the formation of a channel underneath the roadways.

This study encompasses experimental testing and a numerical simulation that was based on a discrete element method (DEM). The data from the experimental testing and the numerical simulation were used in conjunction to examine the soil subsidence, geosynthetic deformation, and the influence range of the soil arching. The numerical parametric study further determined the influence of soil friction angle, overlying soil thickness and grain size distribution on soil subsidence and geosynthetic deformation.

2. Experimental testing

2.1. Testing facility

The experimental testing was designed considering the typical size of pavement subdrain (50–125 mm) as well as the two-dimensional (2D) feature of the channel. A test chamber having a dimension of 875 × 650 × 50 mm^3 (length × width × height) was fabricated for this purpose as shown in Fig. 1. The chamber was made of aluminum alloy except for the front wall that was an acrylic sheet to allow visual observation and photogrammetry measurements. The bottom of the chamber consisted of seven wooden blocks, each of which was 125 mm long and supported by two steel bars. The steel bars can be lowered to create a differential settlement or remove the support to simulate a channel. A layer of non-woven geotextile was placed on top of the wooden blocks, acting as a separator and then basal reinforcement. Cylindrical bars of different diameters but uniform length of 48 mm were used as the substitutes of soil particles in this study to create a two-dimensional condition, namely the bars were constraint in z-direction and could only move in x- and y-direction. The cylindrical bars, made of aluminum alloy, have a specific gravity of 2.7 which is similar to soils'. Aluminum bars have three diameters, i.e., 5.6, 12.7, and 19.0 mm. The length of the bars was 48 mm and slightly less than the width of 50 mm (that is the dimension of the test chamber in z-direction). Thus, the friction between the aluminum bars and the front and back wall of the chamber was negligible. The cross-sections were colored differently based on their diameters. The identification numbers and center crossings were marked on the cross-sections for the purpose of tracking the movement of the bars as shown in Fig. 2. The "soil" was produced by mixing the bars of different diameters with a pre-determined weight ratio, namely $W_{diameter = 19.0\ mm}$: $W_{diameter = 12.7\ mm}$: $W_{diameter = 5.6mm}$ = 1:1:2. The mixing was conducted manually until uniform distribution was achieved. Photogrammetry was adopted to track the movement of the bars. A reference scale was attached to the acrylic sheet. A remote controlled camera was attached rigidly on a heavy-duty tripod and stationed at about 1.5 m away to capture the movements of the bars during the tests. The test chamber was rigidly attached to a shake table that provided vibration to remove excessive void between bars after filling the chamber.

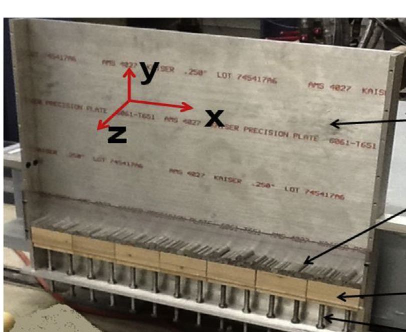

Fig. 1. Test chamber setup.

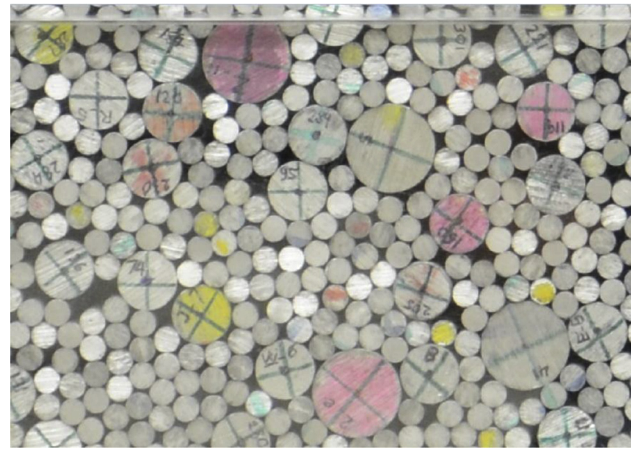

Fig. 2. Simulated soil particles with Bar IDs, center crossings and colors. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2.2. Material properties

The cylindrical aluminum bars have a Young's modulus of 79 GPa. According to the manufacturer, the coefficient of friction of the surface is 0.05. Due to the high Young's modulus of aluminum, the simulated soil movement induced by the deformation of the bars is negligible.

A layer of needle punched non-woven geotextile with an ultimate tensile stiffness of 600 N/m was used. Such type of geosynthetics, though not typically used as reinforcement in the field, was intentionally used in this study since such geotextiles are typically used to separate subdrains from sub-base materials. This geotextile will act as an auxiliary reinforcement when a channel is formed underneath the sub-base.

2.3. Test procedure, instrumentation, and measurements

The test started with proportioning bars to a weight ratio of 1:1:2 and then mixing them manually. The uniformity of the mixing was verified by randomly sampling bars from the batch and weighing the bars for each size. The uniformity was considered being achieved when three consecutive samplings achieved the intended ratio. Before filling the bars into the chamber the wooden blocks at the bottom were aligned to ensure they were at the same elevation. A layer of geosynthetic was placed on top of the wooden blocks. The bars were filled into the box up to the required height (250 mm) with the marks (i.e., color, ID, and crossing) facing the front-view. The filling was handled with caution, namely the bars were dropped from a minimal height to prevent impacting and rolling. A minor vibration was applied to avoid excessive voids among the bars. The filling height was checked with a tape measure.

Upon placing the bars, the camera was fixed at about 1.5 m from the test box, facing the front. Then, the following steps were carried out sequentially: (1) taking a photo to record the initial positions of the bars as shown in Fig. 3(a), (2) lowering the central wooden block until it was not in contact with the geosynthetic, and (3)