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Investigation of load transfer mechanisms in granular platforms reinforced by geosynthetics above cavities

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ABSTRACT

Geosynthetic-reinforced soils constitute an interesting solution for bridging cavities. Many methods have been developed to analyze the stability of soil-geosynthetic-cavity systems, but none of them is able to take into account all the complexities of these mechanisms. Many researchers have assumed mechanisms developed in the reinforced granular platform when cavities appear, such as load transfer and expansion of materials. However, they are not fully understood because many factors can influence the design, such as the cavity opening processes, the type, and the density of the soil.

In this study, a new laboratory apparatus is developed to simulate two different cavity opening procedures (trapdoor and progressive opening) for different geometric configurations. A series of tests is conducted for three granular soils with two different geosynthetic sheets. By measuring the shape of the surface soil settlement and the geosynthetic deflection, the expansion coefficient is calculated. A novel tactile pressure sensor is used to observe the load transfer during the cavity opening. The experimental data are analyzed and the influence of the experimental conditions (geometric and soil properties and the opening procedure) are also discussed. Correspondingly, elicited findings can be used to propose recommendations to improve the existing design methods.

1. Introduction

Today, there is an increasing need to develop infrastructures in many areas. This has led to, among others, the construction of highways and railway line projects. Sometimes, these constructions have to cross hidden underground cavities, and as it is not easy to detect them or cavities can appear after the construction of the infrastructure structures can be damaged.

At present, the use of reinforcement materials, especially geosynthetic materials, provide an acceptable solution to prevent damages due to cavities. This solution has been extensively used because it ensures the stability and durability of structures, and possesses many advantages, including easy installation and minor environmental impacts. The difficulty associated with this solution is the lack of understanding of the behavioral mechanism of geosynthetics that is applied to cavities. In particular, the main knowledge gap pertaining to the latest design methods is the load transfer mechanism acting through the granular embankment (Huckert et al., 2016).

This research study introduces novel laboratory equipment to deal with the load transfer mechanisms of the granular platform reinforced by geosynthetics. A series of 50 physical modeling tests were carried out using two cavity opening methods, a trapdoor and a progressive procedure, two geosynthetics, and three soils. For each type of soil, three platform heights were tested. This experimental study has been pursued to complete the full-scale experiment of Huckert et al. (2016), and to validate experimentally the conclusions of the numerical simulations proposed by Villard et al. (2016) on the influence of the cavity opening mode. From the experimental results, the load transfer mechanisms are analyzed, the soil expansion coefficient is defined, and the influences of the geometrical and physical parameters are studied.

2. Background

2.1. Mechanisms

The existing design methods take into account various mechanisms occurring during the opening of a sinkhole under a geosynthetic-reinforced embankment. Specifically.

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The membrane effect of the geosynthetic sheet
The friction between the soil and the geosynthetic in the anchorage areas around the cavity
The load transfer within the embankment
The expansion of the granular material over the cavity

Geosynthetics have low-bending rigidity due to their structure. When they are subjected to stresses that are perpendicular to their horizontal deformation, they take the shape of a membrane so that the tensile forces guarantee the static equilibrium of the sheet. Based on homogeneous and isotropic sheets considered under a single loading, a two-dimensional (2-D) theory was developed by Giroud (1995) to study membrane effects.

In addition, the horizontal deflection of the sheet could increase due to the displacement of the geosynthetics in the anchorage area required to fully mobilize the friction. The friction between the sheet and soil in the anchorage areas and its stretching occur because of the tension of the sheet developed above the cavity. The mobilization of this friction requires a relative displacement between the geosynthetic sheet and the surrounding soil. The friction at the soil/geosynthetic interfaces is described by the Coulomb friction law (Briançon and Villard, 2008). At the edge of the cavity, due to friction between the curved sheet and the soil, there is a decrease of the geosynthetic tensile force according to the orientation change of the sheet. The design method proposed by Briançon and Villard (2008) was extended by Feng and Lu (2015) to the case where the reinforced platform is subjected to two adjacent voids.

Taking into account the cavity appearance, the volume of subsidence soil should be considered. The shape of the collapsed soil above the cavity could be defined based on different assumptions: a truncated cone or a cylindrical shape. In addition, if shearing mechanisms occur, an arch could appear inside the embankment over the sinkhole. The arching effect is known as the transfer of pressure from a yielding mass of soil onto adjoining stationary parts (Terzaghi, 1943). Even if such design methods propose to evaluate the arching effect from simplified assumptions, the arching mechanism is not well defined due to the influence of various parameters, such as the cavity opening mode, geometrical conditions, geosynthetics, and soil characteristics. Feng et al. (2017a, b) proposed a new method considering a nonlinear Mohr-Coulomb yielding criterion, a non-associated flow rule and a static equilibrium of segmental arches through a dilatancy coefficient. They concluded that their method is more appropriate for reinforced structures with significant geosynthetic deflection.

To appreciate the load transfer mechanisms within the granular embankment, Villard et al. (2016) presented the efficiency ratio (E), which is defined as the ratio between the load on the sides of the cavity and the weight Ws of the cylindrical part of the soil over the cavity. Based on the load that acts on the geosynthetic placed above the cavity F_g, the efficiency of the load transfer within the granular embankment can be defined in accordance to $E = (W_s - F_g)/W_s$ (Fig. 1).

During the collapse of a granular soil layer, movement of particles leads to an increase in the volume of the soil. The expansion coefficient Ce is defined as the ratio between the final volume of the soil, which is located above the cavity, and the initial volume (Villard et al., 2000). The soil expansion could appear in either a truncated cone or a cylindrical soil collapse, thereby leading to a significant reduction in the soil surface settlement. In order to determine this coefficient, it is necessary to compute the volume of the deformed shapes of both the soil surface and the geosynthetic deflection. Many previous researchers assumed that a parabolic fit could be used for the estimation of the value of Ce as the ratio between the maximum deflection of geosynthetics (dg) and the surface settlement (ds) (Fig. 2). Nevertheless, this assumption has not been approved because the shapes of both the surface soil and geosynthetics are not exactly parabolic (Villard et al., 2016). Finally, a plane of equal settlement defined by Terzaghi (1943) can appear if the thickness of soil mass over a cylindrical collapsed area is large enough.

2.2. Existing analytical methods

Currently, two analytical design methods of granular embankment reinforced by geosynthetics are used commonly in Europe. Taking into account a cylindrical soil collapse above the cavities and the soil expansion, a method has been proposed in the findings of the French research project, RAFAEL (Giraud, 1997), based on full-scale experiments and finite element analyses. This method uses the limit equilibrium method of Terzaghi (1943) to calculate the applied load on geosynthetics. In the absence of soil expansion, the British standards BS 8006 (1995, 2010) deal with the peak friction angle to define the subsidence soil, whereas for the collapsed shape, a truncated cone geometry is assumed. Moreover, some of the aspects of RAFAEL's method, including a minor adjustment for expansion computing, suggest the use of the German standards EBGEO (1997, 2011), which elicits similar results to those reported by Schwerdt et al. (2004).

A better understanding of the expansion of the soil and load transfer mechanisms within a granular embankment was accomplished by Briançon and Villard (2008) and Villard and Briançon (2008). This was achieved by considering overlapped areas and continuous sections based on a parametric study of three different cases of geosynthetics with different stiffness and platform height values. This study showed several remarkable influences of the expansion coefficient and cavity diameter. Specifically, an increase in the expansion coefficient led to a considerable decrease in surface settlement, whereas an inverse dependence relationship on cavity diameter was also presented.

During the deformation process, an arching could develop in different shapes affected by many impacts. Considering the load distribution on geosynthetics above the cavity, an assumption of a

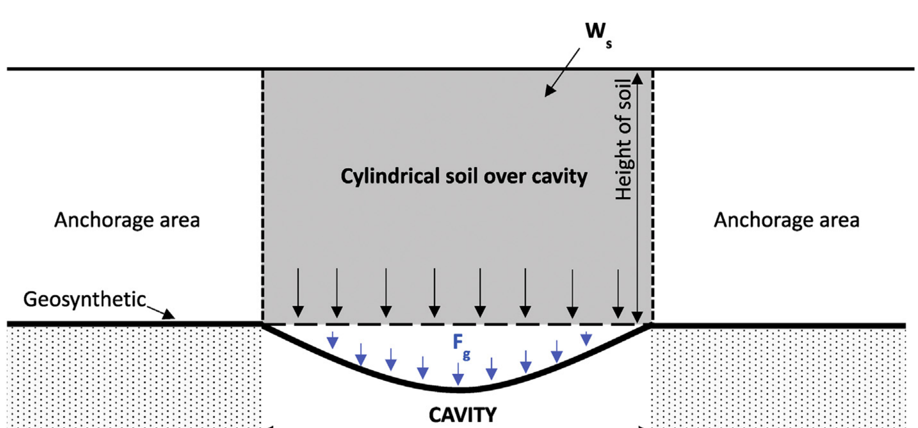

Fig. 1. Definition of efficiency based on W_s and F_g.