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Load transfer mechanisms in geotextile-reinforced embankments overlying voids: Experimental and analytical approaches

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ABSTRACT

The techniques of soil reinforcement by geotextile are easy and economic solutions that limit the surface settlements of embankments prone to sinkholes. The design of such structures is based on understanding complex mechanisms, such as the tensile geosynthetic behavior under vertical loading, the frictional interaction between the soil and the reinforcement, the load transfer mechanisms and the arching effect in the soil embankment. Recently, significant progress has been made, allowing for improvement of the design methods by taking into account the frictional and sliding effects of the geosynthetic sheet in the anchorage areas and the local increase of the vertical stresses in the vicinity of the edges of the cavity. Nevertheless, the soil dilatancy, or the load transfer mechanisms in the embankment during the formation of the cavity or under static or cyclic loadings, remains unknown. Additionally, the reinforced, treated soil layer has not been specifically studied. To focus on the soil embankment behavior over a void, experimental studies were conducted as part of the FUI research project GéoInov.

Sinkholes are experimentally simulated under granular embankments and treated soil layers, both reinforced by geotextiles. Each void is created by a device that allows the progressive formation of a circular cavity with an increasing diameter of 0.75, 1.25 and 2.2 m. This enables reproduction of the formation of some natural sinkholes. After the void reaches a size of 2.2 m wide, traffic loads are applied on the top surface of the embankment. Then, during both the formation of the cavity and the vehicle traffic loading, a dedicated instrumentation is used to measure the dilatancy and the soil movement, the load transfer, the deformation of the geotextile and the surface settlement. The experimental results are then analyzed and compared with existing analytical methods to improve the existing analytical methods.

1. Introduction

In many countries, the construction of new road and railway infrastructures increasingly occurs in areas with poor geotechnical characteristics or even in areas that present a high risk of localized sinkholes, such as karstic regions or former mining exploitation areas. To ensure the stability and longevity of these structures, various reinforcement methods, such as piles, nails, or geosynthetics, are used. These reinforcements are then expected to withstand the formation of a sinkhole with a given diameter after the construction of the infrastructure.

Among reinforcement structures, the use of geosynthetic sheets is widespread because the solution saves time for a moderate cost, with remarkable ease of installation and relatively limited environmental impact. The difficulty of this solution is in the definition of an appropriate design for geosynthetic-reinforced embankments overlying voids because the physical mechanisms involved in such structures are not yet fully understood.

According to the geotechnical environment, the size, the depth and the evolution of an underground cavity may differ between sites. Additionally, the way the void opens at the surface and the

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role of the geosynthetic reinforcement may depend on the embankment material in which the geosynthetic is inserted, such as frictional granular materials or cohesive treated soils.

The main gaps of the latest design methods are due to the misunderstanding of the load transfer mechanisms acting within the granular embankment and to the assumptions made about the nature of the distribution of the loads acting on the geotextile sheet, which are currently considered, both in the anchorage areas and over the cavity, as uniform as a simplification. Another issue raised for the analytical design is the expansion mechanism of the embankment material above the cavity during collapse, which is of prime importance to estimate the surface settlement. A global and uniform expansion factor is usually taken into account, leading to overestimation of the expansion behavior, especially for large cavities. Last, the existing methods only apply to fill embankments made of conventional granular materials. The case of treated soil layers is usually not addressed.

To gain a better understanding of reinforced structures overlying voids, experimental and numerical works were performed as part of the FUI (Inter-Ministry Fund) French research project GéoInov. The aim of this project, supported by the competitiveness poles Techtera (Technical Textiles Rhône Alpes) and Fibers as part of the 10th call for projects of the DGCIS (Direction Générale de la Compétitivité, de l'Industrie et des Services), is to optimize the design and mechanical properties of geosynthetic reinforcements. This project is driven by the manufacturer Texinov and is supported by industrial and researcher partners: Afitex, Egis Géotechnique, IFTH (Institut Français du textile et de l'Habillement), the 3SR Lab (Sols, Solides, Structures, Risques) and the Cnam (Conservatoire National des Arts et Métiers).

This paper describes full-scale experiments specifically designed to integrate the progressive opening of six circular cavities by increasing their diameter under a granular embankment or a treated soil layer.

Dedicated instrumentation was developed to gain a full understanding of the behavior of the structures as whole entities. The results of the experiments are then discussed and compared with results of the latest analytical design method (Briançon and Villard, 2008).

2. Background

2.1. Experiments in this field

At the present time, the technique of reinforcement of road or railway embankments by geosynthetics raises constant interest due to the necessity of building new infrastructure in areas prone to subsidence. In this context, experimental, numerical and analytical works were performed leading to the understanding of some of the mechanisms of the process of reinforcement. This type of reinforcement could be used in landfills (Feng and Lu, 2015), road (Galve et al., 2012; Huang et al., 2015) or railway (Villard et al., 2000).

The first full-scale experiments performed to test this type of reinforcement over a void were two-dimensional sinkhole tests (Kinney, 1986) conducted under narrow trenches (1.22 m–2.07 m wide) and granular embankments of thickness 0.76 m. Due to the low tensile stiffness of the geosynthetics used ($J = 73$ kN/m to 180 kN/m) these experiments led to considerable surface deformations. Additional experiments were performed over trenches (Kinney and Connor, 1987, 1990), which consisted of the excavation of the trench, the installation of a geosynthetic sheet and the implementation of the granular embankment.

Due to the process of realization, these applications provide information about the behavior of the geosynthetic sheet under loading. The first applications dealing with circular cavities were conducted by Kempton et al. (1996), Alexiew (1997) and Bridle and Jenner (1997) using various types of reinforcements.

The experiment conducted by Bridle and Jenner (1997) consisted of the simulation of a circular cavity with a diameter evolving from 3 to 5 m. The overlying granular fill was reinforced by two geogrids, one on top of the other. A relationship between the tensile forces, the geosynthetic deflection and the diameter of the cavity was proposed (Bridle and Jenner, 1997), leading to a method to determine the maximum bearable cavity diameter for the reinforced structure.

The following experimental work, which is currently used by European design methods and standards, refers to the two phases of the French research project “RAFAEL” (Renforcement des Assises Ferroviaires et Autoroutières contre les Effondrements localisés).

The first phase of the RAFAEL project (1997) consisted of the formation of sinkholes of 2 m and 4 m in diameter under a geosynthetic-reinforced cohesive granular embankment by removing the clay pebbles located in the cavity by suction.

The second phase (1999) was performed to highlight the influence of the nature of the fill embankment and consisted of the formation of sinkholes using a circular plate and jacks. The lowering of the plate located under the geosynthetic sheet created circular cavities under soil embankments made of sand, gravel (ballast) or clay. These experiments defined different behaviors of the embankment depending on the ratio H/D of the height of the embankment to the diameter of the cavity. An arch mechanism was also highlighted, and the following developments have yielded a relationship between the height of the embankment and the height of the arch (Villard et al., 2000).

To determine the influence on the surface settlement of the stretching and the sliding of the geosynthetic in the anchorage areas (located on either side of the cavity), a full-scale experiment was conducted on a geosynthetic-reinforced embankment made of gravel located over a trench 2 m long and 1 m wide (Briançon et al., 2004, 2005). The trench was filled with two balloons, one on top of the other, and the remaining space was filled with gravel. A cavity was created by deflating the balloons. The strains of the geosynthetic sheet located above the void and in the anchorage areas were monitored using optical technology, the Geodetect® system. This device uses Bragg gratings on optical fibers to allow strain measurements with great accuracy.

Another, possibly easier, method to simulate a void under a geosynthetic-reinforced embankment and to access to the influence of the reinforcement is to conduct laboratory experiments. As an example, the installation at Dessau University enables the study of different natures or positions of geosynthetic sheets within the granular layer in monitored and controlled conditions. Paul et al. (2002) and Schwerdt et al. (2004a) have performed experiments using this 4.7 m wide installation that enables the opening of a 1.6–2 m wide sinkhole under an approximately 1.75 m embankment. The main interest of this installation is the ability to study the load transfer mechanisms after opening the void or after traffic tests are performed by a series of jacks located at the surface of the embankment. Meyer et al. (2003) summarized the results obtained with the experimental device at Dessau University, highlighting the existence of different load transfer mechanisms depending on the geometry (ratio H/D), the test conditions (opening of a void or traffic tests), and the type of reinforcement (geogrid or geotextile).

As a conclusion, past experiments indicate that it is important to use sensors that do not modify the mechanisms by their presence. To understand the behavior of reinforced platforms above a sinkhole, it is imperative to simulate the cavity opening with care.