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Load transfer mechanisms in geotextile-reinforced embankments overlying voids: Numerical approach and design

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ABSTRACT

A numerical model was used to investigate the mechanical behaviour of granular embankments reinforced by geosynthetics in areas prone to subsidence and to overcome the shortcomings of the current design methods. The ability of the numerical model to consider the load transfer mechanisms and the deflection of the geosynthetic was established by comparison with experimental data. By testing two numerical processes, it was demonstrated that the cavity opening modes have a great influence on the shape of the load distribution transmitted to the geosynthetic sheet above the cavity and on the expansion mechanisms of the soil. An approximate conical load distribution seems well adapted when considering a progressive cavity diameter opening process, whereas an inverted load distribution seems more suitable for a gradual settlement process. In both cases, the intensity of the load transfer mechanism can be approached by the Terzaghi's formulation using an appropriate value for the ratio between the horizontal and vertical stresses. Finally, recommendations based on the experimental and numerical results are proposed to promote a better design of such structures.

1. Introduction

In many countries, new environmental developments (housing, urban substructures, roads and railway infrastructures) increasingly occur 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 the structures, various reinforcement methods such as piles, concrete slabs, nails, or geosynthetics are used. These reinforcements are then supposed to withstand the possible formation of a sinkhole with a determined design diameter after the construction of the infrastructure. This solution can be applied to reinforce platform bridging for buried utilities (El Naggar et al., 2015).

The present study focuses on the geosynthetic solution and its behaviour to prevent surface damage. A particular attention was paid to railway and road infrastructures (new structures or rehabilitations of old structures) for which a low thickness of well graduated granular material is used above the geosynthetic in order to minimize the financial and environmental costs that represent the transport of material and the realization of the structure. In this kind of applications, commonly used in some European countries, the determination of the load transfer mechanisms within the granular embankments, very sensitive to the embankment thickness, is of primary importance. One of the most recent design methods of geosynthetic reinforcement over a cavity (Briançon and Villard, 2008) considers the friction mechanisms in anchorage areas or the change of orientation of the reinforcement sheet at the edges of the cavity. Despite this reformulation, the load transfer mechanisms within the embankment over a cavity are not yet fully understood: the distribution of the load on the geotextile sheet either in anchorage areas or over the cavity is considered to be uniform as a simplification, and the cavity opening mode is not considered.

To better understand the load transfer mechanisms developed within the reinforced platform, a full-scale experimentation has been recently carried out to simulate the progressive opening of the cavity below a reinforced granular platform (Huckert et al., 2016). From the experimental results obtained, it was concluded that the

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opening process of the cavity has a great influence on the intensity and the distribution of the load acting on the geosynthetic sheet. Nevertheless, the analysis of the experimental results does not allow exact determination of these load transfer mechanisms due to the high costs that represent the realization of numerous instrumented tests. Thus, a specific numerical code, coupling finite and discrete element methods, was used to consider two types of cavity openings that can be distinguished depending on the source of the underground initial movement and the nature of soil between the reinforced platform and the underground cavity: a gradual opening of the cavity diameter simulating a progressive subsidence (Process A) or a sinkhole development at a fixed opening diameter characterized by a sudden downward movement of the subsoil (Process B).

Specific post-treatment procedures have been developed to achieve a full understanding of the mechanical and kinematic behaviour of the structure at both microscopic and macroscopic scales. Results for the case of non-cohesive granular embankments are then discussed and compared to experimental measurements.

Based on this better understanding of mechanisms, the analytical design method developed by Briançon and Villard (2008) has been improved to consider the cavity opening mode and its consequences on the intensity and the distribution shape of the load acting on the geosynthetic. Other partially understood mechanisms such as the expansion of the soil or the load transfer mechanisms within the granular embankment are also investigated.

2. Background

2.1. Existing analytical methods

The existing analytical design methods consider various mechanisms (Villard and Briançon, 2008; Huckert et al., 2016) such as the load transfer within the granular embankment, the deflection of the geosynthetic sheet, the frictional mechanics and the elongation of the geosynthetic in the anchorage areas, and the expansion of the granular material above the cavity that allows limitation of the vertical surface settlement (Fig. 1).

The two most commonly used European analytical methods are the British Standards BS 8006 (1995, 2010), and a method derived from the French research program "RAFAEL" (Giraud, 1997) based on full-scale experiments and numerical analysis. These methods both use the membrane effect theory developed in 2 dimensions for homogenous and isotropic sheets under simple load assumptions (Giroud, 1995). Moreover, they are both based on the assumption that the geosynthetic sheet is fixed at the edges of the cavity. The major difference between the BS 8006 and "RAFAEL" methods is the use of a different geometry and behaviour for soil collapsing above the cavity. BS 8006 assumes a truncated geometry for the collapse without any soil expansion, whereas the "RAFAEL" method uses a cylindrical collapse over the cavity and considers the soil expansion with a global expansion factor.

Amongst the most recently published standards, the German method EBGEO (1997, 2011) presents close similarities to the work of Schwerdt et al. (2004), who laid the principles of a method considering the isotropic or anisotropic structure of the geosynthetic reinforcement. In addition, the German standard also suggests the use of the "RAFAEL" method in most cases, with a slight modification of the computation of the expansion factor (Villard et al., 2000).

Finally, the most recent work (Briançon and Villard, 2008) corrected some of the shortcomings in the existing "RAFAEL" method. This complementary approach considers the elongation and the friction behaviour of the geosynthetic sheet in anchorage areas by means of a Coulomb friction law. Another improvement consists of considering the localized mechanisms at the edges of the cavity such as the change in orientation of the sheet and the local increase of the vertical pressure. This phenomenon induces a decreasing tensile force in the geosynthetic at the vicinity of the edges of the cavity.

These methods are nevertheless known for shortcomings due to their strong simplifying assumption (Villard et al., 2009); these are described by Huckert et al. (2016) and are summarized here.

First, the load applied to the geosynthetic sheet above the cavity is computed using either a funnel shape or a cylindrical geometry of the collapsed embankment over the void. Despite the fact that this assumption remains an important design parameter because it determines the load transfer phenomenon within the embankment, this phenomenon was rarely studied. In fact, the cylindrical behaviour has been observed for full-scale experiments on ballast fills (Blivet et al., 2000) whereas the funnel shape, well adapted for granular non-reinforced embankments, is incompatible with the presence of a reinforcement at the base of the embankment from a kinematic perspective.

However, Terzaghi's formulation (Terzaghi, 1943), which is used to compute load transfer along shearing bands for a cylindrical geometry, is associated in many design methods with the active earth pressure coefficient Ka, which does not necessarily integrate real mechanisms such as the rotation of the principal stresses. Actually, various other definitions (Marston and Anderson, 1913; Roscoe, 1970; Vardoulakis et al., 1981; Handy, 1985; Pardo and Saez, 2014) have been proposed in the literature, but none of them has been validated for application to sinkholes. Moreover, the load computed on the geosynthetic either on anchorage areas or

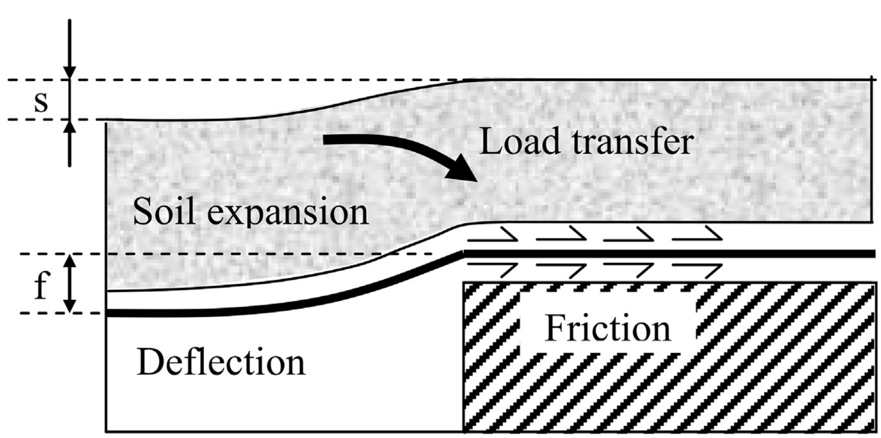

Fig. 1. Main physical mechanisms involved during the sinkhole development.