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Mechanical behaviour of geosynthetic sheets used to reinforce load transfer mattresses in the case of embankments on soft soils reinforced by rigid inclusions

Comportement mécanique des nappes géosynthétiques utilisées pour renforcer les matelas de transfert de charge dans le cas des remblais sur sols mous renforcés par inclusions rigides

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ABSTRACT: Geosynthetic sheets are commonly used to improve the mechanical performances of soft soils reinforced by rigid inclusions and a granular load transfer embankment. In order to establish a design method for such reinforcement a DEM numerical analysis was performed. It was clearly demonstrated that the load due to the granular embankment is transferred on the one hand to the piles by load transfer within the granular embankment and by membrane effect induced by the deformation of the geosynthetic sheet, and on the other hand by the soft soil, which undergoes settlement. From the numerical results, it was shown that the main part of the load transmitted to the piles by membrane effect is due to the deformation of the geosynthetic strips located between the piles. It was also demonstrated that the geometry of the distribution of load supported by membrane effect takes a polynomial shape with concentration of loads at the vicinity of the piles.

RÉSUMÉ: Les nappes géosynthétiques sont couramment utilisées pour améliorer les performances mécaniques des sols mous renforcés par inclusions rigides et par un matelas granulaire de transfert de charge. Afin d'établir une méthode de dimensionnement pour ce type de renforcement, une analyse numérique DEM a été réalisée. Il a été clairement démontré que la charge transmise au remblai granulaire est transférée, d'une part aux pieux par transfert de charge au sein du matelas granulaire et par effet membrane suite à l'incurvation de la nappe géosynthétique, et d'autre part, par le sol compressible qui subit un tassement. A partir des résultats numériques, il a été montré que l'essentiel de la charge transmise aux pieux par effet membrane est due à la déformation des bandes de géosynthétiques situées entre les pieux. Il a également été démontré que la géométrie de la répartition des charges supportées par effet membrane prend une forme polynomiale avec une concentration des charges au voisinage des pieux.

Keywords: Geosynthetic; reinforcement; rigid inclusions; DEM.

1 INTRODUCTION

Soil reinforcement using Rigid Inclusions is a now common technique which, compared to other reinforcement methods, presents certain technical and economic advantages. Geosynthetic sheets are sometimes used to increase the effectiveness of the reinforcement and limit surface settlements to allowable values. The vertical forces acting on the granular mattress are partly transferred to the piles either by membrane effect (contribution of the geosynthetic to the reinforcement) or directly by the arch effect which develops within the granular material (LTP-Load Transfer Platform). The forces not redirected towards the piles are transmitted to the supporting soil that deforms more or less strongly depending on the intensity of the transmitted load.

The membrane effect is the mechanism of deformation of the sheet that allows it, by curving, to balance by its tensioning the forces initially applied perpendicular to its plane (weight of the overlying embankment and the applied overloads). The membrane effect is not proportional to the intensity of the applied load, i.e. significant initial displacements are necessary to generate noticeable tensile forces in the sheet. When the sheet has deformed into a membrane, it is able to support immediately additional vertical forces without deforming too much.

The arching or load transfer mechanisms in the LTP initiate within the granular layer following a modification of the boundary conditions in displacement of the compressible horizon. They consist of a reorientation of forces towards fixed zones (shear forces in the load transfer platform or rotation of the principal stresses when the formation of an arch is possible). The intensity of the load transfer depends on the characteristics of the granular soil, the height of the LTP, the spacing between inclusions and their diameter.

The numerical tool chosen for this study is a numerical software (Villard, 2009) based on the discrete element method (DEM) that makes it possible to take into consideration the discrete nature of the soils, the texture of the reinforcement and the interaction on a local scale between the granular particles and the reinforcement. The simulations were carried out with the aim of describing the in-service behavior of a structure subjected to settlements of reasonable amplitude. Figure 1 presents the basic geometry used for the modeling. To limit calculation times, a quarter of the mesh of the pile network was subsequently modeled.

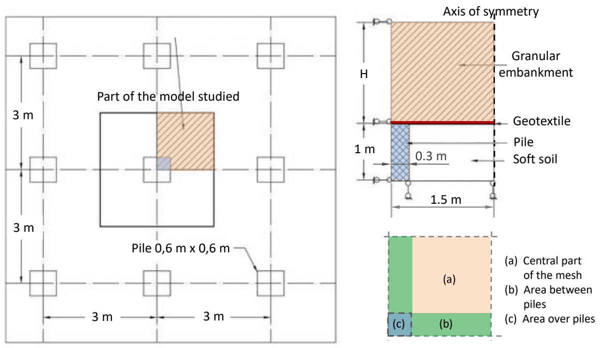

Figure 1. Geometry of the numerical application.

2 PRINCIPLE OF THE DISCRETE ELEMENT MODELLING

The discrete element method (Cundall and Strack, 1979) consists of discretizing any medium by a set of elementary particles of different sizes which interact with each other at their contact points. Interaction laws are introduced locally at the contact level (microscopic laws) which give the whole a specific macroscopic behavior. This behavior depends on the shape, the granular distribution of the particles, the apparent density of the granular medium and the microscopic contact parameters (Salot et al., 2009; Szarf et al., 2011). Considering that there is no direct relationship between the microscopic parameters (normal and tangential stiffness, contact friction coefficient, particle size, particle shape and density of the numerical sample) and the macroscopic parameters (modulus of Young, Poisson's ratio and internal friction angle), a specific calibration process is necessary. A classic way to obtain micro-mechanical parameters is to simulate laboratory tests (triaxial tests in general) carried out under well-controlled conditions and to compare the numerical and experimental results. DEM makes it possible to take into account large displacements between particles (particles can be separated from each other or brought into contact at any time). By its nature, DEM is well suited to granular materials modelling. It allows, among other things, to simulate load transfers, arching, fracturing, compaction, expansion and the evolving behavior of the material following the variation in its density (due to the expansion or shear mechanisms, for example). Specific elements (thin triangular elements) are used to model the geosynthetic reinforcement and to account for its tensile and membrane behavior (Villard, 2009).

The numerical model (Tran, 2019) consists of a granular mattress (apparent density of 1550 kg/m^3) made up of clumps arranged in such a way that the macroscopic behavior of the numerical sample corresponds to a granular material with an internal friction angle at the peak of 40° and a Young modulus of 20 MPa (Figure 2). Each clump is made up of two spheres of diameter D, overlapped and inseparable, whose centers are spaced a distance of 0.8 D. Several heights of the granular embankment were tested: H1=0.75 m (16000 clumps), H2=1.5 m (32000 clumps), H3=2.25 m (48000 clumps) and H4=3m (64000 clumps).

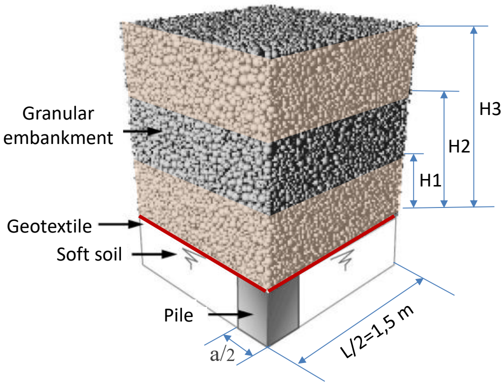

Figure 2. Description of the numerical model (H3).

The geosynthetic layer (2738 thin three nodes triangular elements), positioned at the base of the granular embankment, is reinforced in two directions (longitudinal and transverse directions). The tensile stiffnesses of the geosynthetic in the longitudinal and transverse directions are respectively: J_x=3000 kN/m and J_y=3000 kN/m. A set of spheres regularly distributed under the geosynthetic reinforcement is used to materialize the soft soil and the action of the piles on the reinforcement sheet. The behaviors of the compressible soil and the piles are governed by springs that act vertically on the particles located under the geosynthetic. The compressibility modulus of the soil K_s is defined as the ratio between the oedometric modulus of the soil and the thickness of the soft soil (by default a value of 0.2 MN/m^3 is used for the soft soil and a value of 2000 MN/m^3 for piles). In the following, the interface friction angle between the granular layer, the soft soil and the geosynthetic is 31.5°. Frictionless vertical walls are applied around the perimeter of the model to ensure symmetry conditions.

3 NUMERICAL RESULTS

3.1 Analysis of load transfer mechanisms

The discrete modelling makes it possible to determine the displacements and contact forces between all the particles and elements of the model. It is therefore easy to distinguish the forces that act on the soft soil from those which act on the pile heads or on different areas of the geosynthetic sheet. We thus define the total efficiency of the load transfer mechanism as the ratio between the load supported by the piles and the loads inherent to the weight of the backfill.

In Figure 3 we compare, for different thicknesses of the granular mattress, the total efficiencies of the load transfer mechanisms for embankments on rigid inclusions reinforced by geosynthetics (solid lines) or not reinforced (dotted lines) and this for different values of the stiffness Ks of the soft soil.

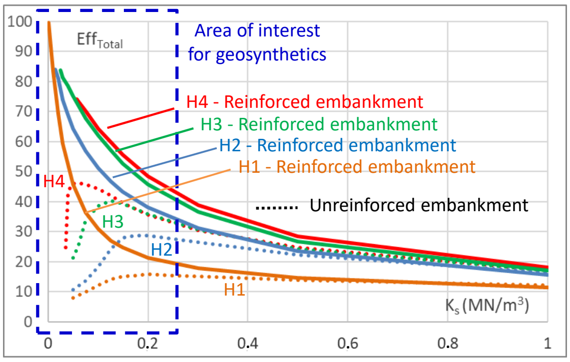

Figure 3. Load transfer efficiency versus the soft soil stiffness.

The results in Figure 3 show that the presence of geosynthetic reinforcement increases the overall efficiency of load transfer to the rigid inclusions, which has the effect of reducing settlement. The interest in using a geosynthetic sheet appears for soft soil stiffnesses that are sufficiently low. Beyond a certain compressibility of the soft soil, reinforcement is of only limited interest. This is explained by the need to produce significant displacements to mobilize membrane effects. In Figure 3, we see, as expected, that the greater the thickness of the LTP, the greater is the efficiency of the load transfers.

The contribution of the geosynthetic sheet to the load transfers mechanism towards the piles is obtained by comparing the sum of the vertical forces acting on the upper face of the geosynthetic sheet to those acting under the sheet. Knowing the total load transfered to the pile it is then possible to determine the load transfer fraction that only develops within the granular mattress. The contributions of the geosynthetic sheet (green dotted line) and the granular mattress (blue dotted line) to the load transfers are presented in Figure 4. It can be seen that the geosynthetic brings a significant contribution to the load transfers. We also note that the load transfers within the granular mattress are quite similar in the reinforced (blue dotted line) and non-reinforced (black dotted line) cases.

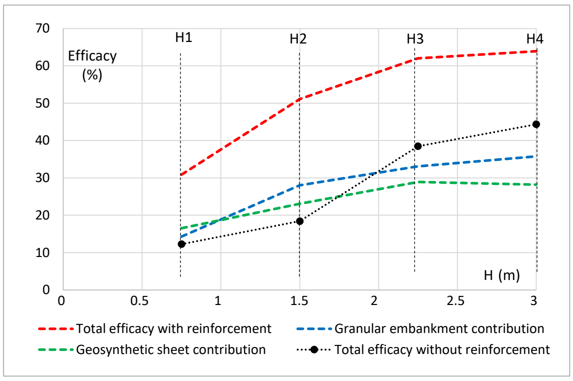

Figure 4. Load transfer mechanisms as a function of the height of the granular platform (K_s = 0.1 MN/m^3).

3.2 Contribution of the geosynthetic sheet to reinforcement

The analysis of the tensile forces in the geosynthetic sheet (Figure 5) shows that it is the geosynthetic strips located between the piles that are mainly stressed in tension.

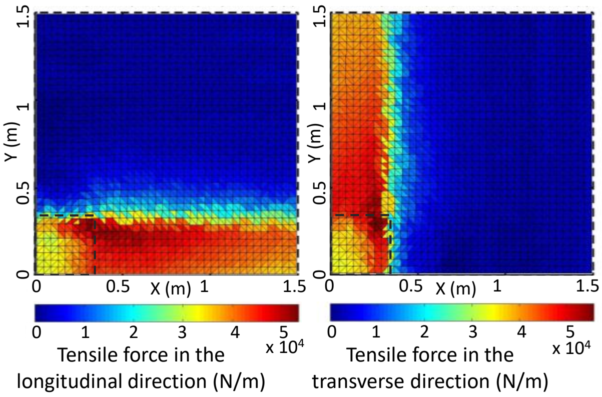

Figure 5. Tensile forces in the longitudinal and transverse directions (K_s=0.2 MN/m^3 - H2).

Between the piles, the distribution of tensions in the geosynthetic sheet (Figure 6) is not uniform due to the frictional forces between it, the soil of the granular mattress and the soft soil. The maximum tensile forces are, as might be expected, concentrated in the vicinity of the piles.

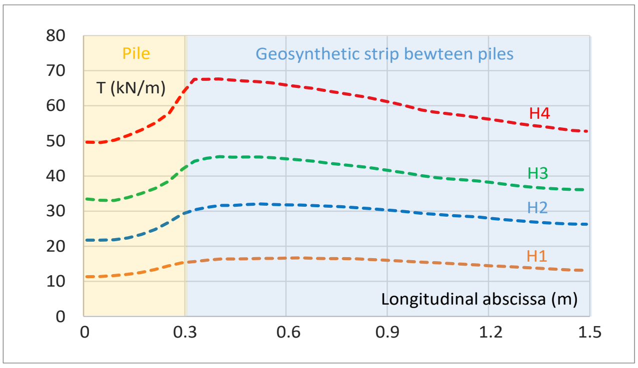

Figure 6. Tensile forces within the geotextile strip located between the piles (Ks=0.2 MN/m^3).

When the geosynthetic sheet curves, it can mobilize part of the vertical forces applied to it through the membrane effect. By comparing the vertical stresses acting on and below the sheet, it is possible to determine the contribution of the geosynthetic to the load transfer mechanism. A zero stress difference means that the vertical forces acting on the sheet are fully transmitted to the soft soil while a non-zero stress difference means that the part of the sheet concerned is stressed by the membrane effect.

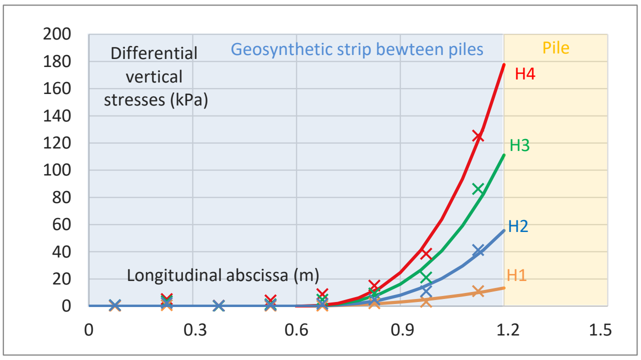

Figure 7. Differential vertical stresses acting on the geosynthetic strip located between piles (Ks=0.2 MN/m^3).

On the strip of geosynthetic located between the piles (Figure 7) we see that the distribution of the differential stresses (difference between the upper and lower stresses) is non-uniform. This distribution is similar to a third-degree polynomial distribution, whatever the height of the granular mattress modeled. This distribution reflects the fact that the geosynthetic sheet is strongly curved in the vicinity of the piles and remains flattened in the center part of the network of piles. The analyze of the distribution of differential stresses on one mesh of the pile network shows that the geosynthetic strips located between the piles mobilize 85% of the whole differential stresses supported by the geosynthetic sheet. So, these geosynthetic strips mainly contribute to the reinforcement.

4 CONCLUSIONS

The numerical results showed that the vertical loads due to the granular emankment are transferred, on the one hand to the piles by load transfer within the granular mattress, by membrane effect following the curvature of the geosynthetic sheet, and to the soft soil which undergoes a vertical settlement. The geosynthetic strips located between the piles are the most stressed and contribute mainly to the reinforcement. The distribution of stresses on these geosynthetic strips takes a third degree polynomial form from which it con be deduced that 85% of the total loads are mobilized by the geosynthetic sheet. It has also been shown that the load transfer mechanisms within the granular fill are little affected by the presence of the geosynthetic sheet. All these conclusions will lead, by studying the vertical equilibrium of a portion of the geosynthetic sheet, to the development of a design method for the geosynthetic.

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