Pull-out behaviour of geosynthetic strip reinforcements in gravel - development of new reinforcement type

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ABSTRACT: Metallic reinforcements are widedly used in Mechanically Stabilised Earth structures. However, to face cases where the backfill is chemically aggressive, systems incorporating the use of non corrodible synthetic reinforcements have been developed, in particular in the form of strips. These synthetic reinforcements present a more complex behaviour due to their relative extensibility. It is thus necessary to refine the current friction models of the soil/reinforcement interface in order to lead to a more realistic modelling. Several pull-out tests have been carried out (Abdelouhab et al 2009) to study the behaviour of the synthetic straps and to deduce the interaction parameters at the soil reinforcement interface in fine sand.
This paper completes that study and first presents the results of pull-out tests carried out on the same synthetic reinforcements but in gravel. It highlights the influence of soil type on the interaction interface. In the second part, a newly developed design of synthetic strips is tested and validated by pull-out tests.

1 INTRODUCTION

In Mechanically Stabilised Earth (MSE) walls, reinforcement is made of metallic or synthetic materials (metallic strips, bar mats, or geosynthetic strips, grids, fabrics). On this study we are concentrating on the behaviour of synthetic strips (geostrips). These are made of high-tenacity PET yarns which exhibit some extensibility under load. The use of such synthetic strips without any metallic intermediary in MSE walls, offers the opportunity to use them in aggressive fill materials which may present lower mechanical properties. Therefore new synthetic strips with improved adherence performance have been developed. These high adherence geostrips have been tested and validated by pull-out tests in the course of this study.

To define the behavioural model of the soil / reinforcement interface, it is necessary to consider the reinforcement properties itself, the fill material and the soil/reinforcement interaction. The classical anchorage models developed for the modelling of steel-reinforced structures are based on a linear strip stiffness model for the reinforcement and an elastoplastic friction model (Cambefort 1964, Frank and Zhao 1982) for the soil/reinforcement interaction. To adapt these models for extensible reinforcement, some authors have kept the same modelling (Schlosser et al. 1981, Segrestin et al. 1996) while others have modified the stiffness model (Bourdeau et al. 1990, Ling et al. 1992) or improved the friction model (Sobhi and Wu 1996, Gurung et al. 1999, Racana et al. 2003).

In order to define the actual behavioural model of the geostrips used in MSE structures, several pull-out tests have been carried out in fine sand (Abdelouhab et al 2009). These tests, carried out in a metallic tank in controlled and instrumented conditions, allowed to study the behaviour of the synthetic straps and to deduce the interaction parameter at the soil reinforcement interface in fine uniform sand. In order to complete this study and to highlight the influence of the soil type on the interface interaction, several pullout tests of the same synthetic reinforcement were carried out in gravel. This paper is focused on the interface friction coefficient which is an important parameter in the design of the MSE structures and will allow defining a more realistic friction model.

2 THREE-DIMENSIONAL PHYSICAL MODELLING OF SYNTHETIC REINFORCEMENTS

The physical modelling consists of pull-out tests allowing to simulate the tensile stress applied on the reinforcement and to define the evolution of the interface parameters during its mobilisation. They highlight the evolution of shear stress and friction along the soil/reinforcement interface; the soil dilatancy and the reinforcement strain. These parameters are taken into account in design methods of MSE walls.

2.1 *Procedure*

The pullout tests were carried out in the following way (Abdelouhab et al. 2009): half of a metallic tank is filled with a gravel. It is set up by successive layers compacted with a metallic mass. A pair of parallel reinforcement straps is then installed on a plane surface of the soil, in order to reproduce their actual layout in MSE wall structures. The reinforcement is connected to an extraction jack positioned in front of the tank. Displacement sensors installed at the back of the tank are connected to various points along the reinforcement to measure displacements and a load sensor installed between the extraction jack and the connection system allows the monitoring of the tensile force applied at the head along the test duration. After connection of all the sensors, the tank is finally filled up with granular material. An air cushion, which permits the application of a surcharge, is then placed between the ground inside the tank and the tank closure. This cushion is inflated by air pressure and controlled by a pressure gauge. Lastly, after closing the tank and application of the pressure in the cushion, the extraction jack is started. This electrical jack makes it possible to study the reinforcement mobilisation at various speeds (0.1mm/min to 8mm/min). Within the framework of our tests, the pull-out speed is fixed at 1mm/min, corresponding to a value commonly adopted (Alfaro et al. 1995).

2.2 *Material*

2.2.1 *Fill material*

Pull-out tests were carried out on synthetic reinforcements in a granular material (Table 1). The fill material used in these tests is named well graded gravel (GW) according to USCS classification (United Soil Classification) which distinguishes coarse from fine soils, according to the percentage of the particles lower than 0,075 mm (Valle 2001).

Table 1. Caracteristics of the gravel

Characteristics	gravel
Granulometry (mm)	0-31.5
Hazen's coefficient Cu	25
Angle of friction from direct shear test (°)	36
Cohesion (kPa)	61 (w = 8.2%)
Dilatancy (°)	8
Density in the tests	1.95

W (%) : the water content of the soil

2.2.2 *Reinforcements*

Two types of reinforcement were tested. The first one is a standard synthetic strip (GeoStrap 37.5) used in MSE structures. The second type is a newly developed strap (HA GeoStrap).

In some particular configurations of MSE walls reinforced by synthetic strips, these strips are placed so that they form a loop at the connection point and two segments of the same strip are running parallel and extend up to the desired reinforcement length. These straps are typically 50mm wide and the space between parallel segments is 50mm too. In order to reproduce a layout as close as possible to the actual structures, the pull-out tests were carried-out on a pair of parallel synthetic straps.

- Standard synthetic strips:

The standard GeoStrap® design refers to strips which are 50 mm wide and 2 mm thick, containing high-tenacity polyester yarns protected by polyethylene sheath (Figure 1). The use of these straps with a special connection system permits to removes any metallic (thus corrodible) intermediary between the concrete facing and the reinforcement strips.

- New high adherence synthetic strips:

The new HA GeoStrap design (Figure 2) is a new reinforcement type developed during this study. Its description and the tests results obtained are presented in the second part of this paper.

Figure 1. Standard GeoStrap design


Figure 2. HA GeoStrap design (patent pending)

3 PULLOUT TESTS RESULTS ON THE STANDARD STRIPS

Six tests have been carried out in the gravel on a pair of parallel standard straps. Three levels of confinement stress (20 kPa, 45 kPa, and 80 kPa) were applied to simulate the behaviour of the reinforcement under various depth levels.

The friction coefficient at the soil reinforcement interface is a parameter which quantifies the adherence of the reinforcement in the soil, and is an important parameter in the justification of the stability of the MSE structure.

In a dense and dilatant granular soil, under the effect of shear stresses τ exerted by reinforcements, the volume of the surrounding zone tends to increase (Schlosser et Elias, 1978; Schlosser et Guilloux, 1981). However this dilatancy effect is constrained, and this results in an increase ($\Delta\sigma_v$) of the local vertical stress σ_{v0}. Hence, the vertical stress σ_v applied on the inclusion becomes:

$$\sigma_v = \sigma_{v0} + \Delta\sigma_v \qquad [1]$$

This phenomenon is named constrained dilatancy. The real friction coefficient f is thus expressed:

$$f = \frac{\tau_{max}}{\sigma_{v0} + \Delta\sigma_v} \qquad [2]$$

With:

$$\tau_{max} = \frac{T_{max}}{2bl} \qquad [3]$$

T_{max} is the maximum tensile force measured at the head of the reinforcement (kN), *l* is the reinforcement length (1.9m in the test configuration) and *b* the reinforcement width (two times 50mm, as there are two strip segments).

Schlosser and Elias 1978, defined an apparent friction coefficient *f** to take this phenomenon into account in practice, through normalisation :

$$f^* = \frac{\tau_{max}}{\sigma_{v0}} \qquad [4]$$

The tests results obtained for the synthetic strips in the gravel confirm this phenomenon (Figure 3) and show that the maximum apparent friction coefficient at the interface decreases as the confinement stress increases, due to constrained dilatancy.

The friction coefficients at the soil/reinforcement interface are significantly higher (approximately 50%) than those used in practice for reinforced soil structures justification (Figure 3). These results show that the friction parameters are used with a high safety margin in the reinforced soil structure design for the gravel.

Friction coefficients obtained in gravel are higher than those obtained in the fine sand by Abdelouhab (2009). It is related to the density and the Hazen's coefficient (Cu) which lead to higher dilatancy and friction at the soil/reinforcement interface.

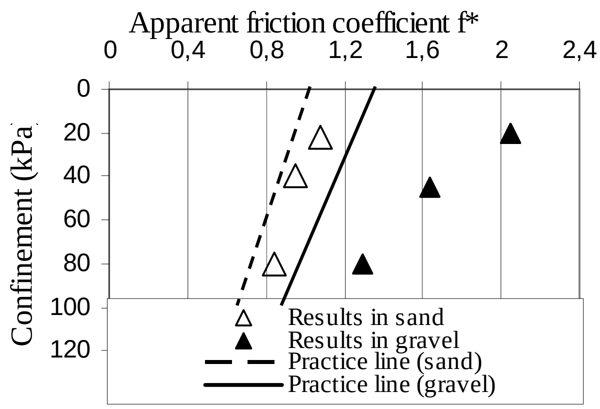

Figure 3. Influence of the confinement stress and the soil type on the friction coefficient (the practice lines correspond to the design value proposed by the recent standard NF P 94 270: 2009 on justification of reinfroced soil structures)

4 NEW HIGH ADHERENCE GEOSTRAP DESIGN

4.1 *Description*

The new synthetic reinforcement is a 50mm wide and 2mm thick strip made of high-tenacity polyester yarns protected by polyethylene sheath (Figure 2). The new strip offers by its geometric shape (lateral teeth) a higher adherence in the soil.

The tests on a pair of standard geostrips show that the lateral dilatancy presents a high influence on the adherence and the friction of the inclusion. Added to the arching effect, a dilatancy of the soil is created between the two straps and thus increases the stress around inclusions (Figure 4). The objective in developing of the new strips, which present lateral teeth, is to improve the lateral dilatancy. To validate this assumption, several pull-out tests in gravel, have been carried out on the new reinforcement type.

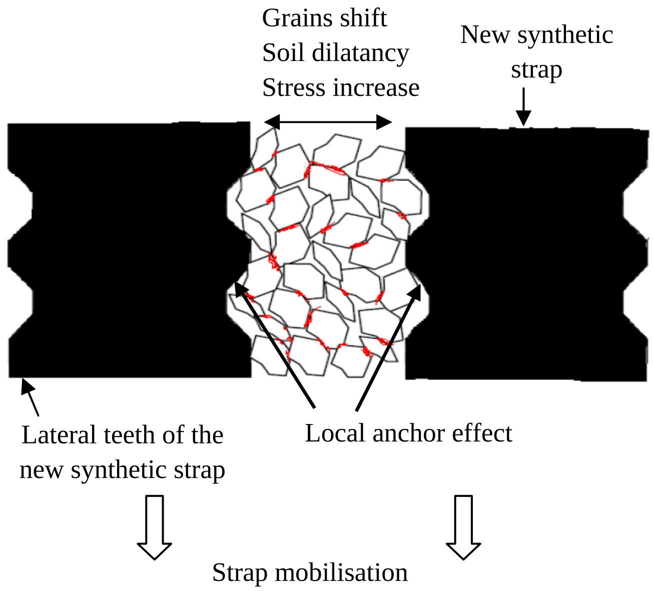

Figure 4. Lateral dilatnacy and abutment phenomenon at the soil/new synthetic straps interface.

4.2 *Pull-Out tests results*

The values of the friction coefficients obtained in gravel with the new strip design are significantly higher (approximately 30%, except under confinement of 80 kPa) than those obtained with the standard straps and largely higher (between 50% and 100%) than the standard coefficients used in reinforced soil structures design (Figure 5).

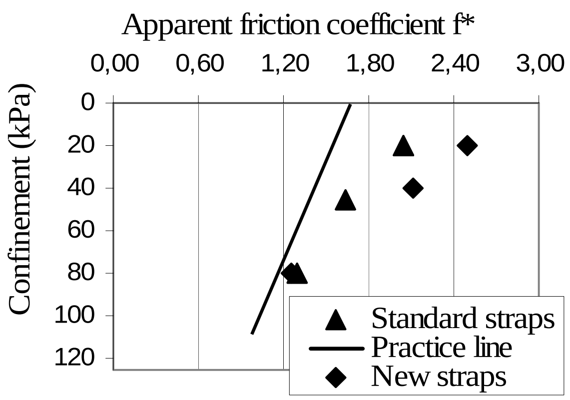

Figure 5. Improvement of the apparent friction coefficient with the new straps in the gravel.

5 CONCLUSION

The pull-out tests enabled us to study and to define the friction coefficient at the synthetic straps/gravel interface under various confinement stress levels. The friction coefficient at this interface decreases as the confinement stress increases on the two types of reinforcement (standard and new high adherence design). This phenomenon is due to the constrained dilatancy of the ground which leads to the increase in the vertical stress under low confinements.

The high density and Hazen's coefficient (Cu) in gravel lead to better friction coefficients compared to those obtained in fine sand. These two parameters lead to a high dilatancy and friction at the soil/reinforcement interface

The new high adherence design shows high friction coefficient and adherence at the soil/reinforcement interface due to its geometric shape (lateral teeth). This strap increases the soil/reinforcement friction by simultaneously mobilising higher shear rates in the soil leading to a higher dilatancy and a localised anchoring effect with the lateral teeth. This new shape is very interesting because it will allow the use of aggressive fill materials which present lower mechanical properties.

This study allowed us to study the behaviour and the adherence of the standard and the new reinforcements in the gravel. The results will complete the data base of the parameters necessary in the design of the MSE structures.

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