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Experimental tests for geosynthetics anchorage trenches

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ABSTRACT: Geosynthetic lining system on slopes requires anchoring at the top of the bank. Depending on the space available at the top of the slope and on the applied load, the anchorage trench may take on different geometries. Various design methods have been proposed in this field but experimental and numerical studies showed that no single formula was capable of describing the behaviour of all types of anchorage, even though some were close to the experimental results in certain cases. To complete the existing studies, experimental tests were carried out on an anchorage facility and in-situ to highlight mechanisms and to determine the best anchorage trench for a fixed length of geotextile or for a space available at the top of the slope.

1 INTRODUCTION

Stability and durability of geosynthetic lining systems on slopes depend partly on the efficiency of the anchors holding the geosynthetic sheets at the top of the slope. However, the design of these anchors is often a problem for the designer. There is no standard rule about this topic and the usual analytical formulas are often not efficient for predicting the strength provided by an anchor trench.

In order to improve knowledge of the behaviour of anchor trenches, experimental study (Briançon 2001, Briançon et al. 2000) and numerical study (Chareyre 2003, Chareyre et al. 2002) were developed jointly; they highlighted the complexity of the mechanisms. Designing methods were proposed for such configurations of anchors in such types of trenches (Briançon 2003, Koerner 1999, Hulling et Sansone 1997, Villard et Chareyre 2004).

In this paper, we propose to compare experimentally three types of anchor trenches in five soils to better understand the mechanisms in the anchor and to determine the best solution for a fixed length of anchored geotextile or for a given space available at the top of the slope. Most of the tests presented are new tests realised in 2004 and 2005 to answer to these two purposes.

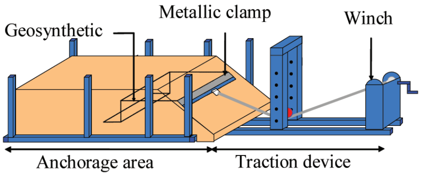

Figure 1. Anchorage bench.

2 ANCHORAGE BENCH TESTS

2.1 *Device and monitoring*

The anchorage apparatus (Fig. 1) included one meter wide anchor block and a tensile system. This tensile system was fixed onto the geotextile using a metal clamp. The tensile force T and the displacement U_0 of the tensile cable were monitored on pulling out using sensors fixed onto the tensile system. In the anchorage zone, a cable measuring system was used to monitor the displacements of the geotextile at different points (Fig. 2). In some cases, the movement of the soil could be observed thanks to columns of coloured sand placed in the anchorage zone before starting the test.

2.2 *Soils and geosynthetic*

Three types of soil were used: sand, silt and sandy silt. Their mainly properties were measured; silt was used for two water contents (Table 1). The geosynthetic used for these experimentations is a reinforcement geosynthetic constituted by a non-woven and PET reinforcement wires needle punched to the non-woven in the production direction.

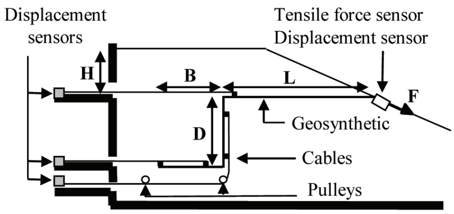

Figure 2. Anchorage bench monitoring.

Table 1. Soils properties.

Soil	γ_d (kN/m^3)	w (%)	ϕ (°)*	c (kPa)*	δ (°)
Sand	15.7	3	41	0	37
Silt 1	13.0	23.5	35	5	30
Silt 2	13.6	19.5	–	–	
Sandy silt	15.7	10.6	–	–	41

*: Triaxial test values.

2.3 *Anchorage trenches geometry*

Various anchorage trenches were carried out to compare their anchorage capacity: horizontal run-out, rectangular trench, V-shaped trench and trapezoidal trench (Fig. 3). Horizontal run-out were specially carried out to determine the friction angle between soil and geotextile.

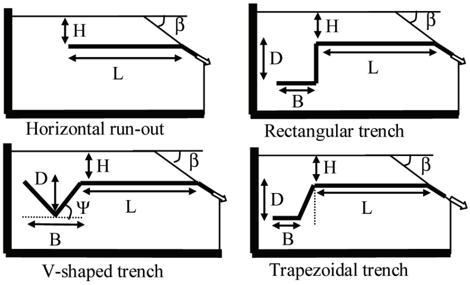

Figure 3. Tested anchorage trenches.

Trapezoidal trenches were added in the new tests for the following reasons:

- They are easier to set up than rectangular trenches; their inclined part is more stable than the vertical part of the rectangular trenches.
- The laying out of the geosynthetic is easier than in the case of a V-shaped trench.

3 FULL-SCALE EXPERIMENT

A full-scale experiment was carried out, in particular in order to eliminate the lateral friction occurred in the anchorage bench. A 2-meter high embankment, inclined at 38°, was built up with a compacted gravely soil whose characteristics are given in Table 2. These characteristics were measured on the part of soil cut down to 25 mm (Nilton-Valle, 2001)

Table 2. Full-scale soil properties.

Soil	γ_d (kN/m^3)	w (%)	ϕ (°)*	δ (°)
flint clay	19.3	12.5	42.6	–

*: Shearing box test values.

Three different anchor trenches (rectangular, V-shaped and trapezoidal) were set up in the soil with the same geotextile as used for bench experiments (Fig. 4).

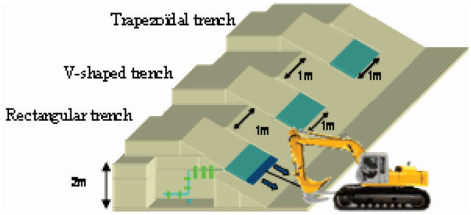

Figure 4. Full-scale experiment.

The tensile force was gradually increased along the slope using a power shovel and monitored by a sensor fixed onto the tensile system (Fig. 5).

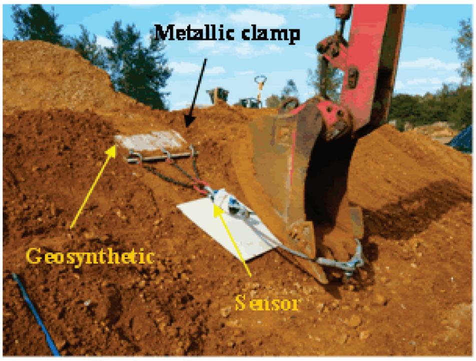

Figure 5. Full-scale tensile system.

The dimensions of anchorage trenches were the same as for bench experiments for a given length of geotextile to anchor (Fig. 11). Before traction, lateral trenches were dug out to observe the displacement of the sheet during the pull-out and to eliminate the lateral friction; moreover, vertical columns of soil were paint to evaluate the displacement of the soil (Fig. 6).

4 TESTS RESULTS

4.1 *Tensile force measurements*

The tensile force T required to pull-out the geotextile has been measured to determine the anchor capacity.

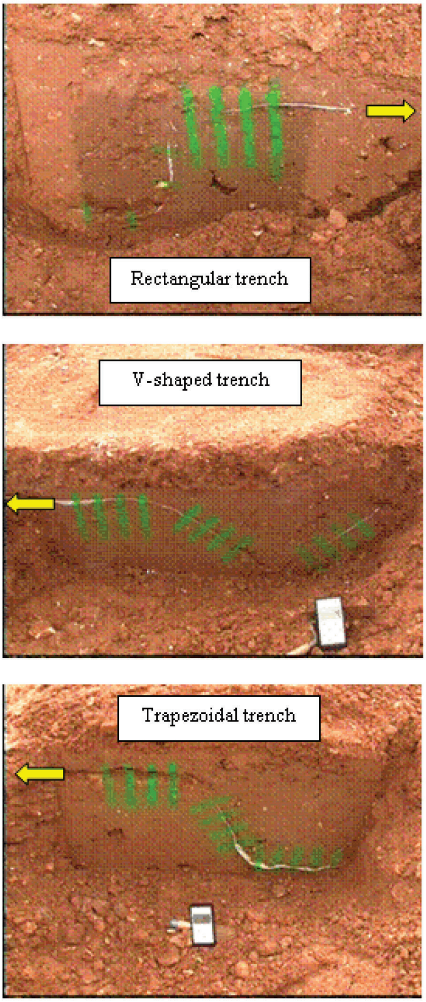

Figure 6. Lateral trenches dug out to observe the behavior of the geosynthetic inside anchorage.

These tests showed that the anchor capacity depends not only on the interface friction between the soil and the geotextile but also on:

– The mechanical resistance of the soil mass: the abutment of soil mass depends of type of soil (cohesion intercept and angle of internal friction) and depends also of L.
– The soil properties: for the rectangular trench in silt, we noticed that a decrease of 4% in water content drives to an increase of 15% in anchor capacity (silt 1 and silt 2).
– The slope: the tensile force required to pullout the geotextile increases with the angle of the slope.

As the usual analytical formulas do not take into account all these parameters, they are not efficient for predicting the strength provided by an anchor trench.

4.2 *Failure mechanisms*

4.2.1 *Rectangular trenches*

In the case of the rectangular anchor in sand, the failure mechanism in soil was identified thanks to the displacement of columns of coloured sand (Fig. 7):

– For L = 1.1 m, there is a localized sliding plane in the sand under the geotextile.
– For L = 0.5 m, the soil mass moves and there are many shearing planes.

For the same anchor in silt for L = 1.1 m, there is no failure in soil mass and in sandy silt there is a localized sliding plane nearest geotextile than in the case of sand.

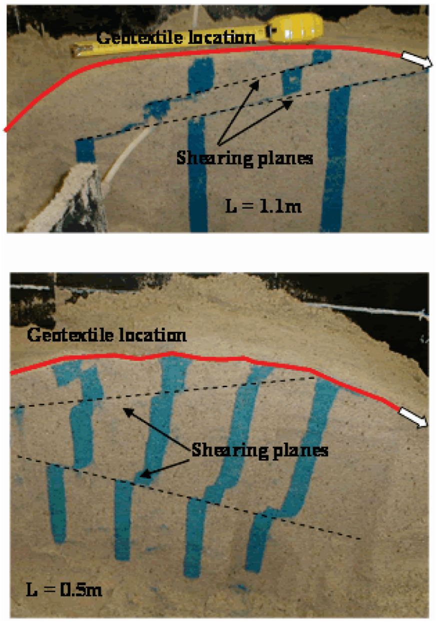

Figure 7. Failure mechanisms for rectangular trenches in sand.

For full-scale experiment, in the case of the rectangular anchor in flint clay, the failure mechanism in soil was followed during the extraction. We noticed that the vertical part of the trench was subjected to large strain. When the tensile force reached to the anchorage capacity, the rectangular trench was rounded (Fig. 8); this phenomenon is probably amplified on account of the lateral trenches.

These observations demonstrate that the soil plays a major role in anchorage failure mechanisms, and that it is not sufficient to consider only the interface friction characteristics for determining anchorage capacity.

Figure 8. Failure of rectangular trench in flint clay.

4.2.2 *V-shaped trenches*

Two V-shaped trench types were carried out to understand the failure mechanisms in sand and sandy silt (Fig. 9):

– Deep trench with $\psi = 45°$.
– Shallow trench with $\psi = 20°$

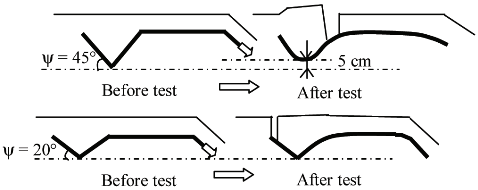

Figure 9. Failure mechanisms in sand for V-trench.

For deep trench ($\psi = 45°$), the soil block remains in place over the V-trench portion. After test, we noticed that the V-trench angles were rounded and that the base of the trench was lifted. For shallow trench ($\psi = 20°$), the soil block moves over the V-trench portion. For all cases, the mass soil is not sheared during the test, except a thin thickness of soil under the geotextile by friction.

The same failure mechanism was observed in flint clay during the full-scale experiment for a deep trench (Fig. 10)

Figure 10. Failure of V-shaped trench in flint clay.

4.2.3 *Trapezoidal trenches*

The trapezoidal trenches were only tested in sandy silt in the anchor bench and in flint clay for the full-scale experiment. In sandy silt, we noticed that there is a localized sliding plane. In this case, the friction angle considered for the design must be the angle of internal friction and not the interface angle friction.

In flint clay, the trapezoidal trench was rounded and the soil above the base of anchorage (on part B, Fig. 3) was lifted when the tensile force reached to the anchorage capacity (Fig. 11). As for the rectangular trench, the lateral trenches dug out to observe the mechanisms decrease the lateral stress and so increase the phenomenon of rounding. The observations of quantity of soil falling in the lateral trenches allow deducing that the abutment of soil in rectangular trenches is greater than those in trapezoidal trenches.

As for the rectangular trenches, these observations demonstrate that the soil plays a major role in anchorage failure mechanisms.

Figure 11. Failure of trapezoidal trench in flint clay.

4.2.4 *Conclusions about the failure mechanisms*

The failure mechanisms are complex; depending on type and geometry of trench, type of soil and state of soil, it could be either failure by friction between the soil and the geotextile, or failure by shearing in the mass soil located between the trench and the slope. The abutment of the soil located between the trench and the slope depends on the trench geometry and the soil.

5 APPLICATION

To determine the optimal solution, we compare from experimental results, the anchorage capacity of rectangular trench, V-shaped trench and trapezoidal trench for:

– A given length of anchored geotextile.
– A given space at the top of the slope.

5.1 *For a given length of geotextile to anchor*

Three anchor trenches were carried out in sandy silt in the anchorage bench and in the full-scale experiment for a length of geotextile equal to 2.1 m. The length between the trench and the slope L and the soil layer above the sheet were the same for the three cases (Fig. 12).

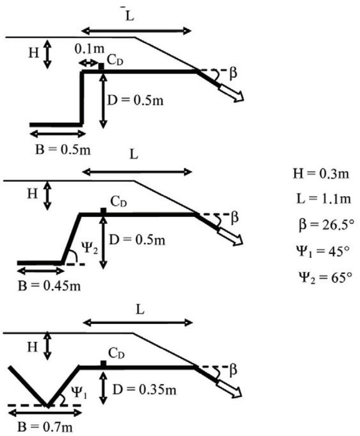

Figure 12. Anchor trenches for a fixed length of geotextile equal to 2.1 m.

To measure the most efficient anchor, we fixed a tensile force criterion and a displacement criterion to determine the anchor capacity of each trench:

– Anchor capacity is equal to the tensile force required to pull-out the geotextile.
– Anchor capacity is equal to the tensile force required for a displacement of 0.1 m of the sensor noted C_D (Fig. 12).

This second criterion has been added because the anchorage must stay in place to avoid too large deformation on the slope.

Whatever the chosen criterion, the V-shaped trench appears to have the lowest anchorage capacity. The trapezoidal trench is more efficient than the rectangular one in anchorage bench when the anchorage capacity is defined by the tensile force (Fig. 13). Nevertheless, as the tensile force is reached for a great displacement of the geotextile, if the displacement criterion is chosen, the anchorage capacity of rectangular and trapezoidal trenches are the same.

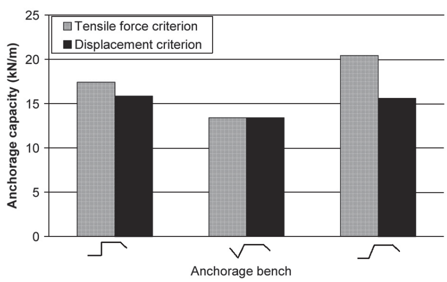

Figure 13. Anchorage capacity for a fixed length of geotextile equal to 2.1 m in sandy silt.

For the full-scale experiment, a mistake of set up induced a different thickness of the soil layer above the trenches: H = 0.3 m for the rectangular and V-shaped trenches and H = 0.2 m for the trapezoidal trench. So we can not compare the anchorage capacities but we notice that the trends observed on anchorage bench seem to be validated (Fig. 14).

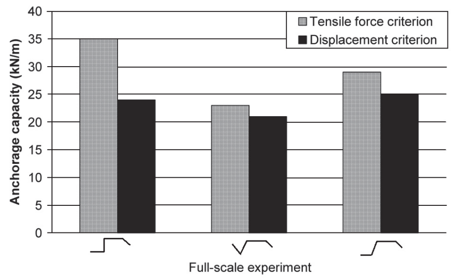

Figure 14. Anchorage capacity for a fixed length of geotextile equal to 2.1 m in flint clay.

5.2 *For a given space at the top of the slope*

Four anchor trenches were carried out in sandy silt in the anchorage bench for a space at the top of the slope equal to 1.6 m. The length between the trench and the slope L and the soil layer above the sheet were the same for the four cases (Fig. 15).

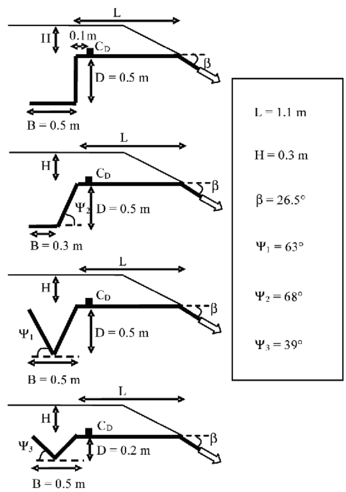

Figure 15. Anchor trenches for a fixed space at the top of the slope equal to 1.6 m.

Rectangular and trapezoidal trenches are more efficient than V-shaped trenches (Fig. 16). With the

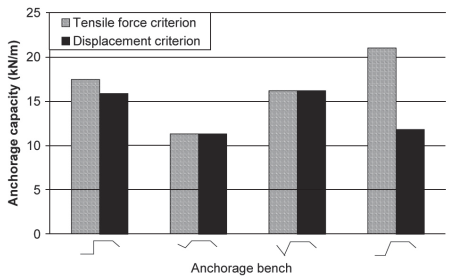

Figure 16. Anchorage capacity for a fixed space at the top of the slope equal to 1.6 m.

displacement criterion, the anchorage capacity of trapezoidal trench becomes less efficient; indeed the maximum tensile force is reached for a displacement of the sensor C_D of 0.2 m.

6 CONCLUSIONS

This experimental study has illustrated a number of important features of deformation and failure for anchorage in trench. The mechanisms are complex and fluctuate with the mobilisation of the tensile force: The normal stresses acting on the interfaces can be very different at failure comparing with the initial stresses, the friction at the soil/geosynthetic interface may be only partially mobilised if the failure occurs in the soil. When designing the anchorage, it is therefore not merely sufficient to consider the geometry of the problem and the interface characteristics: mechanical properties of the anchoring soil must be taken into account.

Comparing anchor trenches for a fixed length of geotextile or for a given space at the top of the slope showed that whatever the chosen criterion, the V-shaped trench appears to have the lowest anchorage capacity. The trapezoidal trench is easier to set up than the others and its anchorage capacity is nearly the same than the rectangular one; but it is important to notice that the maximum value obtained for the trapezoidal trench corresponds to a larger displacement of the geosynthetic. After these tests, we will perform new calculations in order to try to purpose new formulae to designers; in addition, it will be necessary to improve the choice of the displacement criterion and to think about the proposal of safety factors.

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