GEOSYNTHETICS ANCHORAGE: EXPERIMENTAL AND NUMERICAL STUDIES

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Abstract: Nowadays, geosynthetics are used as reinforcing elements in a wide variety of structures: Reinforced slopes and walls, embankments on soft soils, piled embankment, reinforcement in the base layers of railroad and road constructions, reinforced foundation mattresses, bridging of sinkholes or reinforced abutments.

In most cases, these reinforced structures require anchorage areas where the friction forces between the soil and the sheet equilibrate the horizontal tensile force induced in the geosynthetic sheet. Depending on the space available and on the loads applied, the anchorage systems may be configured with different shapes: simple run-out, anchorage or trenches of different geometries, and anchorage with wrap around. Designing the required dimensions of this anchorage remains problematic. In order to improve the knowledge of the behaviour of different kinds of anchorage, experimental and numerical studies were developed jointly.

This paper focuses on the simple run-out and anchorage with wrap around. Laboratory tests consisted in the pullout of a reinforced non-woven needle-punched geotextile anchored following various geometries.

Pullout tests of linear and non linear geosynthetic sheets were simulated using a two-dimensional discrete-element model (DEM). In the DEM, the soil was modelled with elementary particles which are assembled together to make clusters that interact with one another via their contact points. The constitutive behaviour of the soil is defined via micro-mechanical parameters of the contact laws. The geosynthetic was modelled by means of a dynamic spar elements method (DSEM). The advantage of DSEM elements is their ability to reproduce the behaviour of the geosynthetic and its interface directly.

With the parameters selected, numerical results of pullout calculations compare well with experimental data. Comparisons were made on the values of displacements obtained on particular points of the sheet, on tensile force in the sheet and on failure behaviour

Keywords: anchorage length, geosynthetic, laboratory test, numerical, reinforced earth structure, tensile strength.

INTRODUCTION

The stability and durability of geosynthetics in reinforced earth structure depends partly on the efficiency of the anchors holding the geosynthetic sheets. The role of the anchor is to withstand the tension generated in geosynthetic sheets by the structure. Designing the required dimensions of this anchorage remains problematic. In order to improve the knowledge of the behaviour of different kinds of anchorage, experimental and numerical studies were developed jointly (Briançon 2001, Chareyre 2003, Chareyre *et al.* 2002, Girard *et al*. 2006).

This study focuses on the simple run-out and anchorage with wrap around (the interest of the anchorage with wrap around is to reduce the anchorage area). Laboratory tests and two-dimensional discrete-element model were compared on a reinforced non-woven needle-punched geotextile anchored of various geometries in cohesive soil.

In order to alight the mechanisms involved during the extraction of the geosynthetic sheet new simulations were performed with a non-cohesive soil. At the opposite of the linear pullout case, the nature of the soil influences the pullout behaviour in the case of anchorage with wrap around. For both cases anchorage with wrap around (with and without cohesion), it can be seen that the upper part of the sheet is not solicited during the extraction and that the anchorage shape is not deform when the maximum tensile force is reached.

LABORATORY TESTS

Anchorage bench

The anchorage apparatus (Figure 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 area, a cable measuring system was used to monitor the displacements of the geotextile at different points. Two soil pressure cells were set up in soil to measure the increase of horizontal stress during the extraction.

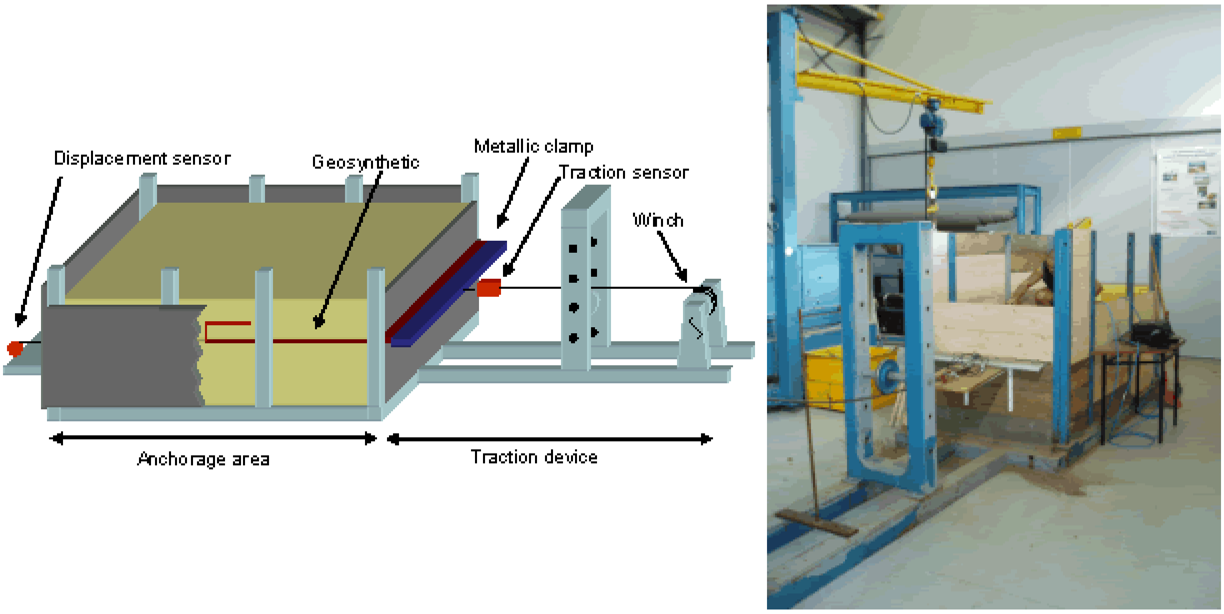

Figure 1. Anchorage bench

Anchorage geometry

Three anchorages were carried out to compare their anchorage capacity: horizontal run-out, anchorage with wrap around for two lengths (Figure 2). Horizontal run-out was specially carried out to determine the friction angle between soil and geotextile. Two anchorages with wrap around were carried out to establish the influence of length sheet on anchorage capacity. Thickness of soil layer above the three tests remains constant to 0.36m.

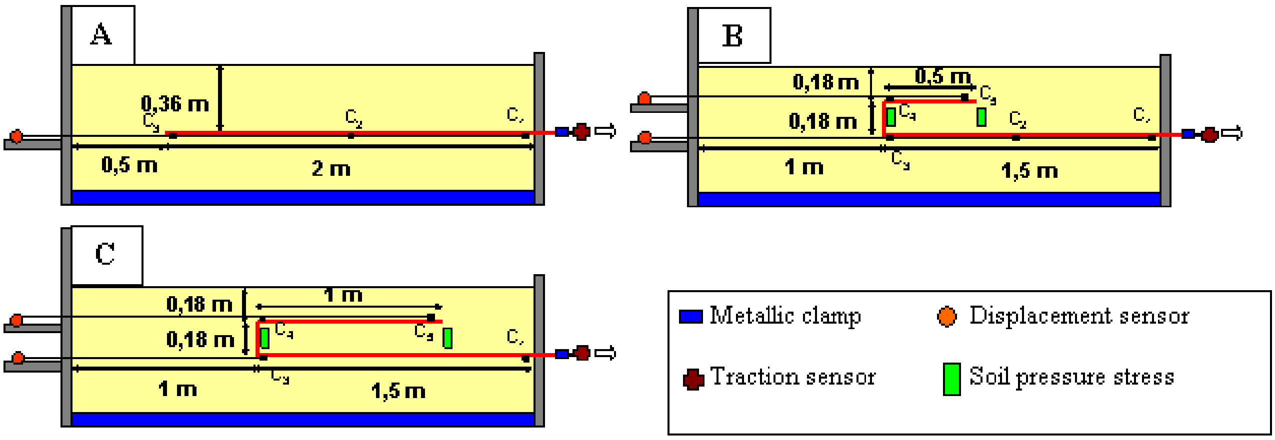

Figure 2. Anchorage geometries

Soil and geosynthetics tested

Sandy silt was used for all tests. Its main properties were measured (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.

Table 1. Soil properties

Soil	γ_d (kN/m^3)	w (%)	ϕ' (°)	c' (kPa)
Sandy silt	15.7	2.5	30	22

EXPERIMENTAL TESTS RESULTS

Simple run-out

The tensile force T required to pullout the geotextile has been measured to determine the anchor capacity. The tensile force reaches a maximum value equal to 14.6 kN (Figure 3, curve A). Assuming that the friction is the same on both geosynthetic sides, the interface friction angle could be calculated by:

$$T = 2.\gamma.H.L.\tan\delta$$

Where : γ is the bulk weight (=16.1 kN/m^3),
H is the soil height above geosynthetic (= 0.36 m),
L is the geosynthetic length (= 2m)
δ is the interface friction angle.

For this case, the interface friction angle is equal to δ = 32.3 °.

Anchorage with wrap around

Two tests with wrap around are carried out for two lengths (curves B & C, Figure 3). Comparing curves A, B and C, the shape of the curve B shows that there was probably a mistake during the laying out of the geosynthetic sheet or for the displacement measurement: the maximum value of tensile force is reached for a too great displacement value.

Anchorage with wrap around of 0.5 m gives the same anchorage capacity than simple run out for the same length of anchored geosynthetic Anchorage with wrap around of 1 m improves slightly the anchorage capacity (15 %). Measures of soil pressure cells show an increase of horizontal stress near the geosynthetic bend.

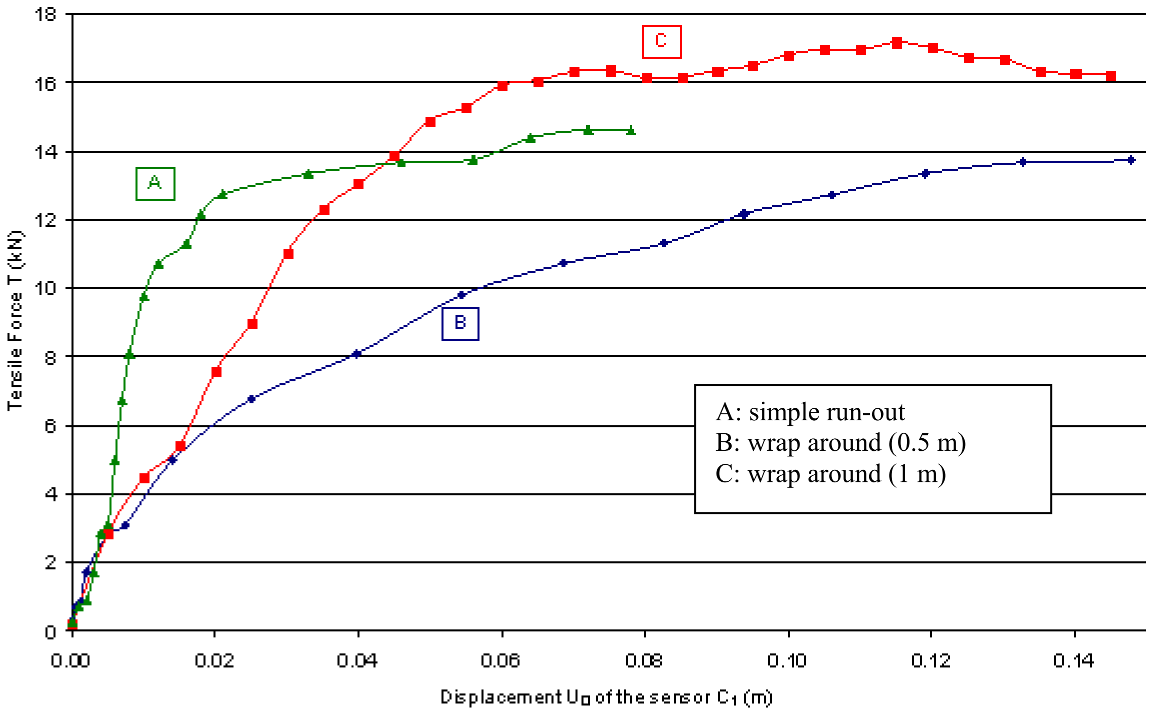

Figure 3. Experimental results for the three experimental tests

NUMERICAL ANALYSIS

Discrete-element model

The numerical modelling was carried out with the discrete-element method (DEM) developed first by Cundall and Strack (1979). This method, based on the molecular dynamics approach, assumes a set of rigid particles interacting with each other through deformable contact points. Interaction laws, locally defined, make it possible to restore a global macroscopic behaviour of the particles assembly.

A two-dimensional discrete-element model (PFC^{2D}, Itasca 1996) was used to investigate the pullout behaviours of linear and non-linear geosynthetic anchorage. The geosynthetic sheet was modelled by the way of spar elements (Chareyre and Villard 2005), which have been implemented into the DEM software. The thin spar elements allow reproducing the tensile behaviours of the geosynthetic sheet (no compression forces and no bending strength in the elements) using the tensile stiffness modulus parameter J (kN/m). The interface friction behaviour is governed by a Mohr-Coulomb law: $\tau_{max} = \sigma_n \tan\delta$ where δ and σ_n are the friction angle and the normal stress acting at the interface.

The soil was modelled with cylindrical particles, which are assembled together to make clusters. Each cluster was made of two jointed cylindrical particles of diameters d and 0.6 d. The granular distribution, initial porosity, shape of clusters and the methodology of setting up the particles have a great influence on macroscopic behaviour restored.

Thus, the clusters were used rather than single cylinders in order to reach high values of the macroscopic internal friction angle of the soil.

The clusters assembly was generated at fix porosity in a rectangular area without gravity using the Radius Expansion with Decrease of Friction process (REDF) (Chareyre, 2005). The elastic behaviour of the granular assembly depends of two local contact parameters: the normal stiffness k_n and shear stiffness k_s. Two contact failure criteria were defined (PFC^{2D}, Itasca 1996): one under tension, characterized by a tensile strength limit a_n, the other based on the elastic perfectly plastic model proposed by Cundall and al. (1979) and characterized by shear strength a_s (independent of normal force) or by a microscopic contact friction angle μ. The cohesion was defined by a normal and tangential local cohesion values C_n and C_s. In order to obtain realistic behaviour of cohesive soil, the local contact bond values C_n and C_s were attributed to every newly created contact during the calculation process.

Macro mechanical behaviour fit

The identification of the micro mechanical parameters of contact (Chareyre and Villard 2002) is obtained by reproducing and fitting the macro mechanical behaviour of a sample of soil submitted to usual laboratory tests. Numerical results of biaxial, traction and compression tests are presented Figure 4. The parameters selected to the definition of the micro mechanical parameters allow reproducing the behaviour of a cohesive material with an elastic modulus of 8 MPa, a cohesion C' of 22 kPa and an internal friction angle ϕ' of 30 °.

Numerical pullout tests were performed using 10000 clusters of several sizes. The displacement boundary conditions were imposed using rigid walls on the left, the right and on the bottom of the numerical sample. The extraction of the geosynthetic was carried out by moving horizontally the first element of the sheet. Due to the random character of the initial granular assembly, two successive simulations of the same problem never give exactly the same result. Thus, each numerical simulation was therefore performed several times to obtain average curves and values.

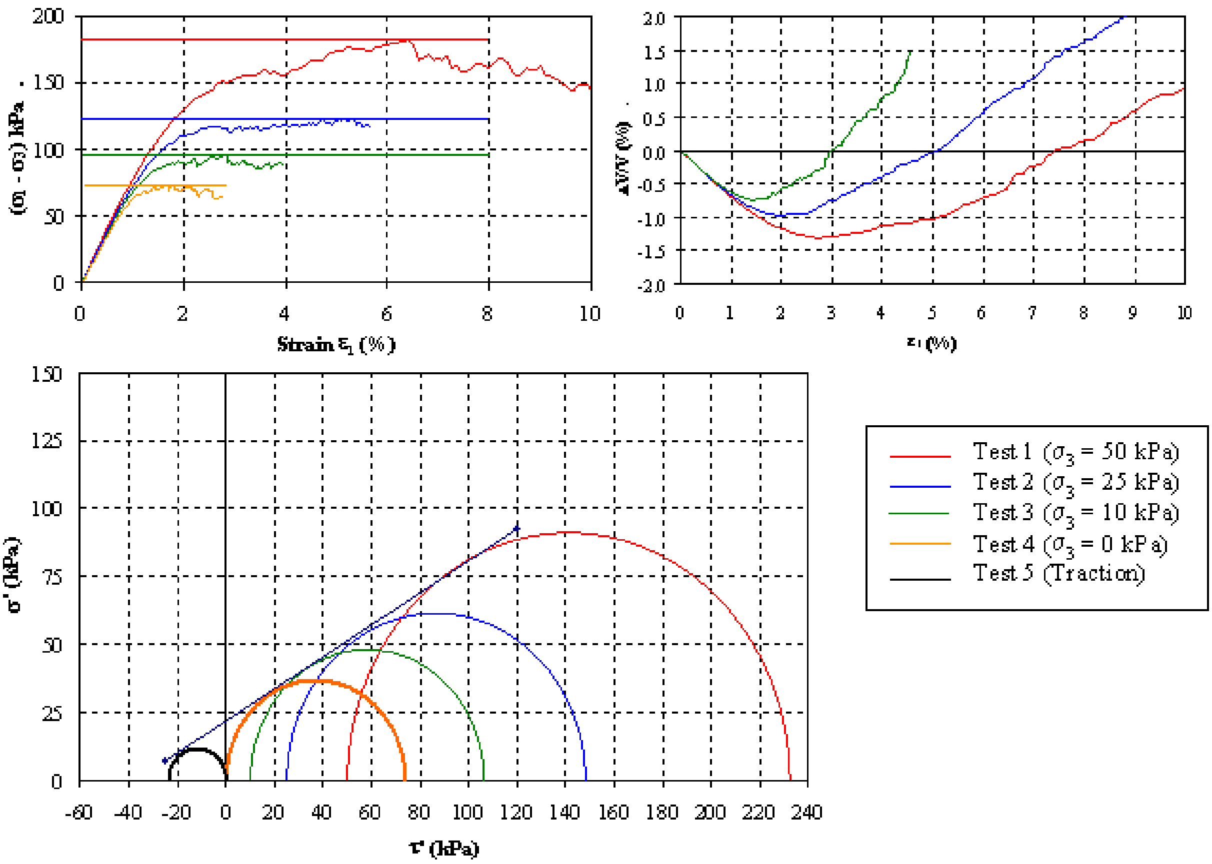

Figure 4. Results of numerical simulations of usual laboratory tests

Comparison between numerical simulation and experiment for linear pullout problem

Numerical results of linear pullout problem were compared figure 5 to the experimental results. We can notice the good agreement between the experimental and numerical curves head tensile force T versus head displacement U_0. Notice that the initial part of the curves deals with the tensile rigidity J of the geosynthetic sheet. In this case, the maximal tensile force depends on the interface friction angle δ and depends on the vertical stress apply on the sheet by the upper layer of soil. Two numerical simulations were performed: results appear to be reasonably consistent.

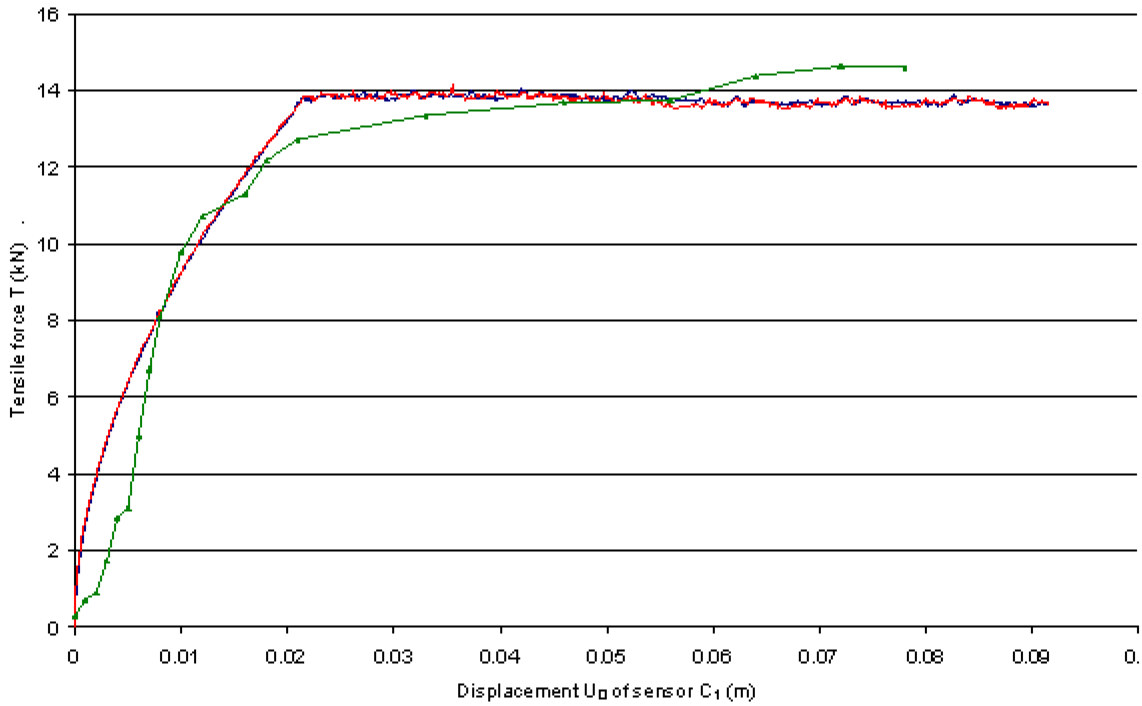

Figure 5. Comparison between numerical and experimental results of linear pullout tests

Comparison between numerical simulation and experiment for anchorage with wrap around

Numerical results of non-linear pullout simulations were presented and compared to the experimental results (Figure 6) for both lengths with wrap around. Numerical simulation curves of figure 6 are the average curves of three numerical tests for both cases. Comparison between both numerical simulations shows that, for this configuration, the length of upper part of sheet does not influence the anchorage capacity. The maximum value is reached for the same displacement and is in good agreement with those measured experimentally in the case of anchorage with wrap around of 1.0 m. The experimental curve of the other anchorage with wrap around of 0.5 m is not taken into account for the comparison because there was probably an experimental mistake during the extraction.

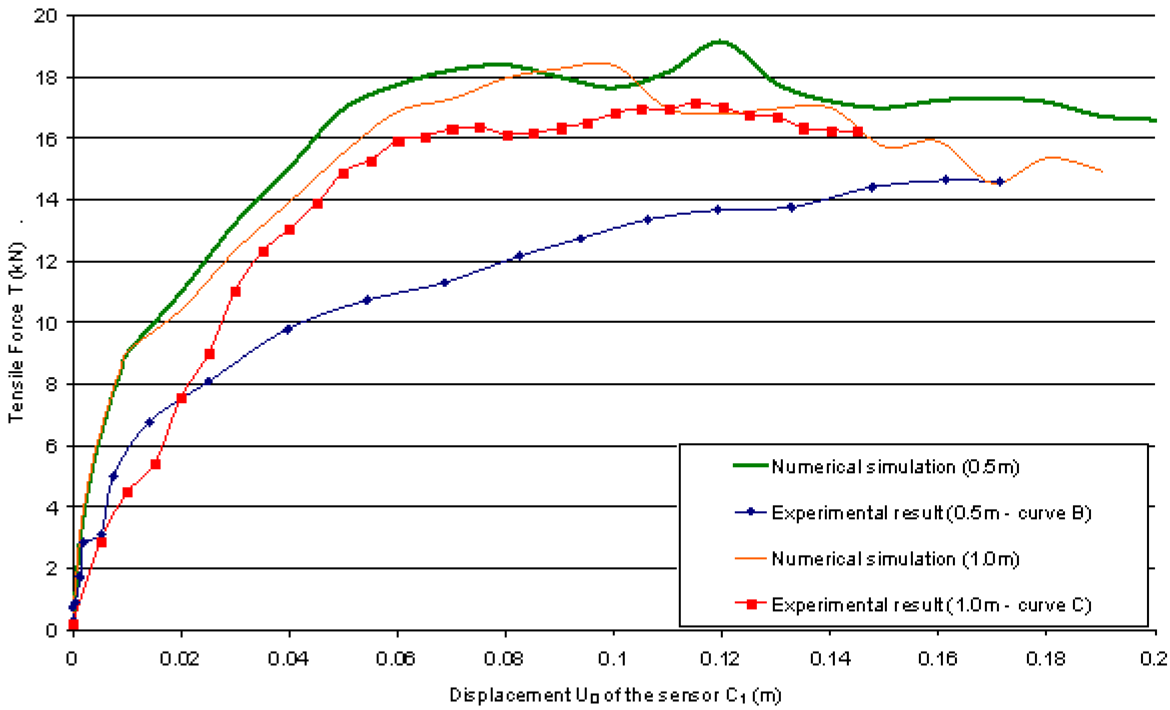

Figure 6. Comparison between numerical and experimental results of anchorage with wrap around

Mechanisms analysis of anchorage with wrap around from simulation

In order to alight the mechanisms involved during the extraction of the geosynthetic sheet new simulations were performed with a non-cohesive soil for anchorage with wrap around of 0.5 m. The curves (figures 7) show that, at the opposite of the linear pullout case, the nature of the soil influences the pullout behaviour. We can notice the good repeatability of simulations for both cases (Figure 7). The agreement is better for the case of soil without cohesion (only friction and no cracks) and for the first part of the curves before that the tensile force has reached to the maximum value (progressive stretching of the sheet) .

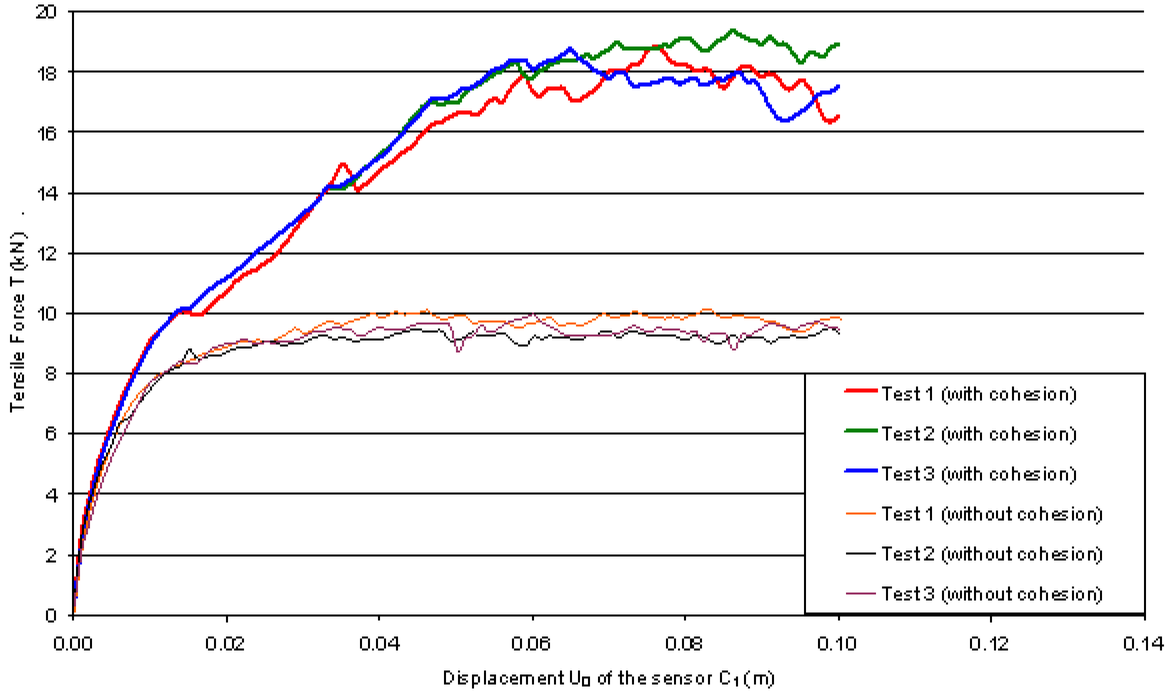

Figure 7. Repeatability of simulations for anchorage with wrap around of 0.5 m

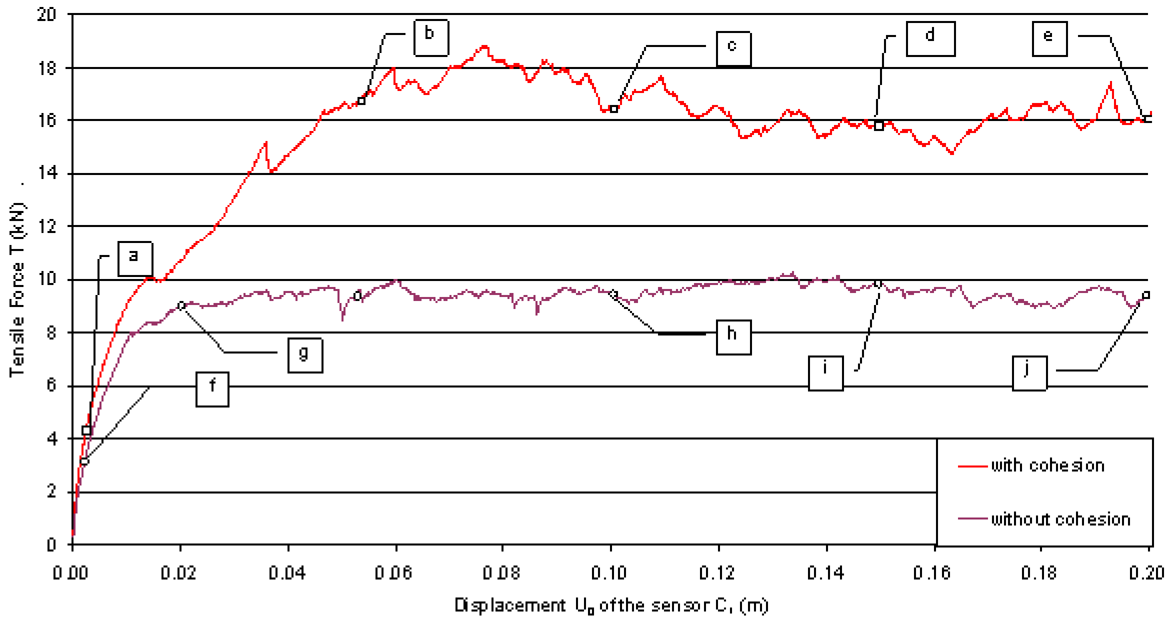

Figure 8. Numerical results of anchorage with wrap around of 0.5 m

Figure 8 presents the simulated tensile forces in the geosynthetic sheet for both cases with and without cohesion. The anchorage capacity is reached for an upper tensile force in the case with cohesion. However, this anchorage capacity is more quickly mobilized in the case without cohesion. To alight the mechanisms involved during the pull out tests, different views of the numerical model with wrap around, corresponding to several steps of loading (repaired by letters on figure 8 from a to e for the case with cohesion and from f to j for the case without cohesion), are given (for cohesive and no cohesive soil) figure 9.

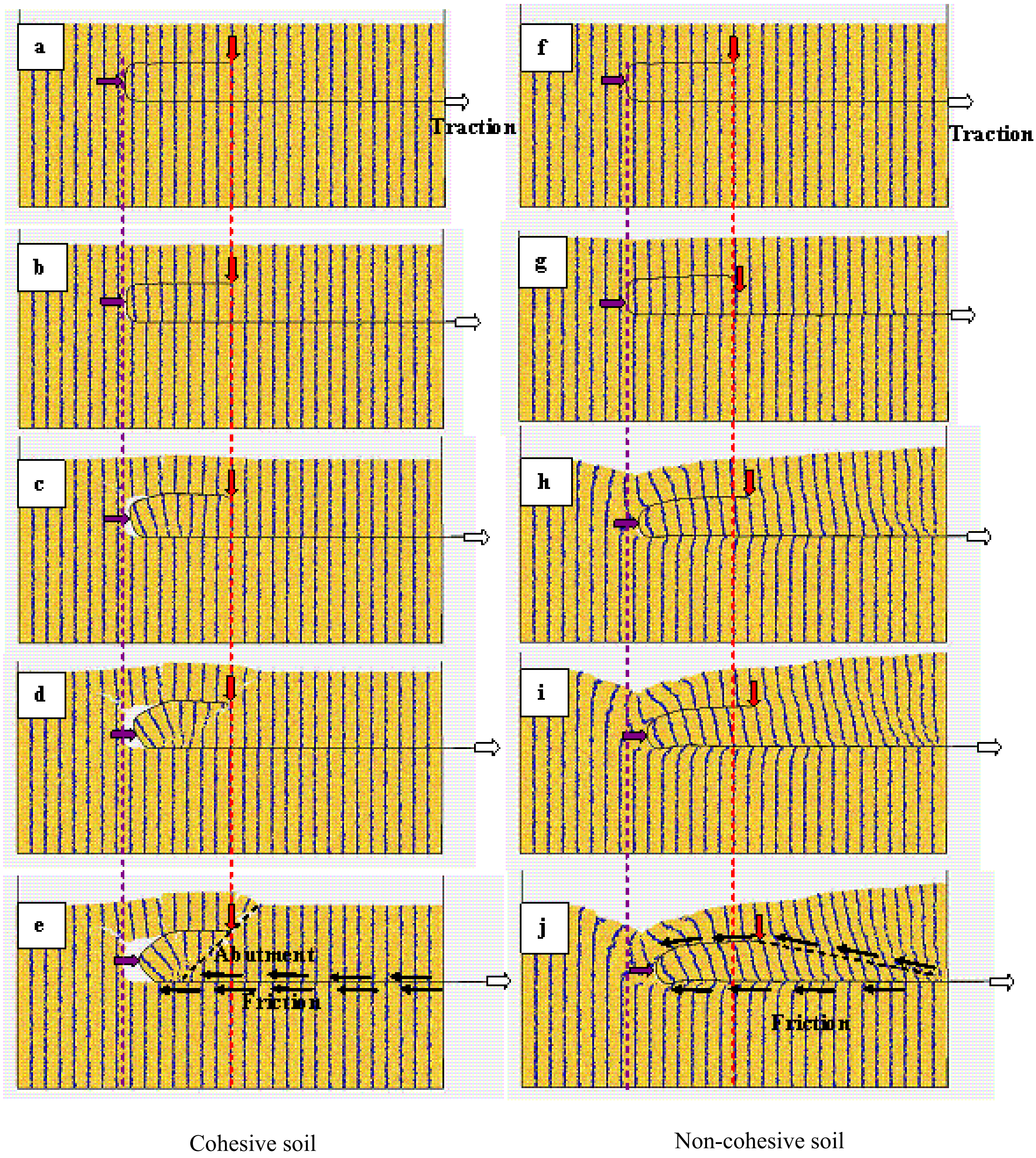

Figure 9. Numerical views of the pull-out tests for anchorage with wrap around for both cases with and without cohesion

We can note, figure 9 that the tensile force reaches its maximum value for a displacement U_0 = 0.02 m for the non-cohesive soil (dot g - Figure 8) and for a displacement U_0 = 0.05 m for the cohesive soil (dot b - Figure 8). For these displacements, the anchorage shapes are not deformed (Figure 9b-9g). For both cases, it can be seen that the upper part of the sheet is not solicited during the extraction. After that, for greater displacement, the anchorage deform differently according to the case.

In the case of cohesive soil, we can notice failure and broken mechanisms during the pullout process for great displacements. The extremity of upper part of sheet does not move. There is a horizontal compaction of soil in the anchorage with an abutment of soil mass and for greater displacement, a shearing plane appears from the lower part of sheet to the soil surface. We notice that the extremity of the upper part of sheet is localized on this shearing plane. On the anchorage, the soil lifts up.

In the case of non-cohesive soil, the extremity of the upper part of sheet moves in the direction of traction with the totality of the geosynthetic anchored.

We distinguish two different behaviours according the type of soil: simple friction on the contour of a soil/geosynthetic bloc for the non-cohesive soil (Figure 9j), friction at the interface soil/geosynthetic and abutment for the cohesive soil (Figure 9e).

CONCLUSION

The experimental and numerical studies have illustrated a number of important features of behaviour for the anchorage with wrap around. Numerical results of linear pullout problem and anchorage with wrap around were compared to the experimental results for a cohesive soil. We have noticed the good agreement between experimental and numerical results and the numerical simulations appear as to be reasonably consistent.

A simulation was performed with a non-cohesive soil to compare the anchorage behaviour according to the type of soil. Contrary to the linear pullout case, the nature of the soil influences the pullout behaviour in the case of anchorage with wrap around. In cohesive soil, an abutment of soil mass appears during the extraction. In non-cohesive soil, the anchorage moves in the direction of the traction.

It can be seen that the upper part of the sheet is not solicited during the extraction for both cases of anchorage with wrap around (with and without cohesion). In the main existing design approaches, the anchorage capacity is calculated assuming the resistance by friction everywhere at the interfaces of soil and geosynthetic. Our study highlights that, for the parameter selected for soil, geometry and geosynthetic, the upper part of geosynthetic sheet does not participate to the anchorage capacity and that designing requires taking into account an abutment for cohesive soil. Numerical modelling and experimental tests show that the anchorage shape is not deformed when the maximum tensile force is reached. Also, it is important to design anchorage with a displacement criterion: for great displacement, even if the tensile force remains constant, the displacement of anchorage becomes non-acceptable for the reinforced earth structure behaviour.

The remaining work consists in performing new modelling simulation and experimental tests for other parameters of anchorage, particularly the distance between upper and lower parts of geosynthetic sheet and the thickness of soil layer above anchorage to determine the optimize anchorage according to the type of soil.

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