Experimental studies of the behaviour of geosynthetic wrap around anchorage

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ABSTRACT: When determining the dimensions of a geosynthetic lining system, it is important to have knowledge of the behaviour of the anchorage of the geotextile sheets. In order to optimise the geometry of the structures in question and then reduce the area taken up by the anchorage, anchorage solutions using trenches of varying forms are sometimes used. This paper focuses on two types of anchors (simple run-out and wrap around). The first author has previously performed some pull-out tests using an anchorage bench under controlled conditions using three types of geosynthetics and two types of soil. The results obtained from that study showed that there is an optimum length for the upper part of the geosynthetic for the wrap around anchorage. A more detailed analysis which describes the behaviour of a geosynthetic for the wrap around anchorage, the influence of the geosynthetic and of the soil types is presented herein.

KEYWORDS: Geosynthetics, Anchorage systems, Geosynthetic behaviour, Pull-out test, Low confinement stresses, Soil reinforcement

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1. INTRODUCTION

The stability and durability of geosynthetics when used in a 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. At the base of a reinforced embankement, the anchorage systems may take on two different shapes: simple run out or wrap around to reduce the anchorage area. Several authors have studied the behaviour of these anchorage systems numerically and experimentally (Chareyre *et al*. 2002; Villard and Chareyre 2004; Chareyre and Villard 2005; De and Vellone 2005; Briançon *et al*. 2008). The available models show that there has been no complete study on the geosynthetic behaviour with a wrap around anchorage. A specific study focused on the simple run-out and anchorage with wrap around (Lajevardi *et al*. 2012a, 2012b, 2014; Lajevardi 2013) highlighted the anchorage mechanisms and especially the effect of geometric parameters on anchorage efficiency for three types of geosynthetics and two types of soil.

From the experimental results of pull-out tests on anchored geosynthetics (Lajevardi 2013), a description of the soil and geosynthetics displacements is provided during the pull-out tests. This helps to improve the understanding of anchorage mechanisms.

2. BACKGROUND

A review of the literature concerning equipment and experiments has shown that the pull-out test is the most suitable test to determine the soil/geosynthetic interface under low and high confinement stress (Chang *et al*. 1977; Palmeira and Milligan 1989; Ochiai *et al*. 1992; Fannin and Raju 1993; Farrag *et al*. 1993; Koerner 1994; Alfaro *et al*. 1995; Raju 1995; Lopes and Ladeira 1996; Sugimoto *et al*. 2001; Moraci *et al*. 2004; Moraci and Recalcati 2006; Palmeira 2009; Abdelouhab *et al*. 2010; Lajevardi *et al*. 2013). They also permit the modelling of the anchorage systems for determining their anchorage capacity and to

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analyse the different mechanisms relating to such systems. Further to these advantages, two standards have been developed concerning the use of pull-out test: an American Standard (ASTM D6706-01) and a European Standard (EN 13738 (BSI 2004)). They specify the characteristics of the apparatus and the conditions in which it has to be used. The pulling out of geosynthetics, conducted under controlled and instrumented conditions will help to establish the difference in behaviour between different anchorage systems.

A bibliographical analysis concerning experimental models has shown that most of the physical tests were carried out for anchorage trenches (L-shape and V-shape) and there is no complete experimental study on the geosynthetic behaviour as anchorage (such as the wrap around case) in the reinforced embankment (Lajevardi *et al.* 2014).

3. EXPERIMENTAL TESTS

In a previous work, Lajevardi (2013) has performed pull-out tests with an anchorage bench (Figure 1) under laboratory controlled conditions with three types of geosynthetic (two geotextiles (Table 1) and one geogrid (Table 2)) and two types of soil (Table 3: gravel and sand).

Figure 2 presents the distribution curve of grain-size for the soils used in the study. The sand used for the tests is known as Hostun RF sand (fine sand). Flavigny *et al.* (1990) have studied this sand. The coarse soil used in the tests is well graded gravel according to the Unified Soil Classification System (USCS) classification procedure.

The geotextiles used for these tests were reinforcement geotextiles (uniaxial or biaxial) constituted by high modulus polyester fibres (wires), attached to a continuous filament nonwoven geotextile backing.

The geogrid used for these tests was a biaxial reinforcement geogrid in the machine direction constituted by high tenacity polyester yarns, which were covered with a polymeric coating, providing high tensile strength with low creep characteristics.

In the previous study mentioned above, the mobilisation and the capacity of geosynthetic sheets for two different anchoring systems were described for simple run-out and wrap around. The results based on pull-out tests showed that the mobilisation of a geosynthetic sheet (head tensile force; T_T versus head displacement; U_0) in two types of soils and for two different anchorage systems is very similar. For the wrap around anchorage, the head tensile force (which is equal to tensile force on the metallic clamp T_T) versus the head displacement may be

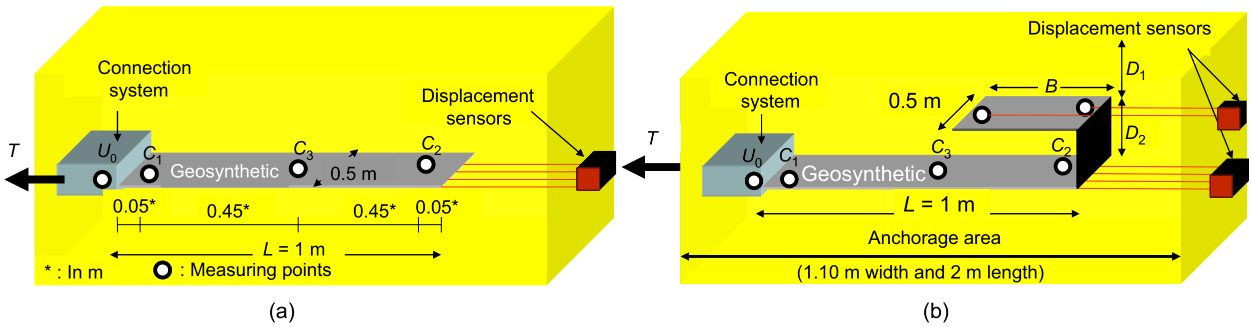

Figure 1. Physical model: (a) simple run-out, (b) wrap around (Lajevardi *et al.* 2014); *unit is metres

Table 1. Geotextile properties (Lajevardi 2013)

Geotextile		Stiffness: J (kN/m)	Thickness (mm)	Tensile strength MD (kN/m)		Mass per unit area (g/m²)
				At 2% strain	Ultimate	
GT_{75}	Biaxial	687	2.6	16	79	440
GT_{230}	Uniaxial	2104	3.2	46	242	620

MD, machine direction.

Table 2. Geogrid properties (Lajevardi 2013)

Geogrid	Thickness (mm)	Tensile strength (kN/m)		Mass per unit area (g/m²)	Number of longitudinal strips per 1 m		Grid aperture size
		At 2% strain	Ultimate		MD	CD	(mm)
GRL	1.6	10	58	255	26	40	25 × 30

MD, machine direction; CD, cross direction.

Table 3. Soil properties (Abdelouhab *et al.* 2010)

Characteristics	Coarse soil	Fine sand
Range of grain size (mm)	0–31.5	0.16–0.63
Hazen's uniformity coefficient: Cu	25	2
Angle of friction (°)	37[a]	35[b]
Cohesion (kPa)	8[a]	1[b]
Dry unit weight (kN/m^3)	19.5	15.2
Maximum dry unit weight (kN/m^3)	20.5	15.99
Minimum dry unit weight (kN/m^3)	19.1	13.24
Relative density (%)	30	70
D_{10} (mm)	0.5	0.22
D_{30} (mm)	2.3	0.3
D_{60} (mm)	9.5	0.42

[a]Direct shear. [b]Triaxial.

assimilated to a tri-linear shape. For the simple run-out one, this mobilisation depends on the stiffness and the nature of the geosynthetic sheet and may vary from a tri-linear shape to a bi-linear one. The rear of the reinforcement moves after a head displacement threshold which depends mainly on the stiffness, the sheet configuration, the stress confinement and the type of soil.

On anchorage capacity, the results showed that for the two values of the thickness of the soil layer above the anchorage (H) 0.4 and 0.5 m, the maximum tensile force (T_T) increased with the increase of the confinement stress. The tests carried out on the geosynthetic sheet showed that for a large head displacement (U_0), the anchorages with wrap around were more resistant than the simple run-out anchorage. The efficiency or capacity of anchorage (head tensile force) for the wrap around and simple run-out anchorages was the same when the head displacements were small.

These authors have also shown that for the wrap-around anchorage, the tensile force was not proportional to the length of upper part of sheet (B) and that was not the only important parameter to determine the efficiency of the anchorage.

4. ANALYSIS OF EXPERIMENTAL RESULTS

An experimental database was created and it has been presented in Lajevardi (2013). The following work is based on the results of these pull-out tests.

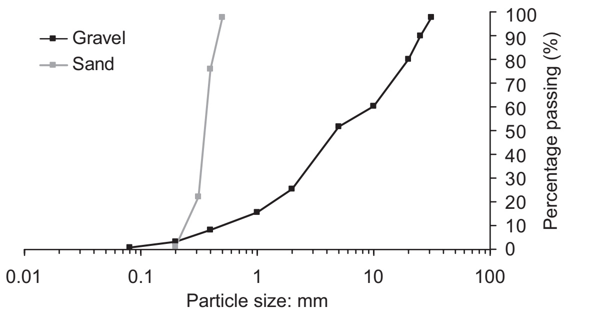

Figure 2. Distribution curves of grain size for the soils used in the study

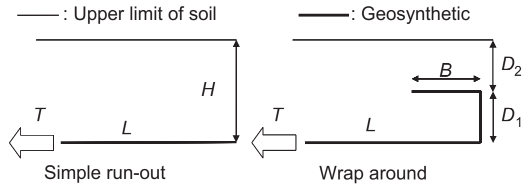

Figure 3. Anchorage geometry (Lajevardi *et al.* 2014)

4.1. Anchorage geometry

Two anchorage systems were tested (Figure 3) to study of the behaviour of geosynthetic anchorage. These systems were carried out with different geometries.

- Thickness of soil layer above anchorage ($H = D_1 + D_2 =$ 0.4 or 0.5 m).
- Distance between upper and lower parts of geosynthetic (D_1 = 0.2 or 0.3 m).
- Length of upper part of sheet (B = 0.25 or 0.5 m).
- D_2 = 0.2 m.
- Length of the geosynthetic (L = 1 m).

The width of the geosynthetic sheet was always equal to 0.5 m.

In order to study the geosynthetic behaviour in the soil, a measurement of the soil surface settlement was performed in the anchorage bench after the pull-out test for each anchorage.

4.2. Vertical movement (heave) of soil over the geosynthetic sheet

4.2.1. *In the case of geotextile GT_{230}*

For the simple run-out, the heave of sand was largest close to the traction system (guidance box). A settlement was observed beyond the rear (portion away from the loading end) of the reinforcement (Figure 4a). All these observations show that small movements occurred in the soil mass over the reinforcement. Then the assumption of friction on both sides of the geosynthetic sheet was satisfactory for these soil heights (H = 0.40 and 0.50 m).

For the wrap around anchorage, this heave was the largest close to the upper part of the sheet and sometimes at the sheet centre. For the two studied cases (B = 0.25 and 0.50 m), heave increased with the increase in the length of the upper part. A settlement of the sand was observed after the rear of the reinforcement (Figure 4a). The curve for B = 0.5 m appears to spike at the point around 0.75 m; this trend was reproduced with three pull-out tests.

Figure 4b shows that the heave in the gravel was similar to the one in the sand, but its value was higher than in the sand. A settlement of the gravel was observed beyond the rear of the reinforcement in the simple run-out but not in the wrap around anchorage.

4.2.2. The case of a geogrid GRL

In the case of the sand, the heaves were very low (Figure 5a). In fact, during the pull-out, the sand passes through the openings of the geogrid especially in the vertical part of the geogrid (D_1).

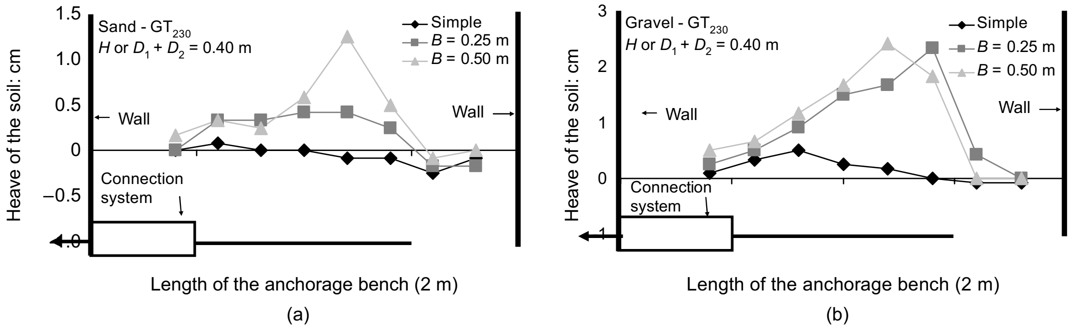

Figure 4. Heave of the soil over the geotextile under two types of anchorage: (a) sand; (b) gravel

In the case of the gravel, this heave was largest in the middle of the geogrid sheet for the case of the simple run-out anchorage. For the wrap around anchorage case, the maximum heave can be located close to the end of the sheet upper part (Figure 5b).

All these observations show that for the sand case and the wrap around anchorage, the heave of geotextile is higher than in the case of the geogrid. Due to the fact that the geotextile has no openings like geogrids, it plays the role of an envelope for the soil mass.

4.3. Geosynthetic behaviour in the wrap around anchorage

In order to study the geosynthetic behaviour for the wrap around anchorage, a measurement of the geosynthetic sheet displacement on the upper and lower parts of the sheet (*B* and *L*) before and after the pull-out test was carried out. For this purpose, the distance between the marked points on the geosynthetic sheet and a constant point on the wall of the anchorage apparatus was measured before and after the test. The difference between two measurements allowed the geosynthetic sheet displacement to be deduced.

Two hypotheses for the geosynthetic behaviour are possible (Figure 6).

- The geosynthetic brings back soil and remains in its initial configuration (Figure 6a).
- The geosynthetic moves in the extraction direction (slides over to line up in the traction axis) (Figure 6b).

4.3.1. *Geosynthetic behaviour in the sand*

In the case of a geotextile in the sand, a displacement of the geotextile (10 to 25 mm) and of the sand can be observed under the length of the sheet upper part (*B*). On the other hand, the distance between upper and lower geotextile parts (D_1) decreased after the test. This decrease in the case of GT_{75} equal to 30 mm was higher than in the case of GT_{230} (equal to 2.5 mm). This shows the dependency of the mechanisms on the stiffness of the geotextile sheet (Figure 7a).

In the case of using a geogrid in sand, no displacement of the geogrid was observed under the sheet upper part (*B*). Moreover, the distance between upper and lower geogrid parts (D_1) remained unchanged (Figure 7b).

4.3.2. *Geotextile behaviour in the gravel*

After the test, a displacement of the geotextile and gravel under the length of upper part of sheet (*B*) was observed (Figure 7c). The value of D_1 decreased and the T_T–U_T curve increased during the test (see Figure 9a below), so it

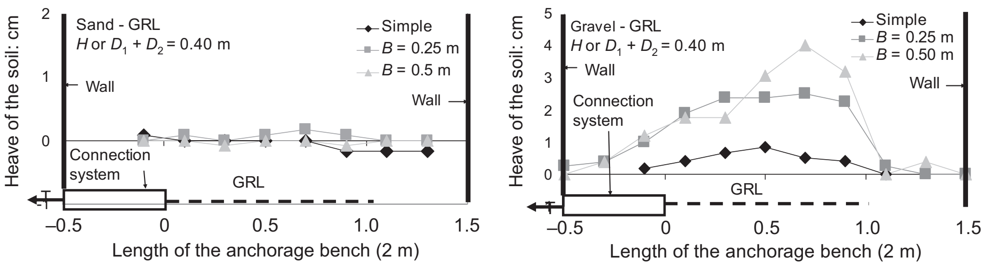

Figure 5. Heave of the soil over the geogrid under two types of anchorage: (a) sand; (b) gravel

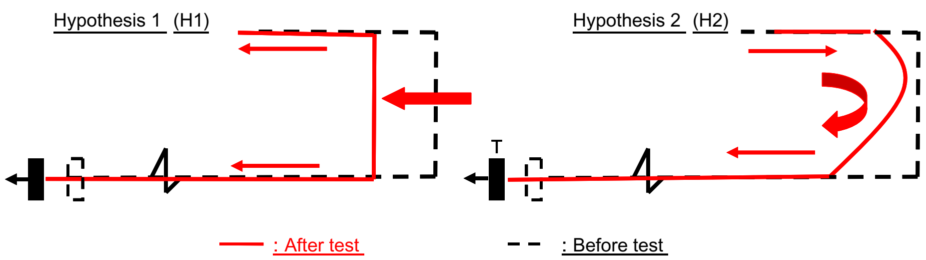

Figure 6. Hypotheses on the geosynthetic behaviour

means that the gravel/geotextile friction in this place was very high.

4.3.3. *Horizontal stress sensor*

A total stress cell, 0.10 m × 0.20 m, was vertically set up in order to measure the horizontal stress during the pull-out. It was located just in front of the geosynthetic bend (Figure 8). The cell was calibrated buried in the soil used for the tests.

This sensor helped to explain the geosynthetic behaviour in the wrap around anchorage. It shows (Figure 8)

- a decrease of the horizontal stress at the beginning of the test highlighting the mechanisms of sliding
- an increase of the horizontal stress until the traction reaches its maximum value highlighting the mechanisms of block displacement.

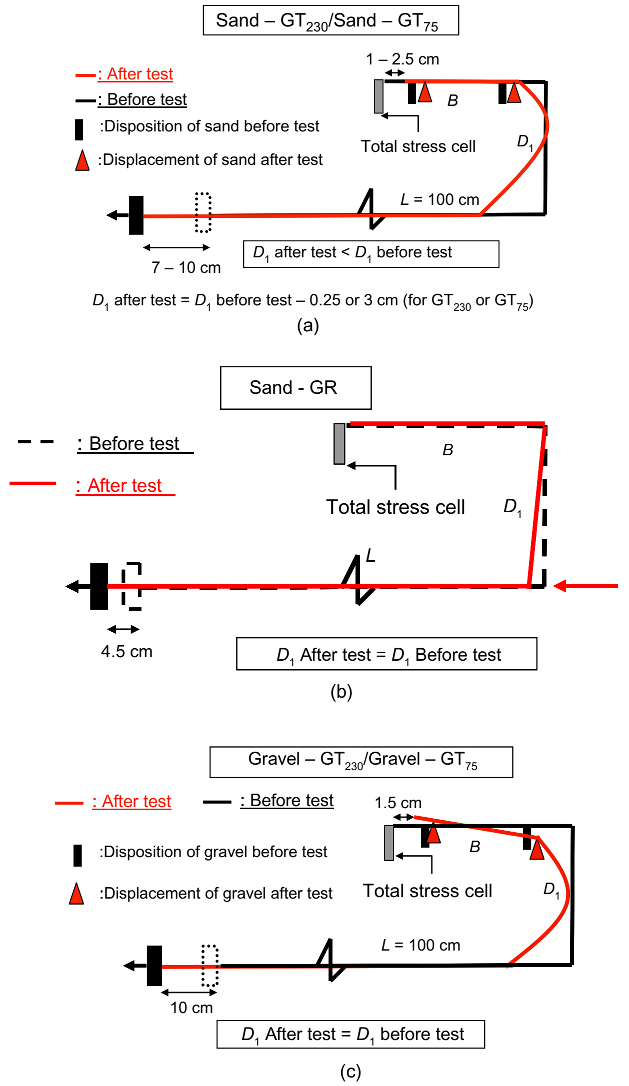

Figure 7. Disposition and displacement of the geosynthetic and soil before and after test: (a) sand–geotextile; (b) sand–geogrid; (c) gravel–geotextile

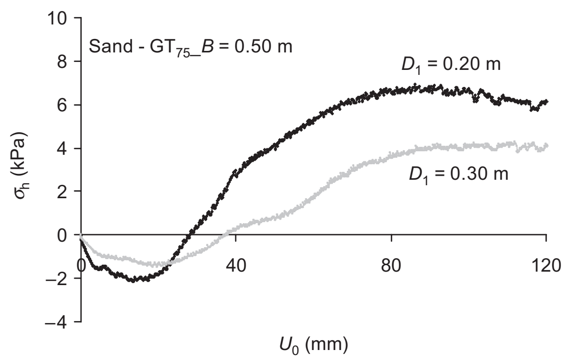

Figure 8. Horizontal stress plotted against head displacement

4.4. Mechanisms analysis of wrap around anchorage for GT_{230} and GRL

In order to highlight the mechanisms involved during the extraction of the geotextile sheet (GT_{230}) and of the geogrid sheet (GRL), the analysis of the pull-out tests was performed with two types of soil under the same confinement stress for the wrap around anchorage of $B = 0.25$ m.

Figure 9 presents the tensile forces at the head (T_T) and the required displacement of the head (U_0) to obtain a rear displacement of the geosynthetic sheet (U_R). This shows that the mobilisation of the lower part of the sheet where $L = 1$ m for both geosynthetics in both soils was progressive.

The anchorage capacity was reached for a higher tensile force in the case of gravel for the same confinement stress (8 kPa).

The tensile force reached its maximum value for a displacement $U_0 = 13$ and 25 mm (for GT_{230} and GRL, respectively) in the sand (dotted line a in Figure 9) and for a displacement $U_0 = 19$ and 42 mm (for GT_{230} and GRL, respectively) in the gravel (dotted line b in Figure 9). For these displacements, the anchorage shapes were not

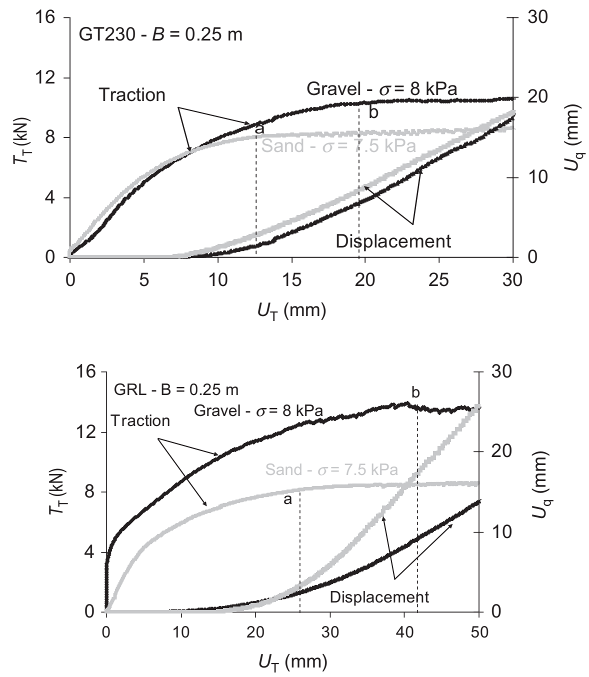

Figure 9. Geosynthetic behaviour of the head in two types of soil under the same confinement stress for wrap around anchorage with $B = 0.25$ m (T_T, head tensile force; U_T, head displacement; U_R, rear displacement): (a) geotextile; (b) geogrid

deformed (Figures 4, 6 and 7). After that, for higher displacements, the anchorage deformed differently according to the type of soil.

4.5. Influence of the geosynthetic stiffness

The influence of the geotextile stiffness on the maximal tensile force for the same applied confinement stress and on both soils was studied. The GT_{75} stiffness was equal to one-third of GT_{230} stiffness. In the tests with gravel (Figure 10a), the tensile force in the case of the GT_{75} was higher than in the case of the GT_{230} (difference of 15% for all anchorages).

In the case of sand (Figure 10b), the tensile force with the GT_{230} was higher than with the GT_{75} (difference of 4% for the simple run-out and a maximum difference of 13% for the wrap around).

By comparing Figures 10a and 10b, in the case of sand, the tensile force with the GT_{230} was higher than the GT_{75}, whereas the opposite was observed in the case of gravel. It also shows the influence of the soil type on the tensile force.

4.6. Influence of the geosynthetic type (GT_{75} and GRL)

In the case of coarse soil (gravel), the pull-out tests show that the maximum tensile force with the geogrid (GRL) was higher than with the geotextile (GT_{75}), whereas in the case of sand, the trends were reversed. The tensile strength of the GT_{75} (without soil) was equal to 79 kN/m and was greater than that of the GRL which was equal to 58 kN/m.

During pulling out and in the gravel/geogrid interface, three mechanisms were mobilised.

- Soil friction on the geogrid surface.
- Soil/soil friction in the geogrid openings.
- Passive resistance of geogrid transversal strips.

Therefore in the case of coarse soil (gravel), the geogrids had a pulling out resistance that was greater than that for the geotextiles. Indeed, the geogrids were able to mobilise soil/soil friction in their openings and a passive resistance in their bearing members (transversal strips).

4.7. Influence of the soil type

The influence of the soil type on the maximum tensile force in the same thickness of soil layer above anchorage ($H = D_1 + D_2 = 0.40$ or 0.50 m) was studied. In these tests, the tensile force in the case of the gravel was higher than in the case of the sand (more than 50% for the GT_{230} (Figure 11a) and more than 100% for the GRL (Figure 11b)) whereas the confinement stress in the case of the gravel was only 30% higher than that in the sand case.

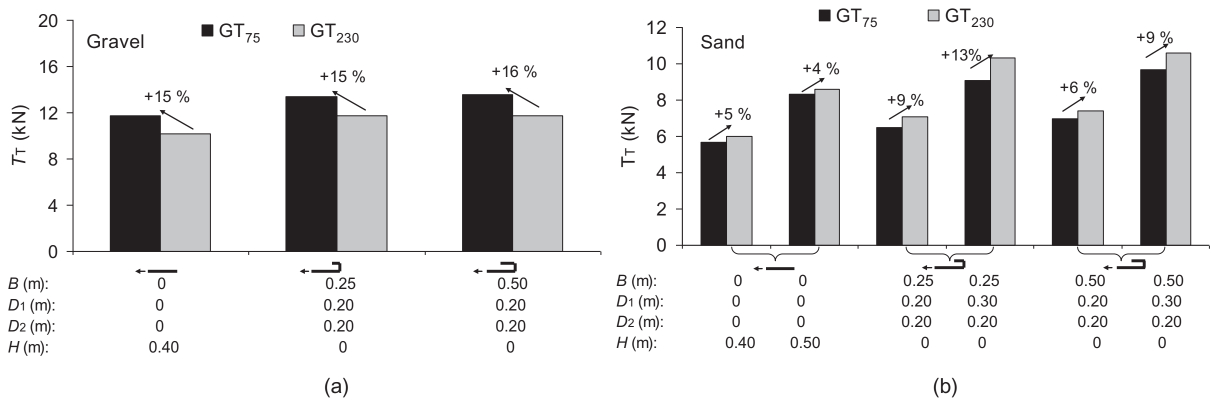

Figure 10. Comparison of the tensile force between GT_{75} and GT_{230} in the same applied confinement and in both soils: (a) gravel; (b) sand

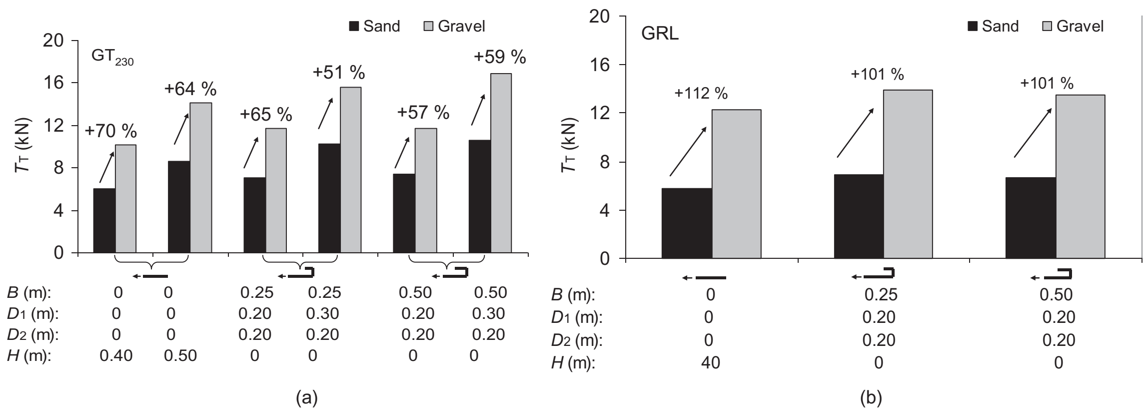

Figure 11. Comparison of the maximum tensile force between the sand and the gravel in the same thickness of soil layer above anchorage: (a) GT_{230}, (b) GRL

This difference in the tensile force is related to the high density and large particles sizes (Hazen's uniformity coefficient: C_u) in the gravel which led to higher friction. The gravel density was higher than the sand density then for the same soil layer thickness, the confinement stress was higher in the gravel case which induced a higher friction coefficient. The interlocking of gravel particles in geogrid are also possible explanations. The influence of the soil type on geogrid sheet is higher than on the geotextile sheet.

5. CONCLUSIONS

Lajevardi (2013) has presented a study based on pull-out tests for several geosynthetic sheets and two types of anchorage: a simple run-out and a wrap around one. This paper describes some aspects of the work and has focused on the behaviour of geosynthetics in anchorage.

The pull-out tests performed in the laboratory allowed parameters such as the head tensile force and the displacement at several points on the geosynthetics to be determined. The analysis of these results allows the geosynthetic behaviour for the wrap around anchorage to be determined. For the simple run-out, the movement (heave) of soil is the largest close to the traction system and for the anchorage with wrap around, this movement was the largest close to the upper part of sheet (B) and away from the traction system.

The study of displacements and movements of soil and geosynthetic during the tests show that the geosynthetic moves in the extraction direction.

The comparison between results from fine sand and coarse soil showed that the tensile force was higher in coarse soils and even more in the case of geogrid. The soil parameters that influence the anchorage behaviour on the geosynthetic sheet and the tensile force are the density, the particles size and their friction angle with the geosynthetic sheet.

This study has allowed some characteristics of the simple run-out and the wrap around anchorage for two types of soil to be highlighted.

NOTATION

Basic SI units are given in parentheses.

- B length of the upper part of the sheet (m)
- C_u Hazen's uniformity coefficient (dimensionless)
- D_1 distance between the upper and the lower part of the geosynthetic (m)
- D_2 distance between the upper part of the geosynthetic and the upper limit of the soil (m)
- D_{10} soil particle diameter corresponding to 10% by weight of finer particles (m)
- D_{30} soil particle diameter corresponding to 30% by weight of finer particles (m)
- D_{60} soil particle diameter corresponding to 60% by weight of finer particles (m)
- H thickness of the soil layer above anchorage (m)
- J geotextile stiffness (N/m)
- L length of the geosynthetic (m)
- T_T head tensile force (N)
- U_0 head displacement of the geosynthetic sheet (m)
- U_R rear displacement of the geosynthetic sheet (m)
- σ confinement stress (Pa)
- σ_h horizontal stress (Pa)

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