



## Experimental studies of the geosynthetic anchorage – Effect of geometric parameters and efficiency of anchorages



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### ABSTRACT

The soil reinforcement by geosynthetic is widely used in civil engineering structures: embankments on compressible soil, slope on stable foundations, embankments on cavities and retaining structures. The stability of these structures specially depends on the efficiency of the anchors holding the geosynthetic sheets. Simple run-out and wrap around anchorages are two most commonly used approaches. In order to improve the available knowledge of the anchorage system behaviour, experimental studies were carried out. This paper focuses on a three-dimensional physical modelling of the geosynthetics behaviour for two types of anchors (simple run-out and wrap around). The pull-out tests were performed with an anchorage bench under laboratory controlled conditions with three types of geosynthetic (two geotextiles and one geogrid) and in the presence of two types of soil (gravel and sand).

The results show that there is an optimum length for the upper part of the geosynthetic for the wrap around anchorage.

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### 1. Introduction

Presently, geosynthetics are utilised as reinforcing elements in a wide variety of structures: reinforced slopes and walls, embankments on soft soils, reinforcement in the base layers of railroads and road constructions, bridging over sinkholes or reinforced abutments. These structures may also present different behaviours according to the reinforcement type, the soil type and the anchorage system type. Extensibility, disposition and shape of reinforcements lead to behaviour more or less complex in terms of deformation and strength. Geotechnical characteristics of the soil have an influence on the stress distribution between the reinforcements and the adhesion at the soil/reinforcement interface. Configurations of anchorages also have an influence on the anchorage capacity.

The stability and durability of geosynthetics in reinforced earth structure depends partly on the efficiency of the anchors holding the geosynthetic lining. The role of the anchor is to withstand the

tension generated in geosynthetic sheets by the structure. In most cases, these reinforced structures need anchoring zones where the friction forces between the soil and the geosynthetic sheet balance the horizontal tensile force induced in the geosynthetic. Depending on the available space and on the applied loads, the anchorage systems can be configured using different shapes: simple run-out, anchorage on trenches with different geometries and anchorage with wrap around. The geosynthetic sheets are often installed in trenches, with a L-shape, V-shape or U-shape (Fig. 1), to optimise the dimensions of the anchor zone (minimal horizontal area occupied) and to ensure effective anchorage. The interest of the wrap around anchorage is to reduce the anchorage zone (Fig. 2). These anchorages are often oversized because of the absence of detailed knowledge about the developed mechanisms. Designing the required sizes of these anchorages remains then problematic.

In order to size the system, it is necessary to estimate the tension that can be mobilised in the anchor (anchorage capacity) according to its geometry and the properties of the constituent materials.

In order to improve the knowledge about the behaviour of different kinds of anchorage, experimental and numerical studies were developed jointly (Briançon, 2001; Briançon et al., 2008; Chareyre, 2003; Chareyre et al., 2002; Chareyre and Villard, 2004; Girard et al., 2006; Lajevardi et al., 2012a,b; Lajevardi, 2013).

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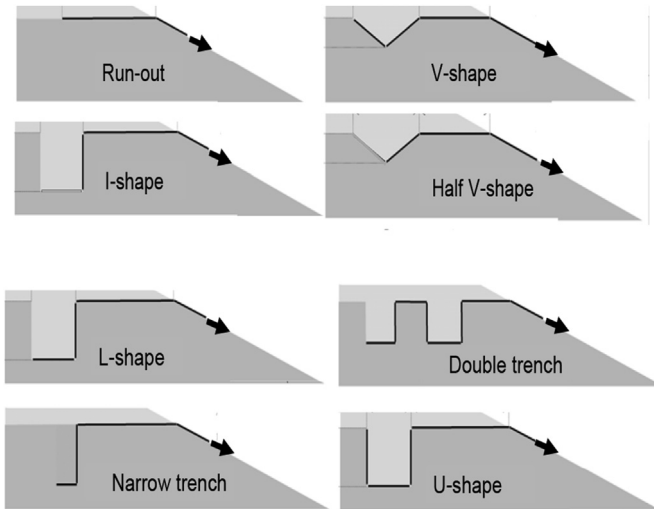


Fig. 1. Different types of anchors trenches.

In the case of experimental studies and after a review of the literature concerning equipment and experiments, the pull-out test is the most suitable test to determine the soil/geosynthetic interface under low and high confinement stress. They also permit to model the anchorage systems for determining their anchorage capacity and to analyse the different mechanisms relating such systems. The pulling out of geosynthetics, conducted under controlled and instrumented conditions will help to establish the difference in behaviour between different anchorage systems.

Several authors have been interested in this type of test to determine the interaction parameters of different types of reinforcements (Abdelouhab et al., 2010; Alfaro et al., 1995; Chang et al., 1977; Fannin and Raju, 1993; Farrag et al., 1993; Koerner, 1994; Lopes and Ladeira, 1996; Moraci et al., 2004; Moraci and Recalcati, 2006; Ochiai et al., 1992; Palmeira and Milligan, 1989; Raju, 1995; Sugimoto et al., 2001).

These authors carried out several tests on different types of extensible reinforcements and different devices.

A review of the literature (Abdelouhab et al., 2010, Bakeer et al., 1998, Goodhue et al., 2001, Lajevardi et al., 2013, Lopes and Ladeira, 1996, Moraci and Recalcati, 2006, Ochiai et al., 1996, Pinho-Lopes et al., 2006, Sieira et al., 2009, Sugimoto et al., 2001, Sugimoto and Alagiyawanne, 2003, Wilson-Fahmy et al., 1994) concerning the laboratory pull-out tests shows that:

- Most of the boxes are of rather rectangular shape, their size (length  $\times$  width) varies between  $0.4 \times 0.25$  and  $2 \times 1.10$  m. Large scale tests should be preferred, particularly due to the fact that increasing the test scale will reduce the boundaries effect.
- In most of the cases, the sample sizes are smaller than the box sizes.

- Many types of soil were used: sand, gravel, clay and lightweight soils.
- Several types of geosynthetics were used with tensile strengths between 6.2 and 200 kN/m: geotextile, geogrid, geocomposite and synthetic strip.
- Pull-out rate varies between 1 and 22 mm/min but most of the tests were performed with a standard rate of 1 mm/min.
- The confinement stress ranges from 5 to 200 kPa and can simulate an embankment or a slope with a height between 0.25 and 10 m.

Available experimental models show that:

- Most of the physical tests were carried out for the anchorage trenches,
- There is no complete experimental study on the geosynthetic behaviour with a wrap around anchorage.

In order to study the capacity and the behaviour of geosynthetics for two different anchoring systems (simple run-out and wrap around) and to analyse the physical mechanisms, a set of instrumented pull-out tests in the presence of two types of soil and of three types of geosynthetic is carried out. Different anchorages geometries are tested under low confinement stresses. This paper describes the effect of geometric parameters of the trench and the efficiency of anchorages.

## 2. Pull-out tests

The anchoring behaviour of a geosynthetic sheet under tension is studied experimentally. The reinforcement was equipped with force and displacement sensors and was set in a box filled with soil. Two physical quantities were monitored: Head geosynthetic tensile force and displacements at different locations in the reinforcement.

### 2.1. Description of the physical model

#### 2.1.1. Experimental box

The pull-out tests were carried out with an experimental device consistent with the standards recommendations ASTM D6706-01 (2007) and EN 00189016 (1998). This physical model (Fig. 3) consists of a 1.10 m wide, 1.10 m depth and 2.00 m long box. The traction system is fixed onto the geosynthetic (geotextile or geogrid) with a metallic clamp located in a guidance box inside the metallic box (supposed to be indeformable). The tensile force (applied on the 0.5 m width geosynthetic sheet) and the displacements of the metallic clamp and the anchorage area are monitored during the pulling out test.

#### 2.1.2. Studied soil materials

The soils studied in these tests are a fine sand (Hostun RF: Flavigny et al., 1990; Gay, 2000) and a coarse soil (gravel 0/31.5 according to the USCS classification procedure). This classification

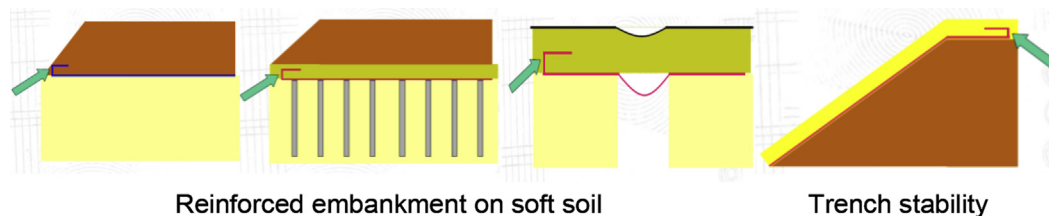


Fig. 2. Different applications of wrap around anchorage.

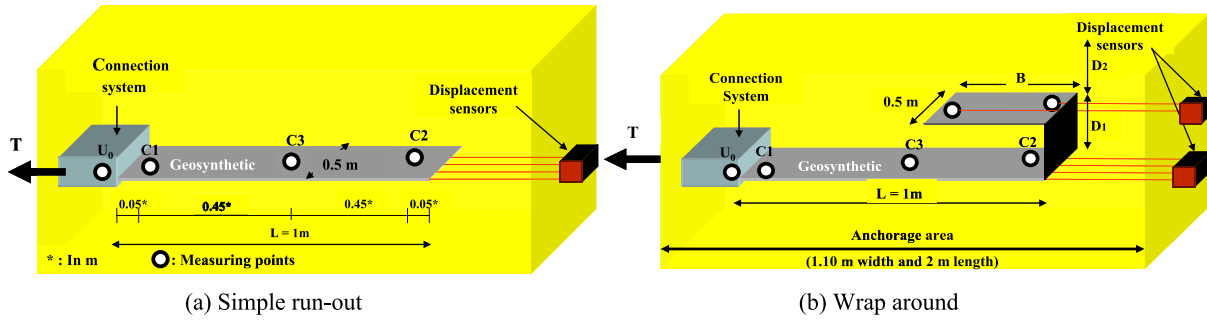


Fig. 3. Physical model.

**Table 1**  
Soil properties (Abdelouhab et al., 2010).

Characteristics	Coarse soil <sup>a</sup>	Fine sand <sup>b</sup>
Particle diameter range (mm)	0–31.5	0.16–0.63
Hazen's uniformity coefficient: Cu	25	2
Angle of friction (°)	37	35
Cohesion (kPa)	8	1
Maximum dry unit weight (kN/m <sup>3</sup> )	20.5	15.99
Minimal dry unit weight (kN/m <sup>3</sup> )	19.1	13.24
D <sub>10</sub> (mm)	0.5	0.22
D <sub>30</sub> (mm)	2.3	0.3
D <sub>60</sub> (mm)	9.5	0.42

<sup>a</sup> Shear direct.  
<sup>b</sup> Triaxial.

distinguishes coarse from fine soils, according to the percentage of the particles diameter inferior to 0.075 mm. The characteristics of coarse soil have been obtained by direct shear test (0.20 m × 0.20 m). Table 1 gives the principal characteristics of the gravel and the fine sand.

2.1.3. Reinforcement

Three types of geosynthetic were used: two geotextiles and one geogrid.

2.1.3.1. Geotextile. The geotextiles used for these tests are reinforcement geotextiles (uniaxial or biaxial) constituted by high modulus polyester fibres (wires), attached to a continuous filament nonwoven geotextile backing (Fig. 4(a) and (b), Table 2).

2.1.3.2. Geogrid. The geogrid used for these tests is a biaxial reinforcement geogrid in the machine direction constituted by high tenacity polyester yarns, which are covered with a polymeric coating, providing high tensile strength with low creep characteristics (Fig. 4(c), Table 3).

2.2. Anchorage geometry

Two anchorage systems were tested (Fig. 5) to analyse mechanisms and to determine the optimum anchorage. Simple run-out anchorage is specially performed to determine the friction angle between the soil and the geosynthetic and to observe the friction mobilisation according to the anchorage length ( $L = 1$  m). The second anchorage tests with wrap around are carried out to find the influence of geometry on anchorage capacity:

- 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.

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

2.3. Sensors

2.3.1. Displacement sensors

To measure displacements of the metallic clamp ( $U_0$ ) and the head, middle and end (C1, C3 and C2) of the reinforcement (Fig. 3), displacement sensors with a capacity of 250 mm were used. This instrumentation allows to follow the displacement of each part of the reinforcement and to highlight the progressive mobilisation of the sheet. Exploiting these results led to the determination of the behaviour of the geosynthetic.

2.3.2. Force sensor

In order to measure the tensile force, a direct-action force sensor with a maximal load of 100 kN is placed between the extraction jack and the connection system and measures the tensile force on the metallic clamp during the pull-out test.

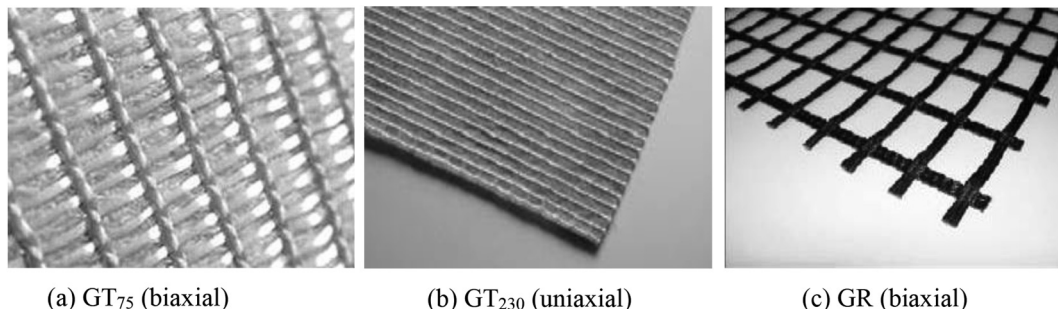


Fig. 4. Geosynthetics.

**Table 2**  
Geotextile properties

Geotextile	Stiffness: J (kN/m)	Thickness (mm)	Tensile strength MD <sup>a</sup> (kN/m)		Mass per unit area (g/m <sup>2</sup> )
			2%	Ult <sup>a</sup>	
GT <sub>75</sub>	bi <sup>a</sup>	687	16	79	440
GT <sub>230</sub>	uni <sup>a</sup>	2104	46	242	620

<sup>a</sup> MD: machine direction, bi: biaxial, uni: uniaxial, Ult: ultimate.

**Table 3**  
Geogrid properties.

Geogrid	Thickness (mm)	Tensile strength (kN/m)		Mass per unit area (g/m <sup>2</sup> )	Number of longitudinal strips per 1 m		Grid aperture size (mm)
		2%	Ult <sup>a</sup>		MD <sup>a</sup>	CD <sup>a</sup>	
GR	1.6	10	58	255	26	40	25 × 30

<sup>a</sup> MD: machine direction, CD: cross direction, Ult: ultimate.

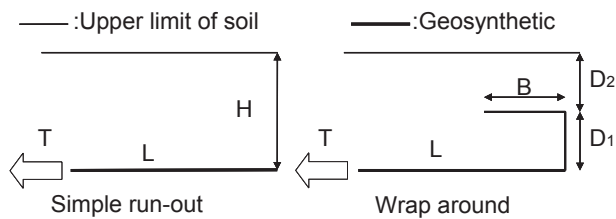


Fig. 5. Anchorage geometry.

### 2.3.3. Pressure sensor

**2.3.3.1. Vertical pressure sensor.** In order to control the vertical stresses distribution, an earth pressure cell,  $0.36 \times 0.36$  m, is horizontally set up on the bottom of the box underneath the sheet, between the guidance box and the back wall of the box (Fig. 6).

**2.3.3.2. Horizontal pressure sensor.** In order to measure the horizontal stress during the pull-out, an earth pressure cell,  $0.10 \times 0.20$  m, is vertically set up in soil. For the simple run-out, this is at the top of the metallic clamp in the box (Fig. 6(a)) and for the wrap around anchorage, between upper and lower parts of geosynthetic (Fig. 6(b)).

These cells have been calibrated buried in the soil used for the tests.

### 2.4. Traction device

The traction device was conceived specifically for this pull-out test. The idea was to build a system able to transmit the tensile force to the geosynthetic such as:

- The pressure is as homogeneous as possible over the width of the sheet,
- There is no relative displacement of the reinforcement from the metallic clamp (no sliding).

The metallic clamp connects the reinforcement to the jack and distributes equally the tension efforts to the reinforcement (Fig. 6). In order to avoid the effects of the front wall (roughness and stiffness), the reinforcement is placed at a certain distance (0.50 m) of it using a guidance box ( $0.50 \text{ m} \times 0.70 \text{ m} \times 0.16 \text{ m}$ ) located inside the box. The metallic clamp is placed in this guidance box to prevent any contact with the soil that would lead to additional tensile efforts (Fig. 6).

### 2.5. Procedure

#### 2.5.1. Initial phase

The tests were carried out in the following way (Fig. 6): an earth pressure cell was set up on the bottom of box and the guidance box ( $0.50$  m long) was then set in position and fixed to the box. A first layer of soil was laid out with an average  $0.18$  m thickness. The soil (gravel or sand) layer was evenly compacted with a rammer. Geosynthetic sheet was set up on the flat surface of the soil and connected to an extraction jack located in the front of the box. Displacement sensors located at the back of the box, were connected to many points along the reinforcement.

#### 2.5.2. Next phase for the simple run-out

After connecting all the displacement sensors, a  $0.40$  or  $0.50$  m thick layer of soil ( $H$ ) was laid out over the reinforcement. The soil was set up layer by layer (for  $H = 0.40$  m: two successive layers with  $0.20$  m high and for  $H = 0.50$  m: three successive layers with  $0.20$ ,

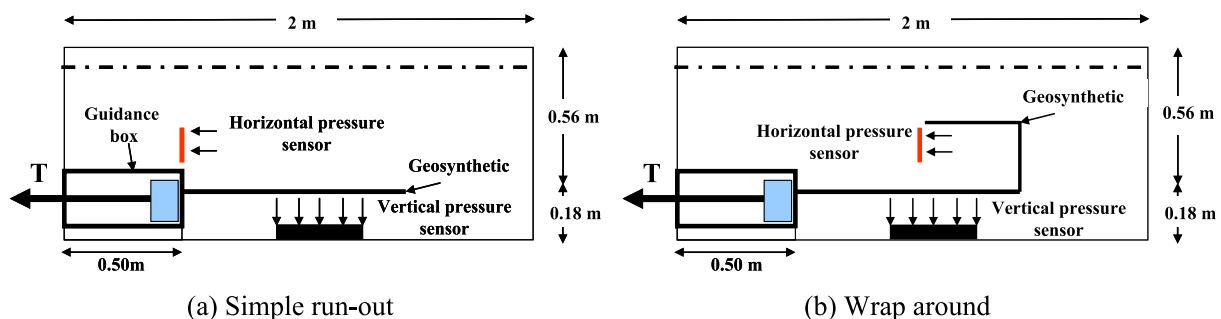


Fig. 6. Pressure sensors positioning.

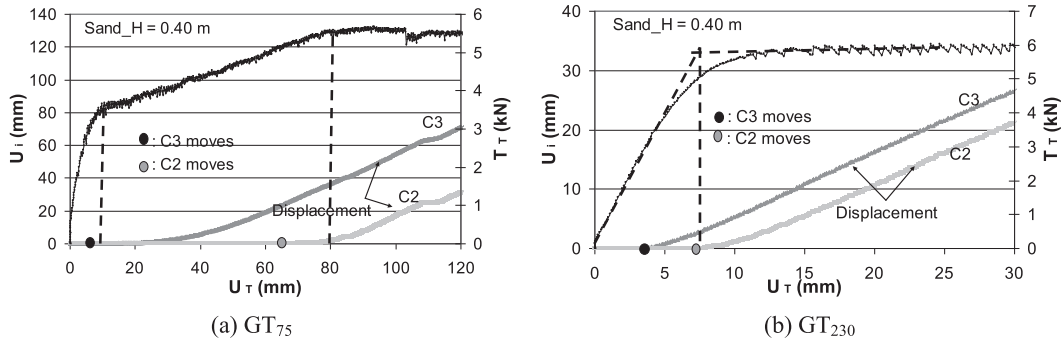


Fig. 7. Difference in the mobilisation behaviour between GT<sub>75</sub> and GT<sub>230</sub> in the simple run-out ( $T_\tau$ : Head tensile force,  $U_\tau$ : Head displacement and  $U_i$ : Different points displacement).

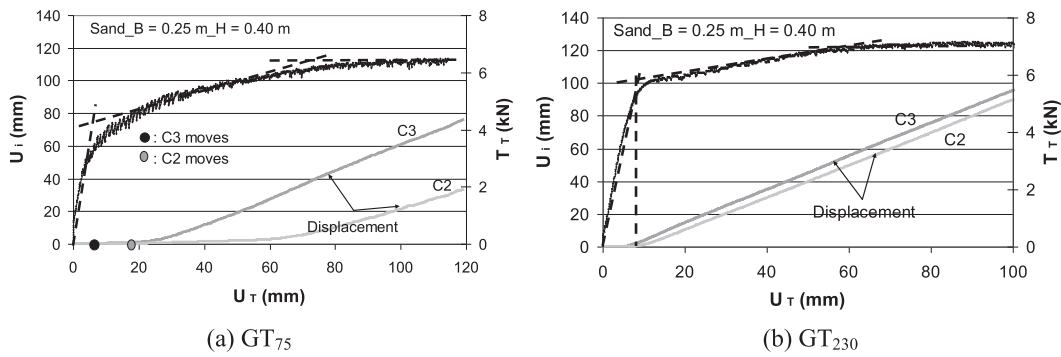


Fig. 8. Head behaviour of the geotextile in the wrap around anchorage.

0.10 and 0.20 m high) and every layer was compacted with a rammer. A monitoring was done at every new layer: for a given volume of soil its weight was measured. After the last compacted layer, the extraction jack was started. Within the framework of these tests, the pull-out rate was fixed at 1 mm/min (Abdelouhab et al., 2010; Alfaro et al., 1995; Lajevardi et al., 2013). The pull-out test was carried out and stopped as soon as the tensile force reaches a plateau and all the displacement sensors monitor displacements. This double condition ensures that the friction was mobilised over the entire length of the reinforcement.

2.5.3. Next phase for the wrap around anchorage

Once the first reinforcement part ( $L = 1$  m) was placed and equipped with displacement sensors, the reinforcement was held vertically to a depth  $D_1$ . Soil layers were laid out above the horizontal reinforcement length ( $L = 1$  m) and were compacted uniformly with a rammer. If the  $D_1 = 0.20$  m, there was only a single layer and if  $D_1 = 0.30$  m, there were two layers of 0.20 and 0.10 m. Once the height  $D_1$  was reached, the reinforcement was folded over a length of  $B$ . This part of reinforcement was also equipped with displacement sensors. One layer of soil was placed above the length of upper part of sheet ( $D_2 = 0.20$  m). After the last compacted layer, the extraction jack was started with a rate of 1 mm/min. The pull-out was carried out and stopped using the same dual criteria as for the simple run-out.

3. Analysis of experimental results

3.1. Test carried out

The pull-out tests (40 tests) were used to study the sensitivity of the following parameters on the anchorage capacity:

- Type of soil (sand or gravel),
- Type of geosynthetic (geotextile or geogrid),

- Type of anchorage (simple run-out or wrap around anchorage),
- Two low confinement stresses,
- Different geometric parameters of the trench ( $D_1$  and  $B$ ).

3.2. Mobilisation of reinforcement in the sand

3.2.1. Sand/geotextile

In the case of GT<sub>230</sub>, the experimental curve of the head tensile force versus the head displacement (geotextile behaviour of the head) under two different confinement stresses for the wrap around anchorage in the sand is similar to that of the GT<sub>75</sub>. It can be assimilated to a tri-linear shape: two slopes and a plateau (Fig. 9). For the simple run-out anchorage, this curve can be assimilated to a bi-linear shape (a slope and a plateau: Fig. 7). The shape of the

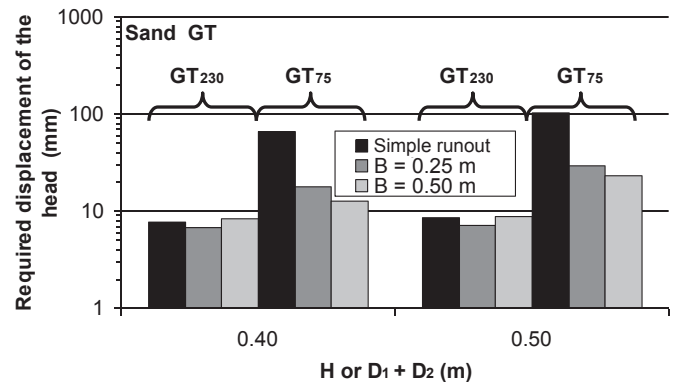


Fig. 9. Comparison of the required displacement of the head to have displacement at the rear of the geotextiles.

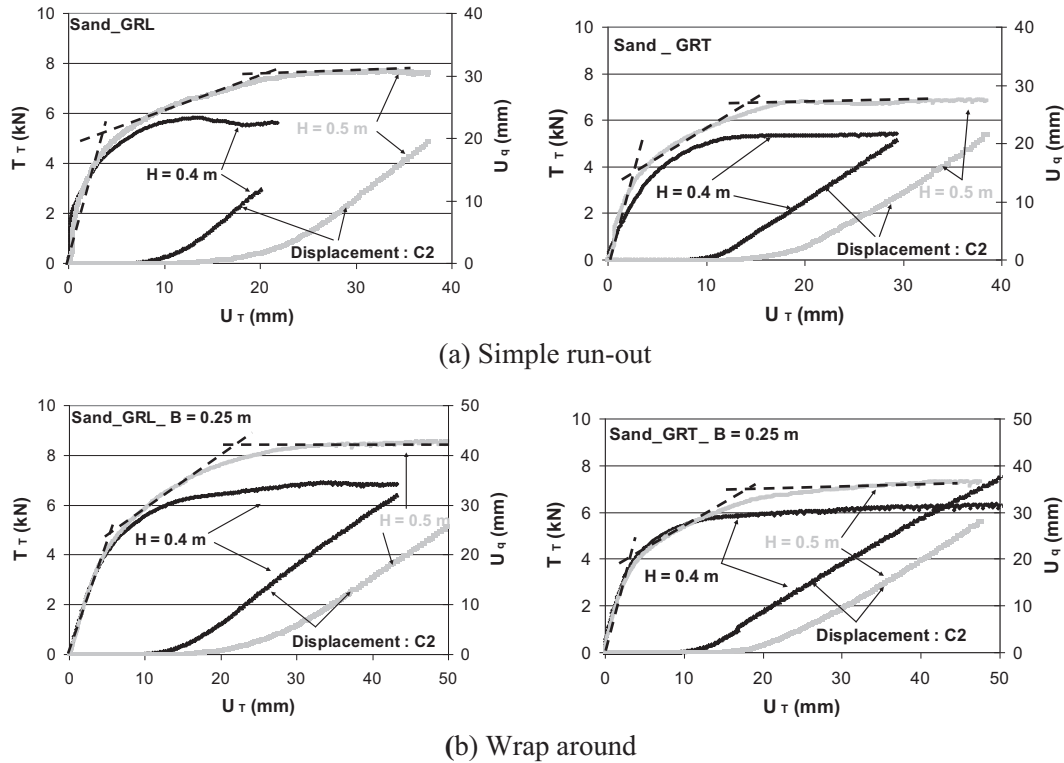


Fig. 10. Head behaviour of the geogrid under two different confinement stresses and two different anchorages in the sand ( $U_q$ : Rear displacement).

curves for these geotextiles is similar whatever the confinement stresses. It seems that the nature and the stiffness of the geotextile sheet have a significant influence on the curve.

3.2.1.1. *Simple run-out.* Fig. 7 shows the different points displacement ( $U_i$ : C2 and C3) of the reinforcement and the head tensile force ( $T_T$ ) versus the head displacement ( $U_T$ : C1) during the extraction. Point C3 is in the middle of the reinforcement and point C2 is in the 0.05 m from the rear of the reinforcement (see Fig. 3).

In the case of GT<sub>75</sub>, the curve  $T_T-U_T$  can be considered as a tri-linear shape (Fig. 7(a)):

- First slope: the slope change in the curve  $T_T-U_T$  is at 10 mm. Point C3 started to move (Fig. 7(a)) when  $U_T$  is equal to 6.7 mm. It shows a tensioning of the first part of the reinforcement (first half) for small head displacements (10 mm).

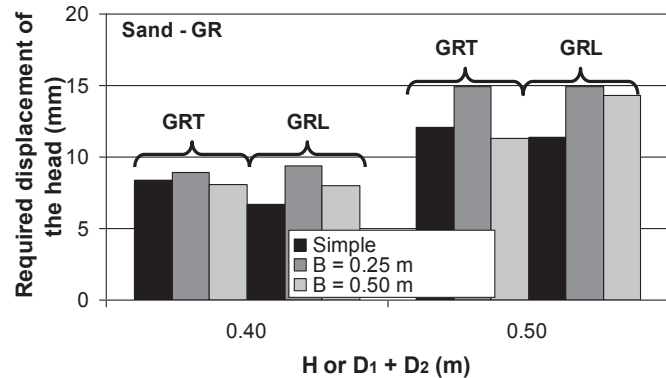


Fig. 11. Required displacement of the head to have displacement at the rear of the geogrid.

- Second slope: the plateau is reached at  $U_T = 80$  mm. Point C2 started to move when  $U_T$  had already reached 62 mm. It shows that all the reinforcement is pulled out and slips for displacements of the order of 10 times greater than for the mobilisation of the first half (C3 moves of 6.7 mm and C2 of 62 mm: Note that the relation is 6.7 mm/62 mm).

On the other hand, the wires longitudinal displacements in the GT<sub>75</sub> were noted at the end of the pull-out test. The displacement of the wires is about 0.08 m in total.

The manner that wires move inside the reinforcement is not known. However, it could explain the existence of the second slope.

At the end of the test, the reinforcement is stretched. This leads to an increase in length and reduction in the width of the reinforcement.

In the case of GT<sub>230</sub>, the curve  $T_T-U_T$  may be assimilated to a bi-linear shape (Fig. 7(b)).

Points C3 and respectively C2 start to move when  $U_T$  is equal to 3.9 and 7.4 mm (Fig. 7(b)). In this case, the displacement of the rear of the reinforcement is 2 times smaller than the one of the middle of reinforcement. On the other hand, the wires displacement measured are quite small (<0.01 m). All these observations show that the reinforcement nature seems unchanged and the reinforcement tension starts at the same time (single slope in the curve  $T_T-U_T$ ).

It seems that the geotextile nature affects not only quantitatively the friction value at the soil/geotextile interface but also qualitatively the head behaviour of the geotextile (woven unidirectional for the GT<sub>230</sub> or bidirectional for the GT<sub>75</sub>).

3.2.1.2. *Wrap around anchorage.* The curve  $T_T-U_T$  follows a tri-linear shape whatever the geotextile (Fig. 8). In this case, the lower part of sheet ( $L = 1$  m) started to move (C2 and C3) when the

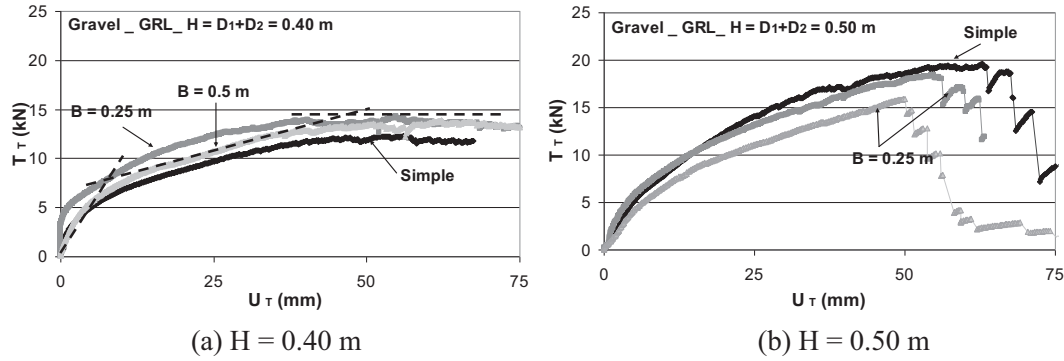


Fig. 12. Head behaviour of the geogrid under two different confinement stresses and two different anchorages in the gravel.

first slope change in the curve was observed. It shows that the rear part of the geosynthetic sheet is tensioned and fully slides.

The results show that the  $T_\tau-U_\tau$  curve assimilated to a tri-linear shape is different between the wrap around anchorage (GT<sub>75</sub> and GT<sub>230</sub>) and the simple run-out anchorage (GT<sub>75</sub>).

The analysis of the rear displacements of the sheet ( $L = 1$  m) versus the head displacements of the two types of geotextile shows that the mobilisation of the reinforcement is not instantaneous.

The tractions and the displacements in the geotextile sheet under a tensile force are gradually mobilised from the head to the rear of the reinforcement. This latter moves after a displacement threshold on the head which depends mainly on the confinement stress and on the geotextile stiffness (Fig. 9). In the case of GT<sub>75</sub>, this threshold increases with increasing the confinement stress, on the other hand this threshold is constant in the case of GT<sub>230</sub>. For the GT<sub>75</sub>, the displacement threshold is higher than for the GT<sub>230</sub>, this is due to the difference in the stiffness and nature of these two geotextiles (Fig. 9).

### 3.2.2. Sand/geogrid

In order to verify that the geogrid reacts identically in the machine direction (MD) and in the cross direction (CD) and for the verification of the influence of the number of longitudinal and transversal strips on the results of geogrid (Lajevardi et al., 2012a), the pull-out tests with this reinforcement were performed in both directions: GRL (MD) and GRT (CD).

Fig. 10 shows the mobilisation of the geogrid sheet for the two different anchorage types in the sand. The experimental curve of the displacements versus tensile force at the head may be assimilated to a tri-linear shape (Lajevardi et al. 2012a,b). These results show that the reinforcement starts to move slowly at the head. This level corresponds to the beginning of the friction mobilisation along the geogrid (first slope of the curve). Then, the displacement

increases when the friction is fully mobilised on a part of the geogrid (second slope of the curve). Finally, when the friction is mobilised on the entire geogrid, it behaves as a stiff reinforcement. The shape of curves is similar whatever the confinement stress and anchorage system.

Fig. 11 shows that the sheet mobilisation of the rear ( $L = 1$  m) for a geogrid sheet in both directions (GRL and GRT) with two different anchorages, is not instantaneous and the displacement threshold is the same.

In the case of the sand/geogrid, the displacement threshold is smaller than that in the case of the sand/geotextile (GT<sub>75</sub> and GT<sub>230</sub>). This means that the geosynthetic shape is an important parameter for this value (Figs. 9 and 11).

### 3.2.3. Conclusion for mobilisation of geosynthetic in sand

The test results show that the trend of the head geotextile behaviour (tri-linear shape) in the wrap around anchorage in the sand is the same whatever the stiffness of geotextile. For the simple run-out, this mobilisation depends on the stiffness and the nature of the geotextile and may vary from a tri-linear to bi-linear shape. Stiffness and geotextile nature have a significant influence on the tensile force, on the displacement threshold and on the reinforcement mobilisation.

The mobilisation of the geogrid in the two types of anchorage system is very similar to the geotextile one.

## 3.3. Mobilisation of friction in the gravel

### 3.3.1. Gravel/geotextile

The head behaviour of the geotextile in the gravel is similar to the one in the sand. This behaviour in the wrap around anchorage is invariable whatever the stiffness of geotextile (tri-linear shape) and for the simple run-out, this behaviour depends on the stiffness and

Table 4  
Influence of parameters on the tensile force for sand/GSY.<sup>a</sup>

Parameter	Definition	Anchorage	Soil	Domain investigation (m)	GSY <sup>a</sup>	Difference for $T_\tau^a$ (%)
$H$	Thickness of soil layer above anchorage	Simple run-out	Sand	0.40–0.50	GT <sub>75</sub>	46
					GT <sub>230</sub>	43
					GRL	33
					GRT	28
$D_1$	Distance between upper and lower parts of geosynthetic	Wrap around		0.20–0.30	GT <sub>75</sub>	39–40
					GT <sub>230</sub>	43–45
					GRL	25
					GRT	14–23
$B$	Length of upper part of sheet			0.25–0.50	GT <sub>75</sub>	7–8
					GT <sub>230</sub>	3–4
					GRL	–3 to –2
					GRT	–5 to 3

<sup>a</sup> GSY: geosynthetic,  $T_\tau$ : tensile force, The parameter “Difference for  $T_\tau$ ” is calculated by reference to the smallest value of the domain investigation. For example:  $((T_{H=0.50\text{ m}} - T_{H=0.40\text{ m}})/T_{H=0.40\text{ m}})$  in %.

**Table 5**  
Influence of parameters on the tensile force for gravel/GSY.<sup>a</sup>

Parameter	Definition	Anchorage	Soil	Domain investigation (m)	GSY <sup>a</sup>	Difference for $T_T^a$ (%)
$H$	Thickness of soil layer above anchorage	Simple run-out	Gravel	0.40–0.50	GT <sub>75</sub>	#
					GT <sub>230</sub>	38
					GRL	#
$D_1$	Distance between upper and lower parts of geosynthetic	Wrap around		0.20–0.30	GT <sub>75</sub>	#
					GT <sub>230</sub>	33–44
					GRL	#
$B$	Length of upper part of sheet			0.25–0.50	GT <sub>75</sub>	1
					GT <sub>230</sub>	0–8
					GRL	–3

<sup>a</sup> See Table 4, #: the failure of the geosynthetic sheet.

the nature of the geotextile in the same way as in the sand. In the case of Gravel/GT<sub>75</sub> and for  $H$  or  $D_1 + D_2$  equal to 0.50 m, the geotextile sheet tore during the pull-out test.

### 3.3.2. Gravel/geogrid

The head behaviour of the geogrid sheet (GRL) with a thickness of soil layer above anchorage ( $H$  or  $D_1 + D_2$ ) equal to 0.40 m under two different anchorage systems in the gravel is similar to that in the sand (Fig. 12 (a)). For  $H$  or  $D_1 + D_2$  equal to 0.50 m, the geogrid sheet tears (Fig. 12(b)). The failure of the geogrid sheet was observed for the case  $B = 0.25$  m (two times), then the test with  $B = 0.50$  m was not continued (Lajevardi et al., 2012b).

### 3.4. Effect of $H$ , $D_1$ and $B$ on the tensile force

A parametric analysis was performed for the experimental results on both geosynthetic types in both soil types. The qualitative influence of parameters ( $H$ ,  $D_1$  and  $B$ ) on the tensile force ( $T_T$ ) is synthesised (Tables 4 and 5).

The increase of the confinement stresses ( $H$  and  $D_1$ ) has a high influence on the tensile force. Table 4 shows that in the sand, this influence is higher than 40% for the geotextiles (GT<sub>75</sub> and GT<sub>230</sub>) and for the geogrid, between 28 and 33% for the simple run-out anchorage and between 14 and 23% for the wrap around anchorage. Table 6 shows that in the gravel and for the GT<sub>230</sub>, this influence is equal to 38% for the simple run-out anchorage and between 33 and 44% for the wrap around anchorage depending on the length of the upper part of the sheet ( $B$ ).

**Table 6**  
Comparison of the maximum tensile force between two anchorage systems.

Parameter	Simple run-out		Wrap around		$T_w^a/T_s^a$
	$T_s^a$ (kN)	$T_w^a$ (kN)	$T_s^a$ (kN)	$T_w^a$ (kN)	
L (m)	1	1	1	1	1.21
H (m)	0.40	0.50	0	0	1.22
$D_1$ (m)	0	0.20	0.20	0.30	1.18
$D_2$ (m)	0	0.20	0.20	0.30	1.13
$B$ (m)	0	0.25–0.50	0.25–0.50	0.25–0.50	1.17
Soil	GSY <sup>a</sup>	$T_s^a$ (kN)	$T_w^a$ (kN)	$T_w^a/T_s^a$	
Sand	GT <sub>230</sub>	6	7.25	1.21	
		8.6	10.45	1.22	
	GT <sub>75</sub>	5.7	6.75	1.18	
		8.3	9.4	1.13	
	GRL	5.8	6.8	1.17	
Gravel		7.7	8.5	1.10	
	GRT	5.4	6.25	1.16	
		6.9	7.4	1.07	
	GT <sub>230</sub>	10.2	11.7	1.15	
		14.1	16.25	1.15	
	GT <sub>75</sub>	11.7	13.5	1.15	
	GRL	12.3	13.7	1.11	

<sup>a</sup> GSY: geosynthetic,  $T_s$ : tensile force for simple run-out,  $T_w$ : tensile force for wrap around.

The value of  $B$  has a low influence on the tensile force (–less than 8%, Table 4 for the sand and Table 5 for the gravel). This means that between two tested lengths for  $B$  ( $B = 0.25$  and 0.50 m), the first (0.25 m) is largely sufficient for this type of anchor.

The tensile force is not proportional to the length of the sheet upper part and the mechanisms induced by this length are not only shearing ones but also include an abutment part. It seems that a minimum length for the upper part of sheet exists to mobilise an abutment in the soil and increase the anchorage capacity and using a longer tail does not have any significant effect on the tensile force.

### 3.5. Efficiency of anchorages

#### 3.5.1. Large head displacement

For a large head displacement, the wrap around anchorages are more resistant than the simple run-out ones with the same length for their lower part ( $L = 1$  m). The increase of the maximum tensile force with two types of geosynthetic sheets in soil (sand and gravel) between these two different anchorage systems can be observed (Table 6). This increase depends on the confinement stress ( $H$  and  $D_1$ ) and its value in the sand is: between 7 and 17% for geogrid, 13 and 18% for GT<sub>75</sub> and 21% for GT<sub>230</sub> and in the gravel is 15% for geotextile and 11% for geogrid.

#### 3.5.2. Small head displacement

For many structures reinforced by geosynthetics, large head displacements are not acceptable to mobilise the anchorage. In order to present efficiency of anchorages, a limited displacement of the head has been fixed and the head tensile force has been verified.

Fig. 13 presents the head tensile force versus limited displacement of the head in the sand and the gravel for geotextile and geogrid. Small displacements of the head vary from 5 to 100 mm. Since the length of the geosynthetic sheet is equal to 1 m, these limited displacements can be considered as a deformation of 0.5–10% if the buried extremity of the reinforcement was fixed.

This figure shows that for the simple run-out anchorages and the wrap around ones, efficiency of anchorages is the same when the deformations are low. With increasing deformation, the efficiency in the case of the wrap around anchorage is more important than the one for the simple run-out.

Consequently, the anchorages with wrap around are not always effective and their efficiency requires a large displacement incompatible with admissible deformations in a soil structure.

## 4. Conclusion

The pull-out tests performed in the laboratory allowed to determine the parameters such as the head tensile force and the displacement at several points on the geosynthetics. The analysis of these results determined the mobilisation and the capacity of the geosynthetics for two different anchoring systems.



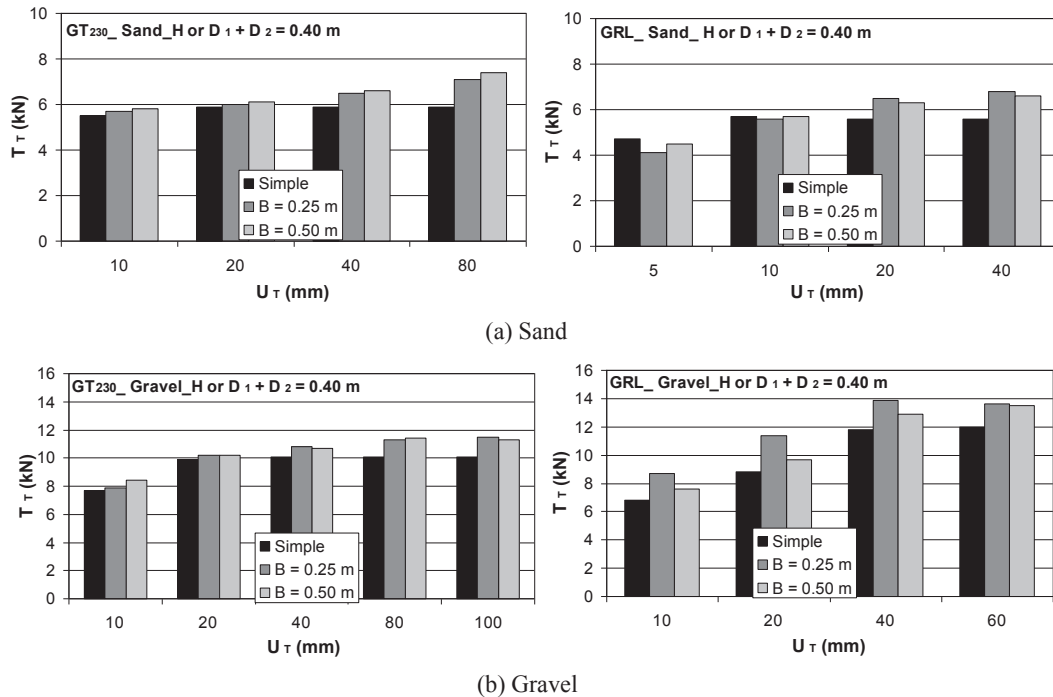


Fig. 13. Comparison of the tensile force between the different displacements limits.

The results show that the mobilisation of a geosynthetic sheet in two types of soils and for two different anchorage systems is very similar. For the wrap around anchorage, the head tensile force versus the head displacement may be 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 and the sheet configuration, the stress confinement and finally the type of soil.

The influence of various parameters is demonstrated from the pull-out tests:

- Anchorage capacity: The maximum tensile force increases with the confinement stress. The tests carried out on the geosynthetic sheet show that for a large head displacement ( $U_T$ ), the wrap around anchorages are more resistant than simple run-out anchorage. The efficiency of anchorage for this two anchorage systems is the same when the head displacements are small.
- Length of upper part of sheet: In the wrap around anchorage, the tensile force is not proportional to the length of upper part of sheet ( $B$ ) and that is not the only important parameter to determine the efficiency of the anchorage. Mechanisms induced by the wrap around are not only from slides but also have an abutment part.

This experimental data have permitted to create a database on which numerical calculations can be developed.

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