Experimental and numerical studies for geosynthetics anchorage with wrap around

S.H. LAJEVARDI
Department of Civil Engineering, Islamic Azad University (IAU), Arak, Iran (hamidlajevardi@yahoo.com)

C. SILVANI & L. BRIANÇON
INSA Lyon, France (claire.silvani@insa-lyon.fr)

INSA Lyon, France (laurent.briancon@insa-lyon.fr)

P. VILLARD & D. DIAS
3SR Lab, Grenoble Alpes University, France (pascal.villard@3sr-grenoble.fr)

3SR Lab, Grenoble Alpes University, France (daniel.dias@univ-grenoble-alpes.fr)

ABSTRACT: The soil reinforcement by geosynthetic is widely used in civil engineering structures: reinforced slopes and walls, embankments on compressible and soft soils, slope on a stable foundation, embankments on cavities and retaining structures, reinforcement in the base layers of railroads and road constructions, bridging over sinkholes or reinforced abutments, piled embankment, reinforced foundation mattresses.
The stability of these structures specially depends on the efficiency of the anchors holding the geosynthetic sheets. The anchorages simple run-out and with wrap around are two most commonly used approaches. Designing the required dimensions of the anchorage with wrap around remains problematic. In order to improve the available knowledge of the anchorage systems behaviour, the experimental and numerical studies were performed jointly. This paper focuses on the physical and numerical models of the geosynthetics behaviour in two anchors (simple run-out and with wrap around). Laboratory pull-out tests, performed with two experimental tanks under controlled conditions, consisted in the pull-out of three reinforced non-woven needle-punched geotextiles (uinaxial or biaxial with different stiffness) anchored following various geometries in different kind of soil.
In order to confirm and to complete the experimental studies presented in these anchorage systems, a two-dimensional discrete-element model (DEM) was performed. The advantage of the numerical model is its ability to reproduce the behaviour of the geosynthetic and the soil/geosynthetic interaction. The parameters deduced from physical model are used in this numerical study.

Keywords: Anchorage systems, Geosynthetic, Pull-out test, Soil reinforcement, Discrete element model.

1 INTRODUCTION

The stability and durability of geosynthetics systems in reinforced earth structure depends partly on the efficiency of the anchors holding the geosynthetic sheets. Wrap around anchorages are used generally at the base of reinforced slopes or walls. 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. Several authors studied the behaviour of these anchorage systems numerically and experimentally. They showed that the pull-out test is the most suitable test to determine the soil/geosynthetic interface under low and high confinement stress and to support numerical studies in order to determine the behaviour and the anchorage capacity (Abdelouhab et al., 2010, Briançon et al., 2008; Chareyre et al., 2002; Chareyre and Villard, 2005; De and Vellon,

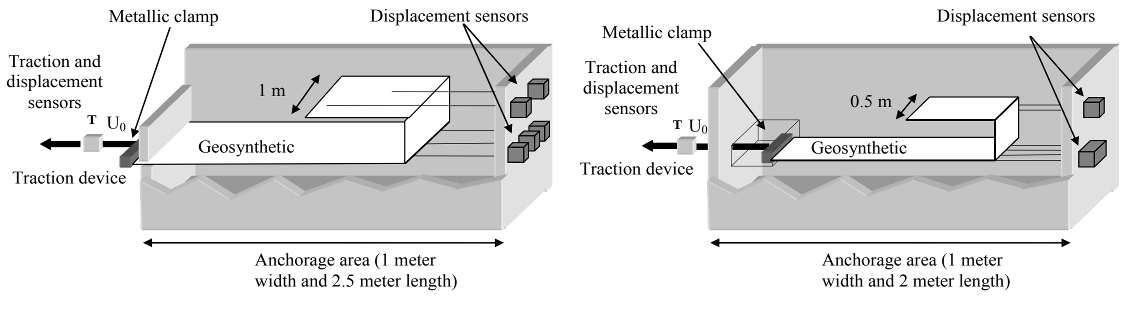
2005; Girard et al., 2006; Gourc et al., 2004; Khedkar and Mandal, 2009; Lajevardi et al., 2013; Lajevardi et al., 2014, 2015; Palmeira, 2009; Sieira et al., 2009; Su et al., 2008).
The discrete-element method (DEM) is an alternative numerical simulation technique, which assumes that the model is composed of particulate matters (Zhang et al. 2013) has been successfully used by many researchers to study the geosynthetic reinforced soil and the embankments behaviour (Chareyre et al., 2002; Villard and Chareyre, 2004; Chareyre and Villard, 2005 for example).
This study focuses on the wrap around anchorages (the interest of the wrap around anchorage is to reduce the anchorage area). Two French research laboratories (Irstea and INSA Lyon) performed jointly tests with two experimental tanks on the same reinforced non-woven needle-punched geotextile and with the same geometry of anchorage in cohesive and non-cohesive soils. Laboratory tests performed with INSA anchorage apparatus (Lajevardi et al. 2014, 2015) are simulated with a two-dimensional discrete-element model. A full description of this work can be found in the paper by Lajevardi et al. (2015).

2 PULL-OUT TESTS

The anchoring behaviour of a geosynthetic sheet under tension is studied experimentally with the pull-out test.

2.1 Experimental tank

The Irstea anchorage apparatus (Figure 1a) included one-meter wide anchor block and a traction device. The tension T (applied on the 1 meter width geosynthetic sheet: b = 1m) and the displacement U_0 of the tensile cable are monitored on pulling out using sensors fixed onto the tensile system. In the anchorage area, a cable measuring system is used to monitor the displacements of the geotextile at different points (at the beginning, middle and end of the geotextile sheet).
The INSA anchorage apparatus (Figure 1b) included one-meter wide anchor block and a traction device allowing the pull out of a 0.5 meter width geosynthetic sheet (b = 0.50 m). As for the first experimental tank, the tension T, the displacement U_0 of the tensile cable and the geotextile displacement are monitored on pulling out using similar sensors.
Principal differences between both apparatus are the localization of the metallic clamp sited between the geosynthetic and the tensile system, the width of geosynthetic samples and pull-out rate.



(a) Irstea tank (b) INSA tank

Figure 1. Experimental tanks.

2.2 Anchorage geometry

Several anchorage shapes have been used to highlight the mechanisms of interaction between soil and geosynthetic (Figure 2) and to determine the optimum anchorage according to the kind of soil and the geosynthetic characteristics. Various anchorages with wrap around are carried out to establish the influence of geometry on anchorage capacity:
- Thickness of soil layer above anchorage ($H = D_1 + D_2 = 0.36$ or 0.4 or 0.5 m),
- Distance between upper and lower parts of geotextile ($D_1 = 0.2$ or 0.3 m),

- Length of upper part of sheet (B = 0.25 or 0.5 or 1 m),
- D_2 = 0.2 m.
- Width of the geosynthetic sheet (anchorage width: b = 0.5 or 1 m).

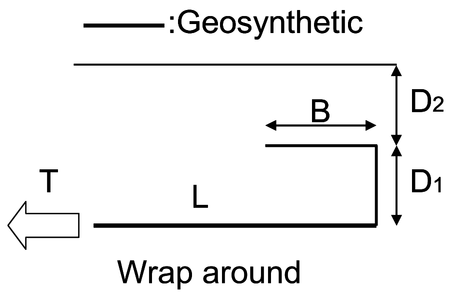


Figure 2. Anchorage geometry.

2.3 Materials tested

Four soils have been used for these tests: two sands, a sandy silt and a gravel. Their main properties have been measured and presented in Table 1. The geosynthetics used for these tests are reinforcement geotextiles (uniaxial or biaxial) constituted by high modulus polyester wires, attached to a continuous filament nonwoven geotextile backing (Table 2).

Table 1. Soil properties.

Soil	γ_d (kN/m^3)	w (%)	d_{10} (mm)	d_{30} (mm)	d_{60} (mm)	ϕ' (°)	c' (kPa)
Sand 1	15.2	1	0.22	0.3	0.42	35	1
Sand 2	20.0	5	0.15	0.3	0.5	37	4
Sandy silt	15.7	2.5	-	-	-	30	22
Gravel	19.5	1	0.5	2.3	9.5	37	8

Table 2. Geosynthetic properties (GSY: geosynthetic, MD: machine direction).

GSY		Stiffness: J (kN/m)	Thickness (mm)	Tensile strength MD (kN/m)		Unit weight (g/m²)
				2 %	Ult.	
GT 75	biaxial	687	2.6	16	79	440
GT 95		870	3	20	100	540
GT 230	uniaxial	2104	3.2	46	242	620

3 EXPERIMENTAL TESTS RESULTS

3.1 Wrap around anchorage

Main experimental results (pull-out curves and maximum tensile forces) supporting the numerical analysis are given Figure 3 and Tables 3 and 4. As it can be seen Tables 3 and 4 the same conclusion can be done whatever the soil or the test apparatus: there is an optimum length of upper part of sheet (B) required to mobilize the maximum pull-out capacity an abutment forces in the soil, equal or lower than the smaller one tested (0.25 m).

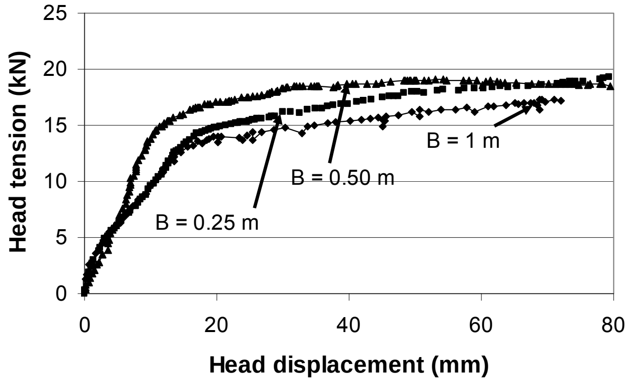


Figure 3. Anchorages with wrap around in the Irstea tank (GT95 - Sand 2- b = 1 m – L = 1.5 m).

Table 3. Results of maximum tension for anchorages with wrap around inside sand 1 with the INSA tank (b=0.5m) (*: wa: wrap around).

GSY	D_1 (m)	H(m)	B (m)	$T_{max\ wa}$*(kN/m)
GT_{75}	0.2	0.4	0.25	13
			0.5	14
	0.3	0.5	0.25	18.1
			0.5	19.4
GT_{230}	0.2	0.4	0.25	14.2
			0.5	14.8
	0.3	0.5	0.25	20.6
			0.5	21.2

Table 4. Results of maximum tension for wrap around anchorages inside gravel with the INSA bench (b=0.5m) (*: wa: wrap around).

GSY	D_1 (m)	H (m)	B (m)	$T_{max\ wa}$ * (kN/m)
GT_{75}	0.2	0.4	0.25	26.8
			0.5	27.2
GT_{230}	0.2	0.4	0.25	23.4
			0.5	23.4
	0.3	0.5	0.25	31.4
			0.5	33.8

4 NUMERICAL MODEL

4.1 Discrete-element model

The numerical modelling was carried out with the discrete-element method (DEM) developed first by Cundall and Strack (1979). The DEM assumes a set of particles interacting with one another at points of contact (Figure 4), and can be used to simulate large relative displacements. This method is particularly well suited to the problem being considered here, since it provides the possibility to take into consideration the major movements and large-scale deformation of the soil (rotation, compression and lifting) as well as the large displacements between the geotextile and the soil (shear bands or overall rotation).

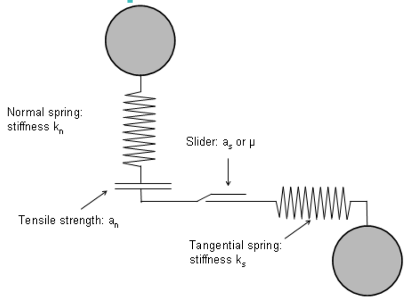


Figure 4. Interaction between two particles with DEM.

Interaction models, locally defined via micromechanical parameters of the contact models, make it possible to restore a global macroscopic behaviour of the particles assembly. This prevents direct introduction of constitutive models such as those defined by the mechanics of continuous media. A two-dimensional discrete-element code (Itasca Consulting Group 1996, PFC2D) was used to investigate the pull-out behaviours of linear and non-linear geosynthetic anchorage. The geosynthetic sheet was modelled by the way of a dynamic spar elements proposed by Chareyre and Villard (2005), which have been implemented into the DEM software. The thin spar elements (Figure 5) 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: $\tau_{max} = a_s + \sigma_n \tan \delta$ where a_s, δ and σ_n are respectively the shear strength at a null normal stress (cohesion), the friction angle and the normal stress acting at the interface.

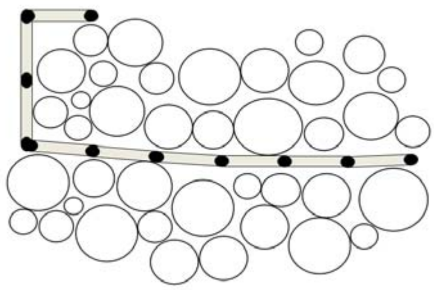


Figure 5. Spar element representation.

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 0.9 d. Clusters were used rather than single cylinders in order to reach high values of the macroscopic internal friction angle of the soil.
The granular distribution, initial porosity, shape of clusters and the methodology of setting up the particles have a high influence on the macroscopic behaviour.
For this study, the clusters assembly was generated at a fixed porosity in a rectangular area without gravity using the Radius Expansion with Decrease of Friction process (REDF) (Chareyre and Villard, 2005). The elastic behaviour of the granular assembly depends of two local contact parameters: the normal stiffness k_n and shear stiffness k_s defined by unit length. Two contact failure criteria were considered (Itasca Consulting Group 1996, PFC2D): one under tension, characterized by a tensile strength limit an, the other based on the elastic perfectly plastic model proposed by Cundall and Strack (1979) and characterized by shear strength a_s (independent of normal force) or by a microscopic contact (friction angle δ).

4.2 Macro mechanical behaviour

The identification of the micro mechanical contact parameters (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 tests with around 4000 clusters are presented (Figure 6). Biaxial compression was simulated by imposing a translation speed V on the upper wall while the interlocked side walls maintained a constant lateral stress σ_0. The four walls were non frictional. A compression speed that was sufficiently slow to eliminate dynamic phenomena interference with the results was chosen. The strains and stresses were deduced directly from the displacement and the forces exerted on the walls.

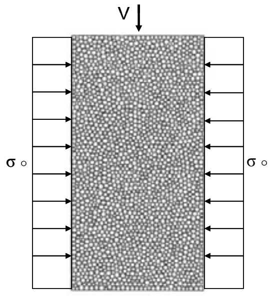


Figure 6. Geometry of the sample.

As the modelling focus on the INSA bench pullout tests on sand 1, triaxial tests on sand 1 were performed at LGCIE laboratory (INSA) with a constant confining stress σ_0 of 10, 20 and 50 kPa during the test procedure. A macroscopic friction angle φ' of 38.4° and an elastic modulus of 20 MPa were obtained.
Micro mechanical parameters were chosen to fit this frictional macro mechanical behaviour (Table 5). k_n is related to the Young modulus, and the ratio k_s/ k_n is related to the Poisson coefficient. k_n is obtained to fit the tangent elastic modulus and a ratio of k_s/ k_n =0.5 is chosen for this study. As-tests are performed on sand, there is no tensile strength (a_n) and no shear strength (a_s) at a null normal stress. The inter-particle friction angle δ has been calibrated with the peak value of the triaxial curve, and the porosity has been obtained with the ratio of the friction angle at the peak over the residual friction angle. The micro mechanical parameters obtained are summarized in Table 5.

Table 5. Micro mechanical parameters obtained by reproducing the macro mechanical behaviour of sand 1.

Soil modelling properties	Value
Micro-mechanical parameters	
Tensile stiffness k_n (kN/m²)	7x 10^4
Shear stiffness k_s (kN/m²)	3.5x
Inter-particle friction angle δ (°)	10^4
Shear strength a_s (N/m)	31
Tensile strength a_n (N/m)	0
Porosity	0
	0.2

4.3 Numerical pull-out tests

Numerical pull-out tests were performed using between 25000 and 40000 clusters (width of 0.5m) 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 sheet element. The dimensions of the experimental model have been kept in the modelling. This model is presented on Figure 7.

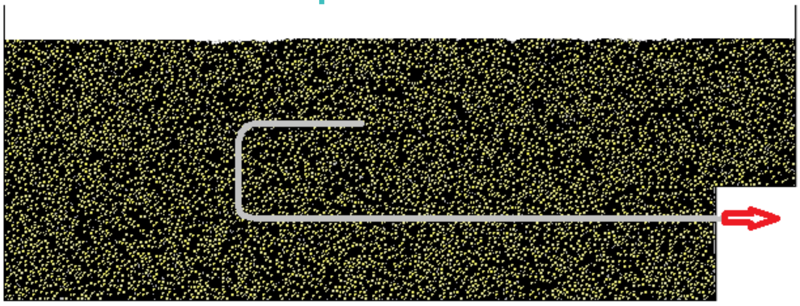


Figure 7. Numerical modelling of INSA pull-out test.

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 three times to obtain average curves and values (Briançon et al., 2008). It permits to verify the good repetability of simulations where the maximum head tension value is reproduced. In the following steps, each numerical curve will be taken as an average of three tests performed with three different initial grain generation.
Numerical tests were only focused on INSA tank on GT_{230} (B=0.5m) for simple run-out and wrap around anchorages in sand 1 only (cohesion a_s=0).
Micro mechanical parameters for soils were kept in these simulations. Parameter for geosynthetic sheet (tensile rigidity: J) was the one given by Table 2 (data from the geosynthetic manufacturer). The numerical interface friction angle between soil and the geosynthetic sheet (Mohr Coulomb model) was calibrated from an experimental test performed on a simple run-out with 0.40 m of thickness of soil layer above anchorage (H). This angle value was kept constant for all the simulations ($\varphi_{soil/geosynthetic}$ =25.6°). As measured in experimental tests, friction between wall and clusters was set to $\varphi_{soil/wall}$ =28°.
Figure 8 shows the calibration from pull-out tests on GT_{230} simple run-out anchorage with 0.40 m of thickness of soil layer above anchorage (H), and the comparison between numerical and experimental (INSA) results with a higher thickness of soil layer above anchorage (H = 0.50 m). The numerical curves have the same shape as experimental curves: a first slope that corresponds to the tensioning and the plateau of the geosynthetic sheet. Experimental and numerical curves with H = 0.50 m of soil fits well for the plateau value. Concerning the tensioning part, numerical curves are steeper, the tensile rigidity J was calculated by the manufacturer using tensile tests without any confining. This means that the influence of the surrounding soil below and above the geosynthetic sheet on the tensile rigidity of the geosynthetic is neglected. Nevertheless, head displacements for the plateau for both curves are quite similar so that following simulations were performed with the former tensile rigidity J.

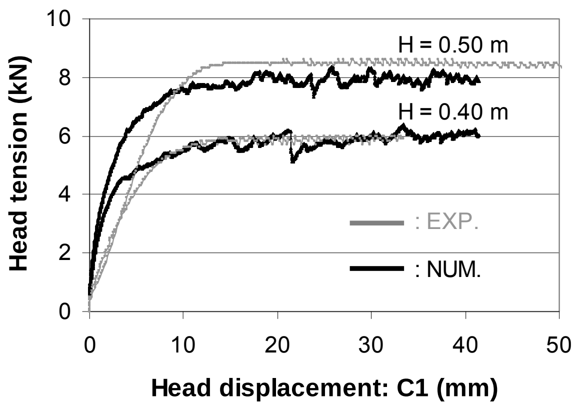


Figure 8 17. Comparison for Sand 1 between numerical and experimental pull-out tests (INSA simple run-out, width b=0.50 m) for H = 0.40 and 0.50 m thickness of soil layer above anchorage (calibration done with L=1m, H = 0.40 m).

Figure 9 shows pull-out tests on geosynthetic sheet with wrap around on GT_{230} with B = 0.25 or 0.50 m of return and 0.40 m of thickness of soil layer above anchorage (0.20 m below D_1 and 0.20 m above D_2 return). Curves still represent the head tension function of the head displacement. The general tendency is reproduced. With the calibration of soil/geosynthetic interface friction on simple run-out anchorage, the numerical curves overestimate the experimental ones with a maximum difference of 8%. Numerical curves also show that between B = 0.25 and 0.50 m, the contribution of return is negligible.

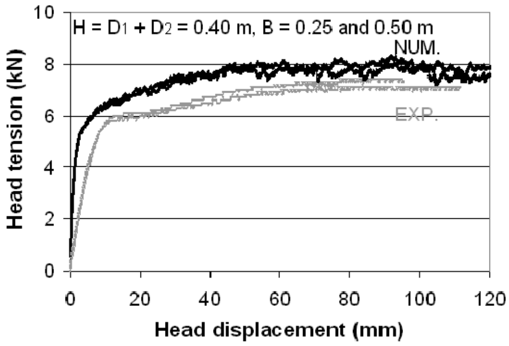


Figure 9. Comparison for Sand 1 between numerical and experimental (INSA, width b=0.50 m) pull-out tests on GT_{230} with wrap around for H = 0.40 m ($D_1 = D_2$ = 0.20 m) for upper part of sheet B = 0.25 and 0.50 m.

These first simulations permit to show that the numerical discrete model permits to well reproduce the experimental pull-out tests.
Additional simulations (Table 6) were performed to evaluate the influence of the length of return B = 0.125, 0.25, 0.50 and 0.75 m. The influence of length upper part of sheet is not significant (8 %). That confirms experimental results where there is an optimum length of upper part of sheet (B) required to mobilize an abutment in the soil.

Table 6. Influence of the upper part of sheet on GT_{230} with wrap around for H = 0.40 m ($D_1 = D_2$ = 0.20 m) for B = 0.125, 0.25, 0.50 and 0.75 m.

B (m)	T_{max} (kN)	T_{max} / $T_{max\ (B = 0.125\ m)}$
0.125	7.9	1
0.25	8.2	1.04
0.50	8.35	1.06
0.75	8.5	1.08

4.4 Analysis at the micro-mechanical scale

The numerical modelling permits to access to the stress-strain behaviour of the pull-out tests and it also permits to better understand what happens inside the soil mass using a fine analysis of some numerical outputs, at the micro-mechanical scale. In that sense, a pull-out test with wrap around anchorage (H = 0.40 m, B = 0.25 m) is studied. Figure 10 presents the particles velocity vectors (between the initial state and the final state) obtained in a representative simulation.

Figure 10. 2D Velocity field during a pull-out test on wrap around anchorage (B = 0.25 m, H = 0.40 m).

Maximum velocities are observed along the horizontal part of the anchorage as it slides, into the return of anchorage which deforms during test. High displacements are also noticed behind anchorage and above the upper part of the sheet where particles tend to move below as the wrap around distorts. Uplift is also observed on the top of sand 1 and at the right side above the wrap around, as soil moves in the direction of tension. Experimental tests on sand 1 where uprising of the soil has been measured confirm qualitatively the numerical results (Figure 11). Nevertheless, it is important to note significant differences in terms of vertical displacements. Numerical modeling can only reproduce qualitatively the phenomena and overestimates the vertical movements (uprising or settlement). This is probably due to the fact that the discrete element model does not reproduce the granulometry of the material and the fact that the discrete elements calculations are not of three dimensional shapes like the soil particles.

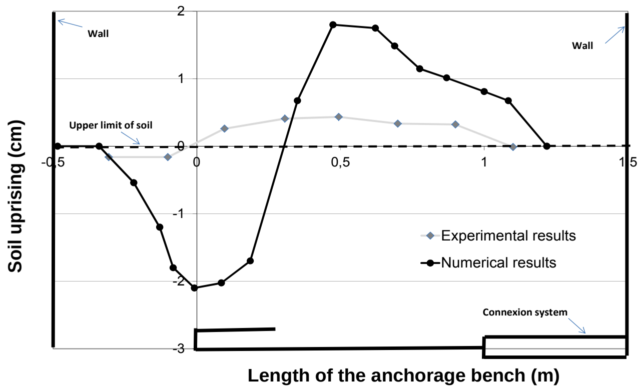
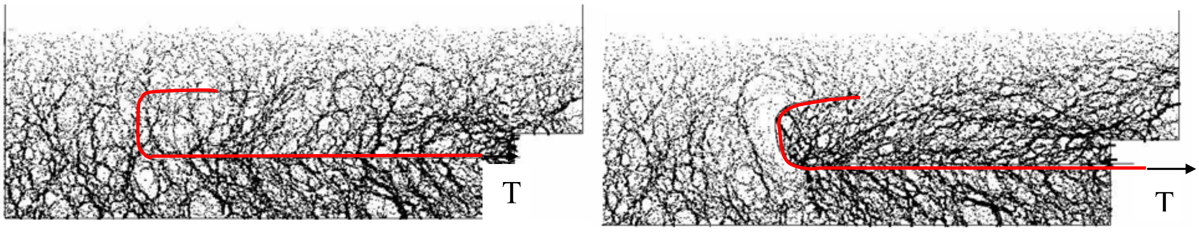


Figure 11. Uprising of the soil (Sand 1, GT_{230}, B = 0.25 m, H = 0.40 m).

4.5 Contact forces into the experimental tank

Contact forces network was explored in wrap around anchorage (Figure 12) for two different displacements during extraction. As it can be seen, there is a change of orientation of the contact forces towards the pull-out direction and a densification of the contact force network at the vicinity of the anchorage return (Figure 12.a) during its deformation during extraction. Soil is confined leading to an abutment of soil mass. Other forces chains concentrations are observed above the anchor block: the soil is pushed towards the vertical wall during the geotextile tension, leading to soil abutment of the bench upper part (Figure 12.b).
On the contrary, the contact forces network is not very dense behind the wrap around anchorage. Particles in this area are destabilized and do not participate any more to the force transmission into the bench.

Finally, contact forces gradually concentrate more and more in the right part of the tank, since the geosynthetic sheet is being pulled towards the right direction. Accordingly, either with the simple run-out or with the wrap around anchorage the contact forces tend globally to orientate diagonally as they initiate from the vertical wall above the anchor block towards the horizontal part of geosynthetic sheet and down to the lower part of the tank, as observed by Tran et al. (2013) and Wang et al. (2014).



(a) 6 mm (b) 60 mm

Figure 12. Contact force distribution in the bench during pull-out tests with wrap around for two different head displacements (6 mm and 60 mm) and H = 0.40 m, B=0.25 m).

5 CONCLUSION

Experimental pull-out tests have been performed with two types of experimental tanks (Irstea – INSA Lyon) under laboratory controlled conditions with three types of geotextiles (uniaxial or biaxial with different stiffness) and in presence of cohesive and non-cohesive soils for the simple run-out and the wrap around anchorages.
The results of the pull-out tests show that the behaviour of a geotextile sheet on the two types of experimental tanks is very similar. These tests allowed to study the influence of various parameters on the geotextile behaviour: anchorage capacity, length of upper part of sheet (B), soil type and geotextile type.
In order to complete the experimental studies, a specific two-dimensional numerical model has been used. The results of experimental tests permit to create an interesting database on which numerical calculations can be validated. Experimental tests performed with INSA anchorage apparatus have been simulated with a discrete-element model.
Numerical pull-out tests have been performed for the simple run-out and the wrap around anchorages in the experimental tank with sand. The numerical model chosen offers a good representation of the phenomena that are observed in the experiments (abutment, uplift).
The results of the numerical model for the simple run-out and the wrap around anchorages (head tension versus head displacement) for the tests with sand shows that the selected numerical method fits relatively well with experimental anchorage tests (with a maximum difference of 8%), thus validating the interest of this model to estimate anchorage capacities. In addition, the contact forces and displacements distribution along the geosynthetic sheet at different clamp displacements showed the load transfer behaviour between the geosynthetic and soil by frictional resistance, giving more insights at a microscopic scale.
Moreover, influence of the length of upper part of geotextile sheet (B) has been studied. The influence of this parameter is not significant (less than 8% for B ranging from 0.125 m to 0.75 m). That confirms experimental results where there is an optimum length of upper part of sheet required to mobilize an abutment in the soil. Therefore a minimum length can be chosen to minimize costs on site.

6 REFERENCES

Abdelouhab, A., Dias, D., Freitag, N.. (2010) “Physical and analytical modelling of geosynthetic strip pull-out behaviour”, *Geotext. Geomemb.* 28 (1), 44-53.

Briançon, L., Girard, H., and Villard, P.(2008). “Geosynthetics Anchorage: Experimental and Numerical Studies”, *EuroGeo4*, Edinburgh.

Chareyre, B. and Villard, P.. (2005) “Dynamic Spar Elements and DEM in Two Dimensions for the modelling of soil-Inclusion Problems”, *Journal of Engineering Mechanics - ASCE*, 131(7): 689-698.

Chareyre, B., Briançon, L., and Villard, P. (2002) “Numerical versus experimental modelling of the anchorage capacity of geotextiles in trenches”, , 9(2): 97-123.

Chareyre, B., and Villard, P. (2002) “Discrete element modelling of curved geosynthetic anchorages with known macro-properties”, Proc. of the First International PFC Symposium, Gelsenkirchen, Germany. 6-7 November 2002. Konietzky (ed): 197-203.

Cundall, P.A., and Strack, O.D.L (1979) “A discrete numerical model for granular assemblies”, *Geotechnique,* 29(1): 47-65.

Girard, H., Briançon, L. and Rey, E. (2006) “Experimental tests for geosynthetic anchorage trenches. Proc. of the Eighth *International Conference on Geosynthetics”*, 8th ICG, Yokohama, Japan, 18-22 September 2006, 211-216.

Gourc, J.P., Reyes-Ramirez, R., Villard, P.(2004) “Assessment of Geosynthetics Interface Friction for Slope Barriers of Landfill”, *GeoAsia*. Korea.

Itasca Consulting Group, Inc. (1996) “Particles flow code in two dimensions: PFC2D”, version 1.1, User's manual. Minneapolis: Itasca.

Khedkar, M.S., Mandal, J.N. (2009) “Pullout behaviour of cellular reinforcements”, *Geotextiles and Geomembranes*. 27 (4), 262-271.

Lajevardi S.H., Silvani C., Dias D., Briançon L., Villard P.(2015) Geosynthetics anchorage with wrap around: Experimental and Numerical Studies. *Geosynthetics International*, Vol 22 No 3.

Lajevardi, S.H., Briançon, L., and Dias, D. (2014).“Experimental studies of the geosynthetic anchorage - Effect of geometric parameters and efficiency of anchorages”, *Geotextiles and Geomembranes*, 42 505-514.

Lajevardi, S.H., Briançon, L., and Dias, D. (2015) Experimental studies of the behaviour of geosynthetic wrap around anchorage. *Geosynthetic international*, 22 (3).

Lajevardi, S.H., Dias, D., Racinais, J. (2013) “Analysis of soil-welded steel mesh reinforcement interface interaction by pull-out tests”, *Geotextiles and Geomembranes*, 4048-57.

Palmeira, E.M. (2009) “Soil-geosynthetic interaction: modelling and analysis”, *Geotext. Geomemb*. 27 (5), 368-390.

Sieira, A.C.C.F., Gerscovich, D., Sayao, A.S.F.J. (2009) “Displacement and load transfer mechanisms of geogrids under pullout condition”, *Geotext. Geomemb*. 27 (4), 241-253.

Su, L.J., Chan, T.C.F., Yin, J.H., Shiu, Y.K., Chiu, S.L. (2008) “Influence of overburden pressure on soil nail pullout: resistance in a compacted fill”, *J. Geotech. Geoenviron*. Eng. 134 (9), 1339-1347.

Tran, V.D.H., Meguid, M.A., and Chouinard, L.E. (2013) “A finite–discrete element framework for the 3D modeling of geogrid–soil interaction under pullout loading conditions”, *Geotextiles and Geomembranes*, 37, 1-9.

Villard, P., Chevalier, B., Hello, B.L., and Combe, G. (2009) “Coupling between finite and discrete element methods for the modelling of earth structures reinforced by geosynthetic”, *Computers and Geotechnics*, 36 (5), 709-717.

Villard, P., and Chareyre, B. (2004) “Design methods for geosynthetic anchor trenches on the basis of true scale experiments and discrete element modelling” *Canadian Geotechnical Journal*, Vol. 41, No. 6, 1193-1205.

Wang, Z., Jacobs, F., Ziegler, M. (2014) Visualization of load transfer behaviour between geogrid and sand using PFC2D, *Geotextiles and Geomembranes*, Volume 42, Issue 2, 83-90.

Zhang, M. X., Qiu, C. C., Javadi, A. A., Lu, Y., & Zhang, S. L. (2013) Discrete-element method simulation of a model test of an embankment reinforced with horizontal–vertical inclusions. *Geosynthetics International*, 20(4), 238-251.