PULL OUT TESTS: EXPERIMENTAL AND NUMERICAL RESULTS

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ABSTRACT: The aim of this paper is to study the soil-geosynthetic interface resistance using pull out tests. The type of geosynthetic is one of the parameters of high importance on the pull out behaviour of geosynthetics. To evaluate the influence of the structure of geosynthetics in their pull out behaviour a series of pull out tests was carried out. Four different geosynthetics, with similar tensile strengths, embedded in standard sand, were tested according to the procedures described on prEN 13738. To characterize the tensile behaviour of the geosynthetics studied wide-width tensile tests were also carried out. In order to approach the liability of the numerical simulation of the pull out tests, one of the experimental tests was modelled numerically by using a FEM program. The results obtained are presented and discussed. The main conclusions from this study are also presented.

1 INTRODUCTION

The aim of this paper is to study the soil-geosynthetic interface resistance using pull out tests.

The type of geosynthetic is one of the parameters of high importance on the pull out behaviour of geosynthetics. To evaluate the influence of the structure of geosynthetics in their pull out behaviour a series of pull out tests was carried out.

Four different geosynthetics, with similar tensile strengths, embedded in standard sand, were tested according to the procedures described on prEN 13738.

To characterize the tensile behaviour of the geosynthetics studied wide-width tensile tests were also carried out.

2 GEOSYNTHETICS

Four different geosynthetics were tested, namely:

- HDPE uniaxial extruded geogrid (GSY1);
- PET woven geogrid (GSY2);
- PET woven geotextile (GSY3);
- Composite geotextile (GSY4).

The materials were chosen with similar values for their tensile strength, ranging from 80 to 100kN/m, so that conclusions could be established about the influence of the structure of the geosynthetic in their pull out behaviour.

3 TENSILE TESTS

In order to characterize the tensile strength of the geosynthetics used in this study tensile tests were performed using the procedures according to EN ISO 10319.

The results obtained are presented on Table 1.

Different clamping systems were used for the tensile tests (Figure 1).

Table 1 Tensile strength of the geosynthetics (EN ISO 10319).

Material	Tensile Strength		
	Mean (kN/m)	Standard deviation (kN/m)	Coefficient of variation (%)
GSY1	109.52	2.31	2.11
GSY2	90.58	2.64	2.92
GSY3	121.61	4.42	3.63
GSY4	98.31	3.50	3.56

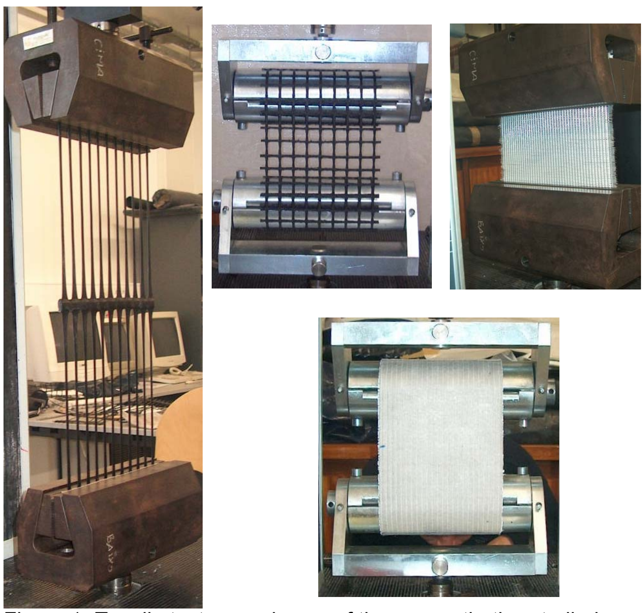

Figure 1 Tensile tests: specimens of the geosynthetics studied.

Capstan clamps, with 100mm diameter, were used to test two of the geosynthetics: GSY2 and GSY4. GSY1 and GSY3 were tested with wedge clamps.

4 PULL OUT TESTS

4.1 *Test equipment*

The pull out tests were carried out using the test equipment in Figure 2.

The interior dimensions of the box are: 1.5m length, 0.90m width and 0.60m height. To reduce the influence of the upper boundary, a 0.025m thick smooth neoprene slab was placed on the top of the box immediately over the soil, and, regarding the front boundary, a steel sleeve 0.20m long was used inside the box, near the front wall.

To have a reduced unconfined length of geosynthetic during the pull out test the clamp is placed inside the metal sleeve with almost zero length of material outside the box (Figure 3). During pull out the unconfined length increases at the displacement rate imposed during the test.

The displacements along the geosynthetic are measured using inextensible wires connected (in one end) to the geosynthetic and (in the other) to linear potentiometers placed outside the box (see Figure 4).

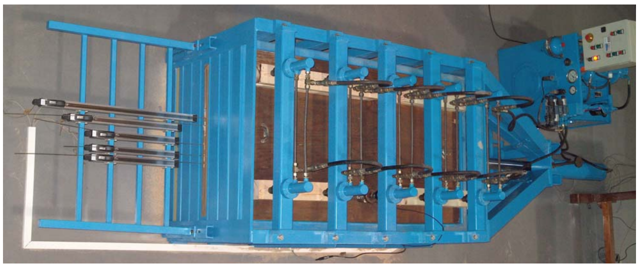

Figure 2 Equipment used for the pull out tests – large box.

Figure 3 Clamp inside the metal sleeve.

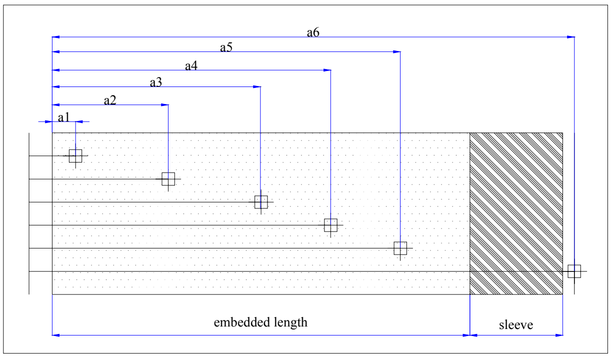

Figure 4 Schematic representation of the distribution of the points to measure displacements.

The tests were carried out at a constant displacement rate of 2mm/min. The pull out force is applied by a hydraulic system and measured by a load cell placed in the clamping system which transmits the force to the reinforcement.

The confining stress is applied by ten small jacks acting on a wood plate on top of the soil and is measured by a load cell.

The results are recorded during the test by an automatic data acquisition system.

A more detailed description of the equipment can be found in LOPES and LADEIRA (1996) and LOPES and LOPES (1999).

4.2 *Test procedure*

To fill the box, the soil was poured from a constant height of 0.50m and placed in 0.15m thick layers. Each layer was levelled and compacted to the required unit weight using an electric vibratory hammer. When the soil reached the metal sleeve at the front of the box (0.30m height), the reinforcement was laid on the surface of the compacted soil and fixed to the clamp outside the box.

The inextensible wires, used to measure the displacement along the reinforcement, were then placed and connected to the linear potentiometers at the back of the box. Five potentiometers were used in the tests. A sixth potentiometer is used to measure the displacement of the clamp.

Finally, two 0.15m thick soil layers were placed, levelled and compacted, resulting in a total soil thickness of 0.60m with the geosynthetic reinforcement at the middle. The geosynthetic specimens were 0.30m wide and 1.00m long (embedded length). The normal stress applied at the reinforcement level (i.e. at 0.30m) was 50kPa and a displacement rate of 2mm/min was used. For each geosynthetic two specimens were tested, giving a total of 8 pull out tests (all performed in the machine direction of the geosynthetic).

During the pull out tests the pull out force, the normal stress applied, the front displacement and the displacements along the geosynthetic were recorded every 4s.

4.3 *Soil*

The soil used in this series of pull out tests is a standard sand. The main parameters of the soil are presented in Table 2 and the grain size distribution is shown in Figure 5.

Table 2 Main characteristics of the soil

D_{min} (mm)	D_{10} (mm)	D_{30} (mm)	D_{50} (mm)	D_{60} (mm)	D_{max} (mm)	C_u -	C_c -
0.075	0.22	0.34	0.43	0.47	4.75	2.16	1.11

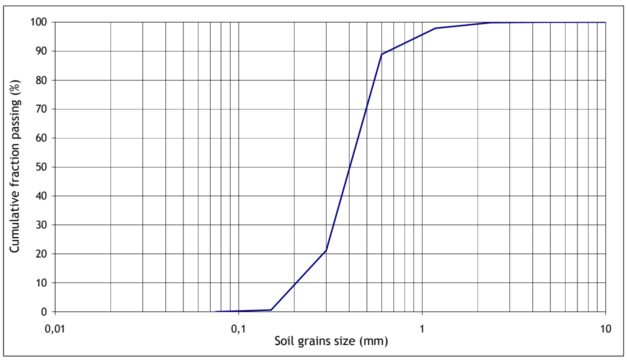

Figure 5 Grain size distribution of the soil

5 PULL OUT TEST RESULTS

The results obtained are summarised in Table 3, by the pull out resistance (P_r), maximum pull out force, and the front displacement (d_f). For all the materials tested the failure occurred by pull out of the geosynthetic from the soil.

Figure 6 shows the pull out plots for the specimens of the four geosynthetics tested.

Table 3 Summary of the pull out test results

Material	Specimen	Pull out resistance (kN/m)	Front displacement (mm)
GSY1	1	55.94	73.40
	2	61.66	85.73
	Average	58.80	79.56
GSY2	1	51.35	101.42
	2	47.39	98.91
	Average	49.37	100.16
GSY3	1	29.04	62.58
	2	30.05	68.86
	Average	29.54	65.72
GSY4	1	19.64	206.89
	2	19.89	213.41
	Average	18.26	210.15

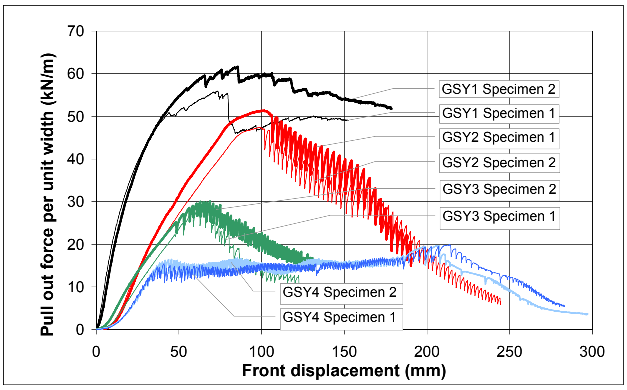

Figure 6 Pull out plots of the specimens tested.

The highest values for the average pull out resistance were obtained with GSY1 (59kN/m) and GSY2 (49kN/m), followed by GSY3 (30kN/m) and GSY4 (18kN/m).

Geosynthetics GSY1 and GSY2 have openings and, therefore, there are additional mechanisms contributing to increase the pull out resistance, than those existing for materials with continuous structure (GSY3 and GSY4).

During pull out, there are three mechanisms that can be mobilized in soil-geogrid interfaces: a) skin friction over the planar geogrid interface; b) soil-soil friction through the geogrid apertures; and c) passive resistance of the geogrid bearing members. Therefore, it was expectable that materials with openings, able to mobilize the soil-soil friction through the apertures and the passive resistance of their bearing members would have higher pull out resistances.

For the composite material, GSY4, in the end of the specimen (farthest from the sleeve) there is another phenomenon: the reinforcing yarns get loose from the geotextile base, inducing a lower value for the pull out resistance of the material.

Figures 7 and 8 show the displacements corresponding to the several points for measurement along specimen 1 for GSY1 and GSY4, respectively.

For material GSY1 the measurement of the displacements is done in the nodes/junctions of the ribs. Due to the length of material embedded, for GSY1 there were only 4 transversal ribs inside the pull out box, therefore it was only possible to measure the displacements in four points.

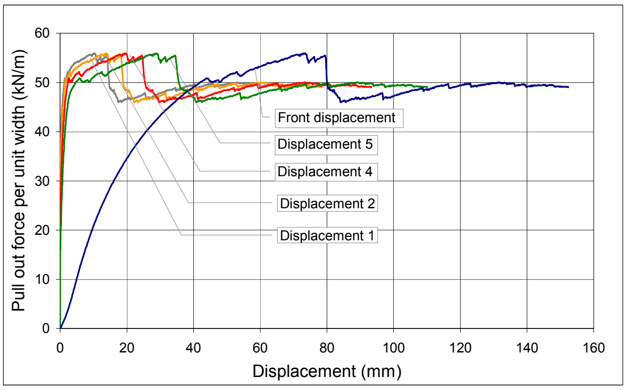

Figure 7 Pull out plot for GSY1 Specimen 1 and displacements along the embedded length of the material.

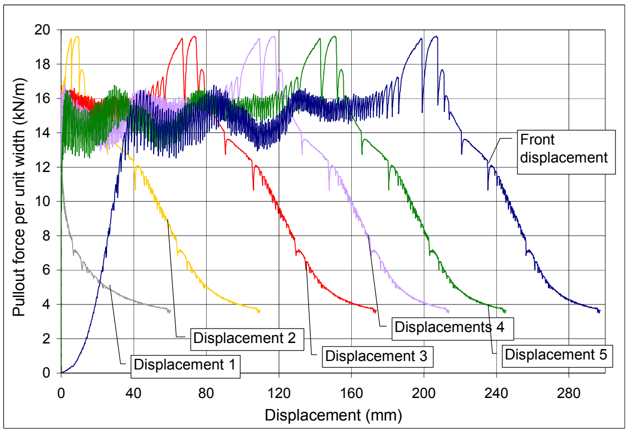

Figure 8 Pull out plot for GSY4 Specimen 1 and displacements along the embedded length of the material.

The different displacement values, at the moment where the pull out resistance of each geosynthetic was reached, are presented in Figure 9, in terms of percentage of the respective front displacement. This normalization of the displacements allows the comparison between the values obtained for the two geosynthetics.

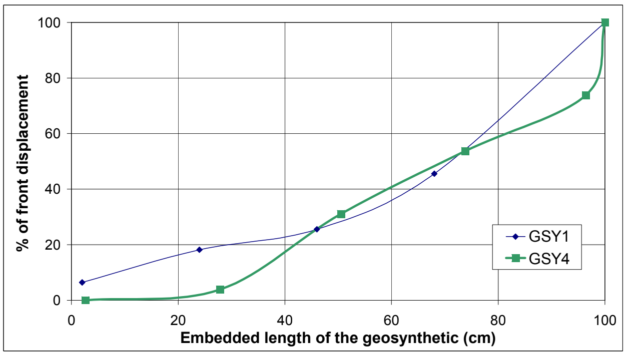

Figure 9 Displacements along GSY1 and GSY4, specimen 1, corresponding to the respective pull out resistance, as a percentage of the corresponding front displacement.

As it is clear from the graphic, the value zero for the embedded length corresponds to the free end of the specimen, while the value 100 cm corresponds to the front end of the geosynthetic (the clamp area).

For GSY1, it is clear that, at the moment where the maximum pullout force is reached, the free end of the geosynthetic is already moving, and that the distribution of displacements along the specimen is more uniform than for GSY4.

For GSY4, at similar moment, the free end of the material has not started to displace, and the main movements of the geosynthetic occur in the front part of the specimen. It is clear that there is some deformation of the material between the clamp area and the point of measurement 5.

6 NUMERICAL ANALYSIS

In order to simulate the test a 2D FEM program has been used. Isoparametric planar elements are adopted to simulate the soil, allowing for the use of different soil models. Joint elements are used to model the soil-geosynthetic interface with a Mohr-Coulomb law that considers the degradation of the peak friction angle for cumulative shear deformation.

One of the experimental tests, GSY4 specimen 1, was simulated numerically. Figure 10 shows the experimental and numerical pull out force versus front displacement plots for specimen 1 of GSY4.

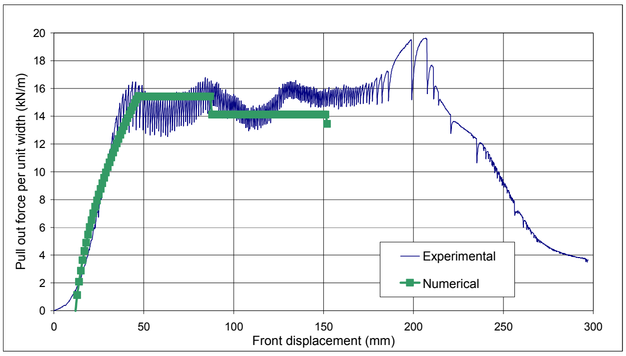

Figure 10 Pull out plots of the GSY4, specimen 1 obtained from the pull out test and from the numerical analysis.

It can be seen that the numerical curve fits well the experimental one until the front displacement reaches 150 mm. However, the maximum pull out force measured by the numerical modelling is about 20% lower than that of the experimental study.

The differences observed on the pull out behaviour of GSY4 specimen 1 in both studies can be justified by the numerical model used, which is a 2D and not 3D as are the real conditions of the pull out tests.

7 CONCLUSION

To study the behaviour of the soil-geosynthetic interface, four geosynthetics with similar tensile strength values were subjected to pull out test from a standard sand. The tensile strength of the materials was characterized using wide width tensile tests.

One of the pull out results was simulated numerically and both plots, experimental and numerical, were compared.

The main conclusions that can be stated from this study are:

- highest values for the average pull out resistance were obtained with GSY1 (59kN/m) and GSY2 (49kN/m);
- followed by GSY3 (30kN/m) and GSY4 (18kN/m);
- the higher values for the pull out resistance are likely to be due to the openings of these geosynthetics;
- the displacements along GSY1, at the moment where the pull out resistance is reached, are more uniform than for GSY4, were there is higher mobilization of the front part of the geosynthetic;
- though the numerical curve fits well the experimental curve in the first part of the test, it will be advisable to use a 3D model instead of a 2D in order to reach the real behaviour of the geosynthetic during pull out.

8 REFERENCE

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