Effect of damage during installation on the pullout behaviour of geosynthetics

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ABSTRACT: Two geosynthetics were subjected to the effect of damage during installation (DDI) using real conditions, when installed in experimental works. The effects of the damage induced on the geosynthetics by these procedures were evaluated using wide-width tensile test. Simultaneously a test program was implemented to carry out pullout tests (according with EN 13738: 2004) to characterize the behaviour of the soil-geosynthetic interface. The geosynthetics tested include two different materials with different structures. The effects of DDI on the pullout behaviour of the geosynthetics is presented and discussed. The values of the reduction factors determined from the results obtained are also presented. The main conclusions are stated.

1 INTRODUCTION

To contribute to the comprehension of the effect of damage during installation (DDI) on mechanisms of interaction between soil and geosynthetics, a research program was established.

Two different geosynthetics have been studied using pullout tests.

Therefore, the effects of DDI on the pullout behaviour of geosynthetics are presented and discussed. The results obtained are compared. The values of the corresponding reduction factors are determined and presented.

2 MATERIALS AND TEST PROGRAM

2.1 *Geosynthetics*

The research program implemented includes a larger number of geosynthetics (Pinho-Lopes 2006). The results presented refer only to two geosynthetics: a woven polypropylene geotextile (GTX) and a biaxial woven polyester geogrid (GGR) - see Table1.

Table 1. Geosynthetics studied

Material		Nominal Strength (kN/m) MD*/CMD†
GTX	Woven polypropylene geotextile	65/65
GGR	Polyester woven geogrid	55/55

* MD – machine direction
† CMD – cross machine direction

To allow the results to be compared, the geosynthetics were chosen with similar values for their nominal tensile strength, ranging from 55 to 65 kN/m. This way, the effect of the type of geosynthetic on the properties studied can be analyzed.

2.2 *Test program*

The test program established consists in: 1) inducing the effects of the installation damage in field, under real conditions, on samples of geosynthetics; and 2) characterising the effects of the damaged induced on the mechanical behaviour of the geosynthetics in isolation.

To carry out field damage tests, experimental embankments were built, using adequate construction procedures. More details can be found in Pinho-Lopes et al. 2002 and Pinho-Lopes 2006. After their installation, the geosynthetic were exhumed and recovered to be tested. The geosynthetic were installed in contact with two different soils: Soil 1 is an aggregate used in road construction, while Soil 2 is a residual soil from granite (Table 2). To study the effect of the compaction energy in the damage induced, two different compaction energies were considered (CE1 – 90% of the normal Proctor and CE2 – 98% of the normal Proctor). Therefore, four different embankments were built.

The evaluation of the damage induced on the geosynthetics was carried out by submitting intact (reference) and damaged materials to same index tests: wide-width tensile tests (EN ISO 10319: 1996) and pullout tests (EN 13738: 2004). More details and description of the equipment of pullout test can be found in Pinho-Lopes 2006.

Table 2. Results obtained from the laboratorial characterization of Soil 1 and Soil 2

Soil	%<0,074mm	D_{10} (mm)	D_{30} (mm)	D_{50} (mm)
Soil 1	5.18	0.22	2.68	11.78
Soil 2	21.53	0.07	0.17	0.38
	D_{60} (mm)	D_{max}(mm)	C_U	C_C
Soil 1	19.15	50.80	87.81	1.71
Soil 2	0.68	5.00	9.64	0.58

The soils used in pullout tests are different than the ones used in the field damage tests (temporary embankments built) - Table 3. Soil 3 is an aggregate used in road construction, similar to Soil 1, and Soil 4 is a residual soil from granite, similar to Soil 2.

Table 3. Results obtained from the laboratorial characterization of Soil 3 and Soil 4

Soil	%<0,074mm	D_{10} (mm)	D_{30} (mm)	D_{50} (mm)
Soil 3	9.52	0.08	1.00	3.50
Soil 4	19.87	-	0.19	0.39
	D_{60} (mm)	D_{max}(mm)	γ_{mim} (kN/m^3)	γ_{max} (kN/m^3)
Soil 3	5.95	37.50	14.12	21.19
Soil 4	0.55	38.10	13.59	17.20

In the pullout tests the soil was compacted to a relative density of 50%. The normal stress at the reinforcement level was 25kPa with Soil 3 and 50kPa with Soil 4. The displacement rate of 2mm/min was used in both pullout tests. More details can be found in Pinho-Lopes 2006 and Araújo 2008.

3 ANALYSES AND RESULTS

3.1 *Tensile tests*

The results obtained from the wide-width tensile tests are presented in Table 4 in terms of the tensile strength, strain for rupture and the corresponding values of the coefficient of variation.

Table 4. Results obtained from the tensile tests – tensile strength (S), coefficient of variation of the tensile strength (CV_S), strain for the tensile strength (ε) and coefficient of variation of the strain ($CV_ε$)

Geosynthetic	Quantity	Intact material	After DDI field tests			
			Soil 1		Soil 2	
			CE1	CE2	CE1	CE2
GTX	S (kN/m)	77.5	43.7	26.4	*	70.4
	CV_s (%)	1.8	8.6	5.0	*	1.0
	ε (%)	13.0	8.9	7.1	*	11.7
	$CV_ε$ (%)	4.8	13.1	7.9	*	5.6
GGR	S (kN/m)	83.4	52.0	45.9	64.5	62.2
	CV_s (%)	2.4	8.8	8.7	6.0	6.3
	ε (%)	14.9	11.8	11.9	13.8	13.2
	$CV_ε$ (%)	5.7	5.1	2.5	4.6	3.1

* It was not possible to obtain this result

The lowest values of the residual strength refer to the samples obtained after DDI with Soil 1 and CE2.

From Table 2 it is clear that the most aggressive soil is Soil 1. In fact, these differences can be explained by the type of soil: Soil 1 (D_{50}=11.78mm), with grains larger than Soil 2 (D_{50}=0.38mm), is more "aggressive" to the geosynthetics inducing more severe consequences.

As expected, the compaction energy used in the field DDI tests influences the changes in the mechanical behaviour of the geosynthetics. In fact, higher compaction energy (CE2) corresponds to lower values of the residual strength and strain.

More details can be found in Pinho Lopes et al. 2000 and 2002 and Paula *et al*. 2008.

3.2 *Pullout tests*

The results from the pullout tests are presented in Table 5, in terms of the maximum pullout strength and de front displacement for the maximum pullout strength, as well as the corresponding values of the coefficient of variation. The normal stress applied at the reinforcement level and type of failure is also represented in Table 6.

Table 5. Results obtained from the pullout test – maximum pullout strength (S_P), coefficient of variation of the pullout strength (CV_{SP}), displacement for the maximum pullout strength (D) and coefficient of variation of the displacement (CV_D)

Geosynthetics		Type Soil	S_P	CV_{SP}	D	CV_D
			kN/m	%	mm	%
GTX	Intact	Soil3	44.81	6.16	96.63	7.15
	Soil 1-CE1		31.60	11.51	81.66	13.34
	Soil 1-CE2		17.11	12.50	44.30	4.35
	Intact	Soil4	47.13	6.97	125.28	6.97
	Soil 2-CE1		*	*	*	*
	Soil 2-CE2		43.02	5.02	131.34	5.94
GGR	Intact	Soil3	49.70	6.14	88.52	5.81
	Soil 1-CE1		45.51	7.65	87.47	8.31
	Soil 1-CE2		20.84	35.12	54.20	7.34
	Intact	Soil4	31.80	5.42	111.07	7.92
	Soil 2-CE1		33.32	5.87	114.59	4.36
	Soil 2-CE2		31.34	4.54	116.87	5.26

* It was not possible to obtain this result

Table 6. Normal stress applied and type of failure on pullout test

Geosynthetics		Type Soil	Normal stress applied (kPa)	Type of failure
GTX	Intact	Soil3	25	Tensile
	Soil 1-CE1		25	Tensile
	Soil 1-CE2		25	Tensile
	Intact	Soil4	50	Pullout
	Soil 2-CE1		50	Pullout
	Soil 2-CE2		*	*
GGR	Intact	Soil3	25	Tensile
	Soil 1-CE1		25	Tensile
	Soil 1-CE2		25	Tensile
	Intact	Soil4	50	Pullout
	Soil 2-CE1		50	Pullout
	Soil 2-CE2		50	Pullout

* It was not possible to obtain this result

In Figure 1 the same results are presented in terms of residual pullout strength and residual displacement for the maximum pullout strength. These quantities are defined by the following equation:

$$X_{residual} = \frac{X_{damaged}}{X_{intact}} \times 100\,(\%)$$

Where $X_{residual}$ is the residual value of the property after DDI (residual pullout strength, $SP_{residual}$, or residual displacement, $D_{residual}$), $X_{damaged}$ is the value of the property after DDI (pullout strength and the displacement of the damaged material) and X_{intact} is the same parameter corresponding to reference (intact) samples.

GTX and GGR had different modes of rupture, depending on the type of soil used: the specimens tested with the Soil 4 suffered a pullout rupture, while the specimens tested with Soil 3 had a tensile failure. One of the possible causes for the tensile failure of these specimens with Soil 3 in the pullout tests is the fact that this is a more aggressive soil for the geosynthetics than Soil 4. In fact, during the process of soil compaction in the pullout tests there may be some additional damage induced on the specimens, which will be more important with Soil 3 than with Soil 4.

Additionally, the tensile failure occurs for a confining stress of 25kPa, while the specimens that failed by pullout were tested with a confining stress of 50kPa. As the pullout phenomenon is more relevant than confining stresses and is more important for lower confining stresses, this question will probably not interfere significantly in the comparison of results.

After DDI there are a few changes in pullout behaviour of geosynthetics. In fact, the maximum pullout force is reduced after DDI. The residual pullout strength for GTX ranges between 38.2% and 91.3%; for GGR, the extreme values for the residual pullout strength are 41.9% and 104.8%. This last value correspond to the samples after DDI with Soil 2 and CE1 where the pullout strength after DDI is high than the intact material. The lowest values of the residual pullout strength refer to the samples obtained after DDI with Soil 1 and CE2.

The residual displacement for the pullout strength of the geosynthetics studied ranges between 45.8% and 105.2%. In general, the reductions of this quantity follow the same trend of the residual pullout strength. Nevertheless, in most cases the reduction of displacement after the damage induced is smaller than the one observed for the pullout strength.

Regarding the type (or structure) of the geosynthetics, Soil 1 induces the most severe consequences. Therefore, for these conditions (i.e., the most aggressive soil) the response of the geogrid is better than the one of the geotextile. This can be partially explained by the area of the geosynthetic in contact with the soil, which is higher for the geotextile, becoming more exposed to the mechanical damage.

To assess the effect of the type of soil, results referring to the same compaction energy should be analysed. It is clear that the most aggressive soil is Soil 1, with values of residual pullout strength of GTX and GGR of 40.3% and 33.9%, respectively (and of 91.3% and 98.6%, for Soil 2). In fact, these differences can be explained by the type of soil, as happened with the tensile tests. The damage induced in field with Soil 1 and the subsequent use of Soil 3 in the pullout test may cause the tensile failure and the great difference between results. In fact, these soils are more "aggressive" than Soils 2 and 4. This is due, as noted above, to the fact that Soil 1 has grains larger than Soil 2, inducing more damage.

The front displacement increases after DDI and with the highest compaction energy applied.

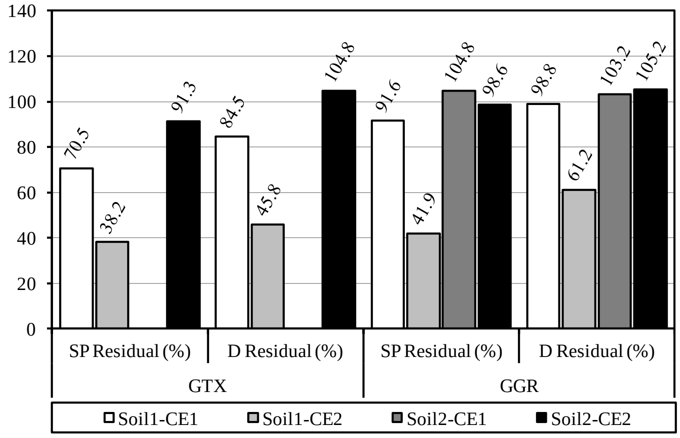

Figure 1. Residual pullout strength ($SP_{residual}$) and residual front displacement ($D_{residual}$) for the maximum pullout strength

As expected, the higher compaction energy (CE2) corresponds to lower values of the residual pullout strength and displacements (in most cases).

In Figure 2, the results of the tensile strength of GTX and GGR when tested with tensile tests (EN ISO 10319: 1996) and the results of the tensile strength when tested by the pullout tests (EN 13738: 2004) with Soil 3 are presented. This comparison is possible in samples where the type of failure in pullout tests was tensile rupture and not pullout rupture (specimens after DDI with Soil 1 and for the two compaction energies, CE1 and CE2).

From the analyses of Figure 2, it is possible to observe that the tensile strength obtained from the pullout tests is quite lower than tensile strength obtained from the tensile tests. For the intact specimens there is a decrease of 42.2% and 40.4% for GTX and GGR, respectively. For the specimens submitted to DDI with two compaction energies, that difference, in general is quite low, 27.7% and 35.2% for GTX and compaction energies of CE1 and CE2, respectively, and 12.5% and 54.7% for GGR and compaction energies of CE1 and CE2, respectively.

This reduction of tensile strength was, probably caused by additional damage induced while introducing the specimen in the two layers of soil in the box and the compaction of the upper soil during the preparation of the pullout tests.

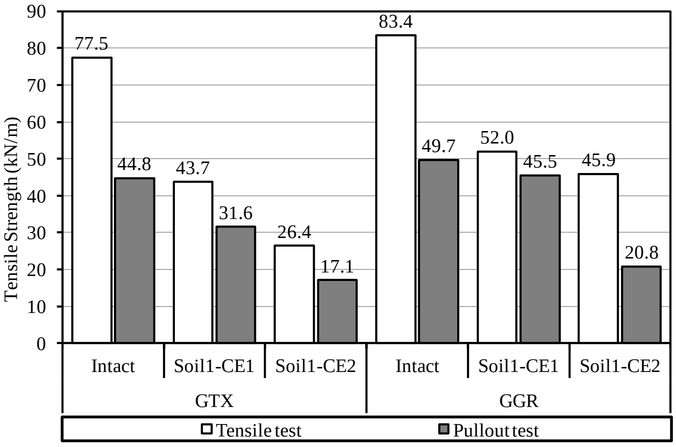

Figure 2. Relationship between tensile test and the pullout test

3.3 *Reduction factors*

After the damage during installation field tests it is possible to define values for the corresponding reduction factors to be used in the design of the geosynthetics (Table 7) from the following equation:

$$RF_{DDI} = \frac{X_{intact}}{X_{damaged}}$$

Where RF_{DDI} is the reduction factor after damage during installation, X_{intact} is the value of the property corresponding to intact samples (tensile strength and the pullout strength), $X_{damaged}$ is the same property after DDI.

Table 7. Reduction factors for damage during installation after pullout tests

Geosynthetic		RF_{DDI}			
		Soil 1		Soil 2	
		CE1	CE2	CE1	CE2
Tensile test	GTX	1.77	2.94	*	1.10
	GGR	1.60	1.82	1.29	1.34
Pullout test	GTX	1.42	2.62	*	1.10
	GGR	1.09	2.38	0.95	1.01

* It was not possible to obtain this result

The values obtained for the reduction factors for the tensile strength and the pullout strength after DDI reflect the influence of the factors referred before. In fact, the values for the reduction factors for DDI obtained for the geogrid are lower than for the geotextile.

4 CONCLUSIONS

From and for the results presented it is possible to conclude:

- The values for the reduction factors for DDI after pullout tests obtained for the geogrid are lower than for the geotextile. The geotextile is generally more sensible to DDI than the geogrid, which can be caused by the larger area in contact with the soil;
- The soil with larger particles is more aggressive (Soil 1) and higher compaction energy (CE2) leads to higher reduction of mechanical properties;
- The specimens tested with the Soil 4 suffered a pullout rupture, while the specimens tested with Soil 3 had a tensile failure. The use of Soil 3 in the pullout tests is more aggressive for the geosynthetics than Soil 4. Additionally, the tensile failure occurs for a confining stress of 25kPa, while the specimens that failed by pullout were tested with a confining stress of 50kPa;
- The tensile strength measured from the pullout tests is quite lower than the tensile strength resulting from the wide-width tensile tests. This is true for specimens after DDI with Soil 1 and for two compaction energies, CE1 and CE2;
- The residual displacement for the pullout strength follows the same trend of the residual pullout strength;
- The damage in field with Soil 1 and the subsequent use of Soil 3 in the pullout tests may be the cause for the tensile failure and for the great difference between results. These soils are more “aggressive” than Soils 2 and 4.

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