Laboratory and field tests for the evaluation of installation damage of geosynthetics in reinforced earth structures

Essais de laboratoire et in situ pour l'évaluation de l'endommegement suite à la mise en oeuvre des géosynthetiques dans structures renforcés

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ABSTRACT: The paper presents the results of an experimental activity to assess the effects of installation damage on mechanical properties of geosynthetics to be used in reinforced earth structures. Installation damage was performed both in laboratory and on site. Trials were undertaken using five different types of geosynthetics. Two coarse grained soils were used. Laboratory damage procedure was carried out in accordance to ENV ISO 10722-1 standard using both types of coarse soils. Also field tests were performed with the same soil used in the second series of laboratory installation damage tests. The changes in mechanical properties of geosynthetics were determined from rapid loading tensile tests (according to EN ISO 10319) using both damaged and undamaged specimens. Finally, comparisons were made with the results obtained from laboratory and field tests.

RÉSUMÉ: L'article présente les résultats de l'activité experimentale développée pour l'évaluation de l'endommegement suite à la mise en oeuvre des géosynthetiques dans structures renforcés. L'endommegement suite à la mise en oeuvre a été étudié, soit en laboratoire, soit en situ, en utilisant cinq types de géosynthetiques et deux types de sols. Les essais de laboratoire ont prevu l'utisation de la norme ENV ISO 10722-1 avec les deux type de sols; un seul type de sol a été utilisé dans les essais en situ. La variation des propriétés méchaniques des géosynthetiques a été étudiée sur la base des essais de traction (suivant la norme EN ISO 10319) sur les échantillons soit vierges soit endommegés. Des interessantes correlations entre les essais en laboratoire et en situ sont aussi présentées.

1 INTRODUCTION

Geosynthetics used in reinforced earth structures are subjected to damage during installation. The installation damage depends on a large number of factors.

In order to understand this problem, several installation trials were made in the last ten years (Troost and Ploeg, 1990; Watts and Brady, 1990, 1994; Koerner et al., 1993; Rainey and Barksdale, 1993; Sandri et al., 1993; Austin, 1997; Elvidge and Raymond, 1999; Sprague et al., 1999).

Installation damage depends on two main factors: the materials used and the construction activities. Materials include both geosynthetics and soils, while the construction activities are mainly related to two crucial aspects: the installation of geosynthetics and the compaction of soils. In Table 1 a schematic approach is reported.

Field installation tests allow the designers to calculate installation damage safety factor in close relation with the local conditions (particular materials used, construction equipment and procedure...). However, comparison between different tests is difficult and a general approach is not possible.

The ENV ISO 10722-1 (1998) was proposed as experimental standard reference procedure to evaluate the installation damage due to coarse grained soils.

The experimental activity here presented was carried out to assess the effects of installation damage on mechanical properties of geosynthetics both in field conditions and in laboratory simulations.

2 TEST PROGRAM

Laboratory tests were performed at the Geosynthetics and Special Materials Laboratory of Enel.Hydro in Milano, while field tests were carried out at the Geotechnical Laboratory of Province of Trento.

Tests were undertaken using five types of geosynthetics: one nonwoven geotextile, one woven geotextile, two woven geogrids and one extruded geogrid. All geosynthetics were in polypropylene, except one polyester (PVC coated) woven geogrid (symbol GGW1). Moreover, all geosynthetics were selected to have common values of undamaged tensile strength, i.e. between 30 and 40 kN/m (in longitudinal direction).

Table 1. Installation damage: factors of influence

MATERIALS	
Geosynthetics	**Soils**
- Type	- Type
- Dimension and shape of fibre	- Grain size distribution
- Manufacturing technology	- Angularity
- Mass per unit area	- Shape
- Polymer	- Hardness
- Mechanical properties	- Mechanical properties

CONSTRUCTION ACTIVITIES	
Installation Procedure	**Compaction**
- Level of compaction of base layer	- Layer thickness
- Placement procedure of geosynthetics	- Type and weight of equipment used in compaction
- Spreading procedure of the second layer	- Total compaction energy
- Type and weight of equipment used in spreading the soil	- Level of compaction of second layer

Table 2. The five types of geosynthetics tested in this study and their main physical properties measured in laboratory

TRADE NAME	SYMBOL	MANUFACTURER (and country)	MELTING POINT (and polymer)	MASS PER UNIT AREA (g/m^2)	NOMINAL THICKNESS (mm)
Geodren PP/S	GTN	Edilfloor (I)	170 °C (PP)	504	5.1
Mac-Tex WP 200	GTW	Officine Maccaferri (I)	167 °C (PP)	191	0.7
Telegrid 35/25	GGW1	Tele Textiles AS (N)	246 °C (PET)	221	0.8
Fornit 40/40	GGW2	Huesker Synthetic (D)	170 °C (PP)	423	1.6
LBO 330 SAMP	GGE	Tenax (I)	166 °C (PP)	426	2.6

GTN: nonwoven geotextile; GTW: woven geotextile; GGW: woven geogrid; GGE: extruded geogrid;
PP: polypropylene; PET: polyester.

In Table 2 the five types of geosynthetics are listed with the main physical properties measured in laboratory.

Two different coarse grained soils were used for damaging geosynthetics: a sintered aluminium oxide (corindon) artificial aggregate (as required by ENV ISO 10722-1) and a crushed porphyritic quarry soil (used also for field tests). The main characteristics of these soils were accurately measured, to describe the conditions in which the geosynthetics are subjected to installation damage.

In Figure 1 the grain size distributions of the two soils are reported. The corindon aggregate has a very uniform distribution of the particles, between 8 mm and 5 mm, and could be defined as a poor graded medium gravel. The porphyritic soil is a well-graded gravel whit silty sand.

Also in Figure 2 the measures of the angularity of the grains are illustrated. The corindon aggregate particles are angular to very angular, while the porphyry grains are angular.

Laboratory damage procedure was carried out in accordance to ENV ISO 10722-1 standard. As granular damaging material in laboratory tests, both the corindon artificial aggregate and the crushed porphyritic quarry soil were used. Field tests were performed only with the porphyritic soil.

The changes in mechanical properties of geosynthetics were determined from rapid loading tensile tests (according to EN ISO 10319) by comparison of results on both damaged and undamaged specimens.

3 LABORATORY TESTS

The laboratory damaging tests were performed both with the corindon, as required by ENV ISO 10722-1, and with the porphyritic quarry soil (porphyry).

A 250 mm x 350 mm geosynthetic specimen was placed between two layers of soil in a rigid steel box, measuring 350 mm x 350 mm x 155 mm. The thickness of each soil layer was 75 mm, and the first one was loaded with a static pressure of 200 kPa, for 60 s, with a flat rigid plate covering the whole area of the test container (see Figure 3).

The system was then subjected to a dynamic loading using a steel loading plate, placed over the second layer, measuring 200 m x 100 m x 30 mm. A sinusoidal cycle loading has been applied through a semi-dynamic actuator and the applied loads were measured and controlled by a load cell inside the piston. A quasi-sinusoidal cyclic loading was obtained at a frequency of 0.2 Hz, while the load was ranging from 30 to 900 kPa for 200 loading cycles. The geosynthetic specimen was removed from the test apparatus, examined for any visual damage and then subjected to rapid loading tensile test, to measure the change in its original properties, according to EN ISO 10319, as illustrated for example by Cazzuffi et al. (1986).

Six specimens were taken for each tested geosynthetic. To minimise the effects of the variability in the products, in the samples supplied, every damaged specimen was taken adjacent to the undamaged one.

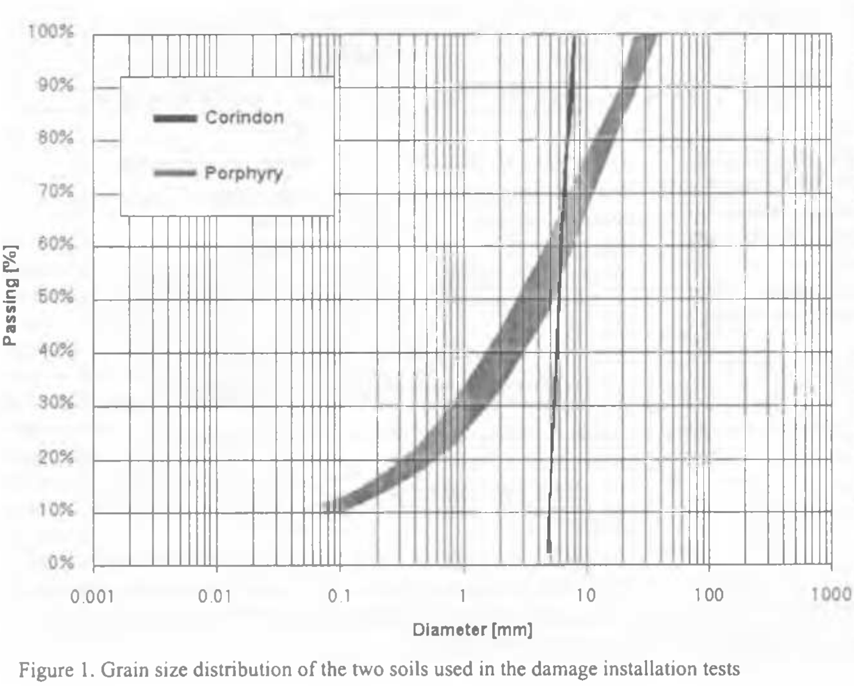

Figure 1. Grain size distribution of the two soils used in the damage installation tests

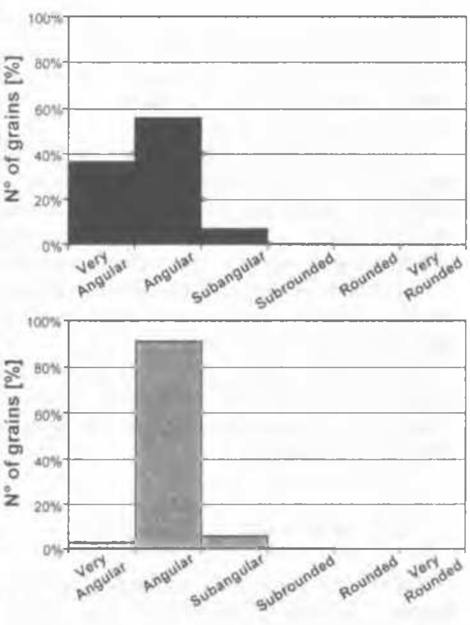

Figure 2. Angularity of the grains of the two soils used in the damage installation tests

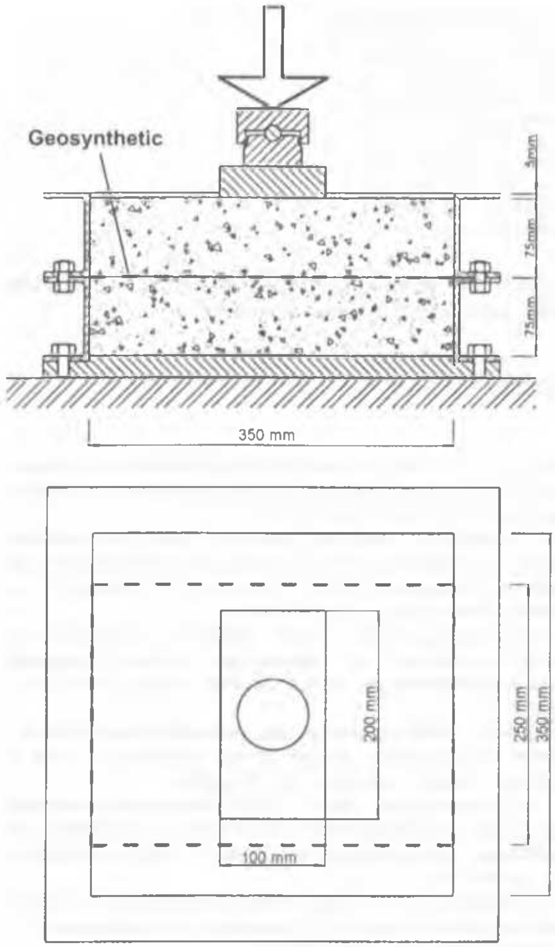

Figure 3. Scheme of the laboratory test apparatus (ENV ISO 10722-1). Top: cross section view, below: plan view.

4 FULL SCALE FIELD TESTS

The field tests were realised in an area of 2 m x 12 m. The size of each installed geosynthetic sample was equal to 2 m x 2 m (see Figure 4). The compaction plant used for the tests was a Dynapac CC21 smooth tandem vibratory roller, with total mass of 6760 kg and mean mass per unit width, for each roller, of 2330 kg/m. The vibration system applies a 71 kN centrifuge force with a frequency of 48 Hz and a 0.7 mm vibration amplitude.

The layers were placed with a small wheeled front loader, with four 0.25 m width wheels, of total mass of 2200 kg and the thickness of the layers were checked at every step of construction. Trafficking of the uncompacted layers was permitted only when the final uncompacted thickness of the layers were achieved.

Compaction was carried out with eight passes of the tandem roller (16 passes of one roller) and the average level of compaction achieved was 102% of the standard Proctor maximum dry density. The soil was placed at its natural moisture content of 4÷5 per cent, while its optimum was about 10 per cent. The average final thickness of the first layer was 110 mm, while the one of the second layer was 125 mm.

The geosynthetics extraction was carried out with the aid of a small tracked excavator, of total mass of approximately 1800 kg, to remove the first crust of the compacted soil and then using hand shovels, brooms and pick axes. Care was used to prevent further damage to the geosynthetics and any additional damage was marked and excluded to the successive evaluation.

5 RESULTS AND COMPARISONS

This experimental activity was designed to allow a comparison between the results of the different tests.

An average residual strength ratio for a geosynthetic subjected to installation damage could be defined as:

$$R = T_D/T_U \tag{1}$$

were: T_U = average strength of the undamaged material (kN/m)
T_D = average strength of the damaged material (kN/m).

The standard deviation σ_R of the variable R may be defined in function of the standard deviations of the variables T_D and T_U as follows:

$$\sigma_R^2 = (\sigma_D^2 + R^2\sigma_U^2)/T_U^2 \tag{2}$$

were: σ_U = standard deviation of variable T_U
σ_D = standard deviation of variable T_D

In Table 3 the average residual strength ratios and the standard deviations of the five geosynthetics tested are reported.

Also in Figure 5 a comparison of the different tests results is illustrated.

Firstly, it should be appreciated the most severe damage in the laboratory tests results using the corindon as damaging material, if compared to the results obtained using the porphyry. This is mainly related to the uniform grain-size distribution and to the extremely high angularity of corindon grains.

The same laboratory procedure, performed with the porphyritic quarry soil, cause less damage than the damage caused by corindon. Moreover, the laboratory-porphyry results seem to be not correlated with the laboratory-corindon ones. Therefore tests undertaken with different soils have different effects on each different geosynthetic. In fact, a different soil implies a different geometrical configuration of the contacts between the particles and therefore a very different mechanical response of the system to the external forces.

On the contrary, the results of the laboratory and field tests

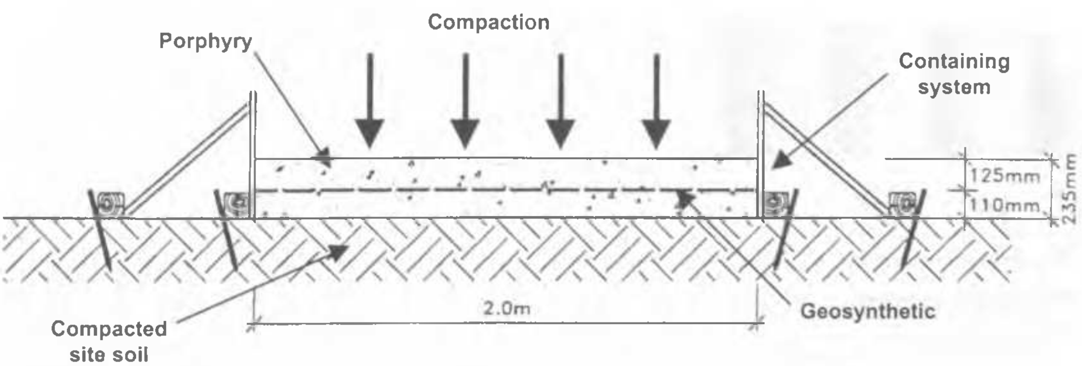

Figure 4. Cross section of the full scale field test

Table 3. Results of the installation damage tests expressed in terms of residual strength ratio R (see Equation 1)

	GTN	GTW	GGW1	GGW2	GGE
Laboratory – corindon	0,87 ± 0,12	0,24 ± 0,03	0,43 ± 0,05	0,92 ± 0,06	1,01 ± 0,05
Laboratory – porphyry	0,97 ± 0,09	0,75 ± 0,04	0,70 ± 0,07	0,98 ± 0,06	0,98 ± 0,06
Site – porphyry	0,92 ± 0,09	0,62 ± 0,05	0,71 ± 0,08	0,98 ± 0,04	1,01 ± 0,06

performed with the same porphyritic quarry soil seems much more close (see Fig. 3).

Only a different visual damage was observed: in fact, in geosynthetics subjected to the site damage tests, a certain amount of punctures, cuts and abrasions was registered.

As mentioned, installation damage strongly depends respectively on geosynthetics and soils properties, and on installation procedure and compaction. This fact clearly appears in the results of the present study.

The structure of the geosynthetic was found very important: in particular, the thicker is the geosynthetic, the lower is the damage observed, using the same soil.

Moreover, the influence of the soil is also related to the particles size distribution and to the angularity of grains. A soil with uniform distribution of the particles (i.e. corindon) is causing more damaging than a well graded soil (i.e. porphyry). Also, the effect of the angularity of the grains seems to be very important for the evaluation of installation damage safety factor.

It was observed that a high resistance to damage to the ENV ISO 10722-1 test implies a high resistance in site conditions, but the contrary is not true. This means that, if a great loss in tensile strength was registered in the ENV ISO 10722-1 test, nothing should be stated to the installation damage in real conditions.

For this reason, the ENV ISO 10722-1 test seems to be adequate for the identification of the geosynthetics that have an excellent resistance to installation damage, because it is a very severe test. Therefore, the use of the ENV ISO 10722-1 test (in its present form), to calculate the installation damage safety factor for earth reinforced structures design, seems to be not totally appropriate because it gives higher reduction factors than might be really experienced.

For the time being, field tests remain the best approach for a correct evaluation of the installation damage safety factor. However, the laboratory tests (in an improved version of the presently available experimental procedure) should also be able to give useful data on installation damage, having the advantage to be easily standardised and less expensive.

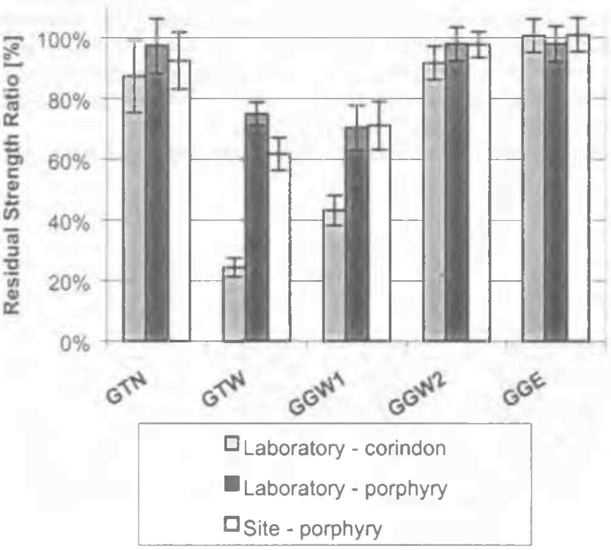

Figure 5. Comparison of the different tests results

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