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Geosynthetics for reinforcement – resistance to damage during installation

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ABSTRACT: The installation may represent the hardest stress on a geosynthetic during its service life. Field installation tests on the 1:1 scale, in combination with outdoor exposure, have been performed on 35 different geotextiles and geogrids. In addition, parts of the geosynthetics have been submitted to a laboratory simulation of the damage during installation. The findings regarding installation and compaction damages on the geosynthetics have been used to determine the corresponding reduction factor which must be taken into account for the rating of constructions reinforced with geosynthetics, in order to determine their long–term tensile strength. The study was part of a research project funded by the Swiss Federal Roads Authority.

1 INTRODUCTION

Structures reinforced with geosynthetics are expected to have a service life of 50 - 100 years, which implies that the corresponding reinforcement will last accordingly. Besides strength and elongation properties (tensile strength, elongation, tensile creep–rupture and tensile creep behaviour), mainly installation survivability and resistance against environmental influences are relevant regarding geosynthetics for reinforcement. The required functional tensile strength "z" for geosynthetics is much lower than the short–term tensile strength "r" (Hufenus et al. 1997):

$$z = \frac{r}{A_C \cdot A_I \cdot A_D \cdot \gamma} \qquad (1)$$

where

A_C = creep reduction factor
A_I = installation damage reduction factor
A_D = durability reduction factor
γ = partial factor of safety

Additional reduction factors have to be introduced for loss of strength due to seams and connections or dynamic influences where applicable.

In most conventional applications, geosynthetics are exposed to the highest mechanical stress during construction. This paper focuses on the resistance of geosynthetics for reinforcement to damage during installation. There is a considerable number of previous studies dealing with this topic. They have shown that, besides the geosynthetic, the level of damage depends on the weight, type and number of passes of the construction and compaction equipment (Watts & Brady 1994), the graduation and angularity of the backfill (Federal Highway Administration 2000) and the lift thickness (Richardson 1998).

Geosynthetic survivability criteria traditionally have applied to the placement of the material over a soft subgrade for separation and stabilization applications. Care must be taken to differentiate such stone/subgrade criteria from the stone/stone criteria developed for reinforced constructions (Richardson 1998). A European prestandard (ENV ISO 10722–1 1998) for simulating damage during installation exists and it shows satisfying correlation (Cancelli & Montanelli 2000).

The aim of the presented study was to find installation damage reduction factors for most relevant types of reinforcing products. The compaction equipment used was comparatively light, thus representing standard installation practice for reinforced constructions in Switzerland (similar tests were performed by Sprague et al. 1999 on PET geowovens and geogrids). The scope covered extensive field installation tests, comparisons to laboratory simulations with different soils and examination of the construction influence on different geosynthetic properties.

2 EXPERIMENTAL

To determine the influence of installation damages, installation tests with geosynthetics have been performed in the summer of 2000, at a 1:1 scale (Fig. 1). Various geotextiles and geogrids have been submitted to the tests (Flum et al. 2001):

A extruded biaxial PP grids
B extruded uniaxial HDPE grids
C PVC coated woven PET grids
D grids made with welded PET flat ribs
E PP slit tape wovens
F fabrics with PET warp / warp knitted PET
G PET grids knitted on a PP nonwoven
H PP nonwovens reinforced with PET filament yarn
I wovens for filtration
J nonwovens for separation and filtration

Figure 2. Field installation test.

In all, 35 different products have been installed in sand (0 ... 4 mm), rounded gravel (0 ... 60 mm) and angular crushed stone (0 ... 22 mm).

The course of the field test is outlined in Figure 2. Well compacted gravel (crushed stone) constituted the subgrade. A wire net was placed on the levelled subgrade and covered loosely with 0.12 m fill material. Geosynthetic samples fastened to the net were laid flat and covered with a further 0.23 m fill material.

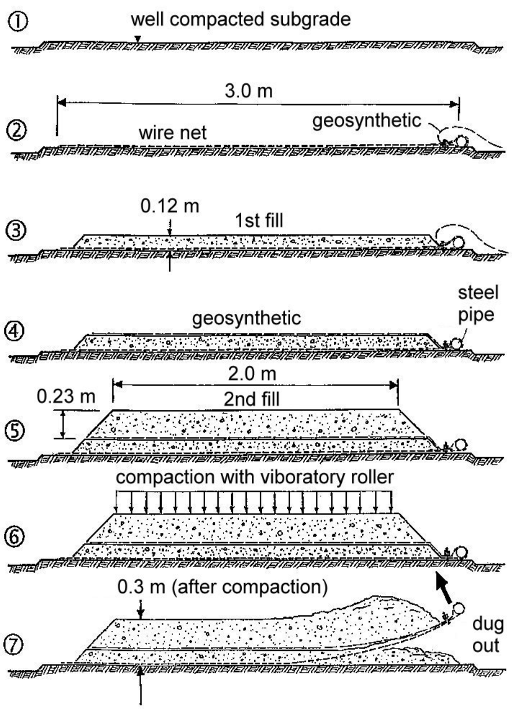

Figure 2. Course of the field installation test.

The dynamic compaction occurred with a vibratory tandem roller with 1025 kg static load and a width of 0.89 m, according to the usual requirements for reinforced fill construction (Fig. 3). After compaction (0.3 m overall compacted lift thickness) and control measuring, the geosynthetic samples have been dug out with caution. The wire net allowed the geosynthetics to be dug out simply, rationally and still gently.

Figure 3. Compaction with vibratory roller.

The soil analysis included controls of the compaction on site and the determination of fill material properties in the laboratory (gradiation curves see Figure 4). To check the compaction, the decrease of the lift thickness was measured after every pass of the roller. The compaction was stopped when the thickness did not change by more than 2 mm. This corresponded to about 95 % modified proctor density. To assess the installation damage, the geosynthetics dug out have been tested for their short–term tensile strength following EN ISO 10319 1996.

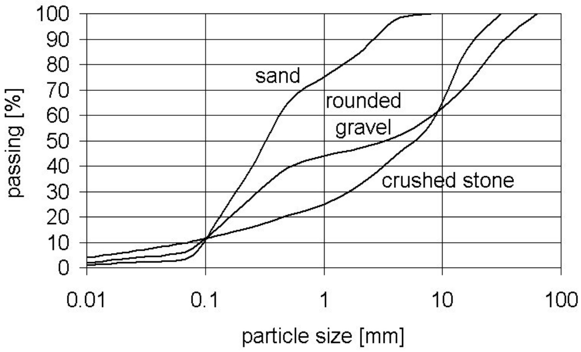

Figure 4. Particle size distribution of fill.

Part of the analysed geosynthetics were submitted to a laboratory simulation of the damage during installation (ENV ISO 10722–1 1998), in which a geosynthetic is placed between two ground layers (Fig. 5) and exposed to the dynamic load of a 100 x 200 mm plate (sinusoidal pressure between 5 and 900 kPa). An angular, sintered corundum (grain diameter 5 ... 10 mm) is used as soil material in the standard test. To allow a more precise forecast of the behaviour in practice, the soil materials of the field test were used. The retained tensile strength has been determined and compared with the results of the field installation tests.

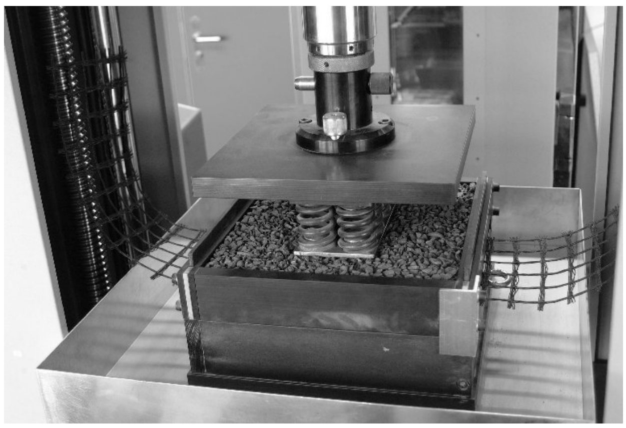

Figure 5. Laboratory simulation of installation damage.

To test the installation resistance of the coating of PET fabrics wrapped with PVC, corresponding samples of the field installation trial have been exposed to the impact of hydrolysis (immersion test following SN 640550 (1996): 15 days at 25 ± 1 °C in 2.5 g/l calcium hydroxide $Ca(OH)_2$, pH 12.5), before and after the installation between crushed stone.

3 RESULTS AND DISCUSSION

A correct calculation and selection of the geosynthetic will allow installation damages to be avoided. In general, the minimum mechanical requirements must be defined in order to prevent the geosynthetic from being damaged by installation to a point where it cannot serve its purposes any more.

Based on literature results of construction damage for a wide range of geosynthetic reinforcements, the Federal Highway Administration has proposed the installation damage reduction factors in Table 1. In this connection, the sand of the field test has to be rated as type 2 backfill, the rounded gravel and crushed stone as type 1.

Table 1. FHWA installation damage reduction factors (Federal Highway Administration 2000).

geosynthetic	type 1 backfill size < 102 mm D50 ≈ 30 mm	type 2 backfill size < 20 mm D50 ≈ 0.7 mm
uniaxial HDPE grids	1.20 ... 1.45	1.10 ... 1.20
biaxial PP grids	1.20 ... 1.45	1.10 ... 1.20
PVC coated PET grids	1.30 .. 1.85	1.10 ... 1.30
acrylic coated PET grids	1.30 .. 2.05	1.20 ... 1.40
PP & PET wovens	1.40 ... 2.20	1.10 ... 1.40
PP & PET nonwovens	1.40 ... 2.50	1.10 ... 1.40
PP slit tape wovens	1.60 ... 3.00	1.10 ... 2.00

A summary of the results of the tensile tests is presented in table 2. From the comparison of the tensile strength before and after the installation, a statement about the degree of damage on single geosynthetics can be made which depends on the bedding material used. It allows the reduction factor due to installation and compaction A_I (Equation 1) to be defined.

Table 2. Mean longitudinal tensile strength [kN/m].

geosynthetic type	prestine	sand	rounded gravel	crushed stone
extruded biaxial PP grids	24.2	21.9	22.9	21.0
	35.8	29.8	31.7	32.6
multilayer biaxial PP grid	7.2	6.8	7.2	7.4
extruded uniaxial HDPE grids	66.2	65.5	64.0	63.4
	63.8	58.1	59.7	59.0
PVC coated woven PET grids	51.7	46.9	46.8	49.0
	160.4	145.2	156.4	142.3
	38.3	36.2	29.0	24.6
grids made with welded PET flat ribs	64.9	57.7	56.4	57.0
	39.4	39.3	38.9	39.0
	40.8	42.7	44.2	46.9
PP slit tape wovens	116.6	115.5	110.3	114.7
	77.3	76.4	76.7	71.0
	44.8	44.3	41.2	35.2
fabrics with PET warp and PA weft	126.8	107.5	96.8	94.1
	386.8	361.2	348.5	314.5
	994.6	887.5	916.0	940.2
warp knitted PET	423.8	372.4	367.2	311.4
PET grids knitted on a PP nonwoven	87.7	67.0	60.4	60.5
	86.8	69.2	55.9	58.2
PP nonwovens reinforced with PET filament yarn	46.9	41.8	41.7	39.5
	97.9	85.4	81.0	74.7
PET nonwoven reinforced with coated aramid grid	48.5	46.5	45.0	38.6
PP nonwovens	92.8	81.7	78.8	67.8
	59.6	54.4	56.2	43.7
	27.9	27.6	28.4	22.5
	18.7	18.8	19.0	18.7
	13.7	15.8	12.4	12.5
	13.7	14.2	14.0	12.1
	8.2	6.8	8.6	6.0
	13.6	10.9	13.6	11.9
	10.0	11.7	15.1	11.3
PP/PE nonwoven	15.0	14.8	16.0	13.4
PE monofil/PP tape woven	15.9	16.8	16.0	8.1
coated fibreglass grid	29.3	16.0	0.0	0.0

Figure 6 illustrates the loss of short–term strength due to installation damage depending on the filling materials sand, gravel and crushed stone. The lower ranges of the retained strength are mainly related to geotextiles which are used for separating and filtering functions, but usually not for reinforcement.

The stress on the geosynthetic is different between fine–grained materials like sand and coarse–grained fill materials. The maximum grain size, the graduation and the geometry of the soil particles (rounded/angular) have an essential influence on the damage caused. The retained strength depends also on the polymer type used and on their varied processing into wovens, nonwovens, grids or composites.

If the backfill material contains coarse components, the geosynthetics can be exposed, during compaction, to more stress due to local pressures, and that in addition to the general extension lengthwise and crosswise. In certain points, they might be overstretched or even perforated. Rough components (like crushed stone) are more likely to damage the geosynthetic with concentrated single–force actions over the edges rather than smooth components with a wider distribution of load.

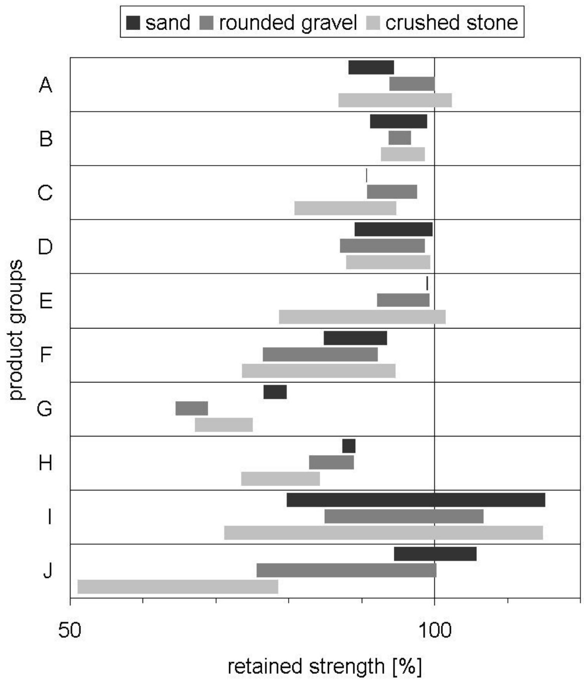

Figure 6. Loss of tensile strength due to installation.

The results of the laboratory simulation of installation damage show a considerably good correlation with the field test (Fig. 7).

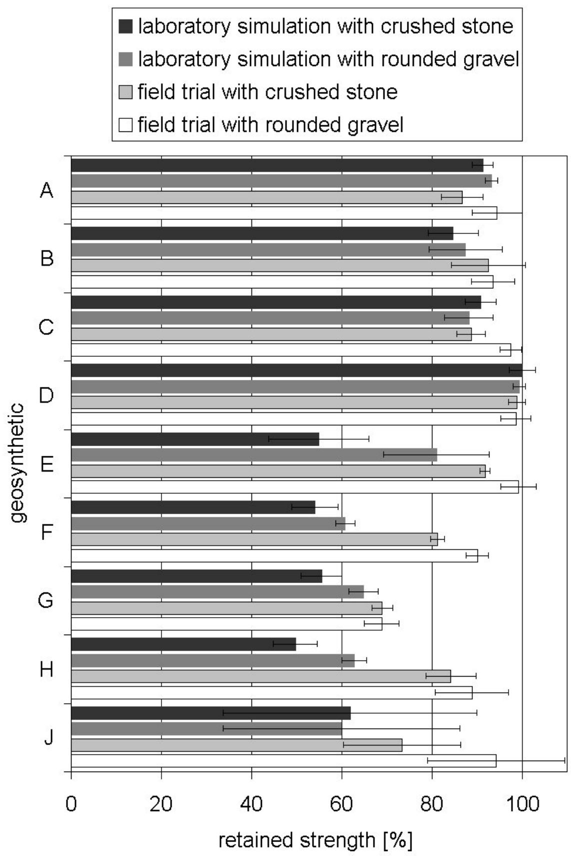

Figure 7. Comparing field and laboratory (ENV ISO 10722-1 1998) tests.

The wovens and nonwovens seem to be more susceptible to damage in the laboratory than in the real site situation. That might be explained by the sensitivity of these products to abrasion strain, which is more likely to occur in the laboratory test. Fine, angular soil particles can get into the geotextile structure and scratch filaments or tape yarns (Bräu 2001).

Embedded particles reduce the mobility of nonwoven fibres (stiffening). That alters the mechanical properties of the geotextile. Especially the increase of elongation at break and tensile creep will be limited. With the embedded ground particles, the nonwoven geotextiles tested for installation damage lost up to 50 % of their elongation capacity, but their maximum tensile strength was hardly reduced. By subsequent washing of the nonwovens the original maximum elongation strain has been recovered (Fig. 8).

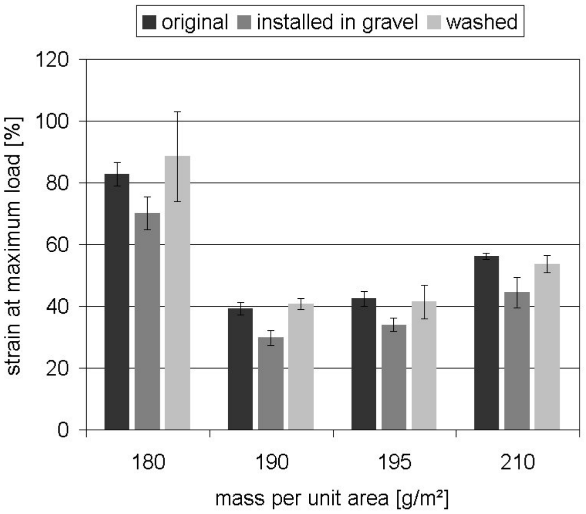

Figure 8. Change in elongation at break due to embedded ground particles in 4 nonwoven geotextiles.

The hydrolysis occurring under the influence of water can represent a possible risk for installed geosynthetics. PA and PET are vulnerable to hydrolysis while polyolefines PP and PE resist to it. Therefore PET fabrics are frequently wrapped into PVC for their protection (and for their mechanical stabilization). The coating must be solid enough to resist installation stress without damage. The immersion of the installed and extracted PVC coated PET fabrics to calcium hydroxide has shown that the coating has not lost its protective function against hydrolysis as a consequence of the installation (Fig. 9).

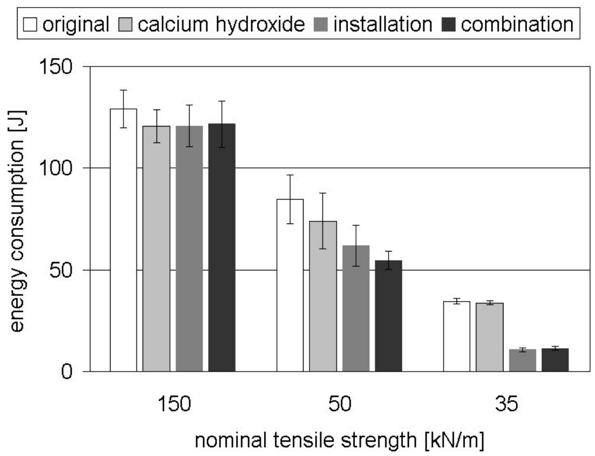

Figure 9. Resistance to hydrolysis of 3 PVC coated PET grids before and after installation in crushed stone.

4 CONCLUSIONS

The findings regarding installation and compaction damages on the geosynthetics tested are used to determine the corresponding reduction factor, which must be taken into account for the rating of constructions reinforced with geosynthetics, in order to determine their long–term tensile strength. Compared with the recommendations of the Federal Highway Administration (Tab. 1), the test results allow lower reduction factors due to installation damage (Tab. 3). This is primary due to the compaction energy in reinforced fill constructions which is considerably lower in Switzerland than in other countries.

Table 3. Swiss proposal for the reduction factor A_I (Equation 1).

	fine–grained soil	rounded coarse–grained soil	angular coarse–grained soil
uniaxial HDPE grids	1.0 ... 1.1	1.1 ... 1.2	1.2 ... 1.4
biaxial PP grids	1.0 ... 1.2	1.1 ... 1.3	1.2 ... 1.5
PET flat rib grids	1.0 ... 1.1	1.0 ... 1.1	1.0 ... 1.1
coated PET grids	1.0 ... 1.1	1.1 ... 1.2	1.2 ... 1.3
PP & PET wovens	1.0 ...1.2	1.1 ... 1.4	1.2 ... 1.5
PP & PET nonwovens	1.0 ... 1.1	1.2 ... 1.4	1.3 ... 1.5
PP slit tape wovens	1.0 ... 1.2	1.1 ... 1.3	1.2 ... 1.4

The data in Table 3 is valid for a subgrade of medium to high load–bearing capacity, 1 ... 3 tons compaction plant and 0.2 ... 0.4 m lift thickness, which can be assumed in reinforced fill constructions. The results of the wovens and nonwovens for separation and filtration where not taken into consideration, as they are not intended for reinforcement applications. They were only included in the test series to prove the ability of the method to separate unsuitable from appropriate geosynthetics.

Further research dealing with the comparision of laboratory and real site installation tests will be undertaken. The results of this study will be integrated into a Swiss standard prescribing requirements for geosynthetics used as reinforcements.

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