DAMAGE DURING INSTALLATION LABORATORY TEST. INFLUENCE OF THE TYPE OF GRANULAR MATERIAL

António Miguel Paula
Research Assistant, Polytechnic School of Bragança, Portugal

Margarida Pinho-Lopes
Research Assistant, Department of Civil Engineering, University of Aveiro, Portugal

Maria de Lurdes Lopes
Associate Professor, Department of Civil Engineering, University of Porto, Portugal

ABSTRACT: Damage during installation of geosynthetics has been subjected to extended studies, and became standardised with the introduction of ENV ISO 10722-1 in form of an index test for laboratory simulated installation damage. These tests should be carried out using a synthetic granular material, however, some authors have discussed the legitimacy of using such material. To contribute to the evaluation of the effect of the granular material used in laboratory damage tests, a research program was established. The test program consisted in performing damage during installation tests on the three geosynthetics using three different methods, over a minimum of five specimens per geosynthetic. To characterise the effect of the damage induced, tensile tests were carried out on both intact and damaged specimens. The three methods used for the DDI tests referred differ in the material used in contact with the geosynthetics: synthetic aggregate (ENV ISO 10722-1), granite aggregate and limestone aggregate. The results obtained after tensile tests (EN ISO 10319) are presented and discussed. The corresponding partial safety factors for damaged during installation of the geosynthetics studied are derived. The main conclusions of this study are presented.

1 INTRODUCTION

Among the agents capable of affecting the behaviour of geosynthetics the damage that can occur during their installation can be significant and has been deeply studied. In fact, during the last years, damage during installation has been subjected to extended studies. It became standardised with the introduction of ENV ISO 10722-1 in form of an index test for laboratory simulated installation damage.

According with this standard each sample of geosynthetic is placed between two layers of a synthetic granular material and subjected to dynamic loading. The material is then removed and tested to assess the degree of damage.

As mentioned, these tests should be carried out using a synthetic granular material, however, some authors have discussed the legitimacy of using such material. To contribute to the evaluation of the effect of the granular material used in laboratory damage tests a research program was established.

Simultaneously, field trials to induce damaged during installation of geosynthetics should be carried out, to compare with the results of the laboratory tests. Some results obtained in other research project, complementary to this one, have been published: PINHO-LOPES *et al.* (2000), PINHO-LOPES *et al.* (2002) and PINHO-LOPES *et al.* (2004).

2 TEST PROGRAM

The test program established consisted in performing damage during installation (DDI) tests on the three geosynthetics using three different methods, over a minimum of five specimens per geosynthetic, and on carrying out tensile tests, on both intact and damaged specimens to characterise the effect of the damage induced.

The three methods referred differ in the material used in contact with the geosynthetics. Results obtained with the conventional DDI laboratory test (using the synthetic granular material), as described in the standard, are compared with the ones obtained with two natural materials.

In total, the results presented correspond to 45 DDI tests and 60 tensile tests, a total of 105 tests carried out.

3 GEOSYNTHETICS

The results presented refer to three geosynthetics (Table 1):

- a woven polypropylene geotextile (Material 1);
- a biaxial woven polyester geogrid (Material 2);
- a biaxial extruded high density polyethylene geogrid (Material 3).

To allow the results to be compared, the geosynthetics were chosen with similar values for their nominal tensile strength: ranging from 40 to 65 kN/m.

Table 1 Geosynthetics studied.

Material		Nominal strength (kN/m) MD / CMD
1	Woven polypropylene geotextile	65/65
2	Woven polyester geogrid	55/55
3	Extruded high density polyethylene geogrid	40/40

MD – machine direction; CMD – Cross machine direction.

4 DDI LABORATORY TESTS

4.1 *Equipment*

The equipment used to carry out damage during installation laboratory tests (Figure 1) was developed according with ENV ISO 10722-1 (Geotextiles and geotextiles-related products – Procedure for simulating damage during installation – Part 1: Installation in granular materials).

The test equipment consists in a frame to apply dynamic loads. The container is divided in a lower and an upper box, with 0.15 m of total height, and dimensions of 0.30 m x 0.30 m, each. The load plate, 0.10 m long 0.20 m wide and 0.015 m high is placed on the box centre.

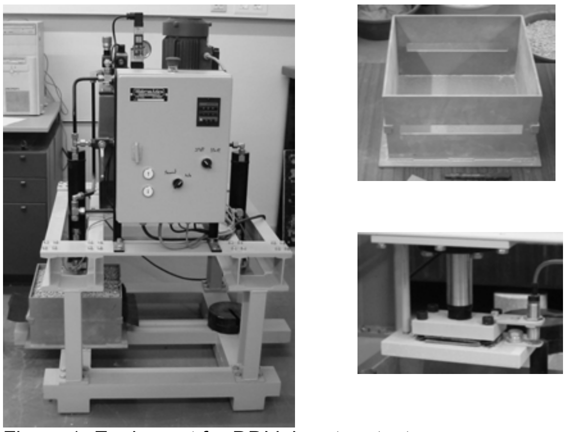


Figure 1 Equipment for DDI laboratory tests.

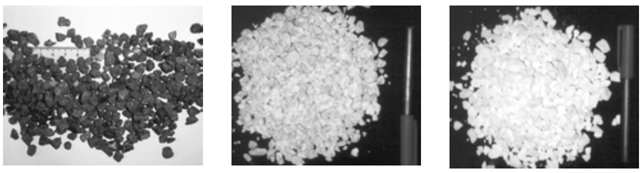
4.2 *Granular materials*

As mentioned before, three granular materials were used in contact with the geosynthetics (Figure 2).

According with ENV ISO 10722-1, the granular material to be used is a synthetic granular material – sintered aluminium oxide. In this paper this material is referred as Aggregate 1. The grading of the synthetic material ranges from 5mm to 10 mm and the Los Angeles (LA) coefficient is 16.

According with ENV ISO 10722-1, the aggregate must be sieved on a 5 mm aperture sieve after every five uses and any material passing the sieve must be discarded. After 20 uses the material must be completely discarded.

The modified tests were carried out using natural aggregates: Aggregate 2, from granite and Aggregate 3, from limestone (Figure 3).



a) b) c)

Figure 2 Granular materials used in the DDI laboratory tests: a) Aggregate 1, synthetic; b) Aggregate 2, granite; and c) Aggregate 3, limestone.

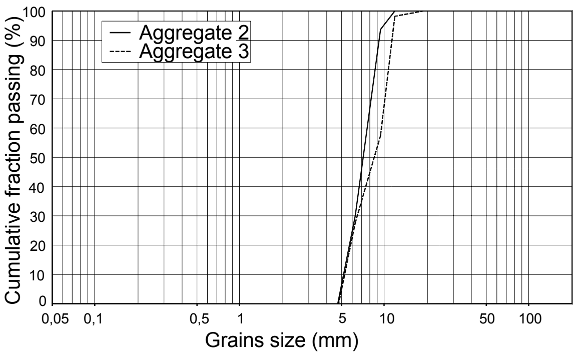


Figure 3 Particle size distributions, Aggregate 2 and Aggregate 3.

The choice of the granular materials was made in order to achieve materials with uniform particle size distributions and the range of particle diameters similar to the one of the synthetic granular material. The particle diameter ranges, for Aggregate 2 from 4.75 to 12.5 mm and for Aggregate 3 from 4.75 to 19 mm. The Los Angeles (LA) coefficient is of 28 and 19 for Aggregate 2 and Aggregate 3, respectively.

Analogue to ENV ISO 10722-1, Aggregate 2 and 3 were sieved on a 5 mm aperture sieve after every five uses and any material passing the sieve was discarded.

4.3 *Test method*

The lower box is filled with two compacted layers of the granular material. These layers are compacted using an appropriate flat plate: 300 mm x 300 mm, during 60 s with a pressure of 200 kPa.

On the top of the lower box the surface must be levelled and the specimen of geosynthetic is placed in the box centre; the free edges must be equally spaced from each side of the container. The free ends must be protected from any damage occurring during the test, for example by being rolled up. The specimen must be smooth, free from wrinkles but not pretensioned.

The upper box is then assembled and filled with loose aggregate, with a total height of 75 mm of aggregate over the geosynthetic. The loading plate (100mm x 200mm x 15mm) is placed on the box centre and dynamic loading is applied. The loading is cyclic from 5 kPa to 900 kPa at a frequency of 1 Hz for 200 loading cycles.

At the end of the test the aggregate is removed carefully, so that there is no additional damage on the geosynthetic specimen that will be tested to access the change in a particular property.

5 TENSILE TESTS

5.1 *Test method*

According with ENV ISO 10722-1, to evaluate the degree of damage induced, a measurement of the damage is made by subjecting undamaged and damaged specimens to the same reference test, usually the EN ISO 10319. Therefore, the tensile tests were carried out using the procedures described on EN ISO 10319.

The specimens, 200 mm wide, are fixed in the jaws of the equipment, allowing a distance between jaws of at least 100mm. The test consists in applying increasing tensile forces to the specimen at a strain rate of 20 % per minute, until the specimen ruptures. A minimum of five specimens for each type of sample was tested.

5.2 *Test results*

The results are presented in terms of the tensile strength of the materials and the corresponding coefficient of variation (Table 2).

The results of the tensile tests carried out to characterise the effect of damage during installation of geosynthetics on their short-term mechanical behaviour are also presented in terms of the residual tensile strength of the different types of specimens (Table 3). The residual strength ($S_{residual}$) is defined by the following expression:

$$S_{residual} = \frac{S_{damaged}}{S_{intact}} \times 100 \text{ (in \%)} \quad (3)$$

Where $S_{damaged}$ is the tensile strength of the damaged material and S_{intact} is the tensile strength of the corresponding reference samples.

Table 2 Results obtained from the tensile tests – tensile strength (S) and coefficient of variation (CV).

	Quantity	Intact	Aggregate 1	Aggregate 2	Aggregate 3
1	S (kN/m)	77.50	33.45	44.63	51.88
	CV (%)	1.78	11.77	4.20	3.80
2	S (kN/m)	66.05	51.11	53.35	59.43
	CV (%)	5.66	12.19	7.40	2.70
3	S (kN/m)	46.99	48.37	43.67	45.51
	CV (%)	0.81	1.32	2.90	2.00

Table 3 Results obtained from the tensile tests – residual strength.

Material	Aggregate 1	Aggregate 2	Aggregate 3
1	43.2	57.6	66.9
2	77.4	88.7	98.8
3	102.9	92.9	96.8

There is some scatter in the results obtained. The residual strength for Material 1 ranges between 43% and 67%; for Material 2, the extreme values for the residual strength are 77% and 99%; while for Material 3, there is little effect of the DDI induced, with residual strengths over 92% for all the aggregates considered.

The coefficient of variation is under 6% for the undamaged samples of geosynthetics, and for the damaged materials ranges between 1.3% and 12.2%. The highest values of the coefficient of variation correspond to the woven materials, geotextile and geogrid, in contact with the synthetic aggregate: about 12%. It is curious to note that the highest values of the coefficient of variation are associated with the lowest values for the residual strength. Though the specimens were damaged and tested (for tensile strength) under the same conditions, there is some scatter of the results obtained.

The effects of the DDI induced on the geosynthetics depend on several factors. Among these are the geosynthetic structure, strength and the aggregate used. In this study, the three geosynthetics studied have different structures and similar values for their nominal tensile strength. On other hand, the aggregates used are different, especially as far as their petrography is concerned. Therefore, the main reasons for the different results obtained have to be related with the geosynthetics structure and with the characteristics of the aggregates, namely petrography.

5.3 *Discussion of the test results*

Analysing the values of the residual strength, for Material 1 (woven geotextile), the effect of the damage during installation is evident. The values of the residual strength are always lower than 70%. In particular, carrying out the laboratory damage tests with the natural aggregates leads to higher values for the residual strength. The highest value of the residual strength corresponds to Aggregate 3, the limestone material, while the lowest valued for the residual strength refers to Aggregate 1.

For this geosynthetic, when using Aggregate 2 instead of Aggregate 1 there is an increase of 33% of the residual strength of the geosynthetic; when using Aggregate 3 instead of Aggregate 1 there is an increase of 55% of the residual strength.

When comparing the results obtained for Material 1 with the two natural aggregates (Aggregates 2 and 3), it is possible to conclude that Aggregate 2 is the most aggressive to this geosynthetic. For Aggregate 2 the value for the residual strength is lower than for Aggregate 3.

For Material 2, similar conclusions can be observed: when using Aggregate 2 instead of Aggregate 1 there is an increase of 15% of the residual strength, and when using Aggregate 3 instead of the Aggregate 1 there is an increase of 28% of the referred quantity. Once again, when comparing the results obtained with the natural aggregates Aggregate 3 leads to a higher residual strength than Aggregate 2.

As far as Material 3 is concerned, the effect of DDI after laboratory tests is not as evident. In fact, the residual strength for this material is always over 92%.

In this case the residual strength after damaged with the synthetic aggregate is the highest and even slightly higher than 100%. This means that the average tensile strength of Material 3 after laboratory damage during installation with the synthetic aggregate is 3% higher than the same quantity for the intact material. However, as this difference is of the same order of the coefficient of variation obtained, it is possible to say that the strength of the material is similar to the one of the intact sample. One possible explanation for the value of the residual strength after damage can be the possibility of occurring a re-orientation of the fibbers during the damage during installation laboratory test.

For Material 3, when considering Aggregate 2 instead of the Aggregate 1 there is a reduction of 10% of the residual strength, and when Aggregate 3 is used (instead of the Aggregate 1) the reduction is of 6%.

Due to its petrography, when subject to the cyclic load in the DDI test, Aggregate 2 (granite material) breaks into sharp elements that will induce cuts and incisions on the geosynthetics. On other hand, Aggregate 3 (limestone aggregate) breaks into smaller particles and the resulting material has rounded edges. In the case of the synthetic aggregate, the actions in the DDI tests induce sharp and cutting edges, which results in a more aggressive material for the geosynthetics.

In the ENV ISO 10722-1, it is referred that, when analysing the hardness of the aggregate, the LA abrasion resistance, determined according with prEN 1072-2, should be used.

The values of the LA coefficient (LA_i) for the granular materials are 16, 28 and 19 for Aggregate 1, Aggregate 2 and Aggregate 3, respectively. If the LA coefficient ($LA_1 < LA_3 < LA_2$) was a good indicator of the "aggressiveness" of the aggregate, as far as the DDI laboratory test is concerned, the residual strength (S_i) associated with these materials should be related in proportional way: S_1; S_3; S_2. However, the results show that, for both Materials 1 and 2: $S_1 < S_2 < S_3$. For Material 3, apart from the result obtained with Aggregate 1, similar relation is observed: $S_2 < S_3$.

In fact, the LA coefficient of the granular materials gives an indication of the fragmentation of the material and of the percentage of material (within a sample) that fragments under specified conditions. However, the type of particles (sharp or rounded) resulting from that fragmentation is likely to have more meaning to evaluate the DDI effects. Probably it would be more helpful to evaluate the effect of a particular aggregate considered in DDI laboratory tests using other criteria, other than the LA coefficient.

With the exception for Material 3, it was verified that the materials in contact with the synthetic aggregate present lower values for the residual strength than with the natural soils. Therefore it is possible to conclude that, for those cases, the synthetic aggregate is the most aggressive.

As far as the natural aggregates are concerned, for the three geosynthetics considered, the results presented also show higher values for the residual strength associated with Aggregate 3. Therefore, this is the less aggressive aggregate for the geosynthetics studied.

5.4 *Partial safety factors for DDI*

After the damage during installation laboratory tests it is possible to define values for the corresponding partial safety factors to be used in the design of the geosynthetics.

The values of these factors are obtained from Equation 2,and presented in Table 4.

$$A_{DDII} = \frac{S_{intact}}{S_{damaged}} \quad (3)$$

Table 4 Derived partial safety factors for DDI.

Material	Aggregate 1	Aggregate 2	Aggregate 3
1	2.32	1.74	1.49
2	1.29	1.24	1.11
3	1.00	1.08	1.03

In the case of Material 3, damaged with the synthetic granular material (Aggregate 1), the value of the corresponding partial safety factor is 1.0 (as this is the minimum value for such factors).

As the standard (ENV ISO 10722-1) refers the use of the synthetic granular material, when analysing the values of the partial safety factors obtained, the values referring to Aggregate 1 will be considered as reference.

It is clear that the values obtained with the natural aggregates are less conservative, with the exception of Material 3 (where the effect of DDI has little significance).

Comparisons with results obtained from field trials of damage during installation of geosynthetics have to be done, to check which results lead to a better prediction of the partial safety factors, for the conditions used in those field trials.

6 CONCLUSION

In this work, three different materials were subjected to laboratory tests to induce damage during installation of geosynthetics.

Three granular materials (one synthetic and two granular) were used. Tensile tests were carried out to assess the level of damage induced.

The residual strength of the different materials was determined and the partial safety factors for damage during installation of these materials under the conditions considered were derived.

As main conclusions that can be stated:

- For Material 1 the residual strength ranges between 43% and 67%;
- For Material 2 the extreme values for the residual strength are 77% and 99%;
- Material 3 presents little effect of the DDI induced, with residual strengths over 92% for all the aggregates considered;
- The adequacy of considering the LA coefficient to assess the “aggressiveness” of the aggregate used in the DDI laboratory tests is discussed;
- The LA coefficient of the granular materials gives an indication of the fragmentation and of the percentage of material (within a sample) that fragments under specified conditions;
- The need of using another parameter, capable of describing the type of particles (sharp or rounded) resulting from that fragmentation, is pointed out;
- For the partial safety factors, and using the values for the synthetic aggregate as reference, it was observed that the values obtained with the natural aggregates are less conservative, with the exception of Material 3.

7 REFERENCE

ENV 10722-1, 1997: Geotextiles and geotextile-related products – Procedure for simulating damage during installation – Part 1: Installation in granular materials.

EN ISO 10319, 1996: Geotexiles – Wide-width tensile test.

Pinho Lopes, M., Recker, C., Müller-Rochholz, J., Lopes, M.L., 2000: Installation damage and creep of geosynthetics and their combined effect – experimental analysis, Proceedings of Eurogeo 2000, Vol. 2, pp. 895-897, Bologna, Italy.

Pinho Lopes, M., Recker, C., Lopes, M.L., Müller-Rochholz, J., 2002: Experimental analysis of the combined effect of installation damage and creep of geosynthetics – new results, Proceedings of 7th International Conference on Geosynthetics, - Vol.4, pp. 1539-1544, Nice, France.

Pinho Lopes, M., Recker, C., Lopes, M.L., Müller-Rochholz, J., 2004: damage during installation and creep of geosynthetics. New test data, Eurogeo 3, Munich, Germany.

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