Deformations and Damage of Non-Woven Geotextiles in Road Construction

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ABSTRACT: SINTEF Civil and Environmental Engineering have performed a research project in two phases on non-woven geotextiles in road constructions. The first phase was a large-scale laboratory test aimed to study the effect of non-woven geotextiles on road deformations at cyclic loading. The second phase was a field test aimed to study the resistance against damage of the geotextiles during construction. The project focused on the correspondence between properties from index tests and the observed behaviour. A clear correspondence was found between the initial tension stiffness of a geotextile and the deformation after cyclic loading. Low correlation was found between observed damage during construction and the evaluation criteria used for classification of geotextiles in Norway. To take into account these findings it is recommended a revision of the evaluation criteria. It is also proposed a survivability criterion based on a combination of deformation energy and stress-strain properties to cover the construction and lifetime requirements.

KEYWORDS: Geotechnical Engineering, soil, geotextile, damage.

1 INTRODUCTION

The criteria for evaluating strength and deformation properties for non-woven geotextiles used in separation and filtration in roads have been discussed for more than twenty years. The first systems for evaluation and classification of geotextiles for separation and filtration in roads were introduced by the Norwegian Road Research Laboratory (NRRL), (Alfheim and Sørli, 1977). Later several systems have been introduced but generally the classification requirements are mainly empirically based, and to some extent dependent on local conditions and experiences (Forschungsgesellscaft für straβen- und Verkehrswesen, 1994, Rathmayer, 1993, AASHTO, 1990). The evaluation criteria and the index test methods which are used, differ between the systems and a possible co-ordination between the systems have been discussed since their introduction.

1.1 The Norwegian classification system

Geotextiles for separation and filtration in roads are in Norway divided into four classes dependent on the type of material (maximum grain size) to be used against the geotextile:

Class 1: Generally not used
Class 2: Sand and gravel with max. diameter 50 mm
Class 3: Crushed stone with max. diameter 100 mm
Class 4: Blasted rock with max. diameter 2/3 of the layer thickness

The classification is based on an evaluation of results from the static puncture tests and the cone drop tests. The tested product will achieve points from the results in the tests referring to each criterion and the classification is then dependent on the total sum of points. For the static puncture test (CBR- test, ISO 12236:1996) the measured force and deformation are used to calculate a corresponding tension (force/mm) and strain (%). The classification criterion is based on the derived tension and strain, the maximum tension, the elongation strain at failure and the tension increase from 20 % to 70% strain (or until strain at failure if less than 70%). The average hole diameter is used as evaluation criterion for the cone drop test (Schalin 1995).

1.2 Relevant properties and test methods

There is a clear need for establishing a more fundamental understanding of the required characteristics of the geotextile to fulfil its functions (separation and filtration) in the road. The required properties must reflect the environmental loads imposed on the geotextile during the installation, construction and service lifetime. A theoretical sound correlation between the required properties and the corresponding required parameters found from index tests should be established. A combination of index tests, large scale performance tests, full scale field tests and collection of experiences from the field is believed to be the best way to establish such a correlation.

2 RESEARCH PROJECT

SINTEF Civil and Environmental Engineering have performed a research project on non-woven geotextiles in road constructions. The NRRL and has participated with observers and supervisors in the project. The project focused on the correspondence between geotextile properties found in index tests and the observed behaviour in laboratory and the field. The first project phase (SINTEF 1996) included index tests and large scale laboratory load test. This part aimed to study the effect of stress-strain properties on non-woven geotextiles on road deformations at cyclic loading. The second phase was a field test (SINTEF 1997) aiming to study the resistance against damage of the geotextiles during the construction. Non woven geotextiles with different production technology and area weight were used in the research projects.

2.1 Laboratory tests

2.1.1 Index tests

The index tests included cone drop tests, static puncture tests and wide width tensile tests. The tests were performed on virgin samples and on samples extracted after the load test. In addition the effect of thermal cycling and stress strain behaviour under frozen conditions were tested. Six different non-woven geotextiles were tested, three corresponding to class 2 and three corresponding to class 3. The geotextiles used in the laboratory tests corresponding to class 3 are listed in Table 1.

Table 1. Class 3 geotextiles used in the laboratory test.

Reference	Type of product	Nominal area weight (g/m^2)
SNP 3A	Staple fibre, needle punched, polypropylene	190
CNP 3B	Continuous filament, needle punched, polypropylene	160
CTP 3C	Continuous filament, thermally bonded, polypropylene	190

A summary of the results from the static puncture tests and the falling cone test on virgin samples for class 3 products is presented in Table 2.

Typical load displacement curves from the static puncture test are shown in Figure 2. Observe the differences in initial stiffness between the different geotextiles.

The thermal cycling had no significant effect on the results from the index test measurements.

Table 2 Results from initial index testing of the geotextiles.

Ref	Weight g/mm^2	Static Puncture test Max force, N	Displ.at max. force , mm	Falling cone Average hole diameter, mm
SNP 3A	197.8	2380	57	14
CNP 3B	171.5	2252	44	24.2
CTP 3C	190.8	1970	50.8	19.1

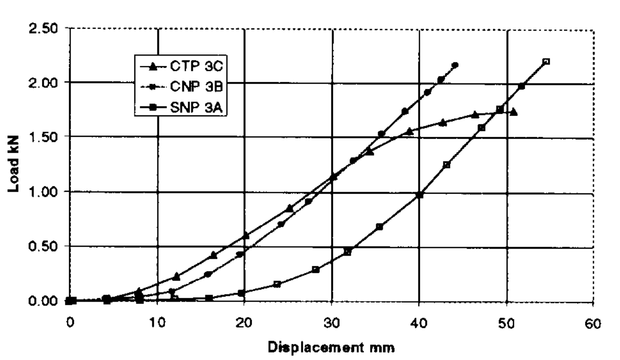

Figure 1. Typical load displacement curves for the class 3 geotextiles.

2.1.2 Large scale load test

The large scale laboratory testing was performed in a 12.5 m long and 1.8 m wide test bin filled with a 650 mm thick layer of soft clay with 2-3 kPa undrained shear strength. The geotextiles was placed on the clay and covered with 150 mm of crushed stone as shown in Figure 2. The geotextile test samples were 2 x 1.8 m. Cyclic and static load was then applied on a circular plate with diameter 250 mm on the bearing layer. The geotextiles used in the large scale laboratory test are listed in Table 1.

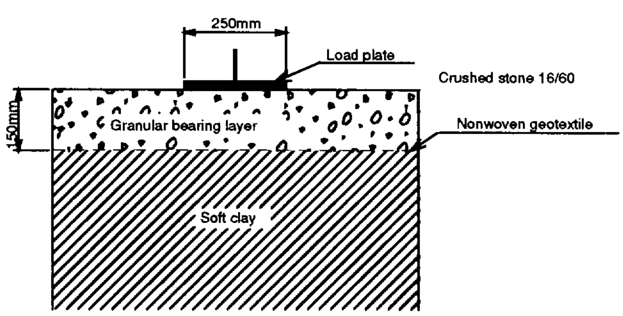

Figure 2. Bearing layer construction.

A cyclic load with frequency 1 Hz and amplitude 0-4 kN was applied on the load plate. A load of 4 kN corresponds to an average applied stress under the load plate of 81.5 kN/m^2. The gradually developing displacement on the geotextile beneath the load plate was measured during the test, the resulting deformation profiles after 1000 cycles are presented in Figure 3.

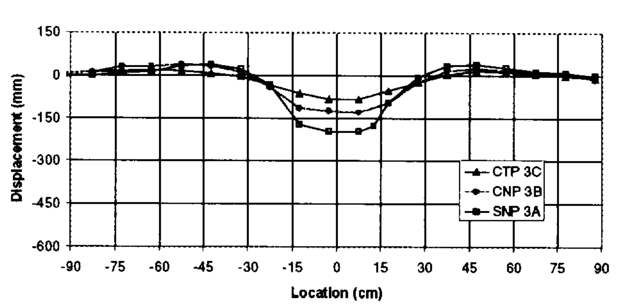

Figure 3. Measured vertical displacement profile of the geotextiles after completed load test.

2.1.3 Evaluation of results

There are considerable differences in the measured deformations and strains in the geotextile in the load test. The observed deformations correspond well with the load displacement relations, Figure 2, measured in the static puncture test. The average strain of the geotextiles was measured to be 10.3%, 4.6% and 1.4% for SNP 3A, CNP 3B and CTP 3C, respectively. Converted to displacement in the static puncture test these strains correspond 19 mm, 12 mm, and 7 mm displacement. Figure 4 shows that the load corresponding to the strain levels is approximately 0.08 kN for all the three geotextiles. In the same figure, the area under the load displacement curve, named as the deformation energy, is shaded. Note that the deformation energy based on these results is about the same for all the tested geotextiles, even with large differences in the strain level.

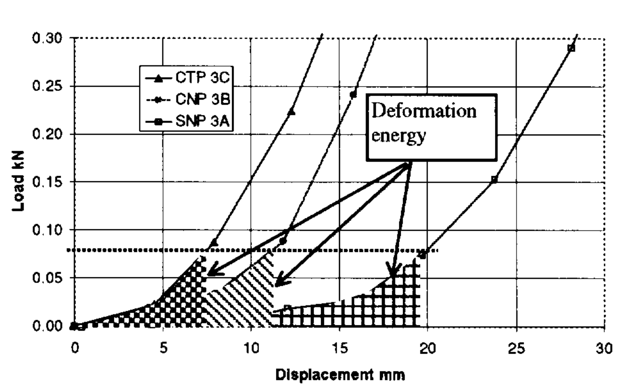

Figure 4. Force-strain relationship related to measured strain for the geotextiles in the load test

This test shows that the strain developing at a typical cyclic loading is strongly dependent of the initial stiffness. A criterion that is aimed to cover the need for remaining strength after construction should include the effect of initial stiffness.

2.2 Full scale field tests

2.2.1 Test set up

The test was performed outdoor on frozen uneven ground. The material in the ground consists of fill masses with silt, sand, clay and occasional stones. Due to rainfall just before and under the installation the upper 50-100 mm of the underground was saturated and muddy during the installation. As the temperature was decreasing during the test, this upper layer was frozen at the time of the extraction. Geotextiles used in the field test are listed in table 3.

Table 3. Geotextiles involved in the testing.

Reference	Type of product	Nominal area weight (g/m2)
CNP 4A	Continuous filament, needle punched, polypropylene	320
SNP 4B	Staple fibre, needle punched, polypropylene	330
SNP 4C	Staple fibre, needle punched, polypropylene	320
CTP 4D *)	Continuous filament, thermally bonded, polypropylene	350
SNP 4E	Staple fibre, needle punched, calendered on one side, polypropylene	300
CTP 4F **)	Continuous filament, thermally bonded, polypropylene and polyethylene	350

*) Not previously classified in class 4 in Norway
**) Tested in a separate field test

The geotextile CTP 4F was tested in a separate test together with CTP 4D that was also tested together with the other products. The results for CTP 4D are used as reference basis for comparing the results. The field test also included five geotextiles from class 2 not reported in this paper. The results from the index tests on virgin material are presented in Table 4. The load deformation relation curves from the static puncture test are shown in Figure 5.

Table 4. Results from index tests on the class 4 geotextiles.

Ref	Measured area weight g/m²	Strength increase 20 - 70% strain N/mm	Push through tension N/mm	Push through strain %	Hole diameter mm	Number of points acc. to the Norw. classif.	Corresp applic class
CNP 4A	310.7	18.94	34.32	60.86	15.90	35	3
SNP 4B	359.0	23.20	38.28	70.78	12.10	44	4
SNP 4C	314.4	17.17	26.17	87.08	10.10	44	4
CTP 4D	353.1	10.60	33.87	70.12	13.90	41	4
SNP 4E	302.3	19.13	28.44	85.46	13.10	44	4
CTP 4F	345.9	14.3	38.9	51.4	20.9	35	3

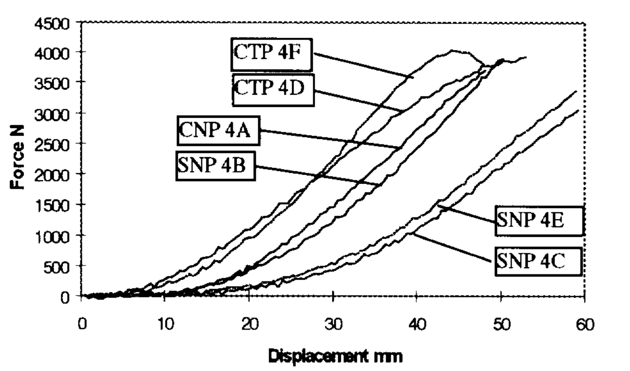

Figure 5. Measured force and displacement from the static puncture test.

The principle for the test fill is shown on Figure 6. The geotextiles were placed directly on the ground and then covered with fill material by the use of a pay loader. The covering was done sideways to ensure that each of the geotextiles was treated equally. For the class 4 material, blasted rock with a maximum diameter of 800 mm was used for the fill. The largest rock fragments were flaky shaped thus a fill height 500 mm was possible.

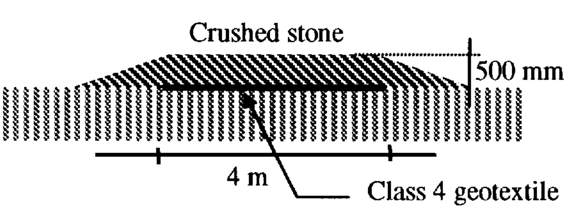

Figure 6. Principle for the test fill.

The fill material was compacted with a heavy vibrating roller with three overpasses along the centre line and on the shoulders on top of each fill. One week after the installation the fill material was removed. The top of the fill material was removed carefully with an excavator. The geotextile was then tied to the excavator and carefully lifted out.

2.2.2 Test results

The amount of damage and deformation of the geotextiles were observed during the extraction. By the visual inspection during extraction some damage in terms of holes could be seen on all the geotextiles. The degree of damage varied. The geotextiles SNP 4B and CTP 4D was less damaged than average, SNP 4C and CNP 4A average damaged while SNP 4E and CTP 4F most damaged. During the extraction it could be observed that the underground was more even under the products having a high initial stiffness compared to the others.

After extraction the samples were brought to the laboratory where the damages (number and size of holes) where counted and measured. The distribution of holes within different diameter ranges is shown in Figure 7.

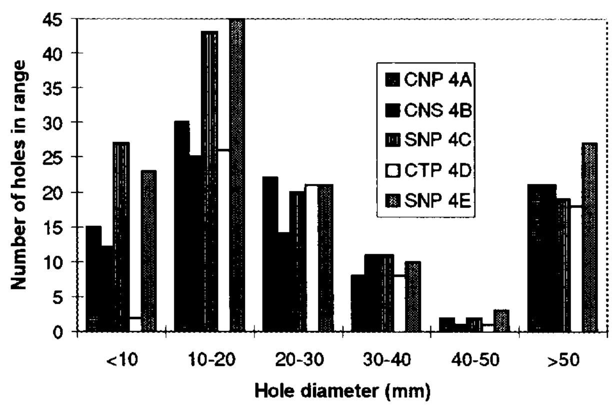

Figure 7. Distribution of holes.

2.2.3 Evaluation of results

In order to correlate the observed damage with index test results the degree of *Damage* on a geotextile is defined as the sum of the measured hole diameters. The *Resistance* *against damage* for one product can then be defined as the average damage divided by the damage on each geotextile as shown in Table 5, that is, the higher number the less damage. In the table the measured damage is normalised with respect to the average value for the five geotextiles, that is, a factor of 1.15 means 15 % less damage than the average.

Table 5. Resistance against damage.

Ref	*Damage* (Sum Of hole diameter)	*Resistance against damage* (Average damage)/(damage)
CNP 4A	2793	1.07
SNP 4B	2613	1.15
SNP 4C	3157	0.95
CTP 4D	2655	1.13
SNP 4E	3759	0.80
CTP 4F	-	0.40*)

*) Based on a scaling of the results

As CTP 4F was tested in a separate test the results can not be compared directly with the others. The additional field test with the geotextiles CTP 4D and CTP 4F used a less heavy compaction equipment resulting in considerably less damage on CTP 4D compared with the first part of the test.

However, by using the results for CTP 4D as a reference basis a possible comparison of the degree of damage can be done. This way of scaling the degree of damage is quite uncertain since it is based on the damages on one geotextile only, but still it illustrates the much higher degree of damage found for CTP 4F compared to the other products tested.

The resistance against damage and the results from the index tests are used to evaluate the requirements in the classification system. The relevancy of an index test parameter for survivability of the geotextile is studied by correlating the parameter with the *resistance against damage* as defined above. The area weights are also included in the correlation. The results of the correlation are shown in Table 7. The test results from geotextile CTP 4F was not included in the correlation.

Table 6. Correlation between index test results and resistance against damage.

Parameter	Correlation
Weight/m^2	0.81
Strength incr. 20-70%	-0.11
Failure strength	0.84
Strain to failure	-0.77
1/(Cone drop hole diam)	-0.26
Number of points	-0.36

The parameters showing best correlation with the resistance against damage is the *push through strength* and the *area weight.* The criteria for *strength increase*, and *the number of points* shows poor correlation. The *strain to failure* and the *cone drop hole diameter* shows a fair negative correlation. The poor correlation for the number of points is remarkable. The low correlation is mainly caused by the fact that the two geotextiles with the most damage have full score based on the criteria in the index test.

The results from the index test do not point out an obvious candidate among the parameters that may explain why CTP 4F should be so severely damaged. In the primary tests the best correlation with the resistance against damage was found for the unit weight and the failure strength. This was not the case for CTP 4F that gives a high score on both unit weight and failure strength. Geotextile CTP 4F has, however, a relatively low value both for *strain to failure* and the *inverse of the cone drop hole diameter.* These low values may partly explain some of the higher degree of damage for the CTP 4F geotextile.

Both CTP 4D and CTP 4F are thermally bonded geotextiles, having a high initial stiffness. As shown in Figure 5, the force-displacement relations from the static puncture test are relatively similar for these to geotextiles compared to the other geotextiles tested. The large difference in degree of damage between CTP 4D and 4F is not reflected by similar differences in the index test results, with a possible exception for the deformation at failure. The damage on CTP 4F is therefore probably caused by material properties not measured in the index tests. A possible explanation may be the properties on the brittleness in the failure or the tear propagation for the geotextile.

3 CONCLUSIONS AND RECOMMENDATIONS

The project has provided useful information for evaluating relevant properties and requirements for geotextiles to be used for separation and filtration in roads. There are considerable differences in stress strain properties of the geotextiles that is also reflected in the behaviour in the field. Noticeable differences are found in the susceptibility for damage during installation. The criteria used in the existing systems for classification and specification do not seem to reflect properly the behaviour in the field. A revision of the criteria is therefore clearly needed.

The deformation of the geotextiles when subjected to loading, that is, in terms of rutting during installation and construction, is clearly linked to the initial stiffness of the geotextile. A criterion for geotextile survivability is clearly relevant, but has to reflect the behaviour during installation, construction and service lifetime. A criterion for geotextile survivability is suggested based on a combination of requirements for deformation energy and remaining stress and strain till failure. The principle is presented in Figure 8.

The deformation energy related to the installation and construction should be chosen with respect to the type of fill material, construction equipment and type of underground.

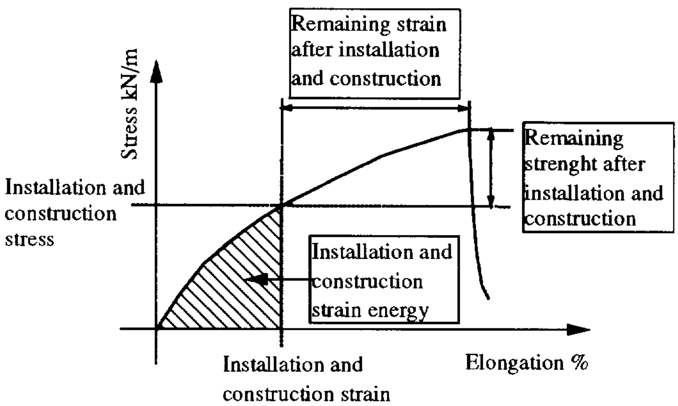

Figure 8. Survivability criterion principle.

The requirements for remaining strength and strain to failure should reflect the expected loads and deformations (settlement) for the service lifetime.

The final criteria should be based on a collection of data from laboratory and field tests correlated with long-term experiences from the field. The field experience should include different type of geotextiles, fill materials, subsoil conditions and construction equipment. This should preferably be done as joint project involving several countries, producers, public authorities and research organisations.

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