Evaluation of geotextiles' survivability by field tests

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ABSTRACT: Proper functioning of a geotextile in separation and filtration function requests close contact to each of the adjacent soil layers without cavities. Theoretical studies and simple laboratory tests have shown, that stresses induced during the installation and the consequent access traffic phase will cause deformations of 30 - 50 % at the boundary surface of a geotextile in separation function. At two construction sites different geotextile types were installed at conditions representing unpaved access roads and were loaded for a selected period of the construction works. At test pits the geotextile surface was excavated and the real shape of the boundary surface measured with a laser-profilometer and samples of the geotextiles were taken for further testing in laboratory. At each test section profiles in length and cross direction were produced from the measured data and calculated values of elongation (in %, related to 20 mm distance) produced. The results show clearly, that peak deformation values appear randomly and are due to penetration of single stones. The results allow the conclusion, that the "softer" a geotextile the more frequent bigger deformations will appear. The level of observed deformations confirm the assumption, that an initial deformation of $\varepsilon > 20$ % may be caused by the installation procedure and access traffic. A requirement assessed to a minimum deformation of $\varepsilon > 45$ % at maximum strength seems therefore justified.

1 INTRODUCTION

A geotextile placed at the boundary between subsoil and fill material will, depending on the installation conditions, adopt a three-dimensional surface configuration. Proper functioning of a geotextile in separation and filtration function requests a close contact at the boundary between each of the three layers. No cavities should remain and the geotextile should adopt the shape of the boundary surface without damage.

Theoretical studies and simple laboratory tests had shown, that stresses induced during the installation and the consequent access traffic phase cause local deformations of approximately 30 - 50 % at the boundary surface of a geotextile in separation function.

These findings are reflected in two criteria of the VTT-GEO geotextile specification applicable to geotextiles in road constructions. These are a minimum deformation at maximum strength and the so called survivability rupture resistance, requiring sufficient strength capacity after a defined initial deformation. These criteria seem to be conflicting in the case of high modulus geotextiles, which are likely offered for reinforcement function.

For these reasons it was considered important to study the loading and deformation conditions at the boundary surface in order to verify the VTT-GEO specification criteria assessed to geotextiles in road constructions in the separation and filtration function.

2 FIELD TESTS

2.1 *General test set up*

At two construction sites each time 7 different nonwoven geotextile types were installed at conditions representing unpaved access roads. The test areas were loaded for a selected period of the construction works and the geotextiles were recovered for further testing.

At test pits, each 3,0 x 3,2 m in size, the gravel cover was carefully removed from the top of the geotextile avoiding any excess loading (footprints, point loads from stones, etc.) during the excavation phase. At a close network of profiles the cleaned geotextile surface was then measured with a laser-profilometer and samples of the geotextiles were taken for further testing in laboratory. With the laser-profilometer the real shape of the boundary surface could be registered. The resolution of the device is 0,1 mm and each profile consists of measurements at 1 mm interval.

At each test section profiles in length and cross direction were produced from the measured data and calculated values of elongation (in %, related to 20 mm distance) produced.

2.2 *Haarjoki access road*

The access road, connecting the Haarajoki “settlement competition” test embankment with the main road VT4, was 1997 made available for testing deformation levels at classified nonwoven geotextiles. Over a length of 60 m seven geotextile types, 5 of which classified in class 3 according to VTT-GEO specification, were installed for testing purposes. Unfortunately 2 of the areas were destroyed during construction works at the main road VT4 before measurements could be performed.

2.2.1 *Soil conditions at the test site*

The Haarajoki trial embankment is a study site for consolidation behaviour of the subsoil and was subject of an international competition for settlement calculations.

The subsoil conditions and the structure of the access road represent conditions specified for class 2 geotextiles. In order to avoid any mixing of soil layers, which could influence the measurement of deformations at the interface, geotextiles classified for class 3 were chosen for the trial.
At the test site the following soil conditions prevailed:
- thickness of clay layer about 15 m, of which thickness of dry crust about 1,2 m
- shear strength at 1,8 - 8 m depth: cu=15-20 kPa
- organic top soil had been removed from the surface
- base layer: gravel, 20 % of grains $\phi > 64$ mm, max. grain size $\phi < 200$ mm (screened).

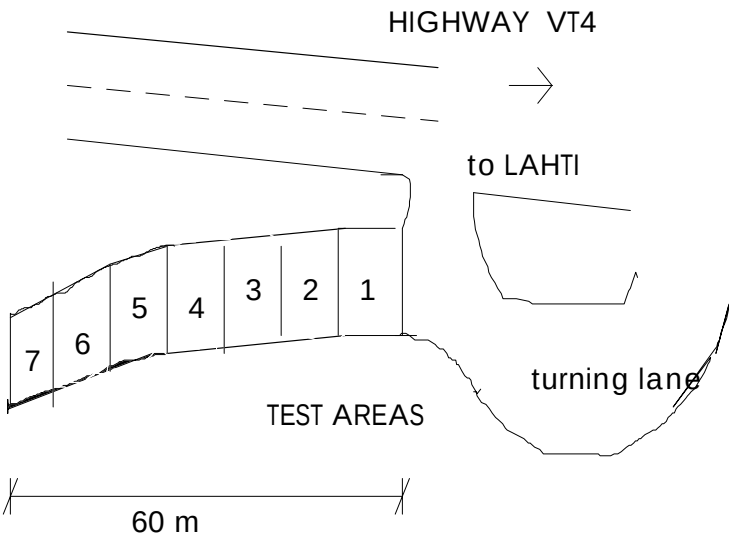

Fig. 1. Haarajoki test site. Lay out of test sections.

2.2.2 *Geotextile types*

At parallel test areas the following geotextiles, mentioned in Table 1, were used. The mass/ unit area varied from 150 to 210 g/m2. These geotextile types are mainly classified in class 3 according to the VTT-GEO geotextile specification.

Table 1. The geotextile types used at the test areas at Haarajoki.

Test area	Geotextile type	Symbol in text & brand name	Mass, g/m2
1 *)	PP - spunbond, mechanically bonded	H1) BIDIM S 41	165
2 *)	PP - staple fibre, mechanically bonded	H2) GEOPLUS 150	155
3	PP - staple fibre, mechanically and heat bonded	H3) TIPPTEX 200	200
4	PP - spunbond, mechanically bonded, stretched	H4) POLYFELT TS-30	155
5	PP - spunbond, heat bonded	H5) TYPAR 190 g/m2	195
6	PP - spunbond, mechanically and heat bonded	H6) FIBERTEX F-320	210
7	PP+PE-spunbond, heat bonded	H7) TERRAM 1500	190

*) Remarks: These test areas were destroyed in October 1997.

2.2.3 *Laboratory testing of the geotextiles*

Samples of the geotextile types delivered to the site were tested according to the testing programme of the VTT-GEO geotextile specification.

In connection with the field measurements samples of the geotextiles were recovered from the sites and tested for changes in properties following a limited testing scheme. Mechanical properties of these samples were tested according to EN ISO 10 319 (wide width tensile test) and EN ISO 12 236 (static puncture test = CBR test).

2.2.4 *Construction of the test areas*

The field test programme to study the survivability properties of geotextiles could be realized under conditions guided by the construction, loading and measurement programme at the Haarajoki con-

solidation test field. An access road to the test embankment could be utilized for the installation of 7 different geotextile types. Starting from a service lane at the state road VT4 the topsoil was removed on 60 m length and the geotextile samples placed directly on the dry crust clay, using an overlap of 1 m in length direction. The 3.5 m wide access road was constructed of gravel, leveled and compacted by a bulldozer to form a 450 - 500 mm thick layer. Further compaction and loading of the areas happened, when gravel was transported to the test embankment. Dry weather prevailed during the construction and loading phases and no problems like insufficient bearing capacity or wetting were encountered.

2.2.5 *Access traffic*

All together 319 truck loads of gravel (á 0.41 MN) were transported along the access road to the test embankment, making a total of 131 MN. Due to the exceptionally dry weather no changes in environmental or ground conditions happened.

The trucks traveled 638 time to deliver the whole gravel fill to the test embankment. Thus the separating geotextiles were loaded by 1900 axle loads of 85 kN each and in addition by 1900 axle loads of 35 kN each (return traffic).

2.2.6 *Field measurements*

At the test pits, 3.0 x 3.2 m in size, the top gravel layer was removed with a light weight excavator . The remaining 80 - 100 mm thick cover was carefully removed by hand from the top of the geotextile. Special attention was paid to recover the geotextile surface at the location of the ruts and to avoid any excess loading (footprints, point loads from stones, etc.) during the excavation phase. Finally a soft brush was used to clean the geotextile surface.

The manually recovered area enabled both the measurements with the laser profilometer and sampling of the geotextile in place for further testing in laboratory.

The profilometer measurements were done in length and cross direction within a frame of size 700 x 700 mm, which was placed symmetrically over one rut in the direction of the traffic. The actual measurement lines were 70 mm apart from each other, except at one slice in each direction, where additional lines were measured at 17.5 mm intervals. With the laser-profilometer the real shape of the boundary surface could be registered. The resolution of the device is 0.1 mm and each profile consists of measurements at 1 mm interval.

After the measurements a geotextile sample of reasonable size was removed from the test and then the test areas were patched with a new piece of geotextile and filled up.

When recovering the geotextiles no significant damages could be observed. This result was to be expected due to the use of class-3 geotextiles in conditions corresponding to class 2 requirements. An analysis of a possible degree of damaging in form of holes, their shape or number, was not appropriate.

2.2.7 *Analysis of test results*

At each test section profiles in length and cross direction were produced from the measured data. In addition the maximum elongation at the boundary (geotextile) surface was calculated, using data averaged from 3 consequent measuring points. Values of elongation (in %, related to 20 mm distance) were calculated for each test area using data from profiles measured in length and cross direction. The results show clearly, that peak deformation values appear randomly and are due to penetration of single stones. A formation of clear ruts with a concentration of longitudinal deformation was not observed.

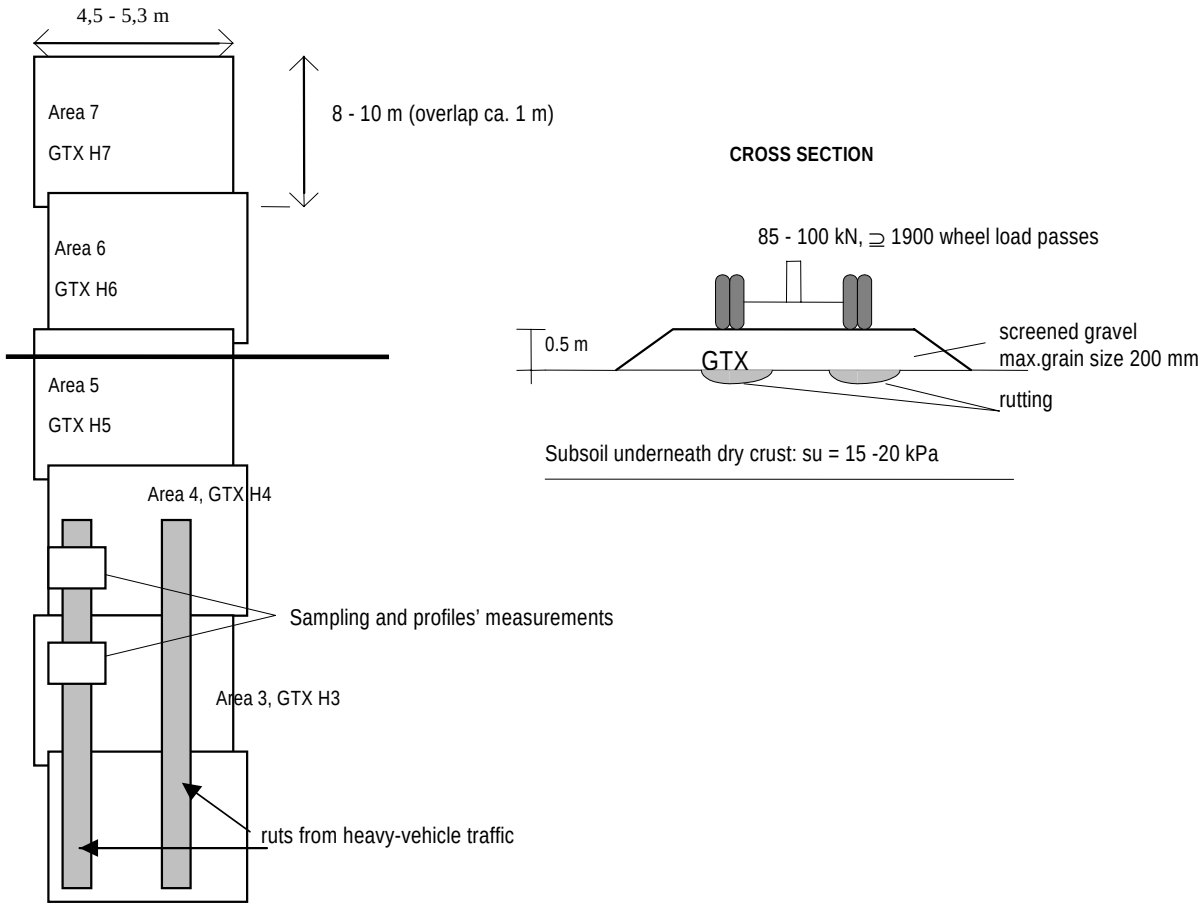

Figure 2. Haarajoki test site. Lay out of measurements.

The deformation data from 20 measurement profiles of each test area (ca.13000 data related to 20 mm distance) were analyzed statistically and the results allow the conclusion, that the "softer" a geotextile more frequently bigger deformations will appear. Other said, such a geotextile is adopting more closely and permanently the shape of the boundary surface. On the other hand, a "stiff" geotextile is obviously distributing the effect of a point load and lifting up from the surface when the load is released (elastic rebound).

A combination of the maximum deformations calculated for different reference intervals (20 mm, 40 mm and 100 mm) is compiled in Table 2 for the Haarajoki test field.

Table 2. Haarajoki test field. Profilometer measurements. Calculated maximum deformations in % (related to reference distances of 20, 40 and 100 mm).

TEST AREA direction of measurement	GEOTEXTILE type	ε, %, Δ= 20 mm	ε, %, Δ= 40 mm	ε, %, Δ=100 mm
3-Cdir	H3	14.9	10.6	8.4
3-Ldir		20.8	14.2	7.8
4-CDir	H4	21.2	15.1	7.7
4-LDir		25.3	16.6	9.9
5-CDir	H5	5.7	4.3	2.2

5-LDir		14.0	8.5	3.7
6-CDir	H6	27.8	20.6	9.7
6-LDir		13.5	12.2	6.1
7-CDir	H7	27.2	17.4	7.6
7-LDir		12.7	6.9	3.8

LDir= length direction, CDir= cross direction

2.3 *Geotextile behaviour: observed changes in mechanical properties*

The geotextile samples recovered from the test areas were further tested in laboratory to determine the changes in mechanical properties (stress-strain behaviour). Both wide width tensile tests according to EN ISO 10 319 and static puncture (= CBR) tests (EN ISO 12 236) were performed.

The observed changes in stress strain properties are similar to those obtained from geotextile abrasion tests with a laboratory sieving device. The abrasion test procedure, where uniformly graded crushed aggregate is placed on a geotextile sample supported by a 20 / 20 mm steel mesh and subjected to vibration like in aggregate sieving, produces similar changes in the stress strain properties of a geotextile. Results of such abrasion tests are reported for different geotextile types in Rathmayer 1997a, b.

2.4 *Test site Salo Pappila junction*

2.4.1 *Subsoil conditions*

The test area represented a 11 – 19 m deep soft clay stratum with a 1.2 – 1.4 m thick dry crust at the surface. At the surface the clay had the following index properties:
- water content w = 29.4 – 37.5%
- dry density: γd= 1.29 – 1.51 g/cm3.

2.4.2 *Construction of the test areas*

The test areas were placed at one side of a 5 – 6 m wide access road used during the construction of the Pappila junction of state road VT-1 near the town Salo. After removal of the topsoil seven different geotextiles were installed and covered with a layer of crushed gravel, 300 ± 25 mm thick. A 140 kN roller was used to compact the fill. The length of the test areas with a geotextile as separator varied between 7.5 – 12 m.

2.4.3 *Geotextile types at the Salo-Pappila junction test areas*

The geotextile types for the test areas were chosen such to meet the requirements of class 3 in the VTT-GEO geotextile specification. At the test areas class 3 conditions prevailed, soft subsoil and a fill of crushed gravel.

Table 3. Geotextile types used at the Salo-Pappila junction test areas.

Test area	Geotextile type	Symbol in text & brand name	Mass, g/m2
1	PP - staple fibre, mechanically and heat bonded	S1) TIPPTEX 200	200
2	PP – staple fibre	S2) LEKTEX 3000	155
3	PP - spunbond, mechanically and heat bonded	S3) FIBERTEX F-32M	235
4	PP - spunbond, mechanically bonded	S4) BIDIM S 041	290
5	PP+PE-spunbond, heat bonded	S5) TERRAM 1500	190
6	PP - spunbond, heat bonded	S6) TYPAR 190 g/m2	195
7	PP - spunbond, mechanically bonded, stretched	S7) POLYFELT TS-30	155

2.4.4 *Traffic load*

The test areas were subjected to traffic loading as demanded by the construction works of the adjacent junction. During a period of 9 days 196 trucks passed the areas, 50% of which fully. loaded with 383 kN, on the way back 120 kN, in total 49.32 MN. Traffic was guided to pass the lane adjacent to the geotextile test areas when clay from the subsoil started to squeeze up in the ruts. The loading phase was terminated at a stage, when the contractor considered to improve the poor trafficability of the access road.

2.4.5 *Field and laboratory measurements*

At the test pits, 2 x 2 m in size, the top gravel layer was removed with a light weight excavator. The remaining 50 - 100 mm thick cover was carefully removed by hand from the top of the geotextile. Special attention was paid to recover the geotextile surface at the location of the ruts and to avoid any excess loading. Finally a soft brush was used to clean the geotextile surface.

Due to the cold weather conditions when the geotextiles were recovered (frost, frozen topsoil), measurements with the laser profilometer were not possible to be done in the field. A part of each excavated geotextile area, 0.8 x 0.8 m in size, was therefore casted in concrete. So the hardened images of the geotextile boundary surfaces could be measured with the laser profilometer afterwards in-house. Samples of the geotextile types were taken for further testing in the laboratory.

Profiles were measured in both directions at intervals of 80 mm and in addition one interval more precisely. The results are summarized in Table 4.

2.4.6 *Observed changes in mechanical properties*

Both number and size of holes was invented for each of the geotextiles at areas of 0.5 x 0.5 m. The results are given in Table 5. In addition to holes signs of abrasion were found at the areas 1, 4, 6 and 7. At area 6 the geotextile had failed alongside the rut and clay had been squeezed up into the gravel layer.

Table 4. Salo-Pappila junction test field. Profilometer measurements. Calculated maximum deformations in % (related to reference distances of 20, 40 and 100 mm).

TEST AREA direction of measurement	GEOTEXTILE type	ε, %, Δ= 20 mm	ε, %, Δ= 40 mm	ε, %, Δ=100 mm
1-Cdir	S1	42.7	26.4	21.6
1-Ldir		33.2	22.7	11.3
2-CDir	S2 *)	23.2	16.7	9.3
2-LDir		21.4	12.5	7.0
3-Cdir	S3 *)	19.7	11.6	7.1
3-Ldir		12.0	9.0	5.5
4-Cdir	S4 *)	30.9	23.2	15.5
4-Ldir		30.8	18.9	8.5
5-Cdir	S5 **)	25.2	17.6	9.8
5-Ldir		44.4	25.3	11.9
6-Cdir	S6 **)	76.2	54.7	37.5
6-Ldir		26.2	17.4	8.2
7-Cdir	S7 *)	20.9	13.9	8.9
7-Ldir		11.2	6.4	3.9

LDir= length direction, CDir= cross direction
Remarks: *) singular defects in the GTX, **) GTX severely damaged

Table 5. Salo Pappila junction. Sice and number of defects after traffic loading.

TEST AREA	GTX-type	0 - 10 mm	10 - 20 mm	20 - 50 mm	50 -100 mm
1	S1	-	-	-	-
2	S2	4	1	-	-
3	S3	1	1	-	-
4	S4	-	1	1	1
5	S5	7	6	4	5
6	S6	7	3	1	1
7	S7	3	2	-	-

The geotextile samples recovered from the test areas were further tested in laboratory to determine the changes in mechanical properties (stress-strain behaviour). Both wide width tensile tests and static puncture tests were performed.

3 GEOTEXTILES' SURVIVABILITY

3.1.1 *Damages*

The field test conditions at Haarajoki (subsoil = dry crust clay, class 3 geotextiles, natural gravel fill, dry summer weather) did not produce significant damage to the installed geotextiles. With the exception of a few small holes the geotextiles remained undamaged at the boundary surface between subsoil and aggregate.

The test conditions at the Salo Pappila junction resulted in damages to some of the installed geotextiles. The measured values of deformation at the boundary surface between geotextile and subsoil thus indicate failure conditions for serviceability of the access road.

3.1.2 *Deformations observed at the boundary surface*

At the Haarajoki test areas the environmental and loading conditions corresponded to class 2 requirements for geotextiles in road constructions, though the maximum grain size of the gravel was 200 mm. Due to the dry summer weather the dry crust clay support combined with a 450 - 500 mm thick gravel base layer provided sufficient bearing capacity for the traffic volume on the access road. No essential rutting occurred at the boundary surface.

At the Salo-Pappila junction test areas the environmental and loading conditions corresponded to class 3 requirements for geotextiles in road constructions. The dry crust clay support was saturated with water and correspondingly soft. The base layer constructed of crushed gravel, only 300 ± 25 mm thick, had to provide the necessary bearing capacity for the traffic volume on the access road. The test had to be terminated when essential rutting prohibited further traffic.

An analysis of the profilometer measurements at Haarajoki showed penetration of single stones from the aggregate into the clay subbase. These produced at the boundary surface linear deformations in the geotextile, which varied from 5 - 28 % (see Table 2). Depending on the initial stiffness and bonding type the geotextile had either adopted permanently the shape of the deformed surface or had formed a bridging membrane between the point loads. This difference in behaviour is reflected in smaller deformation values observed for thermal bonded geotextiles (test areas 5 and 7). The dry environmental conditions did not allow an analysis, to which extent the geotextile had relieved elastically from its support when the gravel was removed.

The Salo-Pappila junction profilometer measurements showed correspondingly penetration of single stones from the aggregate into the clay subbase and rutting, which produced deformations in the range of 11- 76 % (see Table 4) at the boundary surface.

The level of observed deformations under conditions relevant to class 2 and class 3 (according to the VTT-GEO geotextile specification) confirm the assumption, that the installation procedure and the access traffic together produce an initial deformation of $\varepsilon > 20$ %, also called the survivability rupture resistance. Further utilization of the strength properties of the geotextile up to its serviceability limit is linked to additional deformations. The requirement assessed to a minimum deformation at maximum strength, which is $\varepsilon > 45$ % for class 2 and $\varepsilon > 50$ % for class 3 in the VTT-GEO geotextiles specification, seems for that reason justified. The remaining deformability acts as a safety margin for the environmental and loading conditions of the geotextile in service.

3.1.3 *Functional strength properties of geotextiles*

The stress-strain properties of recovered geotextiles deviated essentially from those of virgin samples. The biggest differences occurred in the form of reduced deformation values at break in consequence to the stresses acting on the embedded geotextile. Depending on the type of product, the deformation values at break were reduced by 5 - 50 % of original. The strength values at failure were only slightly reduced under the prevailing conditions.

In connection with the developing work at VTT for a laboratory survivability test different types of geotextiles were treated in a vibrating sieve device with sorted crushed aggregate. After treatment wide width tensile tests were performed to determine the change in stress-strain properties of the geotextile samples. The results of these tests are similar to those obtained from the field installation tests. The laboratory survivability tests are reported in Rathmayer (1997 b).

Static puncture tests (CBR tests) were also performed on the geotextile samples recovered from the field tests. The CBR-penetration resistance is used in the German geotextile classification as one of the class requirements. A class 3 geotextile is required in cases, where the stone content is > 40 %. The required CBR-penetration resistance for a class 3 geotextile is 1,5 - 2,0 kN. All tested geotextiles fulfilled this criteria.

3.2 *Further research needs*

The results obtained from the test installations of geotextiles at Haarajoki confirm, that the requirements on deformability as-sessed in the VTT-GEO specification for class 2 and class 3 geotextiles in separation function are justified. The stresses in-duced by the installation procedure and the consequent access traffic under class 2 environmental conditions (subsoil proper-ties, fill material) produce deformations at the geotextile boundary, which exceed locally 20 %.

A mechanically bonded geotextile accommodates to the lo-cal point loads by stretching accordingly. The geotextile will adopt the shape of the deformed boundary surface . After re-moval of the load the geotextile remains in close contact with the subsoil following exactly the shape of its surface.

A recovered thermal bonded geotextile has the tendency to regain nearly its original surface plane and is partially lifting up from the subsoil. It was not possible to observe the effect of only partial contact at the boundary surface e.g. in the form of accumulation of fines because of the dry summer conditions

At conditions assessed to class 3 and 4 in the VTT-GEO geotextile specification the geotextiles have to resist dipping of crushed and sharp edged aggregate without damage. At those installation conditions higher stresses compared to class 2 con-ditions and consequently higher deformations have to be ex-pected at the points of loading. In addition singular stones may be punched through the geotextile separator.

The test procedure applied at the Haarajoki and the Salo-Pappila junction test sites proofed being applicable to produce data for a verification of the VTT-GEO geotextile specification applicable to geotextiles in road construction. The now ob-tained results represent both the most gentle and severe condi-tions described in the VTT-GEO specification. Further trials at different installation and loading conditions, which request also heavier geotextile types, are necessary to complete this verifi-cation of the requirements assessed in the VTT-GEO geotextile specification.

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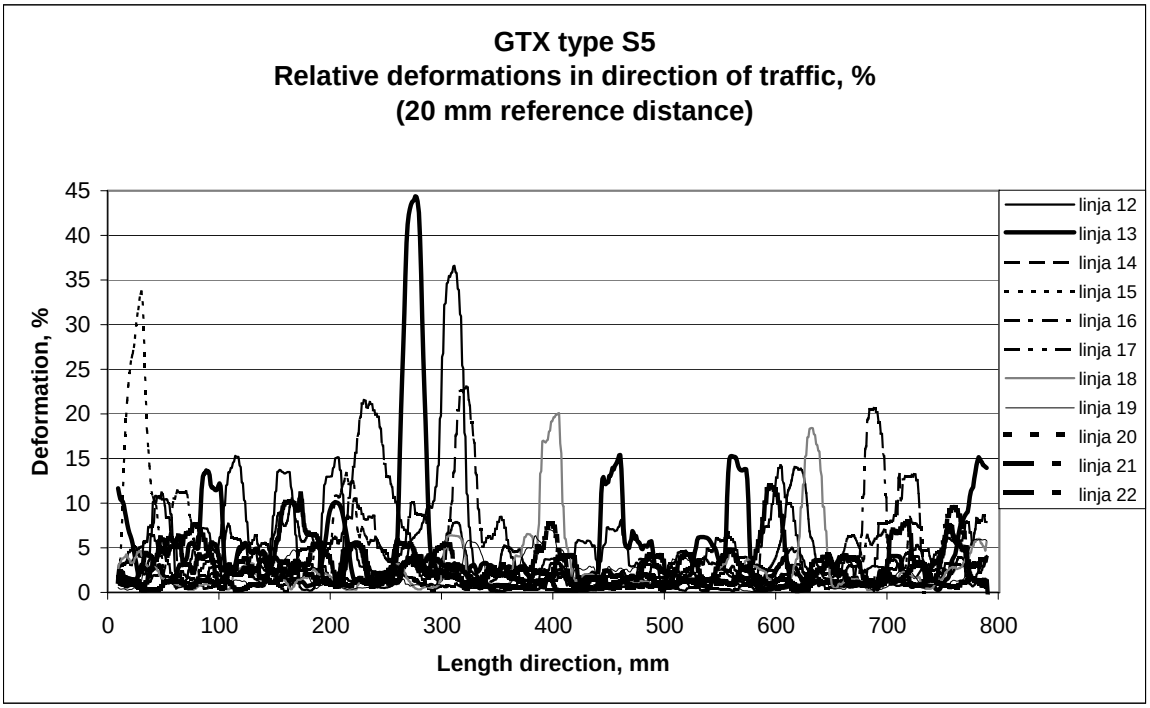

Figure 3. Salo-Pappilamäki test site. Geotextile deformations in direction of access traffic relative to 20 mm reference distance.

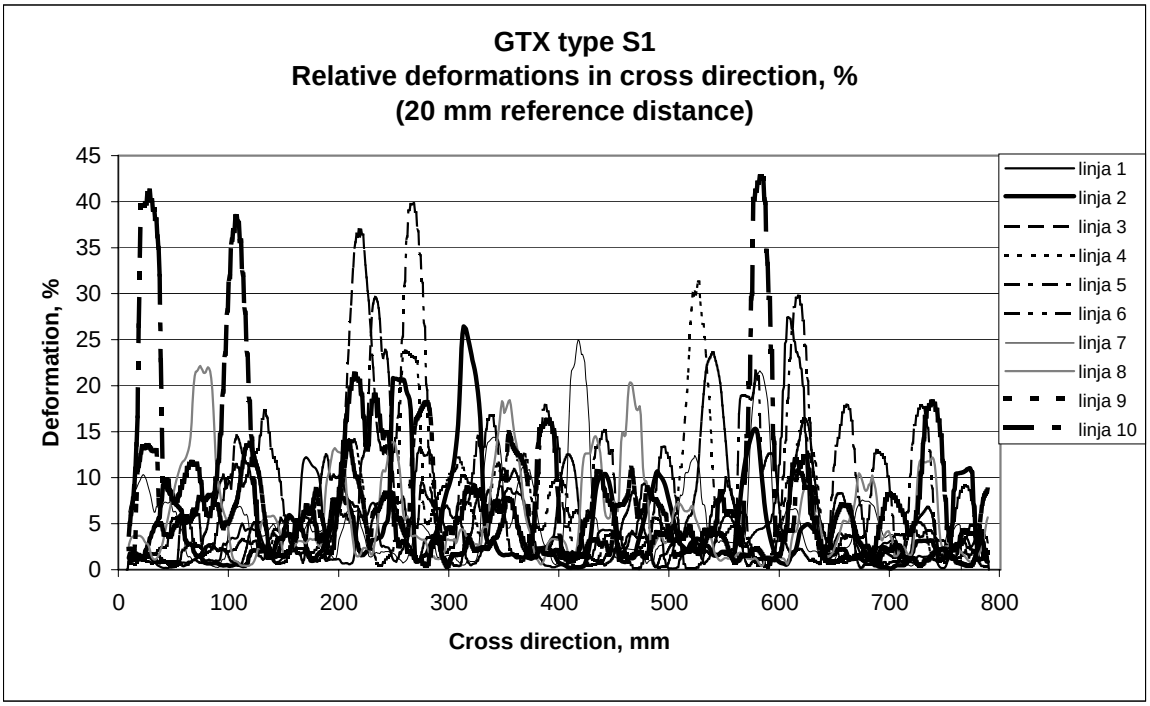

Figure 4. Salo-Pappilamäki test site. Geotextile deformations in cross-direction of access traffic relative to 20 mm reference distance.