Effects of stretched geotextiles in contact with soil

Le comportement des géotextiles allongés dans le sol

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ABSTRACT: Geotextiles are subject to stretching, e.g. due to sliding or the displacement of a construction on slopes, deformations caused at joints, pull-out of adjacent soils and especially through settlement of waste disposal material. The consequences of such stretching on the geotextile behaviour (soil retainment, water permeability, results from cone drop testing on stretched geotextiles and the flexibility) are described in the paper.

RESUME: Les géotextiles sont soumis à l'allongement, par exemple à cause des glissements ou des déplacements d'une construction sur des talus, des déformations causées aux joints, de l'arrachement des sols voisins, et spécialement du tassement des déchets. Les conséquences d'un tel allongement sur le comportement du géotextile (soutènement du sol, perméabilité de l'eau, résultats de l'essai de pénétration au cône sur des géotextiles allongés et flexibilité) sont décrites dans cette contribution.

1 MOTIVE

Already in 1984 extensive research works "On the behaviour of stretched geotextiles" began at the *Franzius-Institut*; the results of this research were published some years later in a little book (Saathoff 1991). Due to the conference *Geofilters 96* with the published contributions of Fourie & Addis (1996) and Den Adel, De Bruin & Hofmans (1996), some of those results again became a matter of topical interest. Also the guidelines *Merkblatt für die Anwendung von Geotextilien und Geogittern im Erdbau des Straßenbaues* (Wilmers, 1994) being valid in Germany gives the user the advice to consider the stretching behaviour of geotextiles. In the 33 examples it is explained 25 times: The stretchability is decisive for the selection. One criterion, however, is missing. Following the results which are in most parts based on examinations of the *Franzius-Institut* are summarized and are thrown open to the public. The geotextiles used in the tests have different abbreviations. The number behind the letter (S for mechanically bonded staple fibre nonwovens, E for mechanically bonded endless fibre nonwovens and T for thermally bonded nonwovens) gives a hint to the mass per unit area. The last digit is chosen as abbreviation for the used raw material (3 for PES, 5 for HDPE and 8 for 70 % PP and 30 % PE).

2 ON THE THICKNESS OF STRETCHED NONWOVENS

In order to simulate the stretching loads, in the laboratory samples were pre-stretched monoaxially with obstructed tying and biaxially; from these stretched samples again samples were taken with a special clamping ring in order to examine for example their perforation behaviour in the cone drop test.

In order to interpret the results, first the modification of the thickness which was caused by stretching was examined in detail. It can generally be stated for mechanically bonded nonwovens that the thickness is reduced by the applied stretching -due to the movability of the single fibres-. The calculated thickness values of stretched mechanically bonded nonwovens are in good conformity with the measured values. For thermally bonded nonwovens it can be stated that the loading is first absorbed by the fibre connection when the stretching is increasing; then the fibre crossings resp. single layers of a thermally bonded nonwoven sticking together dissolve. This behaviour relativizes the reduction of the thickness of a sample generally caused by stretching so that a constant thickness under an applied stretching may be assumed.

With the approach for the assessment of the proportion of pores -under consideration of the "stretched" mass per unit area- the following behaviour can be seen: mechanically bonded nonwovens keep their original proportion of pores in stretched condition since the thickness decreases due to stretching. An applied stretching does not change the thickness of thermally bonded nonwovens, but the proportion of pores change.

3 FILTER TECHNICAL CHARACTERISTIC VALUES

It was the aim of this examination to determine the filter technical effects of different stretching states of geotextiles in quantity.

Theoretically a stretching may result as "increasing fibre density" or as "increasing fibre space". An increasing fibre density which is also caused by an existing loading/normal stress theoretically reduces the water permeability value, the characteristic opening size and the soil passage. An increasing fibre space increases these filter technical characteristic values.

The results of the examinations described below, however, show that the complexity is a result of the fact that the two phenomena cover each other and have an influence on each other. As influencing factors there may be mentioned kind and size of stretching, kind of bonding, mass per unit area and thickness (proportion of pores) as well as normal stress. These influencing factors have effects on (partly beyond practice orientated) stretched geotextiles in different shapes and depending on the stretch size.

3.1 *On the behaviour of characteristic opening size*

According to Fig. 1 the following can be stated on the behaviour of the characteristic opening size $O_{90,w}$ under biaxial stretching:

- Mechanically bonded nonwovens and composites react on stretching with a distinct fibre reorientation. Effects like increasing fibre density and increasing fibre space may cover each other so that no substantial changes of the characteristic opening size occur. With regard to the product S 335 made of HDPE fibre when being stretched with $\varepsilon = 50\,\%$ ($\varepsilon_A = 125\,\%$), however, so-called "islands" (with isolated fibre accumulations and directly adjacent areas with very little fibres) occur, the characteristic opening size, however, only increases slightly.
- Wovens react depending on the stretching size first with an increasing fibre density, then with an increasing fibre space (G 124). The woven G 537 could due to the technical equipment not be stretched biaxially more than $\varepsilon = 5\,\%$, however, it can be stated that the characteristic opening size is reduced from 0.4 mm($\varepsilon = 0$) to 0.129 mm ($\varepsilon = 5\,\%$).
  Also Fourie and Addis (1996) receive the same result for a PP woven slitfilm (reduction of the opening size found in the hydrodynamic sieving test of up to 28 %).
- The adhesively or cohesively bound rigid fibre crossing points of the thermally bonded nonwoven tear up with an increasing biaxial stretching, an increasing fibre space can be seen with -as a result from this- an increase of the characteristic opening size, depending on the applied mass per unit area.

The question whether the filter rules for the determination of the mechanical filter effectiveness are affected by these results can only be answered for a concrete example of application (with a

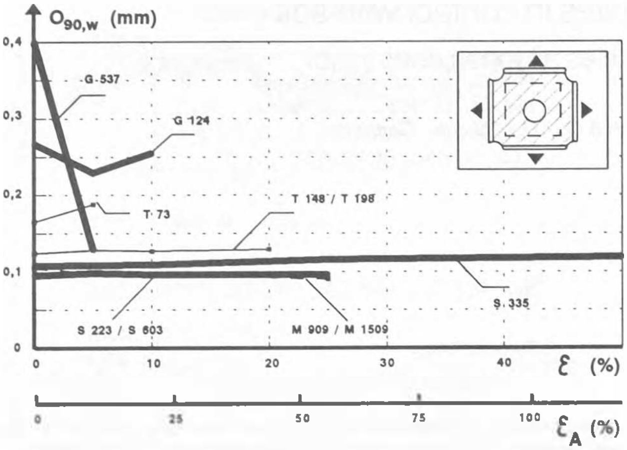

Fig. 1. Selected results on the characteristic opening size of biaxially stretched geotextiles

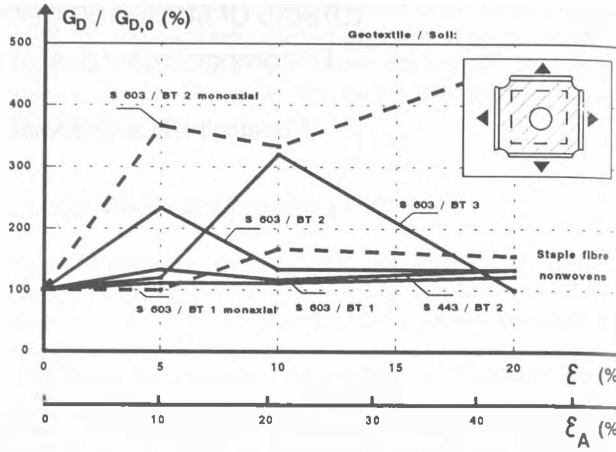

Fig. 2. $G_D/G_{D,0} = f(\varepsilon)$ of selected geotextile-soil-combinations in the turbulence test (biaxial stretching)

given grain size distribution of the soil to be filtered). A reduction of the $O_{90,w}$-value may result in a filter cake formation which endangers the stability of a filter. Thus it becomes obvious that at least for some cases project and product specific tests should be carried out. In the majority of the tests it may be assumed that also in a stretched state the mechanical filter effectiveness is given.

3.2 On the water permeability behaviour

Summarizing it may be stated within the margins of the examined stretching sizes for the selected products that -apart from one exception- the modification of the water permeability coefficient by means of an increasing biaxial stretching ranges at a maximum within half an order of magnitude. The water permeability may clearly decrease in the individual case with an increasing stretching.

With regard to the mechanically only loosely bonded nonwoven S 335 made of HDPE staple fibres, the above mentioned "island formation" caused by stretching does not lead to a fibre compaction, but to an increase of the fibre spaces and thus to an increase of the water permeability coefficients.

The fact that the water permeability behaviour can only hardly be assessed with an increasing stretching, relativizes a little if the permittivity is regarded instead of the k_V-value.

The assessment of the water permeability coefficients (resp. of the permittivity) of stretched geotextiles is proposed on basis of the parametters $n_\varepsilon^4 \bullet m_{A\varepsilon}$ and $n_\varepsilon^4 \bullet d_\varepsilon$.

The hydraulic filter effectiveness of stretched geotextiles has only to be considered for those ones of which the water permeability coefficient decreases by stretching. With regard to all other geotextiles an increase of the water permeability coefficient (at an adherence at the same time to the filter rules for the mechanical filter effectiveness) may be assessed as positiv.

3.3 On the behaviour in the turbulence test

As representative for the soil retaining capacity of stretched geotextiles only selected results in the turbulence test with mechanically bonded staple fibre nonwovens are described in the following. Other results -also from the throughflow method- can be read in Saathoff (1991).

Descriptions of the soil passage depending on the tested soil type (BT 1 to BT 4 of the *Bundesanstalt für Wasserbau*) as well as depending on the corresponding product do not give any clear tendencies. Nearly all stretched nonwovens show an increase of the soil passage up to $\varepsilon = 5$ %. Following this increase there is -depending on the soil type- a slight decrease resp. a nearly constant soil passage (Fig. 2: G_D = soil passage of a correspondingly pre-stretched sample, $G_{D,0}$ = soil passage of a virgin sample).

The following model may explain this behaviour. A stretching load of up to $\varepsilon = 5$ % is absorbed by the entire structure of the nonwoven, i.e. tensile loads are transmitted from the single fibre to the entire structure. Existing pore channels are enlarged and cause an increased soil passage compared to unstretched samples.

Along with an increasing stretching the single fibres begin to orientate to the corresponding tensile direction. In relation to the original position the fibres take a new position. Pore channels are closed by this change of position; the soil passage decreases. In the range of a stretching of 20 % the occurring tensile loads have to be absorbed by the single fibre. Shortly before the state of failure is reached, the single fibres tear or leap out of the entire structure (elongation values reach values which correspond to the length of the staple fibres). Increased masses of soil passages are determined.

By the orientation of the fibres in only one direction (tensile direction), a distinct change in the nonwoven structure has to develop which -compared to a biaxial stretching - cause increased soil passages (at a same mass per unit area). Exactly the advantage of the convoluting position of the fibres of mechanically bonded nonwovens is disturbed by monoaxial stretching. However, it is valid for soils with a high portion of fine grain that already small monoaxial stretches should be considered when carrying out a filter dimensioning. A biaxial stretching does not change the fibre convoluting position of the nonwoven to that degree.

Evaluations show linear relationships of the masses of soil passage ($G_D \bullet d_{10}$ depending on $n^4 \bullet d_\varepsilon$).

4 GEOTEXTILES IN CONE DROP TESTING

In the cone drop test serving as simulation of dynamic loads, a 1 kg heavy falling cone (max. diameter 5 cm, cone apex angle 45°) is being dropped from a height of 50 cm onto the circular sample which is fixed in the test cylinder (internal diameter 15.2 cm). The perforation is being measured by means of special measuring cones:

- d_P Average hole diameter of the perforation in the geotextile (mm),
- h_K cone drop height (cm) and
- h_S average puncture height of the achieved deformation (mm), measured at the measuring cone.

4.1 Testing of influencing quantities on the perforation

First the results of the different geotextiles are examined in detail. Fig. 3 shows the puncture height $h_S = f(d_P)$. The results are as follows: for staple fibre nonwovens high puncture heights at comparably small hole diameters are found, for endless fibre nonwovens there are medium puncture heights at medium hole diameters and for thermally bonded nonwovens low puncture heights (even with the measuring values for the support layer air -apart from one exception- $h_S < 10$ mm) at comparably large hole diameters were determined.

Mechanically bonded staple fibre nonwovens show a good behaviour, as the short staple fibres possess the possibility of displacement and shifting (nearly constantly high h_S-values). Staple fibre nonwovens thus have the best ability of adjusting to the energy caused by the cone.

For rigid fibre crossing or endless fibres these displacements and shifting possibilities are not given (a nearly linear behaviour

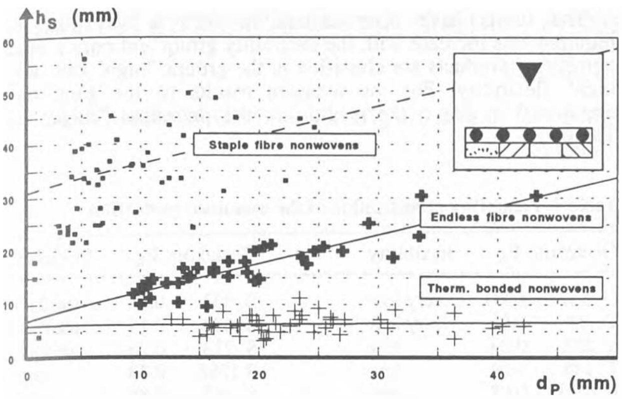

Fig. 3. $h_S = f(d_P)$ for different nonwovens with different support layers, drop heights and different cone shapes

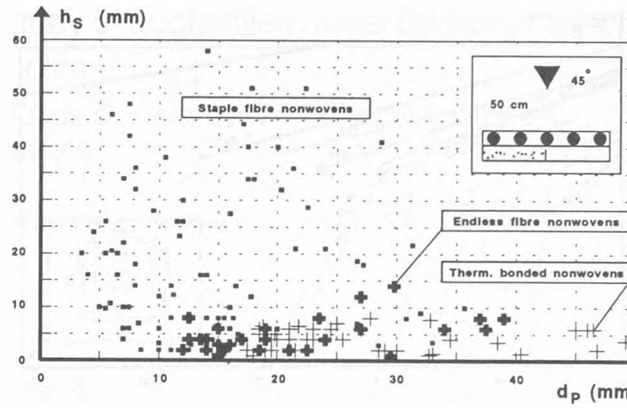

Fig. 5. $h_S = f(d_P)$ for monoaxially and biaxially stretched nonwovens with the support layers air and "glyben"

between h_S and d_P). Thermally bonded nonwovens can hardly be deformed and burst abruptly when hit by the dropping cone -independent from its shape- (nearly constantly small h_S-values).

4.2 The behaviour of mono- and biaxially stretched nonwovens

For the actual cone drop tests the support layers air and "glyben" (a mixture of glycerine and sodium-bentonite) were chosen.

An increase of the average perforation diameter of mono- and biaxially stretched nonwovens in the cone drop test can be seen along with an increase of stretching at all product groups according to the measured values (Fig. 4).

In average, the perforation diameters of monoaxially and biaxially stretched staple fibre nonwovens are increased at the largest stretching values by 1.5 times compared to the perforation diameters of the unstretched nonwovens. Regarding "glyben" no clear differences can be seen for different products depending on the stretching (for monoaxial stretchings as well as for biaxial stretchings); a range of the perforation diameter of ±5 mm can be determined. The perforation diameters have a linear increase at an increasing stretching and achieve approx. 2 to 2.5 times of the corresponding values of unstretched samples at a maximum stage of stretching.

The maximum stretchability of the endless fibre nonwovens is lower than that of the staple fibre nonwovens, furthermore, -in relation to the mass per unit area- comparably larger perforation diameters are found.

The stretchability of thermally bonded products is low. Products of core coating fibres can be pre-stretched to the largest extent -within the group of examined thermally bonded nonwovens. Upon the hitting of the cone onto the sample, the thermally bonded nonwovens burst abruptly (cross-like perforation contrary to mechanically bonded nonwovens where the perforation is circular) -as already known from stretching tests-. The perforation diameters have the tendency to slightly increase with increasing stretching.

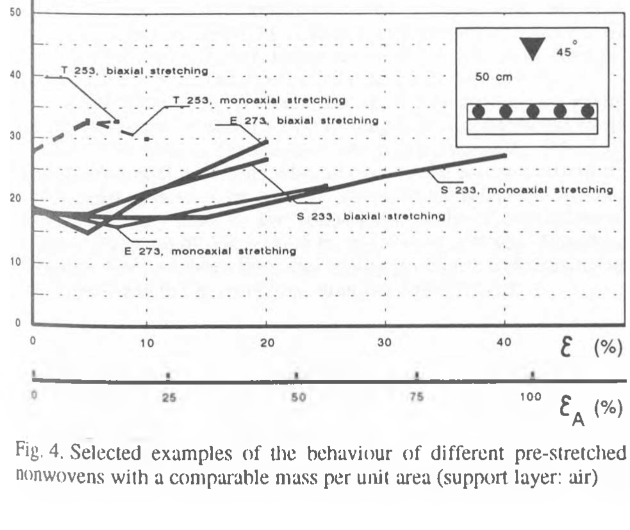

Fig. 4. Selected examples of the behaviour of different pre-stretched nonwovens with a comparable mass per unit area (support layer: air)

The puncture height decreases correspondingly to the applied stretching. Fig. 5 shows the puncture height for each tested sample which was stretched.

For staple fibre nonwovens high puncture heights $h_S = f(d_P)$ -such as for the unstretched samples- are possible for all stretched tests. The puncture heights of thermally bonded nonwovens -at unstretched samples the puncture heights are low, anyway- are further reduced by stretching. This confirms the rigid, inflexible behaviour of the thermally bonded products (total perforations with $d_P > 50$ mm were determined as well). Contrary to the unstretched samples, the puncture heights of endless fibre nonwovens can be found in the same range as those of thermally bonded nonwovens; clearly detectable, different modes of behaviour -as for the unstretched samples (compare Fig. 3)- can no longer be seen.

For mechanically bonded nonwovens, a constant behaviour of the proportion of pores of each product can be determined when stretching is applied ($n_\varepsilon = n$, $d_\varepsilon \# d$). The perforation diameter in the cone drop test is -the dependency of $n^4 \bullet d_\varepsilon$ (resp. $n_\varepsilon{}^4 \bullet d_\varepsilon$) provided- thus only dependent on the thickness d_ε and the proportion of pores n (which remains constant for one product of this stretched nonwovens). The perforation diameter is, therefore, only indirectly dependent on the applied stretching.

As an important result it should be stated that an applied mono- or biaxial stretching (for the selected value $n^4 \bullet d_\varepsilon$) has hardly any influence on the perforation diameter (contrary to the puncture height). The differences in the perforation behaviour of mono- and biaxially stretched samples can be neglected, if the thickness of the stretched samples is considered.

The measuring of thickness of stretched thermally bonded nonwovens resulted in values which were nearly independent of the stretching. Due to the mass per unit area, which decreases when the area remains constant and the stretching increases, the proportion of pores of thermally bonded nonwovens is a value which varies depending on the stretching ($n_\varepsilon \# n$, $d_\varepsilon = d$). Nearly functional relationships for the perforation diameter are achieved -as already in case of unstretched nonwovens- depending on a (stretch dependent) "pore related mass per unit area" $n_\varepsilon{}^4 \bullet m_{A\varepsilon}$. The produced stretching affects a change of the mass per unit area and thus an extension of the perforation diameter in the cone drop test. The fibre type of the product is not important either.

The described relations show that only the changes in thickness, mass per unit area and proportion of pores caused by the stretching are relevant for the evaluation of the perforation; thus the applied stretching is only indirectly included in the mentioned relationships.

5 PROPOSAL FOR A CRITERION OF FLEXIBILITY

Following a criterion of flexibility is recommended in order to determine the possibilities of deformation of geotextiles in their quality.

As "flexibility test" the following test is defined: geotextiles are biaxially stretched in a biaxial tensile testing machine. After the stretching has been achieved, the sample is fixed with clamping rings and is deformed in the plunger puncture test (hyperboloidally) up to the failure. The "load angle" α_B is defined with the angle which occurs at the failure of the sample

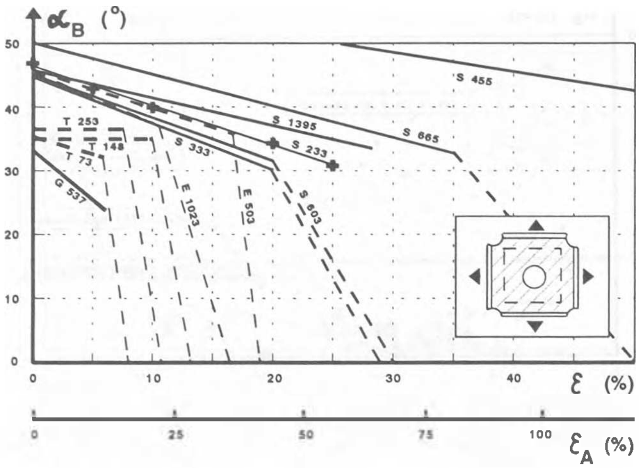

Fig. 6. Flexibility graph α_B = f (ε) (measuring points S 233)

(α_B = 45° means, the plunger way up to the failure corresponds to the distance between plunger and clamping ring).

In Fig. 6 the load angles of the individual geotextiles are applied above the biaxial stretching ε_A. Each presented dashed connection line to the abscissa shows the possible connection to the maximum stretching in the biaxial tensile test.

In Fig. 6 first it is remarkable that all examined products in the unstretched state show nearly the same load angle. The load angle decreases when the biaxial stretching ε_A increases -apart from the tested thermally bonded nonwovens-. Nearly the same tendencies are found for mechanically bonded staple and endless fibre nonwovens.

Due to the basic different possibilities of bonding of different raw materials, nonwovens made of polyester (last digit 3) show smaller load angles α_B than those made of HDPE (last digit 5). Mechanically bonded HDPE nonwovens are extremely flexible. For the product S 455 an area stretching of ε_A = 180 % (maximum due to the technical equipment) could be achieved, i.e. the original area of the sample was nearly tripled) without the product beginning to tear. When the original sample area was doubled (ε_A = 100 %), still a load angle α_B of 45° was achieved.

For the examined thermally bonded nonwovens approx. a maximum area stretching of about ε_A = 10 % is valid.

The woven G 537 could -due to the technical equipment- not be stretched more than presented, however, a decrease of the load angle becomes obvious when the area stretching is increased.

The stretchability of a geotextile, found by means of the biaxial stretching ε_{max} which can be achieved at a maximum in the biaxial tensile testing machine, combined with the value of the load angle at 10 % stretching per axis ($\alpha_{B,\varepsilon=10\%}$) in the plunger puncture test, are regarded as suitable criteria according to Fig. 6. In the following it is valid:

- At an achieved biaxial stretching of ε_{max} = 58.1 % per axis (ε_A = 150 %) a good stretchability of a geotextile shall be valid, at ε_{max} = 10 % per axis a very poor stretchability.
- For the load angle $\alpha_{B,\varepsilon=10\%}$ (in the plunger puncture test) which has been determined for a biaxial stretching of ε = 10 % per axis, a value of 45° shall again represent a very good deformability, a value of $\alpha_{B,\varepsilon=10\%}$ = 35° a very poor one.

Thus the quotients $\varepsilon_{max}/58.1\%$ and $\alpha_{B,\varepsilon=10\%}/45°$ result in the value "1", each for very good stretchability and deformability. Now the aim is to receive as well values in nearly the same range for very poor stretchability and very poor deformability (ε_{max} = 10 % and $\alpha_{B,\varepsilon=10\%}$ = 35°) by modifying one or both quotients and maintaining the value "1" for very good properties. This has been achieved in the following formula:

$$\varepsilon_{max}/58.1\% \approx (\alpha_{B,\varepsilon=10\%}/45°)^7 \qquad (1)$$

Thus the result is the criterion of flexibility:

$$F_K = (\varepsilon_{max}/58.1\%) \bullet (\alpha_{B,\varepsilon=10\%}/45°)^7. \qquad (2)$$

Furthermore, the following division is proposed:

$F_K \leq 0.03$	very low flexibility
$0.03 < F_K \leq 0.10$	low flexibility
$0.10 < F_K \leq 0.30$	medium flexibility
$0.30 < F_K < 1.0$	high flexibility
$F_K \geq 1.0$	very high flexibility

The limits have been chosen in such a way that the requirements increase with the flexibility group and only a small number of products are classified in the groups "high" and "very high" flexibility. For the measure results of the geotextiles mentioned in Fig. 6 the results are the presented "classes" in Table 1.

Table 1. Flexibility classification of the examined geotextiles

Geotextile	F_K	flexibility	Geotextile	F_K	flexibility
G 537	0.001	very low	S 333	0.14	medium
T 73	0.01	very low	S 603	0.17	medium
T 253	0.04	low	S 233	0.25	medium
T 148	0.04	low	S 1395	0.33	high
E 1023	0.08	low	S 665	0.86	high
E 503	0.13	medium	S 455	4.87	very high

It may be stated that the plunger puncture test with stretched geotextiles in connection with the maximum stretching of the geotextiles is a suitable method to assess the flexibility of geotextiles, although the formula which has been developed for this reason and the flexibility limits chosen for it should be confirmed in further tests.

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