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# Investigation on Long-Term Behavior of Geotextiles in Bank Protection Works

# Recherches sur le comportement à long terme des géotextiles utilisés dans la protection des berges

A two years prototype investigation started in 1980 on the long-term behaviour of geotextiles when applied as a filter in bank protection works. Many structures with a minimum age of 7 years, and representing various combinations of circumstances (different types of geotextile, soil, aquatic environment and hydraulic conditions) are involved. The investigation has been set-up primarily to gain knowledge on the hydraulic and soil mechanical behaviour of the geotextile in combination with underlaying soil. Therefore a number of undisturbed ground samples, including the geotextile, are taken in each of the selected sites.
The following laboratory tests have been performed : (a) permeability; both for the ground samples and the geotextile alone, (b) sieve analysis of thin layers of the soil at various depths below the fabric, (c) largest pore sizes of the geotextile and (d) physical-chemical characteristics of the geotextile.
Their results are interpreted by means of a number of factors, enabling judgement of the behaviour of the geotextiles.

Des recherches in-situ sur le comportement à long terme des géotextiles utilisés dans la protection des berges se sont déroulées entre 1980 et 1982. Un grand nombre de constructions, agées d'au moins 7 ans et représentant différentes combinaisons de circonstances (types de géotextile, sols, environnement aquatique et conditions hydrauliques) sont étudiées. Des recherches ont été entreprises principalement en vue d'étendre les connaissances concernant le comportement hydraulique et géomécanique du textile et du sol sous-jacent. Dans ce but, un certain nombre d'échantillons des sols avec le textile ont été relevé dans chaque site sélectionné. Les expériences suivantes ont été réalisées en laboratoire : (a) perméabilité; tant pour les échantillons de sol que pour les textiles seuls, (b) analyses granulométriques de fines couches du sol à différentes profondeurs sous les textiles, (c) caractéristiques des mailles des textiles et (d) caractéristiques physico-chimiques des textiles. Les résultats de ces expériences sont interprétés à l'aide d'un certain nombre de paramètres, permettant ainsi un jugement sur le comportement des géotextiles.

## 1. INTRODUCTION

The "Nederlandse Vereniging Kust- en Oeverwerken" (K&O) started in the seventies a study on standard designs for bank protection works. Its objective is to give standard solutions for the following restricted cases :

- constructions of limited length, for which case normal design procedures would be relatively too expensive,
- constructions being attacked so little, that a minimum construction is sufficient for the given circumstances.

Moreover, costs of bank protection works can be assessed on base of the standard designs in pre-feasibility and feasibility studies.

During the above study it appeared that little was known about the long-term behaviour of geotextiles, being an important part of modern bank protection works. The same lack of knowledge became obvious during the International Conference on the use of fabrics in geotechnics, Paris, 1977.
Both events led to the set-up of a field study to investigate the long-term behaviour of geotextiles when applied as a filter in bank protection works. A pilot investigation, carried out in 1978, brought about that this aim could be attained by setting-up a more extensive investigation (1).
This two years prototype investigation, which started in 1980, is described in this paper. After a brief discussion on the main features of bank protection works and the application of geotextiles in bank protection works, the set-up of the investigation and execution of fieldwork are described. Next, the laboratory tests and their results are presented, followed by the preliminary conclusions drawn so far from the study results.

## 2. MAIN FEATURES OF BANK PROTECTION WORKS

A bank protection must be able to withstand all relevant forces endangering the bank stability. Such forces originate from hydraulic phenomena taking place in the waterway, and can be divided into two types (2) :

a) External forces : acting mainly on the surface layer of the bank protection; being shear and pressure forces due to currents and waves in the waterway.

b) Internal forces : acting on the body of the bank; being pressure forces caused by groundwater flow. Besides the Ground Water Table (G.W.T.), the groundwater flow in the bank is largely influenced by the water level in the waterway and its fluctuations.

Both the external and internal forces thus include (quasi) stationary as well as non-stationary components. Stationary forces are associated with river or canal run-offs, flood waves, tidal motion and seepage flow. Rapidly varied forces are caused by translatory and surface waves and ship induced water motion. With the progressive increase in traffic and ship sizes, the latter is increasingly becoming the major factor governing the design of bank protection works (3).

A bank protection can be either pervious or impervious. The mode of functioning and the mechanisms involved are completely different for both types. In view to the

application of geotextiles as a filter, the discussion in this paper is restricted to the pervious type.
To be able to resist the external current and wave forces, the top layer of the bank protection is usually composed of coarse or very coarse grains. Between this layer and the bank material, one or more layers - called filter layer(s) - are applied. These filter layers are very important; in their absence the bank material can easily erode away amongst the grains of the top layer. The transport would take place due to groundwater flow, which includes here the flow through the grains of the top layer. Depending on the hydraulic phenomena involved, stationary and/or cyclic groundwater flow takes place, having components both parallel and perpendicular to the plane of the bank. For a more detailed discussion of the mechanisms involved, reference is made to (2).

3. APPLICATION OF GEOTEXTILES IN BANK PROTECTION WORKS

Traditionally, granular filter layers have been applied in bank protections, the number of layers being dependent on the size amplification between the bank material and the required top layer. Recently in the Netherlands, geotextiles have been succesfully applied as a replacement of the granular filter layers, not only in bank protection but also in bottom protection works. A typical cross-section of a bank protection including a geotextile is shown in figure 1.

To fulfil its function properly, either the granular or geotextile filter should comply with the following two requirements (4) :
1. It must be more permeable than the bank material, in order to avoid the development of any appreciable uplift pressures.
2. It prevents the bank grains from motion under the effect of expected hydraulic gradients of the groundwater flow (sandtightness).

The Delft Hydraulics Laboratory has developed standard methods to test the above characteristics in the case of a geotextile. These tests, which are described in (5), form a part of the hydraulic tests in the present study.

The geotextile filter has the advantage of being cheaper, easier and quicker in execution than a granular filter. Its main disadvantage, however, is that it is liable to be clogged, not only by silt and other fines in the water or soil, but also due to biological or chemical processes (6). This aspect, and its effect on the functioning of the geotextile, is one of the main items of this study.

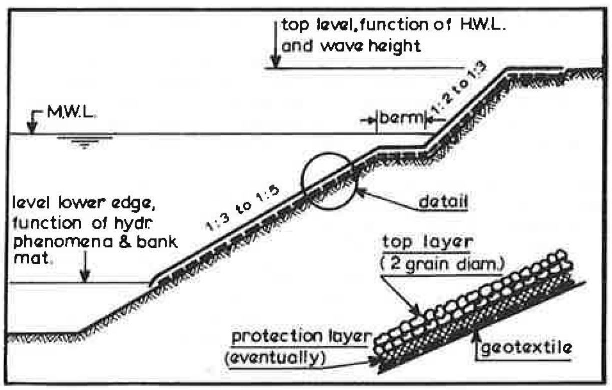


Fig. 1 Typical cross-section of a bank protection including a geotextile filter.

Fig. 2 View of a site during sampling

4. SET-UP OF INVESTIGATION AND EXECUTION OF FIELDWORK

The aim of the investigation is to gain knowledge on the long-term behaviour of geotextiles when applied in bank protection works, particularly with regard to phenomena as ageing, blocking and clogging.
Ageing is a function of composition and characteristics of the raw material used in manufacturing the geotextile water quality (pollution), forces acting on the geotextile and time.
Blocking and clogging are functions of properties of the geotextile (thickness, pore sizes), hydraulic circumstances in the waterway, water quality (silt), composition of the subsoil and time. Their effect may cause a considerable change in the hydraulic gradients and result in an appreciable uplift pressure directly under the bank protection.

The extent of ageing is determined by physical-chemical tests of the geotextile and by comparing the results with the original properties. The extent of blocking and clogging is determined by hydraulic and soil mechanical tests on undisturbed ground samples including the geotextile above it. These laboratory tests are described in section 5.
A similar investigation has been carried out by Heerten (7). However, the geotextile and the subsoil were sampled apart. Due to the ralatively large variations of geotextile and subsoil characteristics, it is important to take samples containing both.

To perform the tests, samples are needed of :
- the geotextile for the physical-chemical tests;
- the geotextile and undisturbed ground samples for the hydraulic and soil mechanical tests.

In the K&O-investigation, samples were taken from 33 sites alongside Dutch canals, rivers and coast. The minimum age of the structures sampled is 7 years. The variables influencing the behaviour of the geotextile in bank protection works are numerous. The most important of these, as well as a broad classification, made in the context of the present study, are given below :

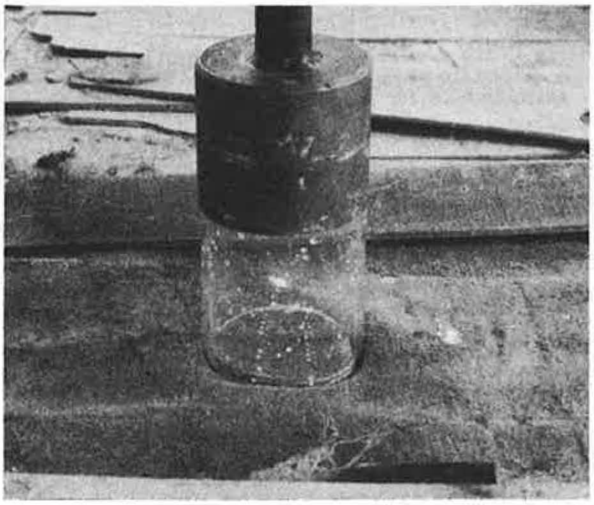

Fig. 3 A plexiglass sampling tube is pressed through the geotextile into the ground.

- Type of geotextile (all woven) : (a) polypropylene, polyethylene (b) polyamide.
- Grain size of the bank material : (a) fine (b) coarse.
- Aquatic environment : (a) salt (b) fresh.
- Hydraulic phenomena acting on the bank protection, including ship-induced water motion : (a) light (b) heavy.
- Location of the fabric : (a) about 1 to 2 m above water level (b) more or less at water level (during sampling). Taking of undisturbed samples under water was not feasible.

The sites selected for sampling were chosen such that all possible combinations of above classes are covered.

The sampling procedure can be divided into three parts :

a) Removing of the surface layers :
First of all the surface layers, covering the geotextile, must be removed. This has to be done very carefully; the geotextile may not be damaged. Mostly a crane is used for the execution of this job. The last layer is removed by hand. The surface cleaned amounts to 20 up to 25 $m^2$.

b) Taking of the samples :
The ground samples are taken by means of a cone penetration apparatus, mounted on a mobile frame (see figure 2). This apparatus presses a plexiglass sampling tube (height 200 mm, diameter 100 mm) through the geotextile into the ground (see figure 3). Prior to this, the geotextile is cut loose circularly (also diameter 100 mm) by a thermal device. Thus, undisturbed samples with a piece of the geotextile on top of it are obtained. Fifteen ground samples are taken at each site. After removing a large piece of the geotextile (about 10 $m^2$), the ground samples are carefully excavated, making sure that they remain undisturbed.

c) Repairing of the construction :
A new geotextile is laid down. The surface layers are restored.

## 5. LABORATORY TESTS AND THEIR RESULTS

### 5.1. Hydraulic and Soil Mechanical Tests

The following tests have been performed at the Delft Hydraulics Laboratory and the Delft Soil Mechanics Laboratory :

i) Permeability tests

A special apparatus has been constructed in which the plexiglass sampling tube can be fitted (see figures 4 and 5). Six holes for connecting 3 mm piezometric tubes are bored, one above the level of the geotextile and 5 below it; at 5, 35, 65, 95 and 125 mm distance.
The piezometric head (h) is measured at the above 6 points at 3 different discharges. The results illustrate the variation of the hydraulic gradient in the bank section under stationary conditions (see figure 6) and provide information on the coefficient of permeability (k) of the various layers directly under the geotextile. The latter is computed according to Darcy's law (i.e. assuming laminar flow).

$$v = k\,i \tag{1}$$

The coefficient of permeability cannot be computed for the upper 5 mm layer soil, since the head difference between points 1 and 2 (see figure 4) includes both the head loss in that layer and across the geotextile.

The head loss over the geotextile is measured in a similar apparatus (see figure 5), where the fabric piece alone is fixed in a socket. In order to count for pre-Darcy regimes (relatively large pores of geotextile), the head difference ($\Delta h$) - filter velocity (v) relationship takes the general form :

$$\Delta h = a\,v^m \tag{2}$$

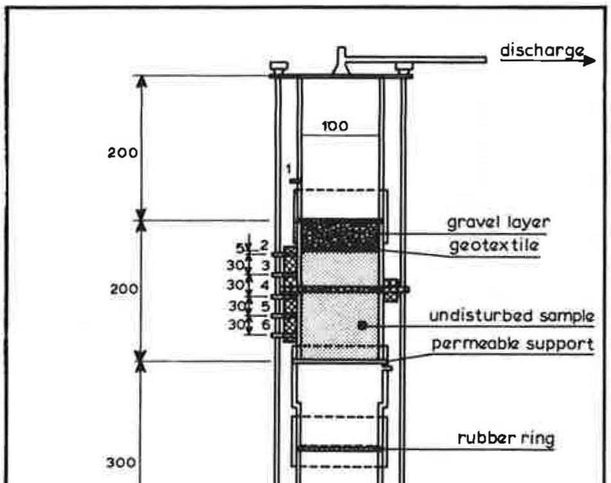


Fig. 4 Permeability apparatus for ground samples

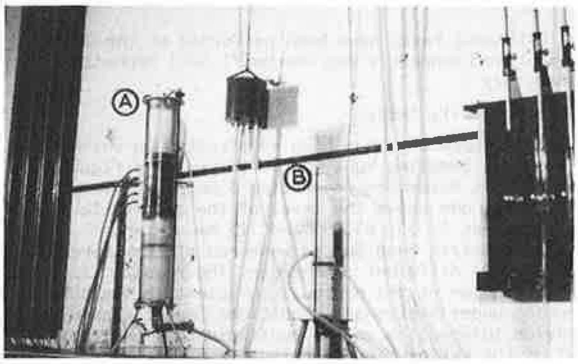


Fig. 5 Permeability apparatus for ground samples (A) and for geotextile alone (B)

where :

a = resistance factor

m = exponent, characterizing the flow regime (= 1 in case of laminar regime, 2 for turbulent regime and in between for transitional regime).

The head difference corresponding to v = 0.01 m/s is taken as the characteristic measure for the geotextile permeability (notation $\Delta h_1$) (4).

The fabric piece on top of the ground sample is first tested. The resulting $\Delta h_1$ is characteristic for its state in the bank protection during sampling. Thereafter, the geotextile piece is cleansed by laying it in an ultrasonic bath for about 30 minutes. The cleansed geotextile is re-tested, yielding $\Delta h_1^*$, which is considered representative for the original state of the geotextile. The above tests have been performed on 5 of the 15 undisturbed samples taken at each site.

ii) Sieve analysis of bank material at various depths

A sieve analysis of 4 thin layers has been carried out on another 5 of the undisturbed ground samples. The layers have a thickness of 5 mm each, being taken between 0-5 mm, 5-10 mm, 10-15 mm and 150-155 mm under the geotextile. The analysis took place by means of standard sieves ($\geqslant$ 37 µm) or by deposition in the cylinder of Attenberg or in an areometer.

The tests (i) and (ii) aim to provide information on possible changes in the composition of the bank material directly under the revetment, as well as changes in the permeability of the geotextile. Two examples of the results obtained are shown in figure 6, giving the readings of the 5 samples used in both tests. The piezometric heads are given as a percentage of the head difference

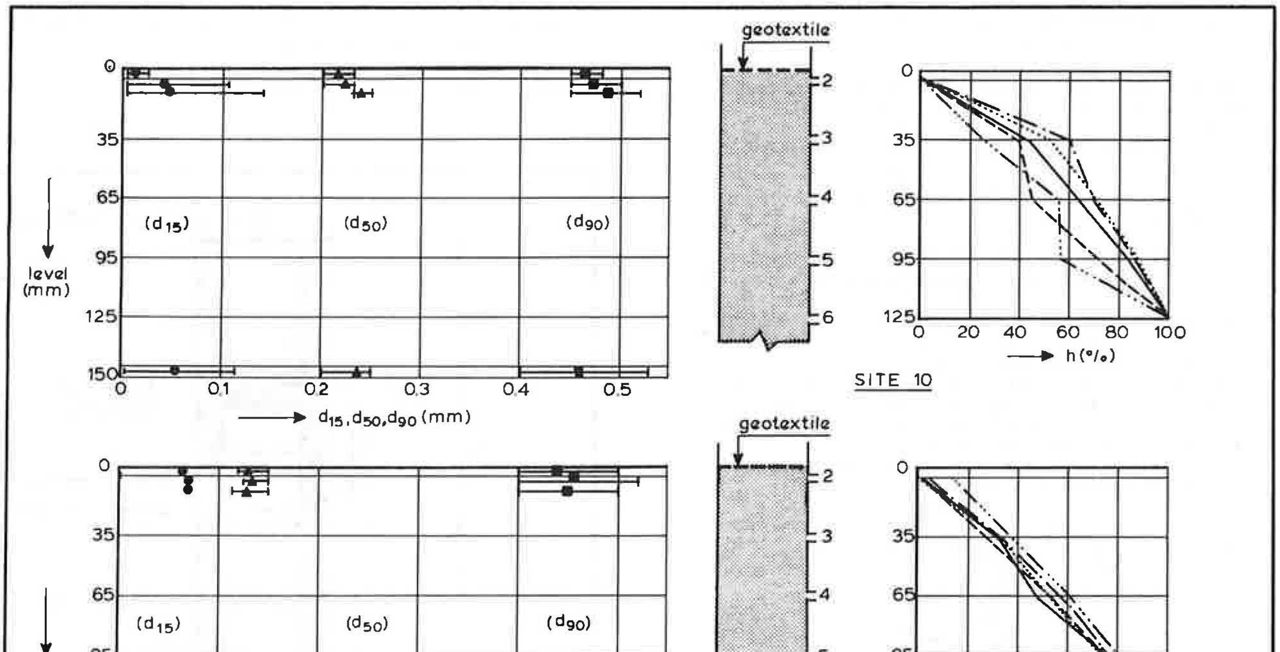


Fig. 6 Two examples of tests (i) and (ii)

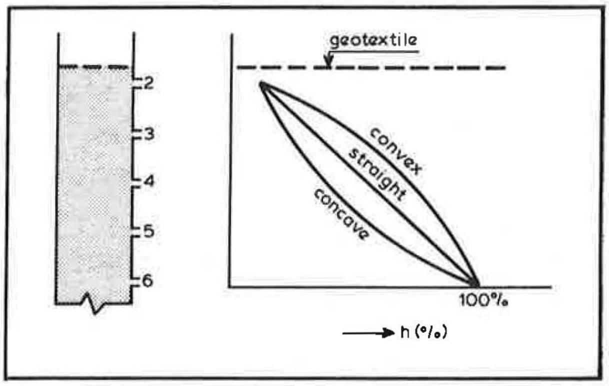


Fig. 7 Form factor hydraulic gradient

between points 1 and 6. Both the mean and the variation (amongst the 5 samples) of the characteristic grain diameters $d_{15}$, $d_{50}$ and $d_{90}$ are shown in the left figure.

The behaviour of the geotextile in the bank protection is judged on base of the following 5 factors, to be determined from the test results :

a) Form factor hydraulic gradient (see figure 7), giving an overall description of the variation of the hydraulic gradient as a function of depth and hence possible changes in the composition of the soil.

b) $F1 = (\Delta h_s - \Delta h_a) / \Delta h_s$ (see figure 8), providing information on the variation of the permeability of the upper 5 mm soil layer relative to the 30 mm layer directly below it.

c) $F2 = (\Delta h_1 - \Delta h_1^*) / \Delta h_1^*$ (see under (i)), yielding the degree of reduction in the geotextile permeability, due to blocking or clogging.

d) $F3 = \Delta h_b$ (in % relative to h at point 6, see figure 6), indicating whether appreciable uplift pressures can be feared. Taking into consideration possible changes in the composition of the subsoil, the permeability design requirement of the geotextile (section 3) can be translated as follows. The hydraulic gradient directly under the toplayer (arbitrarily taken here over the geotextile and underlaying 5 mm soil $= i_g$) must not show an abrupt increase with respect to the average gradient in the subsoil (i). An acceptable $i_g/i$ ratio depends on the prevailing groundwater

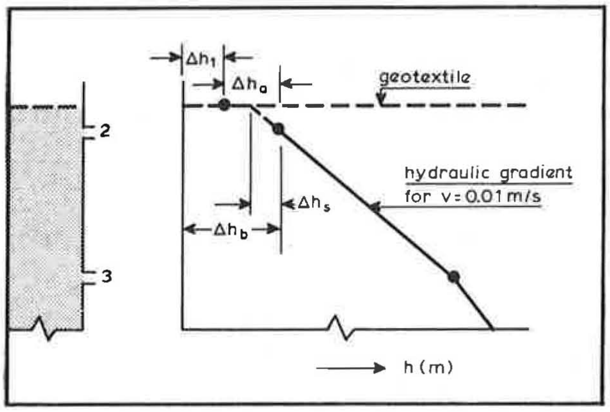


Fig. 8 Basic quantities for calculating factors F1 to F4 (computed for v = 0.01 m/s)

flow and submerged weight of the top layer(s). In the present investigation it has been arbitrarily taken = 2 to 3, which means that there is no fear of unfavorable uplift pressures as long as F3 < 10 % (depth ratio = 1:25).

e) $F4 = \Delta h_1 / \Delta h_b$ (see figure 8), indicating whether an uplift pressure is mainly due to geotextile clogging or due to blocking of the underlaying subsoil.

The above factors as calculated for the two examples shown in figure 6 are given in table 1, together with the subsequent judgement.

The agreement between the conclusions based on the above factors and the results of the sieve analyses (ii) is - in general - moderate. A difficulty thereby is the relatively large scatter in the results.

(iii) Pore sizes of the geotextile

A standard sieve test (5) has been applied to determine the largest pore sizes of the geotextile samples taken at the various sites. Because the geotextile with a sand fraction on top of it is vibrated, the $O_{90}$ and $O_{98}$ determined can be considered to apply for the cleansed geotextile, i.e. in its original state. They are to be compared with the characteristic grain diameters of the subsoil.

For the 33 sites investigated, an analysis - relating the results of tests (i), (ii) and (iii) to the parameters influencing the behaviour of the geotextile - is being currently made.

Table 1. Factors judging long-term behaviour of geotextile

| site | sample | Factors | | | | | Judgement |
|---|---|---|---|---|---|---|---|
| | | Form factor | F1 | F2 | F3 | F4 | |
| 10 | 1 | convex | 0.9 | 34.7 | 0.4 | 1.2 | * Limited layer under the geotextile has become less permeable (except upper 5 mm). |
| | 2 | convex | 0.9 | 169 | 0.5 | 1.5 | * Factor F1 does not agree with sieve analysis results. |
| | 3 | convex | ~1 | 214 | ~0 | --- | * Geotextile clogging is considerable. |
| | 4 | convex | ~1 | 289 | ~0 | --- | * Nevertheless no fear for appreciable uplift pressures. |
| | 5 | straight | 0.7 | 319 | 1.1 | 1.3 | |
| 11 | 1 | straight | 0.8 | ~0 | 0.8 | 0.6 | * Generally no changes in the subsoil. |
| | 2 | straight | 0.6 | 0.6 | 1.7 | 1.0 | * Locally geotextile moderately clogged. |
| | 3 | straight | 0.4 | 11.9 | 2.9 | 7.5 | * Locally fear for appreciable uplift pressures, mainly due to blocking of subsoil. |
| | 4 | straight | -2.7 | ~0 | 14.6 | 0.1 | |
| | 5 | straight | 0.6 | ~0 | 1.6 | 0.3 | |

5.2. Physical-chemical Tests

Tests have been performed at the Fibre Research Institute TNO, Delft (physical tests) and at the Plastics and Rubber Institute TNO, Delft (chemical tests). The results of these tests are compared with the original properties, in order to evaluate the ageing of the geotextiles.

(iv) Physical tests

According to Dutch standards, tests are performed determining the number of threads per 100 mm, yarncount, crimp, breaking strength and elongation at break.

(v) Chemical tests

Tests are performed in order to determine the type of polymer, ratio of weight polypropylene / polyethylene (polypropylene tape fabrics may contain a percentage polyethylene), quality and quantity of additives and thermal resistance. These tests are described in (8).

(vi) Original properties

Comparing the results of above tests with the original properties gives knowledge about possible degradation of the geotextile and the expectation of its long-term behaviour. The tracing of the original properties is sometimes obstructed by the absence of data.
Physical properties have been traced for 70 % of the geotextiles sampled. To determine the chemical properties of the raw material, "archive" geotextiles have been tested, i.e. geotextiles, having the same quality and being as old as the geotextiles sampled. These geotextiles have been stored in an archive. In this way, a good picture is formed of the composition of the raw material, mostly not changing for a number of years. The chemical tests on the archive geotextiles are still running.

Table 2 shows some results of the physical tests of a polypropylene, a polyethylene and a polyamide geotextile. Also the original properties, so far as known, are presented. The mass is calculated from the properties determined.

From the results obtained so far, it appears that geotextile clogging with materials containing iron compounds shortens its lifetime.
Both the physical and the chemical test brought out that some geotextiles were manufactured from yarns of different composition. The location of the geotextile (above water level or more or less at water level) does not lead to differences in degradation of the properties of the geotextile.

Table 2. Results of physical tests

| Properties | Geotextile | | | | | |
|---|---|---|---|---|---|---|
| | polypropylene | | polyethylene | | polyamide | |
| Year of construction bank protection | 1970 | | 1969 | | 1969 | |
| | now | original | now | original | now | original |
| Mass per unit area $\mu$ ($g/m^2$) | 120 | 116 | 212 | 220 | 110 | 92 |
| Breaking force $F_T$ (N) * | | | | | | |
| warp | 26.8 | 34.0 | 26.9 | 30.2 | 12.7 | 13.7 |
| weft | 20.6 | 27.8 | 27.2 | 27.0 | 10.5 | 13.7 |
| Elongation at break (%) | | | | | | |
| warp | 9.0 | 16 - 18 | 26.3 | 34.5 | 20.1 | 20.4 |
| weft | 6.5 | 16 - 18 | 21.2 | 23.5 | 21.0 | 20.4 |

* $F_T$ now : According to International Standard ISO 2062

6. CONCLUSIONS

The conclusions drawn so far are :

1. Changes in the composition of the subsoil usually extend some 40 to 70 mm below the geotextile in bank protection works, sometimes even down to 120 mm or more.
2. The largest changes take place in a thin layer (order of magnitude 5 mm) directly under the geotextile.
3. At the majority of sites investigated, the geotextile was found to be clogged, sometimes to a very large extent. This aspect should therefore be taken into consideration in the design.
4. Appreciable uplift pressures may result due to blocking of the upper soil layer. Clogging of the geotexile has not been the reason in any of the sites investigated, because its permeability is and remains larger than that of the subsoil.
5. Geotextile clogging with materials containing iron compounds shortens its lifetime.
6. The location of the geotextile (above or at water level) does nog affect the degradation of its properties.

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