Third International Conference on Geotextiles, 1986, Vienna, Austria

MOUW, K. A. G. and NEDERLOF, K. D. C., Rijkswaterstaat Oosterschelde Storm Surge Barrier, Netherlands
STUIP, J., Delft University of Technology, Netherlands
VELDHUIJZEN VAN ZANTEN, R., Nederlandse Vereniging Kust- en Oeverwerken, Netherlands

GEOTEXTILES IN SHORE AND BOTTOM PROTECTION WORKS

APPLICATIONS GEOTEXTILES POUR LA PROTECTION DES BERGES ET DES FONDS

GEOTEXTILIEN IN UFEREINFASSUNGEN UND SOHLENBEFESTIGUNGEN

The design of geotextiles in shore and bottom protection works is described in this paper. In an introduction some typical aspects of protection works are discussed with particular reference to geotextiles, attention being given to the functioning of a geotextile in such works. The various limit states, which arise and lead to design criteria in both the construction stage and the end use are discussed. These include, for example, mechanical, hydraulic, chemical and biological limit states.
The influence of various types of construction materials on the design of geotextiles is mentioned. These materials include dumped and placed stones, asphalt and concrete materials and sheet piling. Attention is given to the specific construction aspects when geotextiles are applied above water-level and below water-level.
Also special attention is given to details of transitions between different structural elements and edges.

Der Bericht beschreibt den Entwurf von Geotextilien in Ufereinfassungen und Sohlenbefestigungen.
In einer Einführung werden einige spezifische Gesichtspunkte im Hinblick auf die Verwendung von Geotextilien betrechtet, wobei gerade die Funktion der Geotextilien in solchen Einsatzbereichen berücksichtigt wird. Die verschiedenen Grenzzustände, die entstehen und zur Aufstellung von Kriterien führen, werden eingehend besprochen. Das sind z.B. die mechanischen, hydraulischen, chemischen und biologischen Grenzzustände.
Die Einflüsse der verschiedenen Baustoffe auf den Entwurf der Geotextilien, werden beschrieben. Die spezifischen konstruktiven Gesichtspunkte in Fällen, in denen Geotextilien sowohl oberhalb des Wasserspiegels wie unter dem Wasserstand verlegt werden, werden berücksichtigt. Besondere Aufmerksamkeit wird auch der Detaillierung von Übergängen zu anderen Bauteilen und Anschlüssen gewidmet.

INTRODUCTION

The main elements of a revetment (figure 1) are a covering top layer, a filter layer and, sometimes, one or more intermediate layers.

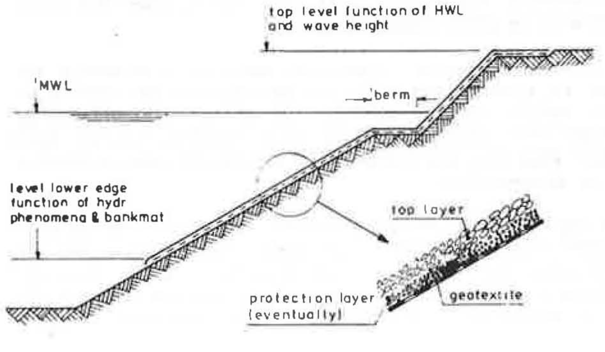

Figure 1: Main elements in a revetment.

The top layer which, in particular, must be able to resist external forces acting on the construction, can be made from various materials or from combinations of materials.
An intermediate layer may serve as a transitional layer between other layers, and/or as a protection for the filter layer. Various materials can also be used for this layer.

The filter layer may consist of one of the following types of materials:

a. granular filters:
- loose grains
- bonded grains
- packed stones

b. fibre filters:
- synthetic materials
- natural materials

ad. a.
In general loose granular filters can have the following advantages:
- under certain circumstances the are "self-healing";
- the elements are generally very durable;
- there is good surface contact between the layers above and below (easy to repair).

Possible disadvantages are:
- larger construction height;
- the spreading composition of the filter;
- the poore dimensions are not known.

ad. b.
Fibre filters can be composed of synthetic materials (geotextiles) or natural materials (e.g. the classical willow mattings). Geotextiles, in particular, have the following advantages:
- small construction height;
- the material has tensile strength in its plane;
- geotextiles are relatively cheap.

Possible disadvantages are:
- uncertainty in the extrapolation of the long-term behaviour;
- connections, particularly with the subsoil, must be made very carefully;
- geotextiles are easily damaged, and rather difficult to repair;
- geotextiles do not follow uneven settlement as well as granular filters.

THE DESIGN OF FILTER ELEMENTS

In situations where a certain load is about to exceed the matching property of strength of the structure, the concept of a "limit state" is introduced. The limit state defines the particular condition of a construction in which it just still fulfils its function.

One of the principles upon which the final choice is based, is the requirement that the strength exceeds the occurring loads. There are two ways to obviate the unacceptable behaviour of a construction:
- by trying to decrease the level of the loads;
- by trying to increase the strength of the structure.

Often the uncertainty concerning the expected load and the target at strength of the construction is accounted for by the application of a safety margin.
The fundamental parameters, which are components of the theoretical relationships upon which the design is based are referred as the basic variables.

There are several ways to distinguish the limit states that have a bearing on geotextiles:
- by the period of occurrence;
- by the nature of the representative load;
- by the properties of the geotextile, for which requirements follow from the limit state.

Also catagorization following the stage of the project is possible (execution, use, rehabilition, demolition, etc.).

Basic variables are:
- local conditions (bankgeometry, stripping, open water level, subsoil condition);
- gradient;
  The performance of the gradient within the construction and the related gradient per distinctive layer depend on:
  - the velocity with which the total fall is imposed; The quicker the waterlevel falls in an open watercoarse, the larger the local head losses will be;
  - the ratio of the permeability of each layer, including the geotextile;
  - the thickness of the separate layers.

In figure 2 various cases are given (l = low, h = high permeability).

The overview shows cases in which the groundwater flow runs off the talus. It appears that the largest pressure drop along the geotextile occurs in the case of low permeability of the geotextile whether or not in combination with a permeable subsoil and a very permeable top layer. The stability of the top layer is also influenced by the permeability of the underlying layers.
A larger gradient over a layer results in a higher load on the specific layer, and in smaller loads on the other layers. In this way the load can be "diverted" to a certain part of the construction, making it possible to dimension on that consciously.
The magnitude of the uphight pressure depends on the relative permeability of the top layer. Figure 3 gives three examples for a complete watertight revetment, an intermediate and a very permeable top layer. For proper functioning geotextiles the last case is in general present.

The water permeability of the geotextile is related to the flow through the construction; there are:
a. situations in which a good connection exists between the geotextiles and the layer to be protected;
b. situations in which this is not the case and some space is present, such as pits, channels, etc.

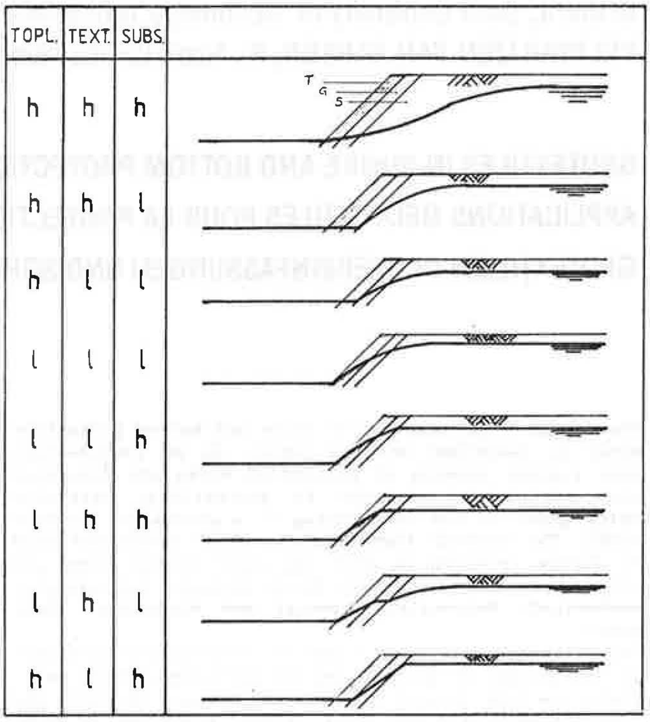

Figure 2: Various combinations of permeability of effect on gradient.

ad. a: Good connection. Here the specific discharge q throught the geotextile is equal to the discharge from the subsoil when the groundwater flow is exclusively perpendicular to the geotextile: qg (geotextile) = qb (subsoil). No erosion will then occur, when the sandtightness is also right.

ad. b: An incomplete connection. Here it is possible for water to flow parallel to the geotextile for some distance before leaving through the filter. The discharge through the geotextile may than locally become much higher than the discharge in the subsoil (perpendicular to the geotextile).

When applying the filter criteria, a distinction is made between stationary and cyclic load. The boundary between stationary and cyclic is not clearly defined. This depends not only on the nature of the load but also on the way in which the construction, or a component, reacts.

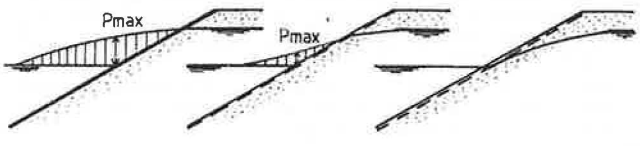

Figure 3: Various cases for permeability of revetments and consequences for pressure distribution.

Perhaps it is possible to speak of filter fatigue. This refers not to mechanical fatigue of the geotextile material, but to the underlying basic material, in particular erosion of the thin filter cake near the interface. With a large number of load changes, a greater amount of basic material is likely to disappear.
To prevent this, the acceptable gradient must be lower. Some cyclic loads are given below, together with their period (order of magnitude). Also indicated is where the stationary situation becomes cyclic.

Table I: Cyclic load and related period.

phenomenon	period(s)	remark
storm surges	10^6	to be considered
tidal waves		stationary for
seiches	10^3	geotextiles
translation waves		
swell		transitional area
wind waves	10	
ship waves	2	cyclic
turbulence		
dynamic impacts	0.01	

The character of the load (or better load effect = gradient) has an impact on the criteria for various criteria for geotextile performance.
For instance, based on laboratory research and field experience, the data given in table II are now suggested to be used as soiltightness criteria.

Table II: Suggested criteria for soiltightness as a function of character of the load and expected consequences or extend of damage.

situation	soiltightness number	criterion
stationary	$O_{90}/d90$	$\leqslant 2$
cyclic with natural filter	$O_{98}/d85$	$\leqslant 2$
cyclic without natural filter		
a. consequences not expected	$O_{98}/d15$	$\leqslant 1.5$
b. consequences expected	$O_{98}/d15$	$\leqslant 1.0$

LIMIT STATES

The concept of limit state is usual in construction engineering. Nowadays this concept becomes also a basis for designing hydraulic structures.
The engineer is forced to express the behaviour of the structure or element and the acceptable limit related to its functioning exactly.
For a geotextile many limit states have to be described and for a specific application to be quantified. Below a list of various limit states is given with some remarks.

Soil tightness

This limit state describes the situation in which erosion of bed or bank material is opposed by the geotextile. This situation occurs as soon as the gradient, or in a given case the flow, in the bed or bank has become such that grains are transported through the geotextile (in terms of gradient i actual > i acceptable). In this case the supply of granular material and the "driving" gradient are the loads, while the soil tightness the geotextile can be regarded as the strength.

Depending on the consequences of exceeding the safety margin between load (or load effect) and strength a criterion is stated (see table II). For instance a low rate of transport of bed material is excepted for a revetment but probably not for a fundation mattress under a concrete superstructure (pier, quaywall, etc.).

Permeability

The geotextile is a filter for the bed material, but also a resistance for the groundwater flow. This introduces a pressure gradient over the geotextile which should be below a limit, following from the equilibrium for a section of the revetment. The flow can be considered as the "load" on the geotextile and its permittivity as the "strength", both resulting in the flow pressure. The flow pressure belongs to the "internal hydraulic loads" category for the construction as a whole.
The flow pressure can vary in time by:

- variations in the flow or, in a given case, the slope in the construction, caused by the changes of internal and external water levels.
- a change in the permeability as a result of, for instance, the clogging of blocking of the geotextile, or, during the construction stage, by the placement of concrete blocks directly onto the fabric.

Excess pressure in itself is tolerable as long as it is compensated by overweight, thus preventing lifting of the filter.
Excess pressure can also be tolerated, provided that it does not cause any softening of the subsoil, which can lead to sliding as a result of a decrease in the shear stress that can be taken up. The excess pressure experienced, depends on the amount of water to be discharged. This amount can vary widely and the maxima can often only be estimated.
Based on the requirement that the gradient over the geotextile, ig, may be at its maximum equal to the gradient of the subsoil, ib, it is possible, by taking into account the characterization of the permeability of the geotextile by Δhl, to adopt the following criterion:

$$\Delta hl \leqslant ib\ 1\ .\ Tg$$

ib 1 = the gradient in the basic or bed material, u being equal to 0,01 m/s
Tg = the thickness of the geotextile

In fact, this limit state brings the filter into harmony with the subsoil. One prerequisite is a uniform contact between the geotextile and the subsoil, since the relation $qf = qb$ breaks down as soon as the filter is insufficiently connected.

Blocking

"Blocking" is the reduction of permeability as a result of grains from the protected layer blocking the openings in the geotextile. This may result from high filtration rates and/or too small openings in the geotextile.
Blocking is a function of:

- type of synthetic filter; from Ogink (1975) it follows that the risk is highest at $O_{90}/d90 \approx 1$;
- characteristics of bed material related to those of the opening distribution of the geotextile. For uniform characteristics of these the risk for blocking is higher;
- time and frequency of load effect (gradient).

Clogging

A geotextile can become clogged as a result of:

- pollution by silt deposit;
- accumulation of silt under the geotextile;
- caking of chemical compounds;
- overgrowth.

Besides the aspects mentioned under "blocking", clogging also depends on the water quality. If, during the execution, the talus that must be covered remains unprotected for a longer period in calm conditions, the possibility exists that a thin silt layer will deposit on it. This layer may later cause clogging.

Fabric flapping
"Fabric flapping" refers to the fact that the fabric will work free from the underlying layer due to cyclic loads. The movement of the geotextile between the stones can cause it to wear out.
In addition the subsoil underneath the fabric may get "liquefied" as a result of the increase in water pressure in the grain skeleton. This endangers the stability of the individual grains, and leads to grain movement along the talus or in the direction of the groundwater flow, over small distances. In this case local depressions may develop which can lead to settlements and (too) high (tension) loads on the geotextile.
In addition the natural filter layer under the geotextile is decomposed and individual grains may readily disappear through the textile. This again may cause the formation of depressions.

Uplift
The uplift of floating criterion is established in order to prevent lifting of the revetment. In other words, pressures which can force up theconstruction should not develop. This can only be achieved if the maximum water pressure does not exceed the dead weight component perpendicular to the talus (figure 4).

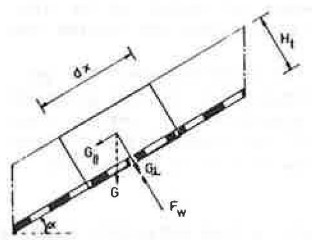

Figure 4: Uplift.

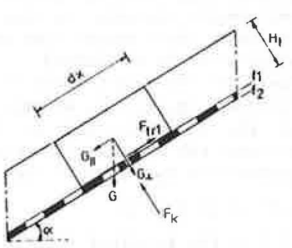

Figure 5: Toplayer over geotextile.

Toplayer over geotextile
In figure 5 the scheme is given for equilibrium. The friction force is acting on the geotextile and causes stress in it. The reaction force for the geotextile may come from the friction between geotextile and subsoil (figure 6) or from stable upper parts which means a relatively high stress in the geotextile.

Toplayer and geotextile over subsoil.
Figure 7 gives the scheme for equilibrium.

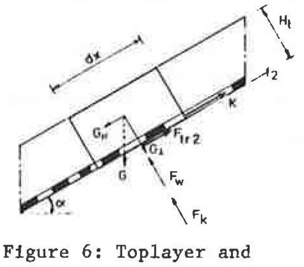

Figure 6: Toplayer and geotextile over subsoil.

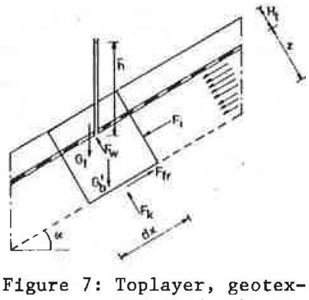

Figure 7: Toplayer, geotextile and subsoil over subsoil.

Toplayer, geotextile and subsoil over subsoil
This limit state describes the sliding of the entire bank protection or a part of it, which may result in tensile stresses in the plane of the geotextile (figure 7). Exceedance can be avoided if the friction under the lining is sufficiently great.
When this limit state is exceeded the construction may hang on an upper (stable) part.

Subsoil/subsoil sliding
This limit state describes the situation in which a slip of the subsoil slips locally under the construction, for example liquefaction. To understand this limit state two extreme cases must be considered:
- very impermeable geotextile; the groundwater runs off parallel to the talus and a static flow pressure exists below the impermeable geotextile (see also figure 3).
- very permeable geotextile; in this case there is a discharge of groundwater from the talus.

Exceeding this limit state the settled subsoil (due to the larger deformations after sliding) is now the active component and the subsoil is "hanging" on the geotextile.

Deformation of subsoil
The situation occurs in which the subsoil locally deforms, while the adjacent part remains unchanged. The deformation can be divided into two categories:
1. non-uniform settlement
2. transport of material underneath the geotextile

ad. 1
Non-uniform settlement may be caused by:
- compaction, for instance as a result of wave impact;
- variation in the bearing capacity of the subsoil;
- variation in the top load, for example in case of a top layer of dumped stones.

Possible consequences for the geotextile are:
- a non-flat surface, causing an increase in tension and strain;
- a change in soil tightness and permeability;
- an increase in the space unterneath the geotextile. This may increase the probability of erosion parallel to the geotextile. The geotextile will at the same time act as a bridging, bearing the full load of the top layer.

ad. 2
Possible causes are:
- excavations along the border of the geotextile;
- an inadequately soil-tight geotextile as a result of:
  - an open geotextile;
  - damage in the form of wear or tears;
- an inadequate connection with the layer to be protected, thus making erosion along the talus and/or via overlaps and seams possible.

Requirements of a geotextile regarding material transport are in essence the primary soil-tightness requirement and the care for a good connection. Nevertheless the geotextile must be dimensioned in such a way that a local excavation does not cause tearing.

A conservative estimate of the tensile stress in the geotextile can be made by means of the catenary formula. This can be used in cases of very local peak loads caused by sagging stones as well as in cases where the geotextile is bridging the space underneath it (fig. 8).

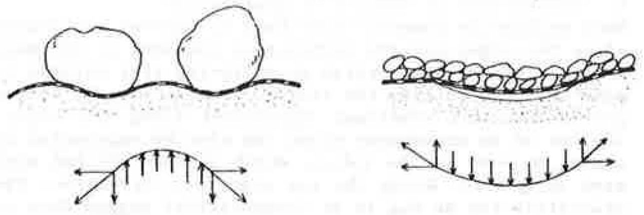

Figure 8: Catenary in a geotextile due to deformation of subsoil.

Atmosphere
- Radiation:
  Polymers are disintegrated more rapidly under the influence of UV-radiation.
- Temperature:
  Excessively high temperatures, not only in the completed structure but also during the storage of the geotextile material may cause deformations such that the geotextile fails to be processable. Temperatures that are too low may affect the material of some geotextile types.
- Wind (erosion):
  Wind may cause erosion, which exposes the geotextile. This leads to the attack by UV-radiation, as mentioned above. The geotextile may start to flap due to the sucking action of the wind. In the long run, the wind may cause abrasive wear of the geotextile.
- Ice:
  Floes of ice may move aside the stone layer protection and subsequently wreck the unprotected geotextile. Floes may also be carried onto the talus, by the wind of as a result of the raising of the water level by the shipping traffic.

Biological environment
- Man:
  Man comes into contact with geotextiles in practising his profession. This includes not only execution, management and maintenance of the construction, but also agricultural activities such as the mowing of grass. In order to prevent the geotextiles form being affected by ignorance, good instructions are necessary. For recreation it is advisable to install special "recreation-friendly" constructions (fishing and mooring sites).
- Animals:
  Geotextiles can be protected against rodents by the addition of glass fibres as components of the material.
  To protect the geotextiles against grazing cattle, a sufficiently thick covering must be applied.
- Overgrowth:
  Due to overgrowth the lining receives a tighter structure. Therefore in some cases it is stimulated.
- Micro organisms:
  In practice, there has until now been little or no evidence of damage to geotextiles by bacteriological impacts. However, when using geotextiles in drainage applications, some bacteria may cause clogging.

Dumping on the geotextile
The application of a rip-rap protection is a construction stage activity, that can pose a severe threat to the condition of the geotextile. The extent of damage is influenced by the following factors:
- The impulse (mass multiplied by velocity, depending on the fall height) of the stone.
- The shape of the stones, with sharp, hard crushed stones being the most unfavourable.
- The tension in the geotextile which often occurs due to anchoring the fabric along the upper side.
- The properties of the geotextile, such as mass per unit area, elongation and the physical properties.
- The stiffness of the subsoil. A greater stiffness provides more collision energy in the form of heat.
- The situation, wet or dry. Falling stones in water have a lower velocity but an additional virtual mass due to the water carried along.

Mattress towing
The forces on the mattress when it is being towed, are uniformly distributed by a beam which is necessary for sinking operation, or by a pontoon, which is often placed in front during towing.

Positioning and sinking
The load acting due to placing and sinking totally depends on the method applied. When using a lifting frame and a slideway the catenary formulae can be applied.

Driving on the geotextile
When the geotextile is spread out and during the dumping of stones that follows there is often the inclination to drive on the geotextile with the supplier equipment. This can cause damage to the geotextile due to the impressing wheels or the stones being dumped on the (in a sense) tensely spread fabric.

Filter fabric heating by asphalt
If warm asphalt is applied on to the geotextile, the contact surface between the two materials will assume a temperature lying between ta (asphalt) and tg (geotextile). The contact temperature tc depends on the thermophysical properties of both materials.

Accidental loads of load effects
These loads have not a stochastic character as the above mentioned limit state states, but are exceptional loads. It depends on the philosophy of the engineer, designer or principal in which way these accidental loads are taken into account.
- Earthquakes
  Generally, geotextiles applied in bank and bed protections have limited strength. Only in a case where the geotextile is also meant as reinforcement must the material have a certain strength.
  Sometimes where earthquakes are frequent statistical data are available to quantify the limit state and the geotextile may have a stabilizing or strengthening function.
- Damage by shipping
  At these anchor sites damage can be prevented by a stone layer some meters thick.
- Chemical calamity
  During transport of chemical compounds there is an increased risk of high concentrations flowing into the water. This may affect the geotextiles present. To avoid or delay replacement special geotextiles may be applied at places where the risk of chemical attack is high (for instance at a port of trans-shipment).

TRANSITION AND EDGE DETAILS FOR CONSTRUCTIONAL ELEMENTS

The same functional requirements as for the normal sections of a bank or bottom protection are generally valid for transitions between different elements and edges of the structure.
Preferable discontinuities in properties of a revetment should be minimized, while during execution special attention has to be paid to these transitional zones. The location of a transition zone can probably be chosen where the (hydraulic) loads are lower or there may be enough freedom in the design to create such a location of lower hydraulic load.

Distinctions can be made between:

a. Joints between identical systems.
In almost all cases these joints can be formed by overlapping of the geotextile and in case of the construction or composition above water by sewn seams. The revetment continues without interruption (loose ballast systems) or also has a joint (prefabricated systems).
For bank protections overlaps are usually made perpendicular to the crest line. Overlaps parallel to the crest line are avoided because of possible tensile stresses during a slide. For bottom protections overlaps are made in both directions.

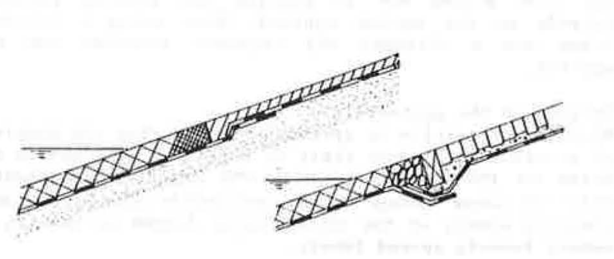

Figure 9: Transitions between different systems.

b. Transitions between different systems.
Particularly with revetments a different system is often used for bank protection above and below the water level. The transition between the two systems often occurs above the lowest water level (average low tide in case of seadikes and normal level for river embankments).
At this transition the slope of the seadike or embankment often merges with the flatter foreshore or in the absence of a flat foreshore a specially constructed berm. The transition is then called a toe construction. However, the slope transitions can also exist higher up, for example, because of repair works or extension of a revetment.
For the transition between a geotextile and a granular filter a form of overlapping can also be applied. The geotextile is then continued over some distance below the adjacent construction, always in such a way that no "leak" can develop, even if differential settlement should occur. Examples of this are shown in figures 9 and 10.

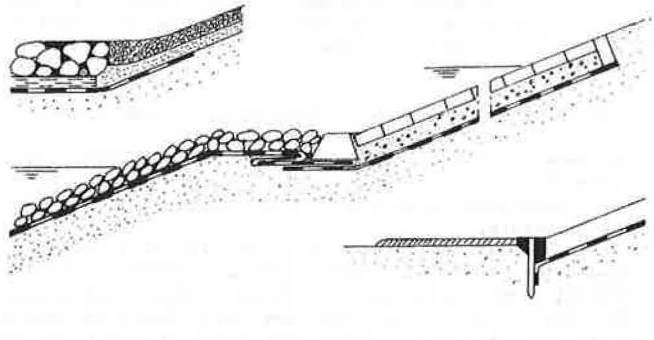

Figure 10: Examples of toe constructions.

c. Terminations of systems or geotextiles.
Many geotextile constructions have no special provisions along the edges and the termination consists of the edge of the prefabricated system or a rip-rap that extends to some distance outside the filter. Terminations of bottom protections are sometimes aggravated along the edges. The toe of an underwater slope can also be aggravated by making a seam in the fabric which is then filled with sand or gravel. Along the top edge of a revetment, the geotextile can be dug in or (temporarily) pegged down to form a type of anchorage which should prevent sliding (figure 11).
It should be noted that tension in the geotextile during dumping of the rockfill can cause a greater risk of damage and at the same time creates an unfavourable condition for a good contact with the subsoil. To avoid this tension, the geotextile can be provided with pleats. Pitched work is usually confined at the upper part by boards.

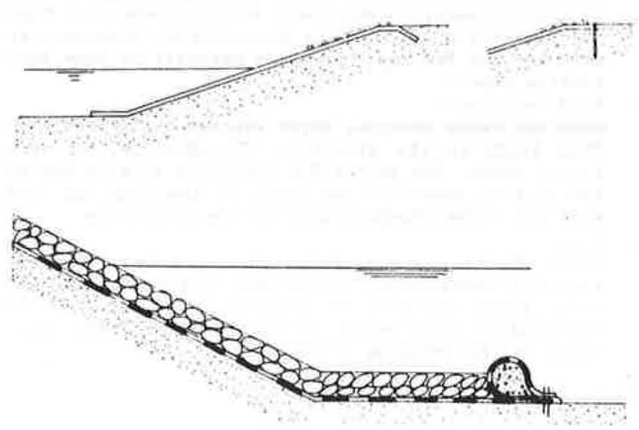

Figure 11: Examples of terminations.

d. Connections to particular parts of a structure.
This comprises in particular connections of geotextiles to sheet piles, toe boards, concrete beams or perforations for anchor rods or pipes, etc.
It can be stated that a design has to be suitable for geotextiles, which means that attempts should be made to achieve flat connections without sharp irregularities. Forces should preferably be transferred by means of line connections and not by point connections.

Acknowledgement
The authors wish to thank the editors and authors of the Manual on Geotextiles and Geomembranes in Civil Engineering for their permission to publish this paper.

REFERENCES
1. The Netherlands Geotextile Organisation (N.G.O.), "Geotextiles and Geomembranes in Civil Engineering"; Balkema, A.A., Rotterdam 1986.
2. Technical Advisory Committee on Waterdefences, "The use of asphalt in hydraulic engineering", Rijkswaterstaat Communications, The Hague 1985.
3. Nederlandse Vereniging Kust- en Oeverwerken, "Kunststoffilters in kust- en oeverwerken", Rotterdam 1982.
4. Nederlandse Vereniging Kust- en Oeverwerken, "Handboek oeverbeschermingskonstrukties", Rotterdam 1983.