Designing of Revetments Incorporating Geotextiles

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ABSTRACT: There is a great number of research reports and publications on filtration of geotextiles and their application in revetment structures. But still, there is a misunderstanding about the function of geotextiles in the total design of these structures, especially in comparison with the granular filters. The general principles of designing of revetments incorporating geotextiles are reviewed. It is shown that simply replacing a granular filter by a geotextile leads to geotechnical instability, especially because the layer thickness and weight of the two are very different.
Further it appears that a thicker granular filter gives a larger geotechnical stability, but a lower cover layer stability (uplift of blocks). The conclusion is therefore that the wave loads must be distributed (balanced) adequately over the sand (shear stress) and the cover layer (uplift pressure). Too much emphasis on one failure mechanism can lead to another mechanism.
KEYWORDS: (block-)revetments, geotextiles, design, bank protection.

1 INTRODUCTION

In bank protection structures geotextiles are often used to protect the subsoil from washing away by the hydraulic loads, such as waves and currents. Here the geotextile replaces a granular filter. Unfortunately the mere replacing of a granular filter by a geotextile can endanger the stability of other components in the bank protection structure. The present paper shows that designing a structure is more than just a proper choice of geotextile.

In the past we have seen too often, in The Netherlands and abroad, that the local experience determined the selection of type and dimensions of the protection system. A satisfying structure of the neighbours is copied, although hydraulic loads and subsoil properties were different. This lead to designs which were unnecessary conservative and consequently too costly, or were inadequate leading to large maintenance costs.

The technical feasibility and dimensioning of protective structures can easily be determined on a more sound basis and supported by a better experience than in the past. Often, however, the solution being considered should still be tested in a scale model since no generally accepted design rules exist for all possible solutions and circumstances.

In this paper we first consider the global design methodology, in which we see various design criteria. One of these criteria, namely the stability against waves and currents, is dealt with in more detail in chapter 3. Attention is focused on block revetments (with cover layer of regularly placed blocks), because in this type of structure the role of the geotextile and the granular filter layer can easily be explained. It is shown that by simply replacing a granular filter by a geotextile leads to geotechnical instability, especially because the layer thickness and weight of the two are very different.
In chapter 4 we summarize the main conclusions.

2 STARTING POINTS & DESIGN METHODOLOGY

The function of a revetment is to protect the slope (dike body, river bank, etc.) against hydraulic (and other) loadings, such as waves and currents. To evaluate the stability, information is required about the hydraulic design conditions, the structural properties and the possible failure mechanisms. When designing revetments the designer should remember that *the geotextile is only one of the components involved*, and that the revetment is only a part of the total project. Therefore, the following overall design aspects have to be considered always: the function of the structure, the physical environment, the construction method, operation and maintenance. The cost of construction and maintenance is generally a decisive factor in determining the type of structure. The starting points for the design should be carefully examined in cooperation with the client or future manager of the project.

The designer's checklist can be a useful tool for this purpose (see PIANC, 1992).

To achieve protection and stabilization of a slope, the following aspects have to be taken into consideration in the design process:
a) stability (cover layer, sublayer, subsoil),
b) flexibility (following the settlement),
c) durability (cover layer, geotextile, cables),
d) possibility of inspection of damage/failure,
e) easy placement and repair (local damage),
f) low cost (construction/maintenance),
g) overall performance,
h) additional functional requirements,
i) environmental considerations.

Geotextiles primarily contribute to criterion a, but must also satisfy the other criteria. These can even be conflicting.

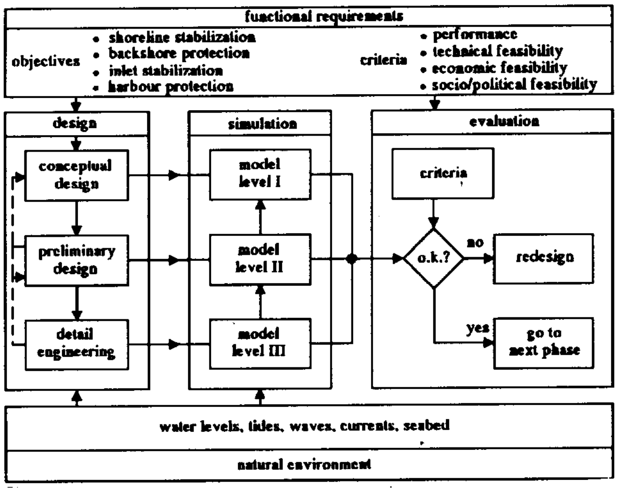


Fig. 1 Design methodology

In the following we will focus on the hydraulic stability of the structure and the specific role of a geotextile herein.

Stability always has to be guaranteed considering the whole system as well as the single element.

The most critical structural design elements are:

1. the stability of the cover layer,
2. the geotechnical stability of the foundation,
3. the minimization of settlement
4. the toe protection against undermining.

All of these are potential causes of failure of protective structures. The review of the key elements that must be considered in the design (dimensioning) of revetment structure is illustrated in Figure 2. All of these design aspects are discussed in PIANC (1992).

The geotextile can serve the three functions, of which only the first two will be considered here:

- prevention of erosion of the subsoil through the structure,
- filtration (permeability),
- reinforcement of the subsoil against sliding.

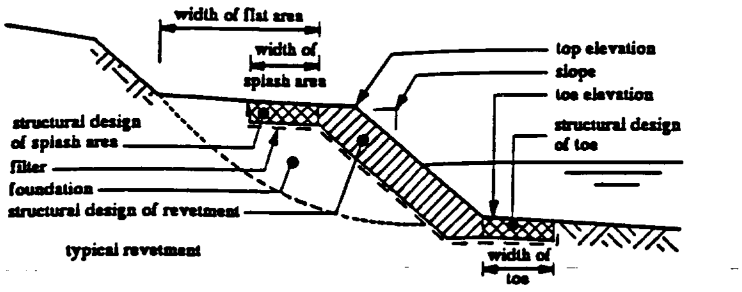


Fig. 2 Design components of typical revetments structure

3 STABILITY CRITERIA

3.1 General criteria for bank protections

Most research problems on water defences have multidisciplinary character, specifically, in the technical sense. This is characterized by all relevant interactions between the element soil, water and structure (so-called SOWASconcept, Figure 3).

The interaction between these components can be described using three Transfer Functions (Figure 4). Information about these functions has been obtained by means of measurements in (scale) models and in nature. All three Transfer Functions can be described in a single 'calculation model', or individually in separate models, depending on the type of structure and the loading (De Groot et al, 1988).

For revetments it is essential to distinguish the nature of the loads and its characteristic period. The load from wind- and shipwaves has a characteristic period of less than a minute, but the variation of the water level caused by tidal and seasonal influences, which can induce groundwater flows, has a period of several hours. The wave load is of importance for all types of revetments, while the slow variation in groundwater flow and in phreatic line is of primary importance for impermeable revetments only.

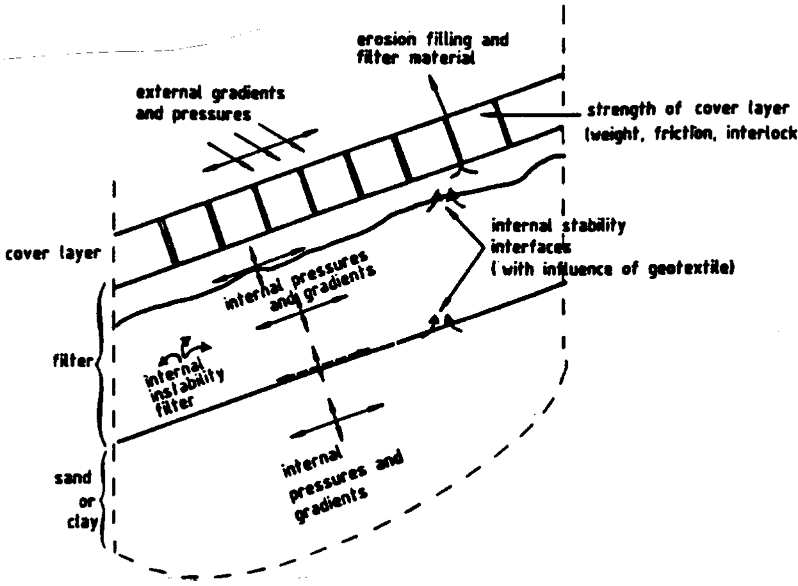


Fig. 3 Components of loads and structure

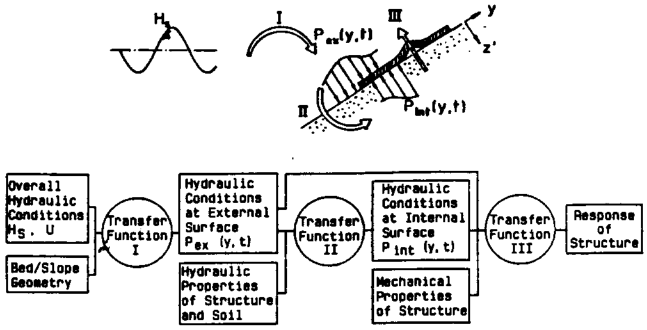


Fig. 4 System approach. Transfer functions

The uplift pressure due to wave attack has to be determined mostly by model (or prototype) tests for each revetment type under consideration. For permeable block-revetments on permeable sublayer numerical models have been developed in the Netherlands (PIANC, 1992 and CUR/TAW, 1994).

Next to wave attack, currents can occur. These are of importance for revetments with irregular surface (i.e. riprap) because they induce high drag forces. However, currents with vortexes (associated with a high turbulence) and eddies (due to local discontinuities in the geometry) may also induce uplift forces.

There are several possible failure mechanisms and related design requirements (criteria). Depending on the composition of the structure and the type of loads one of these is decisive:

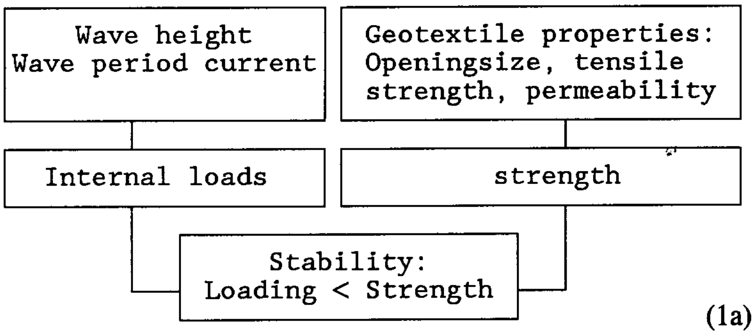
1. Sliding criterion: the revetment should be designed so that it does not slide (e.g. because of poor toe or anchor structure) under frequently occurring loading situations (see Bakker and Meijer, 1988).
2. Equilibrium criterion (total geotechnical stability): the revetment including sublayers and subsoils must be in equilibrium against slip circle failure.

3. Uplift criterion: also in rare loading situations, such as storm surges, the weight of the cover layer should be large enough to withstand the uplift pressure (to avoid that the blocks of cover layer will be washed away).
4. Surface resistance criterion: the outer surface of revetments should have enough resistance against erosion by wave and current attack.
5. Internal stability criteria: the migration of subsoil particles through the structure should be prevented (migration can cause the cover layer to settle).

3.2 Basic principles for geotextile design

The two main functions of geotextiles, separation (soil retention) and filtration (permeability), are also important for granular filters. Therefore, people think that the geotextile can replace the function of granular filter completely. However, this is not the case because a granular filter serves also other functions, related to its thickness and weight. The thickness of a granular filter contributes to the damping of the pressure fluctuations on the cover layer and the weight contributes to the ability of the subsoil to withstand shear stresses. Both are important to withstand slip circle failure. The thickness and weight of the geotextile (less than a few cm) is neglectable in this context.

This omission, combined with the fact that the calculation methods for internal loading are very scarce, has lead several times to the unexpected failure of structure. Moreover, the proper choice of geotextile depends strongly on the type of subsoil/core and the total composition of revetment structure. The main design principles read:



(1a)

or:

Strength = SF * Loading and, (1b)

$$k_{\text{toplayer}} > k_{\text{sublayer incl. geotex.}} > k_{\text{subsoil/core}} \quad \text{or} \tag{2a}$$

$$k_{\text{toplayer}} > \varphi_1\, k_{\text{sublayer incl. geotex.}} > \varphi_2\, k_{\text{subsoil/core}} \tag{2b}$$

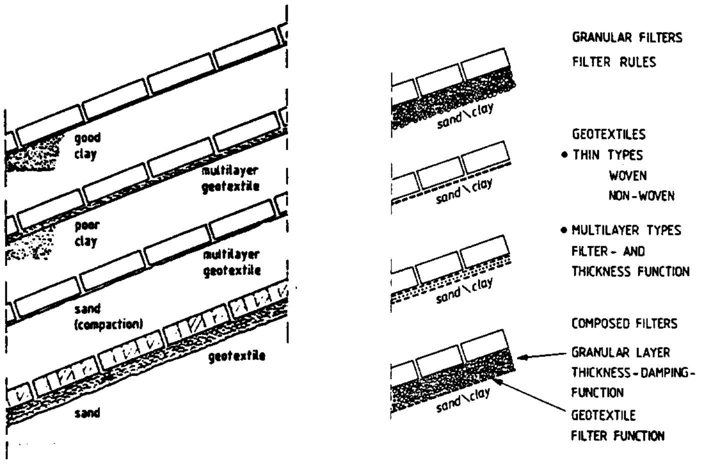
where k = permeability and SF = safety factor and φ = proportionality factor.

For granular filters the well-known filter-rules can be applied for definition of φ. In a case of a geotextile (instead of granular filter) $\varphi_2 \geq 10$ and for a sand subsoil $O_{90}/d_{90} \leq 1$ should be recommended or, when the hydraulic gradients (i_{act}) at the interface with the subsoil are known, the requirement reads $i_{act} < i_{cr}$ (Klein Breteler and Verheij 1990, CUR 1993 and CUR/RWS 1991).

3.3 Interaction of bank protection components

The various components of a bank protection structure influence each other as follows:

a) The stability of the cover layer strongly depends on the sort and composition of sublayers and they must therefore be regarded as an integrated system. As an example, from large scale tests it appeared that a block revetment on a sublayer of "smooth surface of good clay" provides more stability than one on a permeable sublayer.
b) Erosion of sublayers and/or subsoil through the structure can lead to failure of a cover layer. The design of cover layer and sublayers must therefore be balanced in such a way that equal risk of failure is achieved.
The subsoil (sand, clay, ...) plays an important role in the stability of revetments and in the total stability of the protective structure. Thus, the type and state of subsoil can be decisive for the choice of the revetment type.
c) A good tuning of the permeability of the cover layer and sublayers (including geotextiles) is an essential condition for a balanced design. The permeability (k) of each successive layer of the structure must be larger.
d) Granular filters are usually more expensive than geotextiles and especially under water difficult to construct within the requirement limits. A good solution is a combination of a geotextile (filter function) with a graded stone layer (with function to damp the internal hydraulic loads). A geotextile is also recommended on a clay subsoil. A good and often cheaper alternative can be a thick layer of broadly graded waste products such as minestone, slags, silex, etc. with 0.5 m thickness, well compacted and gradation according to criteria of internal stability (see Den Adel et al 1988). But one should be aware of segregation when dumped under water.



a, Composition b, Filter/sublayer

Fig. 5 Examples of block revetment alternatives

3.4 Stability of block revetment

The requirement that the permeability of the cover layer should be larger than the underlayers can not be met in a case of a closed block revetment. The cover layer is less permeable, which introduces uplift pressures during wave attack. In this case the permeability ratio of the cover layer and the filter, represented in the leakage length, is found to be the most important structural parameter, determining the uplift pressure. The leakage length Λ is defined as follows:

$$\frac{\Lambda}{D} = \sqrt{\frac{k}{k'}\frac{b}{D}} \tag{3}$$

where:

Λ = leakage length [m]
b = filter layer thickness [m]
D = thickness of the cover layer [m]

k = permeability of the filter [m/s]
k' = permeability of the cover layer [m/s]

In a case of a geotextile directly under the cover layer, the permeability of the cover layer decreases drastically. Since the geotextile is pressed against the cover layer by the outflowing water, it should be treated as a part of the cover layer. The water flow trough the cover layer is concentrated at the joints between the blocks, reaching very high flow velocities and resulting in a large pressure head over the geotextile. The presence of a geotextile may reduce k' by a factor 10 or more (see example below).

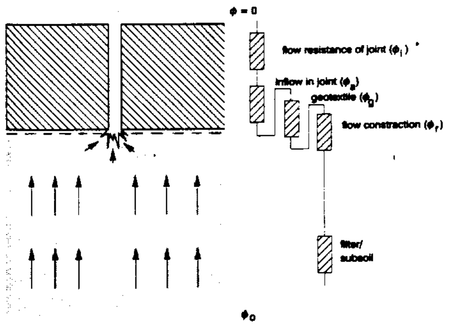


Fig. 6 Combined flow resistance determining the permeability of a system (Klein Breteler et al 1988)

The leakage length clearly takes into account the relationship between k and k' and also the thickness of the cover layer and the filter layer. For the theory behind this relationship reference should be made to literature (see Klein Breteler et al, 1991).

The pressure head difference which develops on the cover layer is larger with a large leakage length than with a small leakage length. This is mainly due to the relationship k/k' in the leakage length formula. The effect of the leakage length on the dimensions of the critical wave is apparent from the following equation:

$$\frac{H_{scr}}{\Delta D} = f\left(\frac{D}{\Lambda \xi_{op}}\right)^{0.67} \quad \text{or} \tag{4a}$$

$$\frac{H_{scr}}{\Delta D} = f\left(\frac{D}{b}\frac{k'}{k}\right)^{0.33} \xi_{op}^{-0.67} \tag{4b}$$

$$\frac{H_{scr}}{\Delta D} = F\,\xi_{op}^{-0.67} \tag{4c}$$

where H_{scr} = significant wave height at which blocks will be lifted out [m]; $\xi_{op} = \tan\alpha/\sqrt{(H_s/(1.56T_p^2))}$ = breaker parameter [-]; T_p = wave period [s]; Δ = relative volumetric mass of cover layer [-] = $(\rho_s - \rho)/\rho$; f = coefficient, mainly dependent on structure type and with minor influence of Δ, $\tan\alpha$ and friction [-]; F = total (black-box) stability factor [-].

These equations indicate the general trends and have been used together with measured data to set up the general calculation model (Klein Breteler 1991).

This method works properly for placed/pitched block revetments and blockmats within the following range: $0.01 < k'/k < 1$ and $0.1 < D/b < 10$. Moreover, when $D/\Lambda > 1$ use $D/\Lambda = 1$, and when $D/\Lambda < 0.01$ use $D/\Lambda = 0.01$. The range of stability coefficient is: $5 < f < 15$; the higher values refer to presence of high friction among blocks or interlocking-system. The following values are recommended for block revetments:

f = 5 for static stability of loose blocks (no friction between the blocks),
f = 7.5 for static stability of a system (with friction between the units),
f = 10 for tolerable/acceptable movement of a system at design conditions.

From these equations, neglecting the usually minor variations of f, it appears that:

- An increase in the volumetric mass, Δ, produces a proportional increase in the critical wave height. If ρ_b is increased from 2300 to 2600kg/m³, H_{scr} is increased by about 23%,
- If the slope angle is reduced from 1:3 to 1:4 ($\tan\alpha$ from 0.33 to 0.25) H_{scr} is increased by about 20% (due to the breaker parameter, ξ_{op}),
- An increase of 20% in the thickness of the cover layer, D, increases H_{scr} by about 27%,
- A 30% reduction in the leakage length , Λ, increases H_{scr} by about 20%. This can generally be achieved by halving the thickness of the filter layer or by doubling the k'/k value. The latter can be achieved by approximation, by:
  - reducing the grain size of the filter by about 50%, or
  - by doubling the number of holes in (between) the blocks, or
  - by making hole sizes 1.5 times larger,or
  - by doubling joint-width between blocks.

Changing the structural parameters changes the coefficient 'f' slightly; the effect of these parameters can only be evaluated by approximation. It should be noted that changing the structural geometry can mean that failure mechanisms other than blocks being lifted may govern the stability of the structure.

EXAMPLE: In 1983 the Armorflex-mat on a slope 1:3 was tested on prototype scale at the Oregon State University: closed blocks with thickness D = 0.12 m and open area 10% on two types of geotextiles and very wide graded subsoil (d_{15} = 0.27 mm, d_{85} = 7 mm).
In the case of a sand-tight geotextile the critical wave height (instability of mat) was only H_{scr} = 0.30 m. In the case of an open net geotextile (opening size about 1mm) the critical wave height was more than 0.75 m (maximum capacity of the wave flume).
The second geotextile was 20 times more permeable than the first. This means that the stability increased by factor $20^{0.33} = 2.7$.

In most cases the permeabilities of the cover layer and sublayer(s) are not exactly known. However, based on the physical principles as described above, the practical 'black-box' method has been established where parameter Λ and coefficient 'f' are combined to one stability factor 'F'.

F depends on the type of structure, characterised by the ratio's of k'/k and D/b. With the permeability formulas from (CUR/TAW, 1994) it is concluded that the parameter (k'/k)·(D/b) ranges between 0.01 and 10, leading to a subdivision into 3 ranges of one decade each. Therefore the following types are defined:
a) Low stability: (k'/k)(D/b) < 0.05 .. 0.1
b) Normal stability: 0.05 .. 0.1 < (k'/k)(D/b) < 0.5 .. 1
c) High stability: (k'/k)(D/b) > 0.5 .. 1

For a cover layer lying on a geotextile on sand or clay, without granular filter, the leakage length cannot be determined because the size of b and k cannot be calculated. The physical description of the flow is different for this type of structure. For these structures there is no such a theory as for the blocks on a granular filter. However, it has been experimentally proved that eq. 4c also is valid for these structures.

We can conclude that the theory has led to a simple stability formula (eq.4c) and a subdivision into 4 types of block revetment structures:

a1) cover layer on granular filter ev. incl. geotextile, low stability
a2) cover layer on granular filter ev. incl. geotextile, normal stability
a3) cover layer on geotextile on sand
a4) cover layer on clay/geotextile on clay

The coefficient, F, is quantified for each structure type by way of fitting eq. 4c to the results of a large collection of results of model studies from all over the world. Only large-scale studies are used because both the waves and the wave induced flow in the filter should be well represented in the model. In the classification of structures according to the value of (k'D/kb), the upper limit of (k'D/kb) is 10 times the lower limit. Therefore the upper limit of F of each structure type (besides a1.1) is assumed $10^{0.33} = 2.14$ times the lower limit, since $F = f\,(k'D/kb)^{0.33}$. A second curve is drawn with this value of F.

In the Table 1 all available tests are summarised and for each type of structure a lower and upper boundary for the value of F is given (see also an example in Fig. 7). The lower boundary gives with eq. 4c a stability curve under which stability is guaranteed. Between the upper and lower boundary the stability is uncertain. It depends on various unpredictable influences if the structure will be stable or not. The upper boundary gives a curve above which instability is (almost) certain.

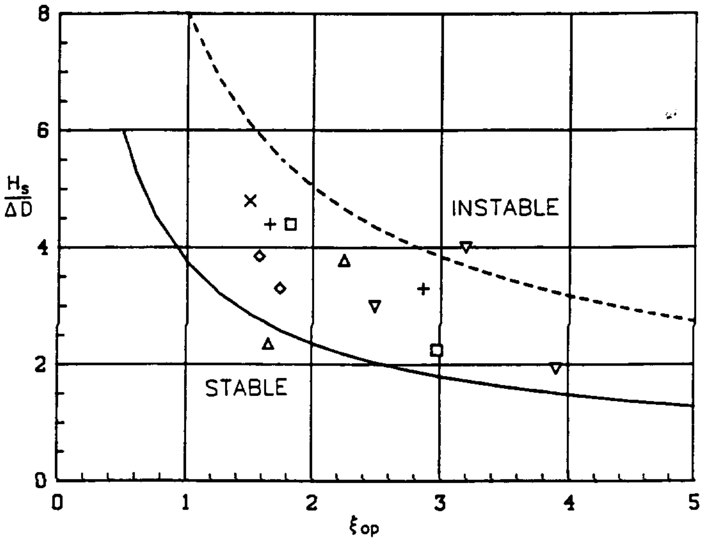


Fig. 7 Example of stability function for type a3 (loose blocks on geotextile on sand)

Table 1 Lower and upper value for F

type	description	low F	high F
a1.1	pitched irregular natural stones on granular filter	2.0	3.0
a1.2	loose blocks/basalt on granular filter, low stability	3.0	6.5
a2	loose blocks on granular filter, normal stability	3.7	8.0
a3	loose blocks on geotextile on sand/clay	3.7	8.0
a4	loose blocks on clay	5.1	10.0

The results for structure type a3 (blocks on geotextile on sand) may only be applied if the wave load is small ($H_s < 1$ or 1.5 m (max.)) or to structures with subsoil of course sand ($d_{50} > 0.3$ mm) and gentile slope ($\tan\alpha < 0.25$), because the geotechnical failure is assumed to be the dominant damage mechanism (instead of uplift of blocks).

The good compaction of sand is essential to avoid sliding or even liquefaction. For loads higher than $H = 1.2$ m a well graded layer of stone on a geotextile is recommended (e.g. layer 0.3-0.5 m for $1.2 \text{ m} < H < 2.5$ m).

The results for structure type a4 can be applied on the condition that clay of high quality and with a smooth surface is used. If there is no such clay present, then a geotextile is recommended to prevent erosion during (long duration) wave loading. The stability is than equal to that of structure type a3 but without restriction regarding the absolute wave height H_s. The general design criteria for geotextiles on cohesive soils are given by Klein Breteler et al (1994).

In the case of loose blocks an individual block can be lifted out of the revetment with a force exceeding own weight and friction. It is not possible with the cover layers with linked or interlocking blocks. Examples of the second type are: block-mattresses, ship-lap blocks and cable-mats. However, in this case high forces will exert on the connections between the blocks and/or geotextile. In a case of blocks connected to geotextiles (i.e. by pins), the stability should be treated as for loose blocks in order to avoid the mechanical abrasion of geotextiles by moving blocks.

The lower boundary of stability of cabled-mats can be increased by factor 1.25 (or 1.5, if additionally grouted) in comparison with loose blocks. Such increase of stability is only allowable when special measures are taken with respect to the proper connection between the mats.

The upper boundary of stability remains the same for all systems. Application of this higher stability requires optimization of design. This optimization technique (incl. application of geometrically open but stable filters and geotextiles) can be found in (CUR, 1993 and CUR/TAW, 1994).

3.5 Sliding and geotechnical instability

Generally the friction between the cover layer and the sublayers prevents the cover layer from sliding down the slope. Toe structures or, in the case of block mattresses, anchors are needed under certain conditions to give support against sliding.

Sliding is more likely if a geotextile is placed between the cover layer and the sublayer, because the friction coefficient between blocks and geotextile is only 0.25 - 0.30, while the friction coefficient between blocks and granular filter is 0.35–0.40 (CUR/TAW 1994). Decisive for the cover layer is the moment that the friction forces are reduced temporarily by upward pressure forces due to wave attack. This aspect is discussed by Bakker and Meijers (1988).

Geotechnical instability leads to a slip circle in the subsoil and deformation of the slope into an S-profile (Bezuijen et al., 1986). It will occur when the water pressure increases rapidly, so that the particle interaction decreases. This results in a smaller shear capacity of the soil; eventually even smaller than the existing shear stresses.

This rapid increase of the water pressure can be initiated by one or more of the following mechanisms:

1) Elastic behaviour of the pore water in the subsoil. A sudden pressure decrease during wave attack (run-down) will give an expansion of the air-bubbles in the pore water. The resulting outflow decreases the particle interaction. Usually 5 to 15% of the pore volume is filled with air instead of water.

2) Compaction of the subsoil due to wave impacts. This is only possible if the subsoil is poorly compacted.
3) Rise of the phreatic line in the subsoil during wave attack, as a result of the fact that wave run-up is always larger than wave run-down.

The risk for these mechanisms can be reduced, or even diminished by:
- Adequate compaction of subsoil (to a Proctor density of 95% or more);
- Applying a filter layer with a proper thickness.

The influence of a granular filter on the damping of the pressure fluctuations in the subsoil is studied by the Delft Geotechnics. With proper simplifications and schematisations an equation is developed by Bezuijen et al (1990) for the minimum grain stress in the subsoil needed to prevent geotechnical instability during wave run-down. It can be used to calculate the necessary minimum thickness of the revetment, that is, the thickness of the filter layer (b) plus the thickness of the cover layer (D). This equation is plotted in Figure 8 (for one specific case) (CUR/TAW, 1994). From this it is clear that the replacement of a granular filter by a geotextile means a much smaller value a cover layer weight and consequently a smaller stability against geotechnical failure.

From Figure 8 it appears that a thicker granular filter gives a larger geotechnical stability. This is in contrast however to the tendency for cover layer stability (the lifting out of a block) where it appears that a thicker filter layer gives a larger load on the blocks (uplift pressure). The conclusion is therefore that the wave loads must be distributed (balanced) adequately over the sand (shear stress) and the cover layer (uplift pressure on the blocks). Too much emphasis on one failure mechanism can divert loads to elsewhere and possibly lead to failure due to another mechanism.

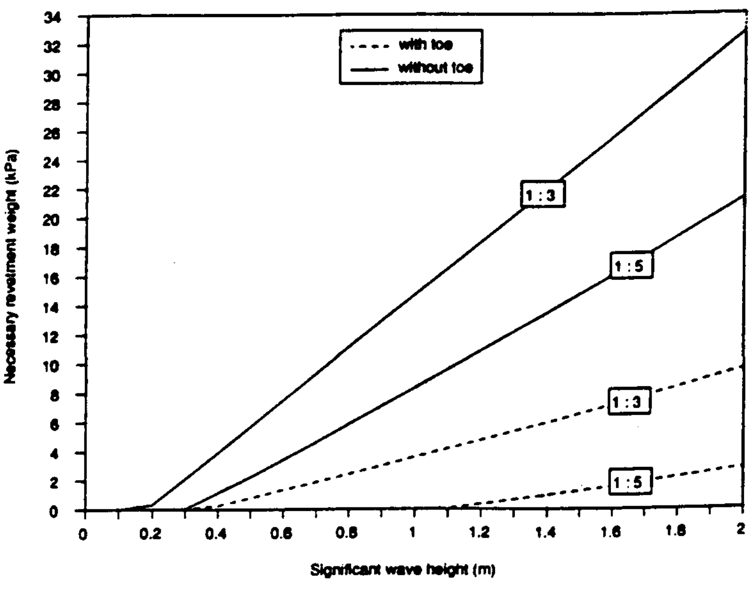


Fig. 8 Necessary weight of revetment (cover layer and filter) and influence of toe on geotechnical instability ($H_s/L_{op} = 0.03$, $d_{50} = 0.2$ mm and $\cot\alpha = 3$ or 5).

The other geotechnical items related to the revetments can be found in (Bezuijen, 1991, PIANC, 1992 and CUR/TAW, 1994).

4 CONCLUSIONS

1. Geotextiles are only one of the components of structural design and must be considered in conjunction with, or as an alternative to granular filters or other options.
2. The combination of the stability formula, that was derived from theory, together with the results of many large-scale model studies from all over the world has produced a reliable design tool for the preliminary design of placed block-revetments.
3. It is shown that the replacement of a granular filter by a geotextile means a much smaller weight on the sub soil and consequently a smaller stability against geotechnical failure.
4. Further prototype verification of developed dimensioning criteria is still needed. Careful evaluation of prototype failure-cases may provide useful information/data for verification purposes.
5. In all cases, experience and sound engineering judgement play an important role in applying these design rules, or else mathematical or physical testing can provide an optimum solution.

REFERENCES

Bakker, K.J. and Meijers, P., 1988. Stability against sliding of flexible revetments, Int. Symp. on Modelling Soil-Water-Structure Interactions, Delft, Publ. A. Balkema

Bezuijen, A., M. Klein Breteler and K.W. Pilarczyk, 1986. Large scale tests on a block revetment placed on sand with a geotextile as separation layer, 3rd Int. Conf. on Geotex-tiles, Vienna, Austria

Bezuijen, A., Kohler, H.J. and Schulz, H., 1990. Rip-rap revetments using geotextiles, measurements and numerical simulation, 4th Int. Conf. Geotextiles, The Hague

Bezuijen, A (1991), Geotechnical Failure of Revetments, Coastal Zone'91, Los Angeles

CUR 1993. Filters in Hydraulic Engineering, report no. 161, CUR Gouda, The Netherlands

CUR/TAW 1994. Handbook for the design of block revetments, Report no. 155, Centre for Civil Engineering Research and Codes (CUR), P.O. Box 420, 2800 AK Gouda, NL

CUR/RWS 1991. Manual on use of rock in hydraulic engineering, CUR/CIRIA report 154 Gouda, Netherlands

De Groot, M.B., Bezuijen, A., Burger, A.M. and Konter, J.L.M., 1988. The interaction between soil, water and bed or slope protection. Int. Symp. on Modelling Soil-Water-Structure Interactions, Delft, Balkema

Den Adel, H, K.J. Bakker and M. Klein Breteler, 1988. Internal stability of minestone. Int. Symp. on Modelling Soil-Water-Structure Interactions, Delft, Balkema

Klein Breteler, M. and A. Bezuijen, 1988. The permeability of closely placed blocks on gravel. Int. Symp. on Modelling Soil-Water-Structure Interactions, Delft, Balkema.

Klein Breteler, M. and H. Verhey, 1990. Erosion control by hydrodynamically sandtight geotextiles, 4th Int. Conf. on Geotextiles, The Hague, Netherlands

Klein Breteler, M. and A. Bezuijen, 1991. Simplified design method for block revetments. Conference on Coastal structures and breakwaters, Thomas and Telford, London.

Klein Breteler, M., G. Smith and K.W. Pilarczyk, 1994. Performance of geotextiles on clay, silt and fine sand in bed and bank protection structures, 5th Int. Conf. on Geotextiles, Singapore

PIANC 1992. Guidelines for the design and construction of flexible revetments incorporating geotextiles in marine environment, Suppl. to Bulletin 78/79, Brussels