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Permeability of cover layers including geotextiles

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ABSTRACT: The stability of revetments with a geotextile (block mats and concrete mattresses) is highly influenced by the permeability of the entire revetment system. The high uplift pressures, induced by wave action, can only be relieved through the joints or filter points in the revetment, but these are covered by a geotextile. The resulting high flow velocity (flow contraction to openings in cover layer) through the geotextile results in a significant contribution of the geotextile permeability in the total permeability of the revetment system.
Performance tests and theoretical considerations have led to Equations to calculate the permeability of the system, based on the permeability of the geotextile.

1 INTRODUCTION

The flow resistance that can be expected when a fluid flows through a medium or a structure is an important parameter when designing hydraulic structures. It is of special importance in case of revetments with a relatively low permeability of top layer including a geotextile underneath, such as block mats and concrete mattresses. The permeability of the revetment system is a decisive factor determining its stability, especially under wave attack (Figure 1), and also it has an important influence on the stability of the subsoil.

The permeability of a layer of closely placed concrete blocks on a filter layer with and without a geotextile has been investigated in recent years in the Netherlands in the scope of the research programme on stability of revetments. The results indicate that the permeability of the block layer can be described as a combination of the joints and the permeability of the geotextile and the granular layer below the cover layer.

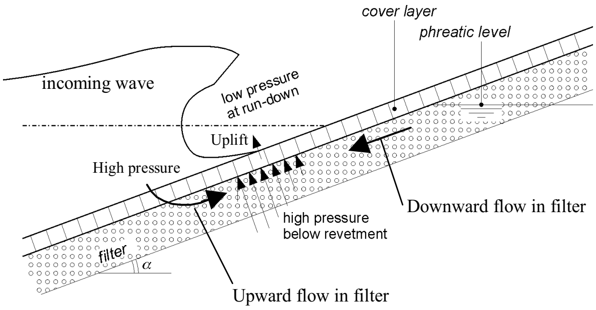

Figure 1. Pressure acting on cover layer.

The flow resistance by a geotextile can be incorporated in the calculation if the permeability and the thickness of the geotextile are known, or if the head loss is known as a function of the filter velocity. The head loss over the geotextile in contact with granular material is considerably more than the head loss as measured in an index test (Köhler & Bezuijen, 1994). As a result in most cases, a considerable contribution by the geotextile to the total resistance, and thus to the total loading of the cover layer, can be expected.

2 PRINCIPLES OF CALCULATION MODEL

2.1 *Stability of revetment*

The usual requirement that the permeability of the cover layer should be larger than that of the under layers is normally not met in the case of a closed block revetment and other systems with low permeable cover layer (i.e. concrete geomattresses). The low permeable cover layer 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.

Wave attack on revetments will lead to a complex flow over and through the revetment structure (filter and cover layer), which are quantified in analytical and numercial models (Bezuijen et al 1987, Die Küβte 1993, Bezuijen and Klein Breteler 1996, McConnell 1998). Wave run-down will lead to two important mechanisms (see Figure 1):

- There will be a downward flow gradient in the filter with a typical gradient equaling the slope angle, which may result in sliding.
- During maximum wave run-down there will be an incoming wave that a moment later will cause a wave impact. Just before impact there is a ‘wall’ of water giving a high pressure under the point of maximum run-down. Above the run-down point the surface of the revetment is almost dry and therefore there is a low pressure on the structure. The high pressure front will lead to an upward flow in the filter. This flow will meet the downward flow in the run-down region. The result is an outward flow and uplift pressure near the point of maximum wave run-down (Figure 1).

In the analytical model nearly all physical parameters that are relevant to the stability have been incorporated in the "leakage length" factor. For systems on a filter layer, the leakage length Λ is given as:

$$\Lambda = \sqrt{\frac{bDk}{k'}} \qquad (1)$$

where: Λ=leakage length (m) b = thickness of the filter layer (m), D = thickness of cover layer (m), k = permeability of the filter layer or subsoil (m/s), and k’ = permeability of the top (cover)layer (m/s).

The pressure head difference, which develops on the cover layer, is larger with a large leakage length than with a small leakage length. To demonstrate this influence we use a simple calculation model that has been developed using the results of analytical calculations and measurements (CUR, 1995, Pilarczyk, 1998)

The effect of the leakage length on the dimensions of the critical wave for semi-permeable revetments is apparent from the following equation:

$$\frac{H_{scr}}{\Delta D} = f\left(\frac{D}{\Lambda \xi_{op}}\right)^{0.67} \qquad (2)$$

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); H_s = significant wave height at toe of structure (m); Δ = relative volumetric mass of cover layer = $(\rho_s - \rho)/\rho$; ρ = density of water (kg/m^3); ρ = density of cover layer material (kg/m^3); and f = stability coefficient mainly dependent on structure type and with minor influence of Δ, $\tan\alpha$ and friction.

This method works properly for placed/pitched block revetments and block mats 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 the stability coefficient is: $5 < f < 15$; the higher values refer to the presence of high friction among blocks or interlocking systems. 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:

- 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.

2.2 *Example showing the influence of permeability*

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 low permeability 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) and high permeability 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 one. This means that the stability increased by factor $20^{0.33} = 2.7$ according to Equation (2).

3 INFLUENCE OF A GEOTEXTILE ON THE PERMEABILITY OF A SYSTEM

3.1 *Introduction*

The geotextile applied as a component of a revetment will have influence on permeability of the system and thus on the value of the leakage length and the total stability of the revetment. The qualitative influence of geotextile is outlined below.

The reference revetment is schematised in Figure 1. The following assumptions were made in order to describe the flow resistance:

- the flow resistance of the cover layer is defined as the difference between the resistance of a cover layer (possibly with a geotextile) on a granular layer and the resistance of granular material without a cover layer; consequently, the head loss in the granular material and geotextile due to flow contraction near the joints is interpreted as a part of the resistance of the cover layer,
- the total resistance can be divided in various parts, the total resistance is the sum of these parts.

Using these assumptions the various components of the flow resistance can be distinguished (see Figure 2) as follows:

1. The resistance in that part of the granular filter where the flow is contracted to meet the small area of the joint.
2. The geotextile resistance between filter and cover layer.
3. The resistance due to the fact that the water has to accelerate to flow through the narrow joint. The kinetic energy acquired as a result of this acceleration is destroyed in the outflow region at the top of the joint.
4. The resistance due to the shear stress caused by walls of the joints.

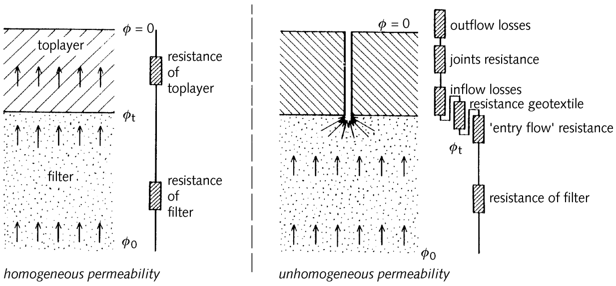

Figure 2. Schematization of flow resistances.

These resistance components may be laminar and turbulent, and therefore the general relationship, including a laminar and turbulent term, has been chosen. These formulations for all the components involved are described in detail in the next chapter. Furthermore the results of the verification tests are briefly discussed.

3.2 *Mathematical formulations of permeability*

As mentioned in Section 1 (see Equation 2), the permeability of the cover layer is a parameter which greatly affects the leakage length and thus the pressure head difference on the cover layer during wave attack. Because of the geometry of the block revetments or the concrete mattresses the permeability of the cover layer is not distributed over the surface area but concentrated in the interspaces or joints. This introduces the additional resistance components, which the water must overcome as it flows upwards through the cover layer (see Figure 2). Due to this fact, the calculation of the effective permeability of the cover layer is rather complicated.

Moreover, the permeability will be over estimated when using the index test "Permeability normal to the plane" (EN ISO 11058), because the holes in the geotextile are partly closed by the filter material underneath the geotextile. For geotextile between a filter layer and top layer of rip-rap material Bezuijen and Köhler (1994) found a permeability of only 20% of the permeability determined in an index test.

For the general case of a revetment on a geotextile on a filter layer the following Equationtions have been derived in WL/GD, (1990), part XVIII:

$$k' = \frac{-a' + \sqrt{(a')^2 + 4b'}}{2b'} \qquad (3)$$

with:

$$a' = \frac{a_f}{D}\sqrt{\frac{A}{4\pi}}\left(\frac{1}{r_{min}}\sqrt{\frac{A}{4\pi}} - 2\right) + \frac{a_g T_g}{\Omega D} \quad (4)$$

$$b' = \frac{1}{2gD\Omega^2}\left(\left(\frac{1}{n} - 1\right)^2 + 1\right) + \frac{b_f}{D}\sqrt{\frac{A}{4\pi}}\left(3\left(\frac{1}{r_{min}}\sqrt{\frac{A}{4\pi}}\right)^3 - 4\right) + \frac{b_g T_g}{\Omega^2 D}$$

where:

a' = linear resistance component of cover layer (s/m)
b' = second power resistance component of cover layer (s^2/m^2)
a_f = linear resistance component of a filter (s/m)
b_f = second power resistance component of a filter (s^2/m^2)
a_g = linear resistance component of geotextile (s/m)
b_g = second pover resistance component of geotextile (s^2/m^2)

Ω = ratio of the area through which water can pass to the total area (-)
D = average thickness of top layer (m)
A = area of top layer per interspace or filter point (m^2)
T_g = thickness of geotextile (m)
r_{min} = $\max(D_{f15}/2;\ 0.4\sqrt{A_p})$;
A_p = area of Filter Point (m^2)
D_{f15} = grain size of the filter (lying directly under the mattress), 15% by weight of which is less than the stated size (m)

For revetments directly on sand or clay some terms in the Equations can be neglected:

- cavities or gullies underneath: $a_f = 0$ and $b_f = 0$,
- without cavities: the first term b' disappeares:

$$\frac{1}{2gD\Omega^2}\left(\left(\frac{1}{n} - 1\right)^2 + 1\right) = 0 \quad (5)$$

The thickness of the mattress is defined as an average thickness. The resistance components of the geotextile (a_g and b_g) are usually unknown. Therefore, as an approximation, one may assume $a_g = 0$ and $b_g = 1/k_g^2$ (with k_g the linearised permeability of a geotextile placed on granular material).

3.3 *Revetments with gullies or thick geotextiles*

For structures without a filter layer, where the cover layer is placed directly on a sand or clay subsoil, the pressure transmission parallel to the slope cannot take place through a filter and will find other ways. Sometimes small channels or gullies form between the cover layer and the subsoil. These channels are very well capable of transmitting the pressure leading to a pressure difference across the cover layer.

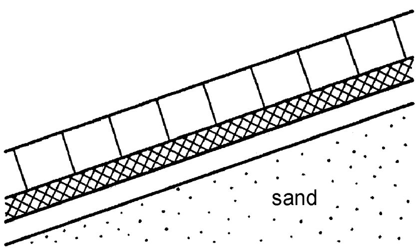

Figure 3. Revetment without filter

In case of channels underneath the mattresses (= surface irregularities and/or erosion channels) the leakage length is calculated according to (Luth, 1993):

$$\Lambda = \sqrt{\frac{dDk}{k'}} \quad (6)$$

and,

$$k = 5.75\sqrt{\frac{gd}{0.6}}\ \log\left(\frac{6d}{k_s}\right) \quad (7)$$

with: D = top layer thickness (m), d = depth of channel or gully (m), k = permeability of the channel or gully (m/s), and k_s = Nikuradse roughness of the channel or gully (about 0.5 mm = 0.0005 m). The Equations have been checked with the results of large scale model tests in the Delta Flume of Delft Hydraulics (Luth 1993).

If a very thick geotextile is applied between the cover layer and the subsoil, thicker than approximately 3 mm, the pressure transmission will take place through the geotextile. This means that the geotextile will act as a filter layer and should be treated as such in the calculation of the leakage length. This is demonstrated in the next Equation:

$$\Lambda = \sqrt{\frac{(k_f d_g + k_g T_g) D}{k'}} \quad (8)$$

with: k_f = permeability of the channels (gully), if present (m/s), d_g = gully depth (m), k_g = in plane permeability of the geotextile (m/s), T_g = thickness of the geotextile (m), D = thickness of the top layer (m), and k' = permeability of the top layer (m/s).

For a system without a filter layer, directly on sand or clay and without gullies being formed under the top layer, it is not the permeability of the filter layer, but the permeability of the subsoil in combination with the geotextile that has to be used in the Equations. For the thickness of the filter layer it is investigated to which depth changes at the surface affect the subsoil. One can fill in 0.5 m for sand and 0.05 m for clay.

3.4 *Model test results*

An extensive series of model tests have been performed, aiming at verifying the Equations derived and finding values of the coefficients. These tests have been performed in the Delft Hydraulics filterbox. A cross section of the test facility is giving in Figure 4. The filter box has an upstream buffer tank in which a constant water level is maintained by a weir. The water flows from the upstream buffer tank into the bottom part of the model section and from there in a vertical direction through the model. Finally the water passes over a weir at the downstream end of the facility, where the discharge is measured.

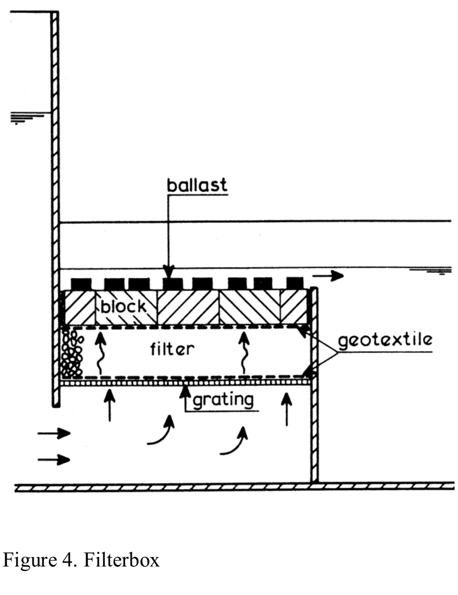

Figure 4. Filterbox

The layout of the model section is such that the pressure piezometric head is equal at each location under the filter. This is also true for each location on top of the model revetment.
The piezometric head in the filter was measured by means of piezometric tubes in which the rise could be read with an accuracy of approximately 1 mm. During some of the test series the pressure potential was also measured under the blocks and in the joints between the blocks.

Many types of revetments and filter layers have been investigated. In two test series a geotextile was installed between the cover layer and the filter layer to measure the influence of the geotextile on the permeability. For these test series a geotextile was selected with a very high permeability. The characteristics of this geotextile were:

- Nicolon 66336, woven geotextile
- polyetheen, 117 g/m^2
- $a_g = 118$ s/m
- $b_g = 0$
- $T_g = 0.57$ mm
- $O_{90} = 0.38$ mm

The velocity in the joints, v_s, was not measured but calculated from the measured discharge per square metre, q, and the joint width: $v_s = qBL/((B+L)/s)$.

The piezometric head across the cover layer was calculated using the measured piezometric head in the filter. The piezometric head was extrapolated linearly to the cover layer, resulting in a virtual piezometric head under the blocks, which is equal to the piezometric head under a homogeneous cover layer with the same permeability.

The tests were performed with blocks of 25x25x10 cm^3 and a filter layer with characteristic grain size $D_{15} = 1.6$ mm. The joint width between the blocks was 1.6 mm. The tests have resulted in an average permeability of the cover layer of k' = 3.5 mm/s. In spite of the very high permeability of the geotextile, there was a pressure head difference over the geotextile of 21 mm during a tests with a pressure head difference over the cover layer of 100 mm. It means that 21% of the flow resistance is due to the geotextile.

The permeability of the cover layer was also calculated with the above given Equations. The result was k' = 3.8 mm/s. This result shows that for this situation the Equations work quite well.

4 CONCLUSIONS.

It is shown that the stability of a revetment is dependent on the stability of the cover layer. Equations have been derived to determine the permeability of a cover layer including a geotextile.

The performance tests, in which the permeability of the cover layer including a geotextile was measured, agree very well with the Equations.

The Equations showed that only a careful chosen combination of cover layer and geotextile guaranties a sufficient permeability of the cover layer. Even a very open geotextile can add considerably to the head difference over a cover layer and thus decrease the stability of a revetment.

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