CHAPTER 121

FIELD MEASUREMENTS ON PLACED BLOCK REVETMENTS

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Abstract

A report is given on a field measurement campaign on placed block revetments. Four types of measurement are described. Typical results are presented and discussed. The entire campaign shows a consistant image of changing physical properties in the field.

Introduction

Placed block revetments are a type of coastal protection commonly used in the Netherlands and Germany. Extensive research has been carried out on this type of construction, including small and large scale model tests (Burger et al, 1990, Sparboom and Führböter, 1990). Analytical and numerical design methods are available (Burger et al, 1990 and Bezuijen et al, 1987). However, until recently little field data of this type of construction in marine conditions has been reported. Therefore, Rijkswaterstaat, the Dutch Ministry of Public Works, has initiated a field measurement campaign. The scope of this work was to compare the results of model tests and calculation models with the physical behaviour of revetments in the field.

Some theory on placed block revetments

Shown in figure 1 is a common construction in the Netherlands. You see a top layer of carefully placed blocks and a permeable filter layer underneath.

The theory behind this type of revetment can be simplified into four statements:

- first, wave action causes pressures on the top layer.
- in the filter layer a reaction to these pressures takes place. This reaction depends largely on the permeabilities of top layer and filter layer. This can be characterized by one

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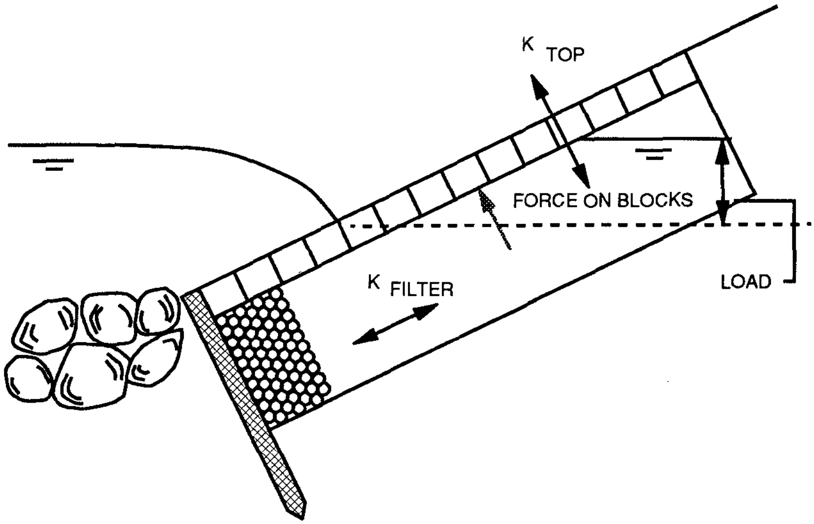

Figure 1 Placed block revetment

parameter; the leakage length. This parameter can be expressed as:

$$\Lambda = \sqrt{(\frac{b \cdot D \cdot k}{k'})} \qquad [1]$$

with: Λ = leakage length [m]
b = thickness of filter layer [m]
D = thickness of top layer [m]
k = permeability of filter layer [m/s]
k' = permeability of top layer [m/s]

- the load on the top layer is the difference in pressures on top and underneath the top layer.
- the load on the top layer can be compared to the strength. A certain force is required to push a block out of the revetment.

In the analytical and numerical models wave pressures, permeabilities and leakage length are used to calculate the reaction in the filter layer and consequently the load on the top layer. The load is compared to the strength, which is expressed in terms of one or more times the block weight.

Overview of performed measurements

The same factors as mentioned above return in the overview of performed measurements. Four types of measurement are discussed, respectively:

1. Permeability tests
   It is clear that the permeability of the top layer is an important factor. This can be measured directly in the permeability test. The amount of water that disappears from a reservoir is measured. This can be linked to the permeability of the top layer.
2. Infiltration tests
   The reaction in the filter layer to an imposed water-column is measured in the infiltration test. As this reaction is a function of the leakage length, the leakage length can be predicted.
3. Wave and pore pressure tests
   In the wave and pore pressure test the wave pressure on the top layer and the pore pressure beneath the top layer are measured simultaneously. The difference is the load on the top layer. The results are used to hindcast the leakage length.
4. Pull-out tests
   Blocks are pulled out of the revetment. The force required to do this is measured. This gives an impression of the strength of the top layer.

Permeability test

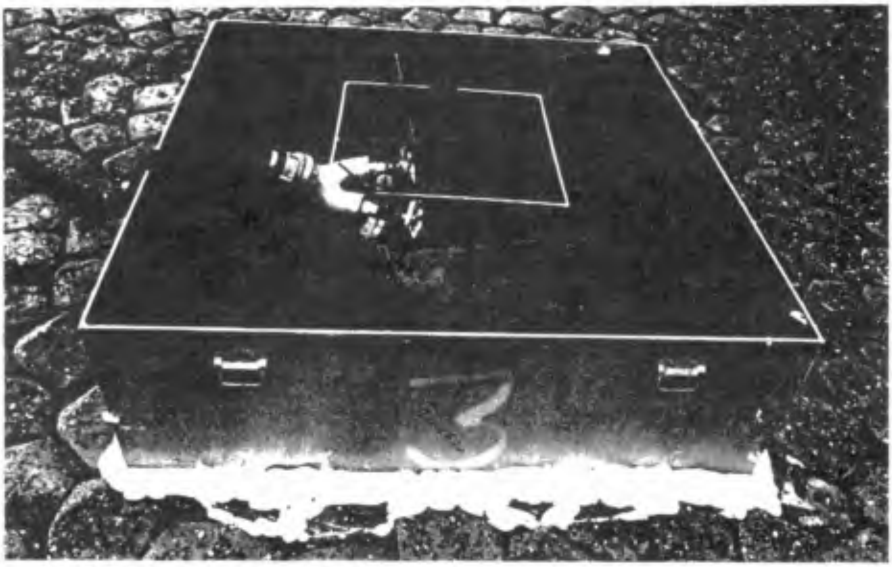

Figure 2 Set-up of permeability test

As shown in figure 2, the permeability of the top layer is measured by placing a reservoir with a known surface of the open bottom on the top layer. Leakage through the gaps between the top layer and the reservoirs is reduced to a minimum by applying foam around the sides. A second reservoir is placed around the inner reservoir to make sure that the flow through the top layer is as one dimensional as possible. Next, the reservoirs are both filled with water. The amount of water disappearing in a fixed period of time from the inner reservoir through the top layer is measured. This can be linked to the permeability of the top layer.

Results of permeability test

Measurements of the permeability of the top layer are performed at different heights.
Roughly, three zones can be distinguished:

- the tidal zone with a permeability of $5 \cdot 10^{-7}$ m/s.
- the zone between high water level and high high water level, with a permeabilty a 100 times higher than in the tidal zone.
- the storm surge level, again with a permeability which is again 100 times higher than the zone below.

The conclusion is, that the permeability in the tidal zone has decreased with a factor 10,000 during the lifetime of the construction. This permeability is also much lower than normally found in model tests. The reason for this sharp decrease in permeability was found when some blocks were lifted. The joints between the blocks are completely filled with sand and other fine material. Especially in the tidal zone, biological growth can influence the permeability. The filter layer, which originally consisted of gravel, is now a mixture of gravel and sand. However, as the decrease in permeability of the filter layer is less dramatic than the decrease in permeability of the top layer, inevitably the leakage length increases. As a large leakage length yields larger loads this is unfavourable.

Infiltration test

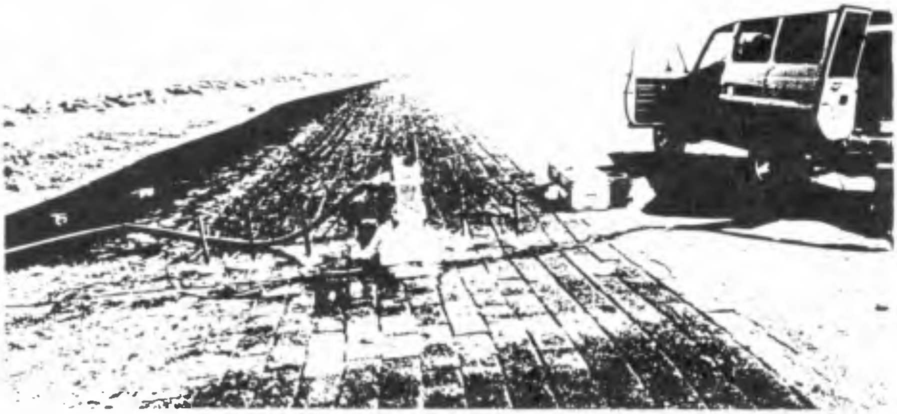

Figure 3 Infiltration test, measurement set-up

The next type of test presented here is the infiltration test. This test is used to determine the leakage length. The state of the art in modelling allows us to calculate the reaction in the filter layer to a given load, if only the leakage length is known. Therefore, some elements of the top layer are removed and a box of 1 m height is placed in the hole. Water is pumped into the box to a certain, constant, level, so that the local load on the filter layer is known. The decrease in pore pressure, as a function of distance from the location where the load is applied is measured.

A long leakage length means that the permeability of the top layer is relatively small compared to the permeability of the filter layer (see also equation [1]). Therefore the decrease in pore pressure with increasing distance from the infiltration point is small. A short leakage on the other hand means that the permeability of the top layer is relatively large. The decrease in pore pressures takes place over a limited distance.

Figure 3 shows the measurement set-up. An infiltration reservoir is placed on the top layer. Bore holes are made through the top layer. This enables the placement of pore pressure transducers in the filter layer. Next, the reservoir of 1 m height is filled to overflow level and kept there until a stationary situation is obtained. At that moment the pore pressures in the filter layer are determined.

Results infiltration test

Shown in figure 4 is the measured decrease in pore pressure as a function of height. Schematically drawn are also the revetment, the infiltration reservoir, and the measured pore pressures. In a one-dimensional situation, that can be reached with several infiltration points in a horizontal row with laminar flow, an analytical solution is possible.

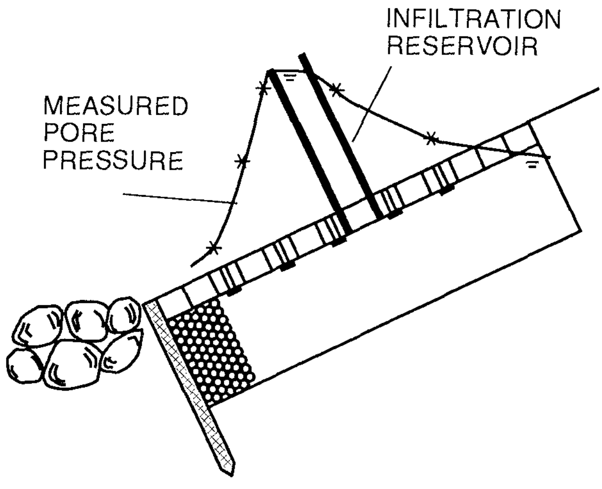

Figure 4 Result of infiltration test

In practice however, only one or two infiltration points are used, and around the infiltration points turbulent flow is dominant. This means two dimensional flow has to be dealt with to determine the leakage length. Calculations are performed with the same numerical model that is used to investigate the influence of oblique wave attack on revetments (Bezuijen et al, 1992). The result of a calculation with this model can be seen in figure 5.

Shown is the calculated piezometric head for a two dimensional situation. The leakage length in this case is relatively short, about 0.8 m. The drawn lines are lines of equal pore pressure. Vertically is set out the height on the revetment (not the distance along the surface of the slope), horizontally the horizontal distance. The calculation is performed on a dry slope; the tidal level is below the toe of the revetment.

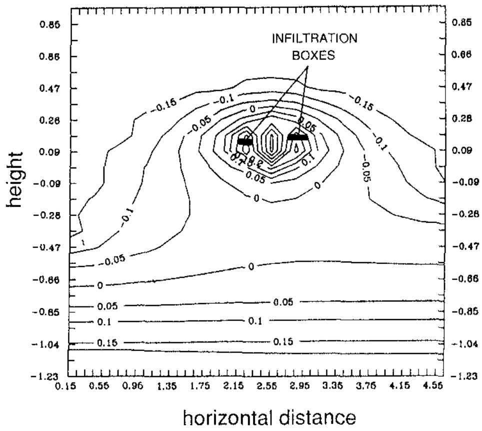

Figure 5 Result of calculation model

Around the infiltration point the water flows down the slope in a kind of umbrella shape. If the pore pressure is measured in several points, this can be compared to the calculated piezometric head in figure 5. Shown is the difference in peizometric head over the cover layer. A negative value means, that the water level lies below the cover layer at that position. Only if this value is positive, water will flow through the cover layer out of the construction. The minus 0.15 m-line represents the phreatic surface in the filter layer. The positive values on the bottom of the graph represent a build-up of difference in piezometric head that is caused by an impermeable toe construction. Good agreement is found, provided the right leakage length is chosen.

Wave and pore pressure test

In the wave and pore pressure test, a measuring beam with a length of six to nine metres is placed on the top layer, as shown in figure 6. On top of the measuring beam 12 wave pressure transducers are fixed. Along the measuring beam 3 bore holes are made through the top layer. Through the bore holes pore pressure transducers are placed in the filter layer.

Measurements are only useful when there is enough wind to generate waves of some height. Measurements are possible up to Beaufort 7 to 8. During fairly stormy weather the wave pressures on the top layer and the pore pressures beneath the top layer are measured simultaneously. The difference between them is the load on the top layer. Therefore, the wave and pore pressure test is a direct measurement of the load on the top layer.

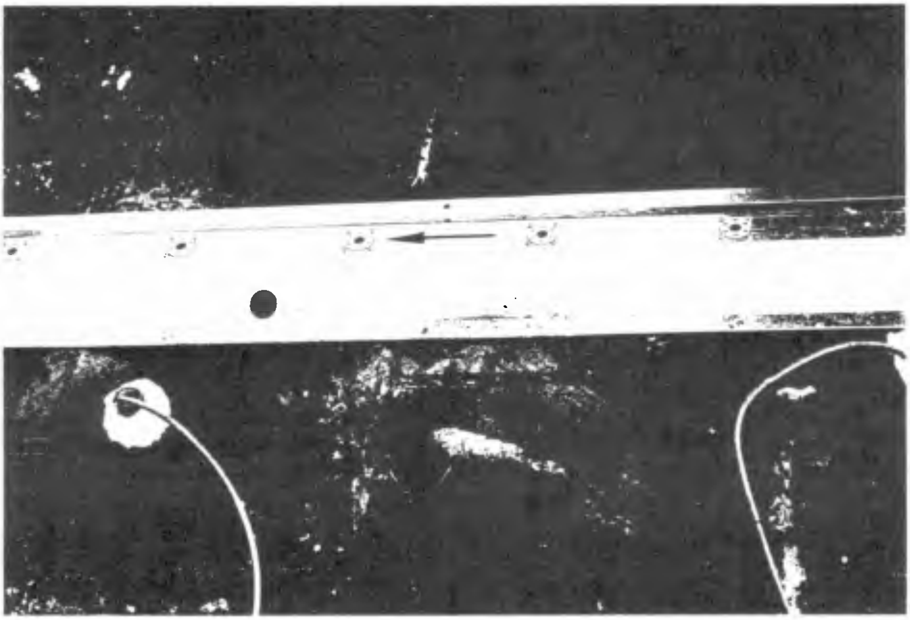

Figure 6 Measurement beam and bore holes

Results of wave and pore pressure test

Shown in the graph in figure 7 are the measured wave pressure, the measured pore pressure and the difference between these two, which is the load on the top layer.

The wave height on the spot of the pore pressure transducers is some 20 cm, the reaction in the filter layer is about 2 cm. This reaction in the filter layer is much smaller than expected, because the permeability of the cover layer in the tidal zone is much lower than expected. The result of such a small reaction in the filter layer is, that a wave height of one fifth of the design wave height will be sufficient to cause a load on the top layer that is equal to the weight of the blocks. The same theory, however, also explains that with permeabilities that are very low, little water can reach the critical point. A much higher load is required to actually cause damage.

According to the theory on placed block revetments the reaction of the pore pressures to the wave pressures is determined by the leakage length. The wave and pore pressure test therefore can also be used to make a hindcast of the leakage length.

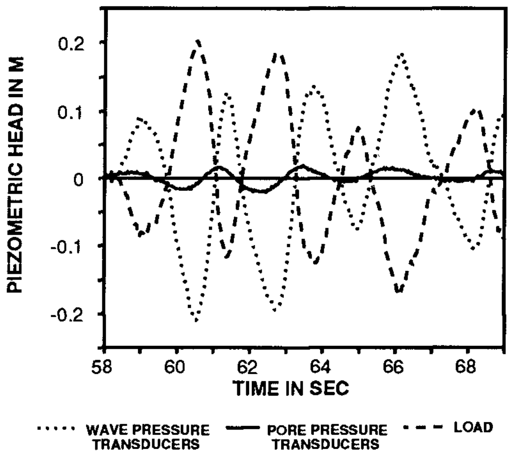

Figure 7 Result of wave and pore pressure test

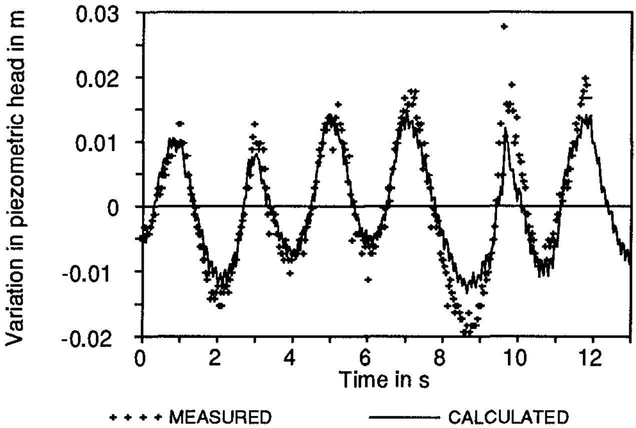

Figure 8 Simulation of pore pressures

This hindcast is performed done with a numerical calculation model STEENZET/1. The measured wave pressures are used as input for the model. The pore pressures in the filter layer are calculated and compared to the measured pore pressures. A good correspondence between measured pore pressures and calculated pore pressures can be found, provided the right leakage length is chosen. In figure 8 both these properties are given.

The leakage length used for this simulation is 13 m. This is 10 to 20 times larger than usually found in model tests. As a long leakage length yields large loads, this is unfavourable.

A different aspect is found when we take a look at the phreatic surface in the filter layer. The test is repeated at different tidal levels. This information can be used to compare the phreatic surface in the filter layer with the mean sea water level. Because of the small permeability of the top layer, the phreatic surface does not respond instantaneously to a change in tidal level. This difference in water levels can cause a considerable extra load on the top layer if the tidal level drops and the phreatic surface does not react accordingly, as shown in figure 9.

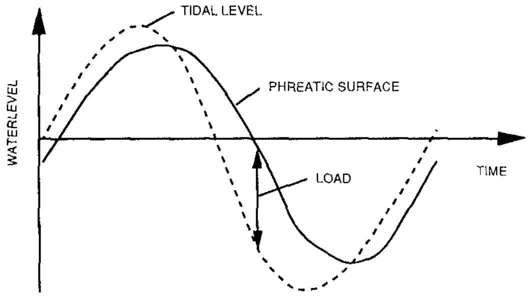

Figure 9 Phreatic surface and tidal level

So far this phenomenon has never been observed in model tests, simply because these tests are performed on newly made constructions. Therefore, also in calculation models it is always assumed that the mean water level in and outside the construction is more or less equal. This proves to be a dangerous assumption.

Pull-out test

So far only the load on the top layer has been considered. As it is shown in the previous paragraphs that this load can be much larger than expected, it is important to compare this load to the strength of the top layer.

An impression of the strength of the revetment can be obtained by pulling blocks out of the revetment and registering the force required to do this.

Shown in figure 10 is a pulling unit, consisting of a trailer which is fixated on the top layer with four supports. On board of the trailer a computer-controlled system is mounted that is able to lift a block over a vertical distance of 2.5 cm by exerting a hydraulically controlled pulling force of about 6 times the block weight. The maximum pull-out force is about 10 kN.

A large number of blocks (over one thousand) was pulled out, ensuring that a statistical evaluation of the results is valid. The aim of the test was to answer the question how many blocks are loose blocks that can be lifted easily during wave attack.

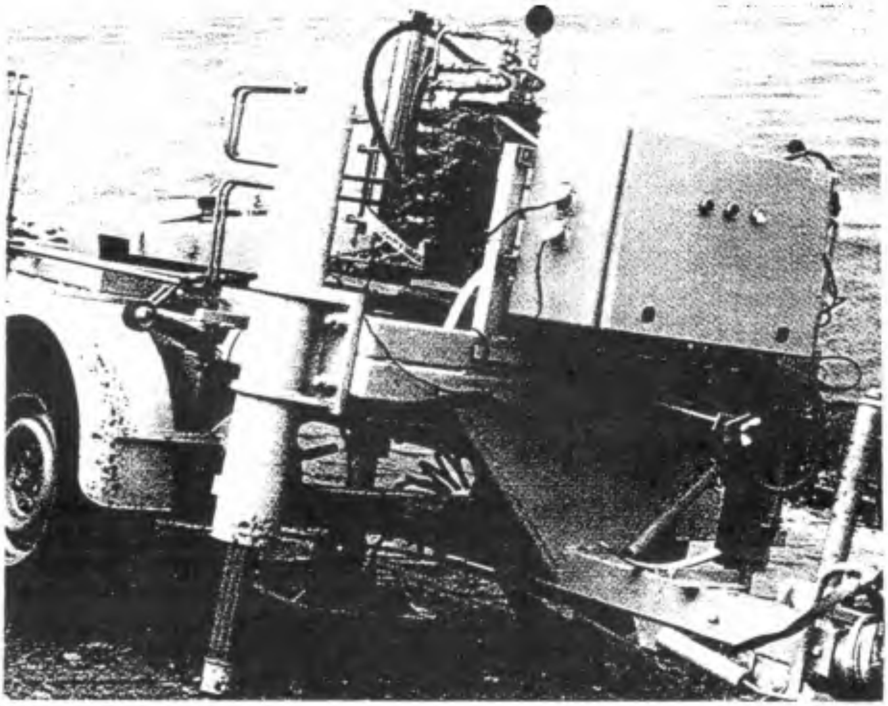

Figure 10 Pulling unit

Results of pull-out tests

Shown in figure 11 are the results of pull-out tests on three different levels.

Three things can be read from this graph:

- the influence of the height is evident: the lower on the revetment the higher the strength of the construction.
- at a pull-out force equal to the block weight less than one percent of all the blocks is pulled out
- the percentage of blocks that is not pulled out of the revetment, even at a pull-out force of 6 times the block weight is considerable. Depending on the level, only 15, 30 or 70 percent of the blocks was lifted.

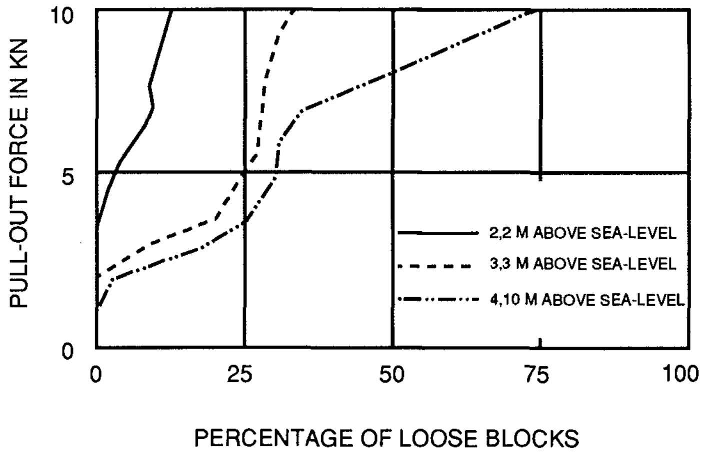

Figure 11 Results of pull-out tests

Not shown in this graph is the fact that in the tidal zone no blocks could be pulled out. In general, the required pull-out force is higher than expected. This is caused by friction forces and clamping forces in case of a slight rotation of the block.
It is stressed that, during wave attack, the load on the blocks can be different than the schematized load of the pull out tests. Also, it is possible that more than one block at a time will move.
Still, the strength of older placed block revetments with a low permeability of the cover layer can be considered higher than the strength of loose blocks.

Conclusions

The entire campaign of field measurements shows a consistent image from which the following conclusions can be safely made:

- first, it is clear that physical properties in the field, especially permeabilities, can differ dramatically from properties in model tests. This means that existing revetments can show physical behaviour that differs from the behaviour found in model tests.
- in time permeabilities decrease due to biological activity and migration of sand and fine material.
- in the tidal zone this influence is larger than in the zones above it. Properties vary with height.
- if the permeability of the cover layer decreases more than the permeability in the filter layer, the load on the top layer increases. At the same time however, also the strength seems to increase.

Existing design methods are based on the concept of loose blocks. The methods have been verified in model tests, and therefore they are valid for revetments with relatively large permeabilities and short leakage length. Usually, a revetment is designed on the properties as expected directly after construction.

In the measurement campaign it is shown, that the concept of loose blocks is valid at storm surge level, but not necessarily in the tidal zone. Also, it is shown, that permeabilities decrease, the leakage length grows and consequently the load on the top layer increases. Permeabilities in the tidal zone can decrease to a degree that, even if there is a large uplift pressure, still no block movement will occur, as no water can flow towards the attacked block. In practice, also the pull-out force can be much higher than expected.

As a consequence for the design of placed block revetments the change in physical behaviour with time should be anticipated for the entire lifetime of the construction.

References

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