Proceedings of the 6th International Conference on the Application of Physical Modelling in Coastal and Port Engineering and Science (Coastlab16)

Ottawa, Canada, May 10-13, 2016

COASTAL STRUCTURES WITH OPEN FILTERS UNDER WAVE LOADING

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ABSTRACT

Permeable coastal structures under wave loading typically contain granular filters in one or more layers. The transition from the armour layer to the filter layer, and transitions between other layers within the structure, are normally geometrically tight to prevent material washout. This requires a limited ratio of the material size of the upper layer and neighbouring layer. An alternative is a geometrically open filter where in principle underlayer material can be transported into the upper layer, but if the hydraulic load at this transition between two layers remains low, the transition can be designed such that no or limited transport occurs. This allows for larger ratios of material sizes, which can reduce the number of filter layers, and can lead to considerable cost savings. Some structures have been constructed in which the transition between the armour layer and the filter layer of rock underneath is an open filter, but proper design guidelines for such open filters are not available yet. Physical model tests for the transition between a layer of rock and an underlayer that consists of sand have been performed and design guidelines have been derived. The developed guidelines based on physical model tests in combination with the numerical modelling lead to valuable insights into the possibilities of this new design approach.

KEYWORDS: Rock slopes, Open filters, Erosion, Physical model tests; Settlement.

1 INTRODUCTION

Permeable coastal structures that consist of rock typically contain granular filters. These filters fulfill several functions. They prevent the erosion (washing out) of finer base material due to waves and currents, contribute to the energy dissipation by turbulent flow through the voids, and provide drainage. Granular filters can be designed as geometrically tight filters or as geometrically open filters. The design of geometrically tight filters (no material washout) is relatively straightforward (see *e.g.* CUR Report 161/233, 1993; CIRIA-CUR-CETMEF, 2007), but in many instances a large number of filter layers and material volume is required. Each layer should have a minimum thickness of at least a few diameters but for practical reasons also a minimum thickness irrespective of the size of the material (*e.g.* 0.5 m) is required. For a granular filter of a number of layers, the mentioned minimum thickness may lead to a substantial size of the total filter.

One alternative is a geometrically open filter in which no transport of material of the filter layer (base material) occurs because the hydraulic load is smaller than the threshold value for incipient motion (hydraulically closed filter). Another alternative is a transport filter where some movement of the base material within the granular filter layer is allowed. In this case the hydraulic load is larger than the threshold value for incipient motion. The design of a transport filter is based on the principle that the layer thickness is such that erosion of base material (or settlement) remains below an acceptable level. In practice, limited settlement is often permitted.

The transition from the armour layer to the next rock layer underneath can be geometrically tight or geometrically open, as well as the transitions between other layers. Also the transition between the lowest layer of rock and the sand underneath (if sand is used as base material) can be an open filter. In case of an open filter, the risk of washing out of base material is of course larger than for geometrically tight filters. Therefore, open filters can only be applied if they are properly designed. For open filters where both the toplayer and the underlayer (base material) consist of rock, no adequate design guidelines exist. For open transport filters where the toplayer consists of rock and the underlayer (base material) consists of sand, guidelines have been developed (see Van Gent and Wolters, 2015, and Van Gent et *al.*, 2015). Care should be taken when applying open filters because if unforeseen damage or settlement occurs, the possibilities to repair of the structure may be relatively limited and expensive. Nevertheless, since the construction costs may be considerably lower if properly designed open filters are applied, it is worthwhile to develop design guidelines for open filters.

Here physical model tests to develop guidelines for open transport filters with sand as base material are discussed as well as a numerical model that can model erosion and deposition of sand within a layer of rock. An example of a transport filter under wave loading can be seen in Figure 1.

Figure 1. Physical model tests with open transport filters with rock on top of sand (from Van Gent and Wolters, 2015).

In the 1980s and 1990s a large number of tests have been performed by for instance De Graauw et *al.* (1983), Bakker et *al.* (1994) and Klein Breteler et *al.* (1992) to determine criteria for the initiation of motion in granular filters. These criteria are based on estimates of the hydraulic gradients parallel or perpendicular to the interface between sand and the granular filter. This resulted in various formulae and a design diagram for interface stability of granular filters; see for instance CUR Report 161 (1993). Furthermore, new criteria for interface stability were for instance introduced in CUR Report 233 (2010) and Van de Sande et *al.* (2014). These studies have been conducted with a focus on the beginning of base material transport through the filter. The studies do not specifically address material transport itself or effects of filter settling.

Uelman (2006) investigated a sloped granular filter structure (1:3) on a sand core using wave flume experiments with regular waves. Ockeloen (2007) continued the research by Uelman (2006) with irregular wave loading and proposed an equation for the erosion area based on the pressure gradient parallel to the slope (estimated from video recordings of the water surface measured above the filter layer), the relative filter thickness (*i.e.* the filter thickness divided by the rock diameter: d_f / D_{50f}) and the wave loading (wave height, wave length, number of waves). Dixen et *al* (2008) extended the study of Sumer et *al* (2001), which determined the onset of base material removal from between armour blocks for currents, to waves and combined waves and currents. The behaviour of a filter layer of regularly placed armour blocks (very rough) on a base of sand was investigated. The filter consisted of both a single and multiple layers of the same armour stones (various sizes and forms were tested). Zoon (2010) analysed various large scale tests in the Delta Flume (cobble beach) and the GWK (Elastocoast revetment experiments) regarding the stability of sand underlying a single filter layer under wave loading. Wolters and Van Gent (2012) studied granular open filters on a horizontal sand bed under wave and current loading. Based on their study they proposed formulae for base material transport in horizontal granular filters based on the hydraulic gradient parallel to the filter-bed interface and the filter velocity respectively. In Van Gent and Wolters (2015) physical model tests were performed with 1:4 and 1:7 slopes, with one or two layers of rock on top of sand. The erosion and accretion were analysed and a set of prediction formulae for open filters under wave loading was derived. In Van Gent et *al.* (2015) the hydraulic loading on the transition from rock to sand was computed by means of a CFD-model (see Jacobsen et *al.* (2012, 2015). In Jacobsen et *al.* (2016) not only the loading at the internal interface is computed but also the erosion and accretion of sand within the rock layer has been modelled numerically. This first approach to numerically model erosion and accretion of sand within the rock layer above shows that open filters with sand as base material, can be modelled rather accurately.

Chapter 2 summarises the results and the design guidelines derived from Van Gent and Wolters (2015). In Chapter 3 an overview of the numerical modelling of open filters is given. Finally, in Chapter 4 the main conclusions and recommendations for future research on open filters have been summarised.

2 DESIGN GUIDELINES BASED ON PHYSICAL MODELLING

Design guidelines for open filters under wave loading were derived based on physical model tests. The tested structures consisted of one layer of rock on top of a sandy slope or two layers of rock on top of a sandy slope. Tests were carried out for 1:4 and 1:7 slopes. Wide and narrow graded rock was applied. Figure 2 shows sketches of the tested configurations: A) One layer of rock with wide graded rock on top of sand, B) One layer of rock with normal/narrow graded rock on top of sand, and C) Two layers of rock on top of sand.

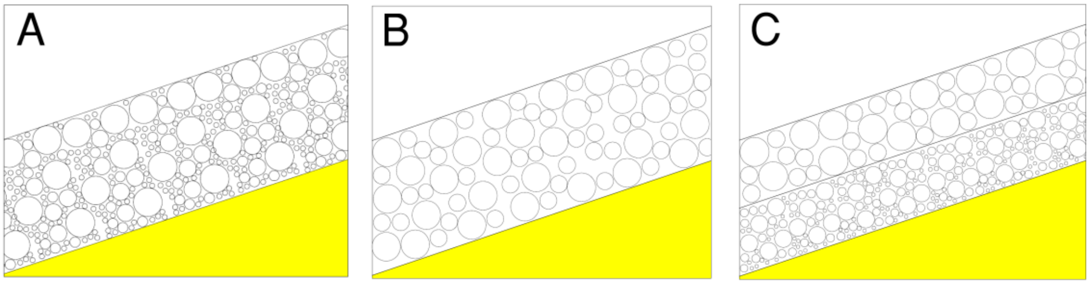

Figure 2. Tested configurations of the open filter (rock on top of sand).

The following parameters were measured:

$A_{e,r}$: Outer rock profile: Area of the eroded part of the top/filter layer of rock.

$A_{e,s}$: Internal interface: Area of sand erosion at the internal sand-rock interface.

A_{acc} : Internal interface: Area of sand accretion at the internal sand-rock interface.

z_s : Maximum erosion depth of sand (measured in vertical direction).

z_{acc} : Maximum accretion height of sand within the filter layer (measured in vertical direction).

Figure 3 shows a schematization of these parameters. The test results showed that if the rock is stable under direct wave loading (*e.g.* by applying high-density rock in the tests), the eroded part of the external surface of the rock layer ($A_{e,r}$) was more or less equal to the eroded part of the internal sand surface ($A_{e,s}$).

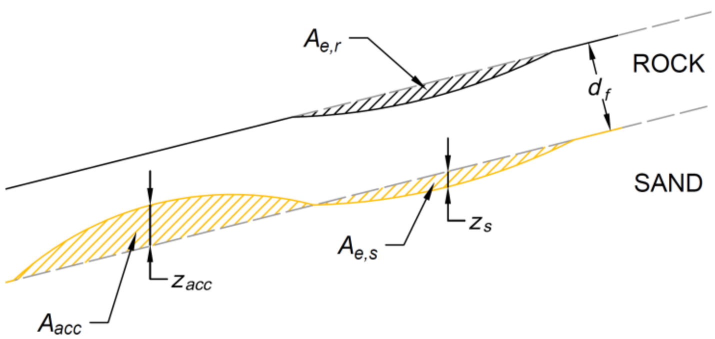

Figure 3. Erosion and accretion pattern (parameter definition).

The test results also showed that there is a clear relation between the accretion area and the accretion height (left panel in Figure 4). Also a clear relation was observed between the erosion area and the erosion depth (right panel in Figure 4).

Besides above mentioned parameters also the hydraulic gradients along the internal rock-sand interface were measured. It appeared that there is a reasonably clear relation between measured accretion and the ratio of the measured hydraulic gradient and the critical hydraulic gradient. The measured erosion shows a similar dependency. Figure 5 shows these relations for the test results with a 1:4 slope (lines) and a 1:7 slope (dashed lines). The critical hydraulic gradients were obtained by the method proposed by Klein Breteler et *al.* (1992). This critical hydraulic gradient depends on the size and permeability of the rock material, and on the size, angle of repose and the relative density of the sand. It was observed that the hydraulic gradient could be estimated by a rather simple relation, where this hydraulic gradient along the slope depends on the ratio of the wave height and the layer thickness. Substituting the estimates of the hydraulic gradients in the observed relations between accretion or erosion and the hydraulic gradients provided the set of equations as described in Box 1. For a configuration with two layers of rock use is made of an equivalent layer thickness, such that the same expressions can be used for a configuration with two layers of rock as well. A comparison of measured and predicted accretion heights and erosion depths are shown in Figure 6.

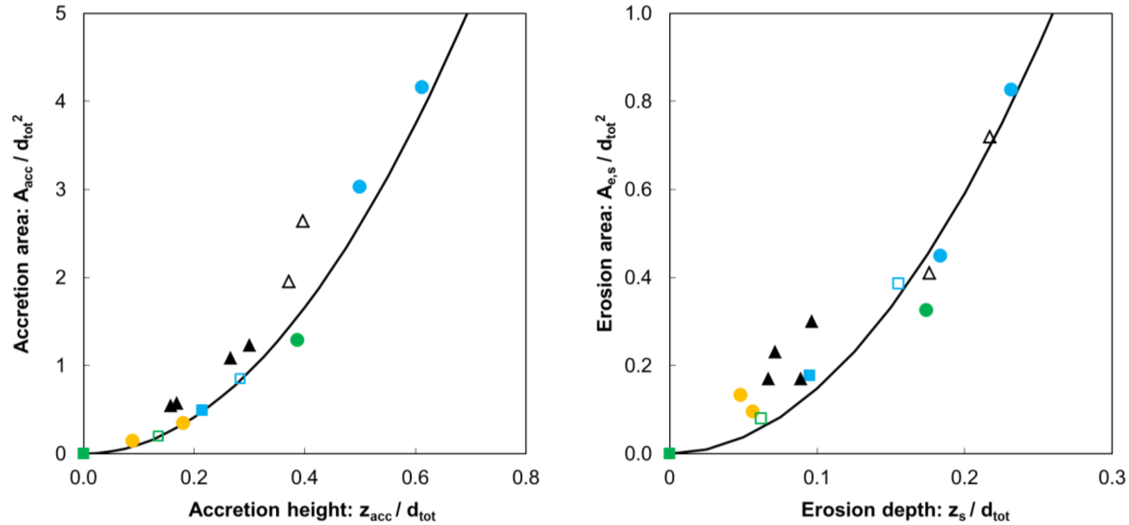

Figure 4. Sand accretion and erosion: Observed relation between area and height of accretion (left) and erosion (right).

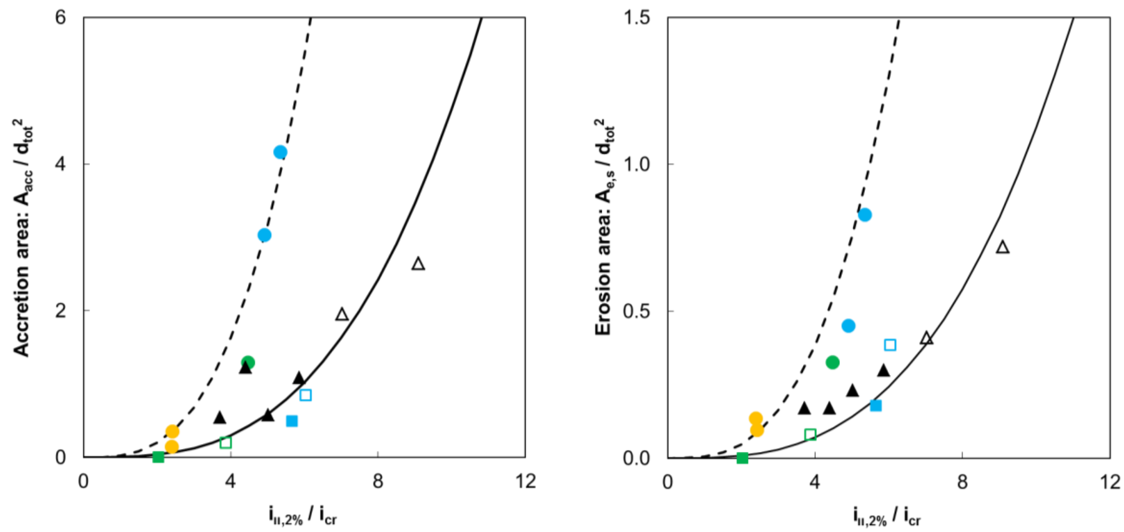

Figure 5. Sand accretion and erosion: Area of accretion (left) and erosion (right) versus the hydraulic gradients at interface.

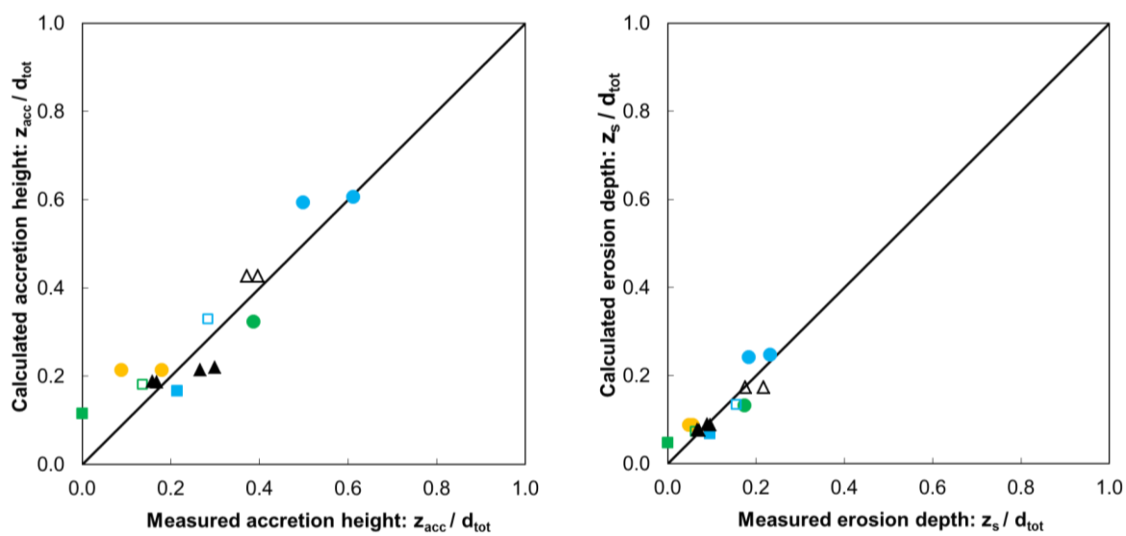

Figure 6. Sand accretion and erosion: Comparison of measured and calculated accretion (left) and erosion (right).

Internal interface (Sand-Rock):

Sand accretion:

$$\frac{A_{acc}}{d_{tot}^2} = \left(0.0084 \frac{\cot\alpha \, H_{m0}}{i_{cr} d_{eq}} \right)^3$$

Sand accretion height:

$$\frac{z_{acc}}{d_{tot}} = 0.00024 \left(\frac{\cot\alpha \, H_{m0}}{i_{cr} d_{eq}} \right)^{1.5}$$

Sand erosion:

$$\frac{A_{e,s}}{d_{tot}^2} = \left(0.0052 \frac{\cot\alpha \, H_{m0}}{i_{cr} d_{eq}} \right)^3$$

Sand erosion depth:

$$\frac{z_s}{d_{tot}} = 0.0001 \left(\frac{\cot\alpha \, H_{m0}}{i_{cr} d_{eq}} \right)^{1.5}$$

with

Equivalent layer thickness:

$$d_{eq} = d_f + (d_{tot} - d_f) \frac{D_{50,f}}{D_{50,a}} \frac{\left(\frac{1-n_a}{n_a^3} \right)}{\left(\frac{1-n_f}{n_f^3} \right)}$$

with the validity criterion: $z_{acc} < (d_{tot} - 2\, D_{n50,a})$

Box 1. Prediction method for open filters by Van Gent and Wolters (2015).

The main equations that have been derived are shown in Box 1. The symbols in Box 1 denote:

d_f : Thickness of the filter layer (m).

d_a : Thickness of the toplayer in the case of a system with two layers of rock (m).

d_{tot} : Total thickness of the rock layer(s): $d_{tot} = d_a + d_f$ (m).

$D_{50,f}$: Filter material diameter, of which 50% (by mass) is smaller (m).

$D_{50,a}$: Toplayer material diameter, of which 50% (by mass) is smaller, in the case of a system with two layers of rock: $D_{n50,a} = 0.84\, D_{50,a}$ (m).

H_{m0} : Spectral significant wave height (m).

i_{cr} : Critical hydraulic gradient proposed by Klein Breteler et *al* (1992) (-).

n_f : Porosity of filter material (-).

n_a : Porosity of toplayer material in the case of a system with two layers of rock (-).

α : Slope (-).

Ranges of validity

Box 1 shows the set of equations to describe sand accretion and erosion under (perpendicular) wave loading at the rock-sand interface and the resulting settlement of the rock layer. Since the equations are based on tests with 1:4 and 1:7 slopes, the equations are considered valid in the range between 1:4 and 1:7 slopes. Another important limitation of the validity is that the rock slopes should show no or minor damage due to direct wave attack. For higher damage levels, the interface between rock and sand may be affected beyond the range of the test results. The width of the rock grading has been varied between D_{85}/D_{15} = 2 and 6.5. The thickness of rock layers on top of sand has been varied such that the expressions are considered valid for a thickness of the rock layer of $0.3 < d_f / H_{m0} < 3$ and $d_{tot} < 10\ D_{n50,f}$. Also tests have been performed with two layers of rock on top of sand where the ratio of layer thicknesses was: $0.5 < d_f / d_a < 1$ and the ratio of rock sizes of these two layers was $D_{n50,f} / D_{n50,a} \geq 0.5$.

The expressions are not valid for very thin layers where sand entrains directly into the water column. Therefore, the range of validity is limited by using the criterion $z_{acc} < (d_{tot} - 2D_{n50,a})$ where $D_{n50,\mathrm{a}}$ is the size of the material in the outer rock layer. The wave steepness based on the peak wave period was varied between $s_p = 0.015$ and $s_p = 0.04$, although the number of tests with variation of the wave steepness was rather limited.

The duration of the tests was up to a number of waves of $N = 5000$ ($s_p = 0.015$) to 10000 ($s_p = 0.04$) per wave condition. The proposed equations are considered applicable for these durations only. For shorter durations the proposed equations provide conservative estimates. During these conditions the water level did not vary. The expressions are considered valid for a structure if the peak of a (design) storm can be schematized by a constant water level. The conditions during the peak of the storm should not exceed $i_{\parallel,2\%} / i_{cr} > 8$. It is recommended that all other conditions within the storm and other storm conditions during the lifetime of a structure should not lead to transport of sand, unless it can be guaranteed that after an accumulation of all expected storms that lead to transport of sand, the earlier mentioned criterion $z_{acc} < (d_{tot} - 2\ D_{n50,a})$ will still be satisfied. The mentioned test results do, however, not provide information on the effects of an accumulation of storms that lead to transport of sand (with different water levels).

Criteria for open filters

For the design of open filters not only the erosion and accretion need to be predicted, also criteria for the acceptable amount of erosion and accretion are needed.

Criteria related to the acceptable amount of damage to rock slopes under direct wave attack vary between initial damage and intermediate damage. These criteria are for conditions without washing out of material from the layer underneath the toplayer (armour layer). Since the damage to the toplayer affects the loading on the rock-sand interface, the criteria for acceptable erosion of sand depend on the damage to the toplayer. Here, considerations are described based on no or only minor damage to the toplayer.

Geometrically closed filters are often applied with a layer thickness that is about two times the size of the rock diameter. For open filters a thicker layer is applied, firstly to reduce the hydrodynamic loading at the interface between rock and sand, and secondly to compensate for erosion of sand and settlement of the rock layer as a result of this sand erosion. It is reasonable that if for a rock toplayer (armour layer) of two diameters thick with a traditional geometrically closed filter only initial damage would be considered acceptable, that for a toplayer with an open filter again two diameters of armour rock need to show only minor damage.

Furthermore, it is proposed that the design criterion be based on the sand accretion height within the filter and not on the sand erosion depth. This is due to the fact that the sand accretion height within the filter layer is typically larger than the erosion depth, due to the effect of the porosity of the rock layer. Typically strong wash-out of sand starts when the distance between the outer rock profile and the accretion level becomes less than 2 D_{n50}. If accretion reaches a level of less than $2D_{n50}$ underneath the outer rock profile, washing out of material occurs. The described deliberations led to the following criterion:

- The accretion of sand within the filter should be limited to such an amount that along the entire slope a thickness of 2 D_{n50} remains unaffected by sand accretion: $z_{acc} < (d_{tot} - 2\ D_{n50,a})$
- Damage to the rock toplayer (armour layer) due to the combined effects of direct wave loading and settlement caused by sand erosion underneath should result in damage values of $A_{e,r} / D_{n50}^{2} < 2$.

Note that these criteria are for the lifetime of the structure, and not criteria for the performance within a single storm. All storms that lead to transport of sand from the underlayer should be taken into account, including effects of such storms at different water levels. In the design of a structure with an open filter, also the accuracy of the predictions of accretion and erosion needs to be taken into account.

3 NUMERICAL MODELLING

The design guidelines as discussed in the previous section (Van Gent and Wolters, 2015) have been derived based on physical model tests. The derived expressions are considered valid within the range of the applied structural and hydraulic parameters, but not necessarily outside these ranges. Therefore, it is useful to develop a numerical model that can also be applied outside the range of tested structure configurations.

For modelling wave interaction with permeable coastal structures such as structures with open filters, a numerical model is required that is capable of simulating wave breaking and porous media flow. The first VOF-model for permeable coastal structures solving the Navier-Stokes equations for the free-surface flow and for porous media flow showed that this approach can provide valuable insight into the physical processes of wave interaction with permeable coastal structures (Van Gent et *al*., 1994). Several other models have been developed based on the VOF-model (Liu et *al*., 1999, Shen et *al*., 2004, Losada et *al.* 2008, Jensen et *al*., 2014 and Higuera et *al*., 2014). Here, the numerical modelling framework that has been used is that of OpenFoam (version foam-extend-3.1). Jacobsen et *al.* (2015) showed that the form of the Navier-Stokes equations accounting for the presence of permeable parts of coastal structures as presented by Jensen et *al.* (2014) can be applied successfully for breakwaters. It was seen in Jacobsen et *al.* (2015) that the standard values of α and β in the Forchheimer relation for porous media flow suggested by Van Gent (1995) gave good results for a range of experimental cases. These formulations have been used in the numerical model of which results are discussed here.

Thus, first a numerical model taking into account detailed modelling of the wave motion outside the structure and the porous media flow in the permeable rock layers, was selected, validated and applied. After that, the response of the sand within the rock armour layer needed to be modelled. The physical model tests provided data to calibrate and validate the numerical model. After validation of the numerical model several applications within and outside the range of validity of the design guidelines could be performed. The performed numerical modelling can be divided into two steps:

Step 1: Model the hydraulic loading at the internal rock-sand interface;

Step 2: Model the response (erosion and accretion) of the internal rock-sand interface.

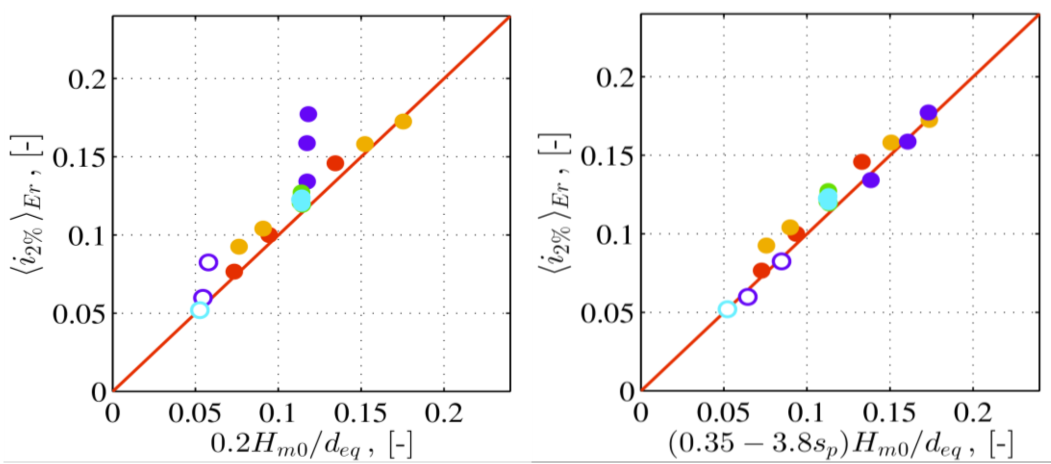

Figure 7: Left: Calculated hydraulic gradients in the area of erosion versus the expression derived from experiments. Right: Calculated hydraulic gradients versus an extended expression including the wave steepness (from Van Gent et *al.*, 2015).

Step 1:

The design guidelines use the hydraulic gradient along the interface between rock and sand to describe the hydraulic loading at this interface. In Van Gent et *al*. (2015) a comparison was made between the experimental results and the numerical model results. The comparison showed that the model is accurate and suitable to calculate hydraulic gradients at the internal rock-sand interface. The computational results indicated the following:

- The hydraulic gradients at the internal rock-sand interface depend on the wave height, layer thickness, and the wave steepness, but not on the rock diameter and the porosity. A suggestion to incorporate the influence of the wave steepness in estimates of the hydraulic gradient at the internal interface has been done (see also right graph in Figure 7), although this calculated dependency needs to be verified based on physical model tests.
- The transition from accretion to erosion (inflection point) can be estimated with a simple relation based on the layer thickness (see also Figure 8).
- The hydraulic gradients in the area of accretion are rather symmetric while in the area of erosion the hydraulic gradients are asymmetric. In the area of erosion there is a net offshore (mean) velocity driven by a mean onshore hydraulic gradient.

The numerical model showed to be a valuable tool to estimate the hydraulic loading at the internal rock-sand interface and to analyse the performance of open filters. Therefore, the model was further developed by including the response (erosion and accretion) of the internal rock-sand interface (Step 2).

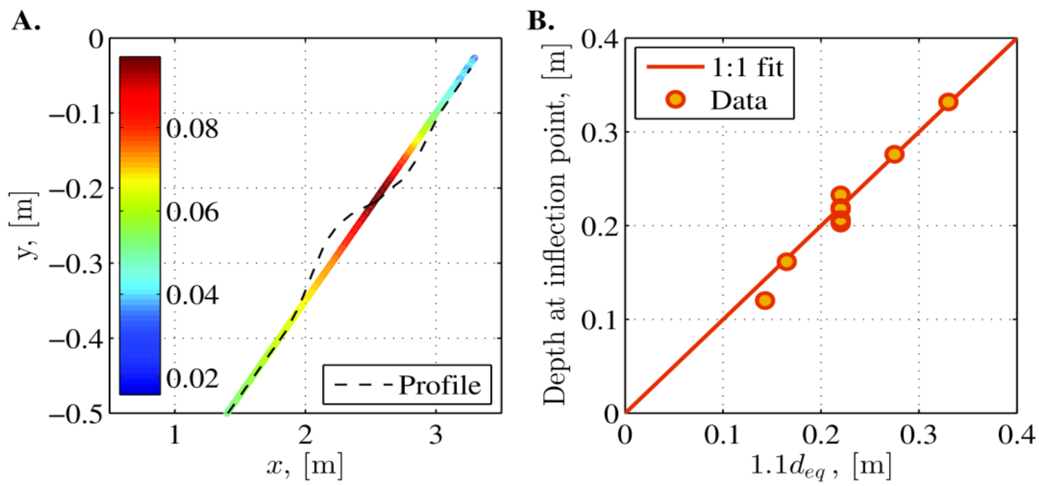

Figure 8: Left: Location of calculated hydraulic gradients and the measured inflection point. Colours indicate the magnitude of hydraulic gradients and the dashed line the measured profile. Right: The water depth at the maximum value of hydraulic gradients as a function of the layer thickness (from Van Gent et *al.*, 2015).

Step 2:

Accurate modelling of the hydraulic loading at the internal rock-sand interface allows for the modelling of morphological changes as a result of this hydraulic loading. Since such a morphological model of sand erosion and sand accretion within permeable structures did not exist, a novel computational framework needed to be developed (see Jacobsen et *al.*, 2016). The following aspects characterise the numerical modelling:

- Since sand can only be deposited inside the pores of the permeable part of the structure, the Exner equation needed to be modified. The result is that the area of accretion (sand in pores of rock layer) is significantly larger than the area of erosion (sand only), as in reality.
- After erosion of sand, the eroded area is filled with rock, as in reality. Although this settlement leads to settlement of the external boundary of the slope, changes of the external boundary of the structure have not been modelled.
- There is a lack of a sediment transport formulation applicable inside permeable structures. Consequently, a sediment transport formulation had to be reverse-engineered based on calibration and validation against existing experimental data sets for the deformation of the sand inside the structure. Irrespectively of some discrepancies between the measured and predicted erosion and deposition patterns, the model was found to be directly applicable for inter-comparing applications for open filters (see also Figure 9 for an example).
- The applications with the numerical model span the effect of the incident wave properties, the effect of changes to the profile of rock layer, and the effect of changes of the water level relative to the (non-uniform) rock layer. The numerical model results show that the wave period is an important property for the magnitude of the erosion.
- The model can provide information on the initiation of motion. This is important to distinguish between hydraulically-closed filters (geometrically open filters but without transport of material due to a limited hydraulic loading) and open transport filters (for which a limited amount of transport of sand occurs). Although the hydraulic gradient may be above the critical hydraulic gradient (initiating motion of sand) the hydraulic gradient that leads to a net transport of sand to other positions along the slope, is larger. Wolters and Van Gent (2012) indicated that for a net transport of sand a hydraulic gradient is required that is about 3 times larger than the critical hydraulic gradient ($i_{2\%}/i_{cr} > 3$). The numerical model can provide further information on the start of a net transport of sand under specific hydraulic and structural circumstances.

The numerical model has proven to be a valuable tool to assess aspects of the potential erosion and accretion of sand at the internal rock-sand interface in permeable coastal structures with an open filter. For further information on the numerical model see Jacobsen et *al.* (2016).

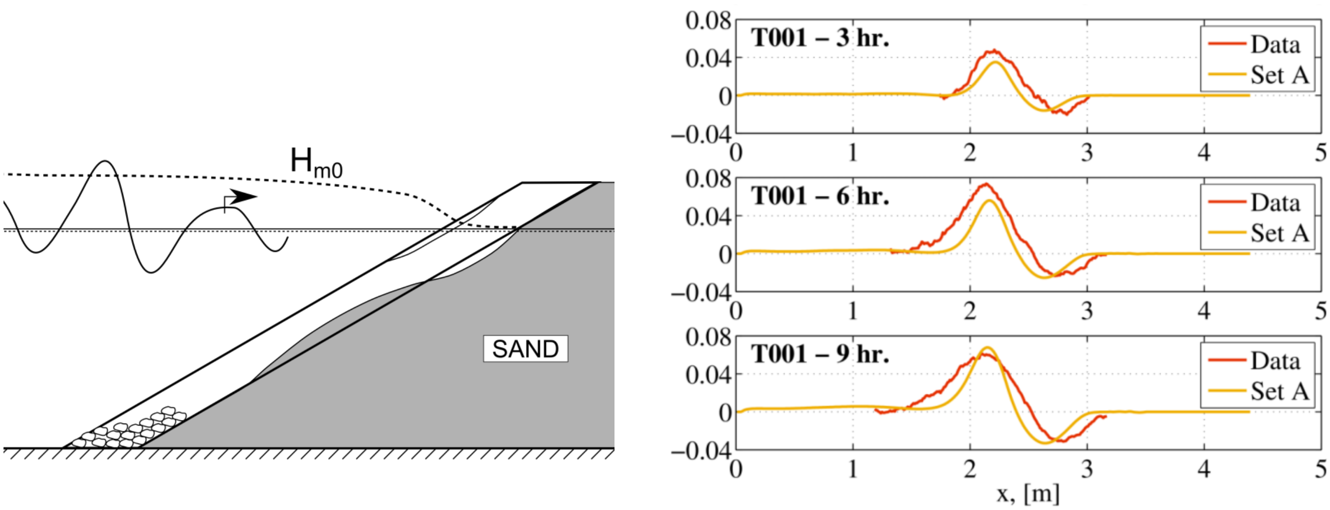

Figure 9: Left: Schematised configuration in numerical model (1:4 slope). Right: Comparison of measured versus calculated deformed internal rock-sand interface (deformation in [m] on vertical axis) (courtesy Jacobsen et *al.*, 2016).

4 CONCLUSIONS

Open granular filters in permeable coastal structures under wave loading can reduce the number of required rock layers compared with structures with geometrically tight filters. Since open filters have a large ratio of the material size of upper layer and the base material, transport of base material can occur. For hydraulically-closed filters, transport of base material can occur but is prevented by assuring that the hydraulic load is small enough. For open transport filters some transport of base material can be allowed. However, this transport of base material should be predicted accurately since the amount of transport should be limited and not lead to washing out of material (out of the structure). Open filters can be designed for rock layers on top of smaller rock, or rock layers on top of sand. For the first (rock on top of rock) no adequate design guidelines are available yet. For the second (rock on top of sand) guidelines have been developed. These guidelines have their limitations that can partly be overcome by using a numerical model that is capable of modelling the erosion and accretion of sand within the rock layer above.

Available guidelines are based on physical model tests (Van Gent and Wolters, 2015). These were focussed on sloped granular filters where one or two layers of rock material were placed directly on sand. Some of the conclusions were:

- If the accretion of sand within the layer of rock reaches a level of two stone diameters or less underneath the outer rock profile, wave action on the slope causes that sand will be entrained directly into the water column. If this occurs, the application of open filters is not recommended.
- Sand accretion and sand erosion at the rock-sand interface can be predicted reasonably well by the derived expressions. Also the settlement of the outer rock profile as a result of the sand erosion can be predicted reasonably well. It is recommended to apply the expressions within the range of validity and to apply them only as first estimates for applications outside the range of validity.
- The sand erosion and accretion depend on the wave height, the thickness and permeability of the rock layer(s), the slope, and the critical hydraulic gradient at the internal rock-sand interface. Numerical model computations clearly indicate that also the wave steepness is important, but in the physical model tests the wave steepness has not been varied sufficiently to draw firm conclusions on effects of the wave steepness. The critical hydraulic gradient at the rock-sand interface depends on the size and permeability of the rock material, and on the size, angle of repose and the relative density of the sand.
- A numerical model has been developed to predict the morphological response of the sand underneath the rock. This model can be used in combination with information from the physical model tests in order to obtain first estimates of the morphological response for non-tested conditions and configurations.

A number of important aspects have not been taken into account in guidelines so far. Therefore, it is recommended to analyse the influence of scale effects, the effects of the storm duration, and the influence of the accumulation of accretion and erosion under storm conditions with various water levels. Furthermore, it is recommended to analyse whether the approach to account for effects of oblique waves on the stability of armour layers, as presented in Van Gent (2014), can also be applied to account for the effects of oblique waves on open filters. Besides research on open transport filters it is recommended to analyse the initiation of transport of base material for applications with hydraulically-closed filters.

Besides filters where the toplayer consists of rock and the base material consists of sand, it is recommended to study geometrically open filters for configurations in which both the toplayer and the layer underneath consist of rock.

ACKNOWLEDGEMENT

Dr Guido Wolters and Dr Niels Jacobsen of Deltares (Department of Coastal Structures & Waves) are acknowledged for their contribution to the described research on open filters.

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