CHAPTER 124

PORE PRESSURES IN RUBBLE MOUND BREAKWATERS

M.B. de Groot[1], H. Yamazaki[2], M.R.A. van Gent[3] and Z. Kheyruri[4]

ABSTRACT

Economic breakwater design requires knowledge of the wave induced pore pressures in the rockfill in view of sliding stability, filter requirements, wave transmission, wave overtopping and internal set-up. A mathematical model for the prediction of these pressures and the associated pore water flow has been developed. The model gives an integrated description of both external flow and internal flow. The sensitivity of the output to several input parameters and the validation of the external flow to model tests is discussed.

1. INTRODUCTION

Wave induced pore pressures influence the behaviour of rubble mound breakwaters in several ways. This may be relevant for the design. A numerical model, MBREAK/ODIFLOCS, has been developed for the prediction of pore water flow and pore pressures in the mound. Use is made of the progress made in the description of the external flow by Kobayashi and others (1987) and that made in the description of the internal flow by Barends and Hölscher (1988). The new model, however, gives an integrated description of both flow types. See Figure 1.

The paper will describe the relevancy of the pore pressures for the design, the basic features of the model, its potentials and its limitations. The results of a systematic series of calculations will be presented and the validation of the model with the help of measurements performed in flume tests, will be discussed.

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[1] Delft Geotechnics, P.O. Box 69, 2600 AB Delft; [2] Port and Harbour Research Institute, Yokosuka; [3] Delft University; [4] I.H.E., Delft.

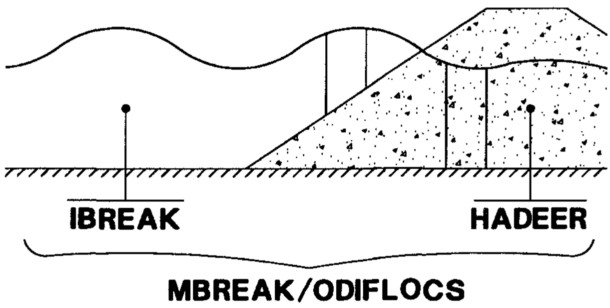

Figure 1 MBREAK/ODIFLOCS as a combination of two existing models

2 PORE PRESSURES AND DESIGN

Economic breakwater design requires knowledge of the wave induced pore pressures in the rockfill. Figure 2 illustrates five design features that may be influenced by the pore pressures and pore water flow:

A) Sliding stability may be seriously affected by the combination of a high pressure head in the rock fill mass and the low pressure head at the slope during run-down.

B) A three layer thick geometric filter is often needed underneath a rubble mound breakwater constructed at a sandy seabed, according to traditional filter design. More economic "hydraulic" filter design enables a reduction of the number of filterlayers where the pore pressure gradients are low (de Groot et al 1993).

C) The wave climate inside any harbour basin partly depends on the wave transmission through the rubble mound, which mainly depends on the absorption of wave energy due to pore water flow.

D) Wave overtopping also influences the wave climate in the harbour. It is greatly influenced by the discharge of water seeping into the mound during run-up, which discharge is an important feature of the pore water flow.

E) The water table in any sandy back-fill may rise one or two meters due to wave induced internal set-up, depending on the flow characteristics inside the mound.

A) Sliding stability

B) Reduction number of filterlayers

C) Wave transmission

D) Runup level reduced by porous flow

E) Internal set-up in sand backfill

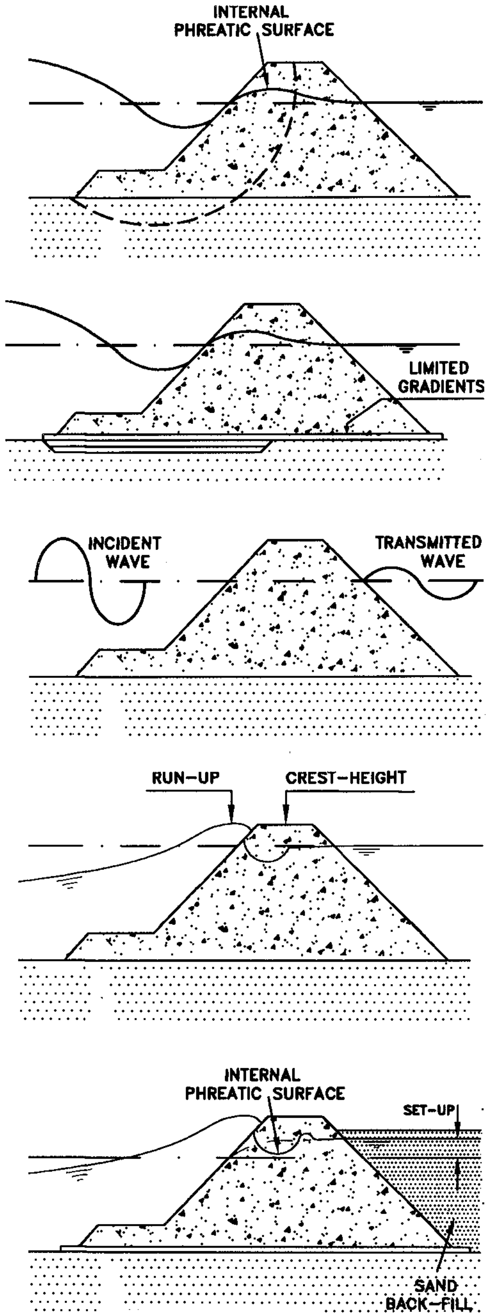

Figure 2 Breakwater design influenced by pore pressures

3. EXTERNAL AND INTERNAL FLOW

External and internal flow have much in common. Water level variations dominate both flow types. The pressure variations in vertical direction are roughly hydrostatic in most regions. The momentum in horizontal direction is determined in both flow types by inertia (including momentum convection), gravity (including pressure gradient) and friction.

There are, however, some important differences. Friction in the porous flow is much larger than friction in the external flow. Thus, the internal flow is dominated by friction and gravity; the external flow by inertia and gravity. The large friction limits the internal water velocities much more than the external velocities. As the water surface cannot move quicker than the water, also the motion of the internal phreatic surface is more limited than the motion of the external free surface. Thus, the friction causes a limited upward speed of the internal phreatic surface during uprush (Figure 3) and a limited downward speed during downrush. This yields the phenomenon of "disconnection" of the water surfaces: the point E where the external water surface meets the slope, is higher than the point I where the internal phreatic surface meets the slope during wave uprush (Fig.4A) and the other way around during downrush (Fig.4B)

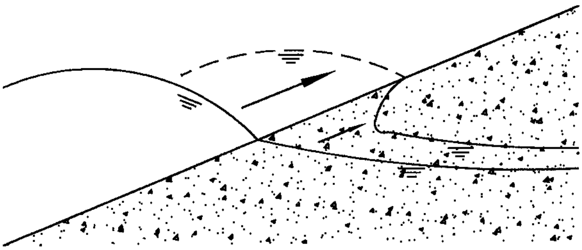

Figure 3 Speed difference between external and internal watersurfaces

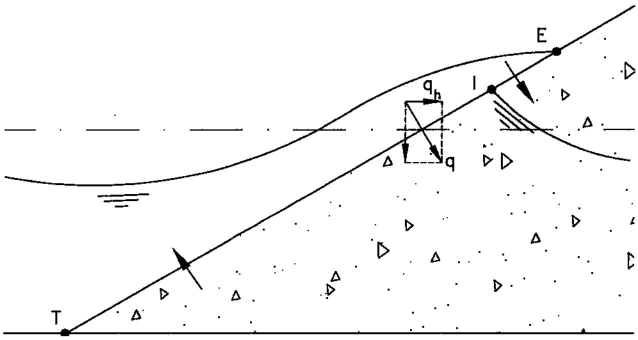

Figure 4A Water surfaces during maximum run-up

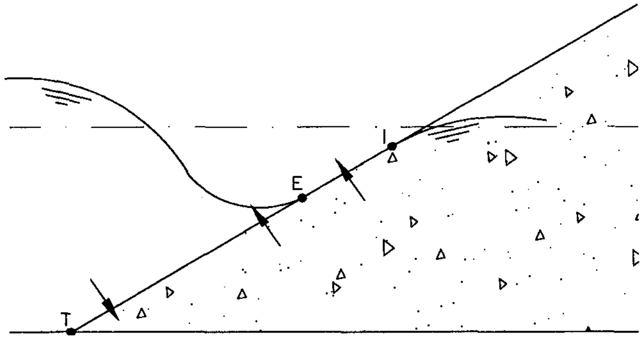

Figure 4B Water surfaces during maximum run-down

4. MODEL DESCRIPTION

The above given flow characteristics enable both flow types to be largely described with long wave equations: for each flow type one storage equation and one equation for the momentum in horizontal direction. The coupling between both flow types requires a term to be added to the usual terms in each equation (Figure 5): an additional term in each of both storage equations for the infiltration discharge through the slope, q, and one in each of both momentum equations for the product of q with its horizontal component, q_h. Last term, however, can be neglected in many cases.

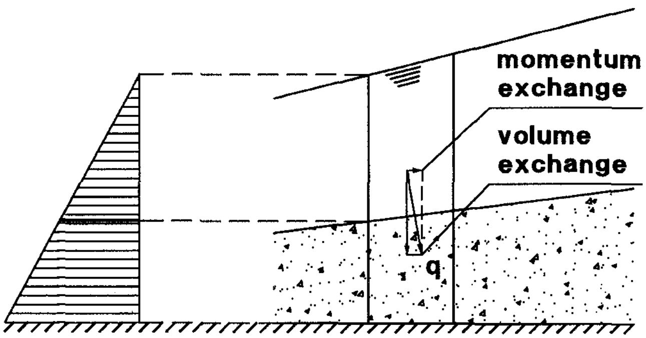

Figure 5 Coupling terms to be added to storage and momentum equations

At the seaward boundary of the external flow an incident wave is computed either with the Stokes second-order wave theory or the Cnoidal wave theory (Figure 6). The seaward boundary allows a reflected wave to leave the computational domain. This is calculated with the method of characteristics. This method allows water and momentum to leave the computational domain.

The modelling of the harbourside boundary of the external flow is based on work by Kobayashi et al. (1987). It uses a minimum waterdepth ("waterfilm") at the wave front above which level the slope is set dry.

The discharge through the slope, q, is a given boundary condition for the external flow, derived from the calculation of the internal flow. However, when point E is higher than point I (Fig. 4A), q between those points is the discharge of water freely falling through the partly saturated area. It is taken equal to the discharge which occurs when the downward head gradient equals unity. The water is supposed to reach the phreatic surface of the internal flow immediately.

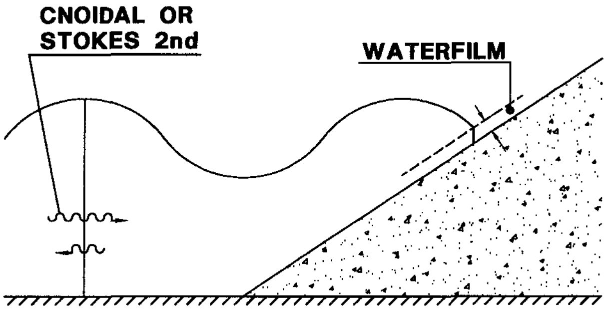

Figure 6 Modelling of the external flow

The slope between the toe, T, and point I makes up the seaward boundary of the internal flow. There the pressurehead is a given boundary condition, derived from the calculation of the external flow. When point E is lower than point I (Fig. 4B), then the head between those points is taken equal to the slope surface.

The harbourside boundary can be either an open boundary, allowing a wave to leave the calculation domain (Figure 7A) or a closed boundary at which a wave reflects completely (Figure 7B). A breakwater with a sand backfill can be modelled with last option.

Two or more layers with different stone sizes can be modelled. At the boundary between two layers disconnection can take place, just like at the external slope.

The water movement in and over a breakwater with limited crest height can be described with a special model option, allowing for the prediction of the wave radiating into the harbour by a combination of overtopping and penetration through the porous mound (Figure 7C).

Three different versions of the model have been made: 1) ODIFLOCS, 2) a one dimensional version of MBREAK and 3) a semi two-dimensional version of MBREAK. The numerical schemes of ODIFLOCS and MBREAK differ, as do certain minor assumptions about the flow properties. Version 3) is realised by alternately calculating the two-dimensional internal velocities with a stationary model with given preatic surface, calculating the corresponding horizontal discharge and calculating the phreatic surface change with the one-dimensional model. Application of the different versions for the same situation yields a helpful tool to study the influence of numerical effects and particular assumptions.

A more extensive description of the different versions of the model can be found in (van Gent and Engering 1992); more about ODIFLOCS in (van Gent 1994).

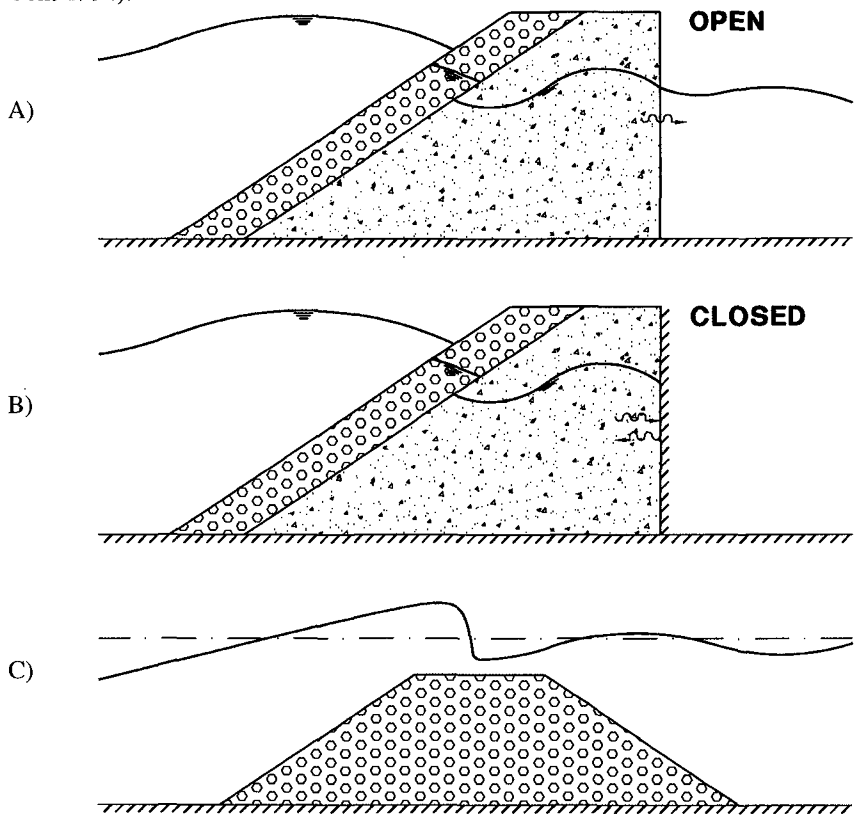

Figure 7 Different options for breakwater modelling

5 VALIDATION

The validation of the model started with an extensive sensitivity analysis for both model parameters and physical parameters. Application of the model requires assumptions concerning several model parameters, like the mesh size, the water film thickness, the maximum variation speed of the internal water level, the friction coefficients for the external and internal flow, the coefficient for added mass. Many calculations have been done in which these parameters have been varied to find out which parameter values would yield reasonable values.

The waterfilm thickness has a very large influence on many output parameters. An example is presented in Figure 8. It is seen that small values of the waterfilm thickness yield unreliable values of the run-down. An advise about the waterfilm thickness in proportion to the waveheight is formulated based on these results and a comparison with measurements of the run-down.

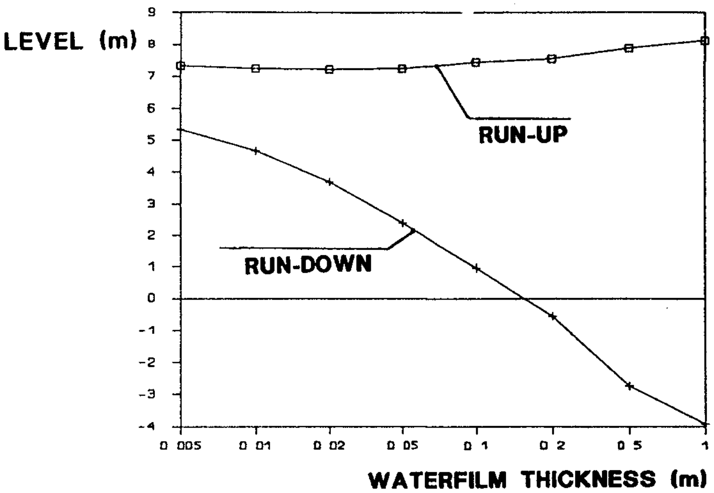

Figure 8 Influence of waterfilm thickness on run-up and run-down

Another important model parameter is related to the disconnection of the external and internal watersurface. A realistic limit to the speed of the internal watersurface must be selected. It can be shown that the maximum value of the downward speed equals the "free fall velocity" of the water, i.e. the downward water discharge per unit area occurring with a downward head gradient of unity, which means a pressure constant with depth. The upward watersurface speed may be more, because the effective upward gradient may reach higher values than unity during uprush (Hölscher et al 1988). Values up to 3 times the free fall velocity seem possible. A much higher limit yields the same results as no limit at all.

The external run-up and run-down, i.e. the highest level and the lowest level of the points E of Figure 4, are hardly influenced by the limit to the internal watersurface speed. However, the internal run-up and run-down, i.e. the highest level and the lowest level of the points I of Figure 4, do depend a lot on this limit (Figure 9). It is of great interest to study this limit more in detail.

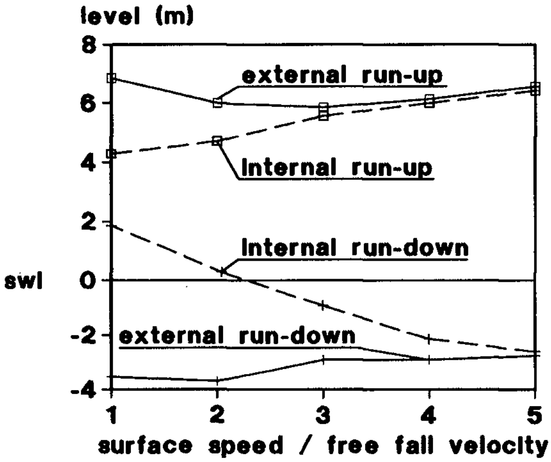

Figure 9 Influence of limit to internal water surface speed

Not only model input parameters have been varied during the sensitivity analysis, but also physical input parameters: the surf similarity parameter ξ, slope roughness, stone size, porosity, number of stone layers. Stone size and porosity determine the permeability of the rock fill. Its large influence on the external flow is illustrated in Figure 10 for a breakwater with impermeable core and permeable berm and for a completely impermeable berm breakwater (scaled to prototype dimensions). The thin lines show the water levels for the permeable breakwater at different moments during one wave. The thick lines represent their envelop. The envelop for the impermeable breakwater is indicated with interrupted lines. It is seen that the permeability of the breakwater has a large influence on the external head distribution, including run-up and run-down.

The relative influence of the different input parameters to one output parameter has been presented in Figure 11 as a kind of summary of the sensitivity analysis. The choice of the waterfilm thickness has the largest influence on output parameters like run-up level and discharge through the slope. Other important input parameters are the friction factors, the porosity the armour stone size and the wave period.

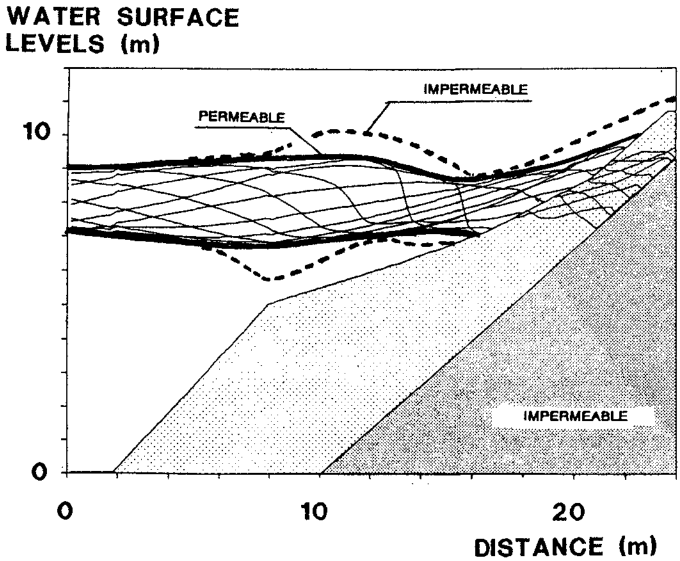

Figure 10 Influence of permeability on external water surfaces

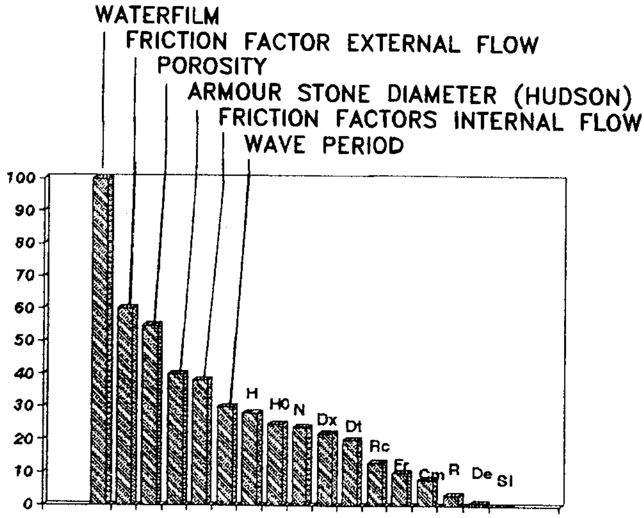

Figure 11 Relative influence of different input parameters to one output parameter

The effects of the parameter variation on the internal pore pressures and the external water movement, observed in these and other calculations, were qualitatively reliable. Whether they are quantitatively correct, however, can only be judged by comparison with model tests.

Many model test results are available on run-up values. Calculations made with MBREAK/ODIFLOCS for impermeable slopes for different values of the surf similarity parameter ξ, yield external run-up and run-down values which agree very well with model results. The same holds for the run-up values calculated for the breakwaters with permeable coverlayers tested by Ahrens (1975), as illustrated in Figure 12.

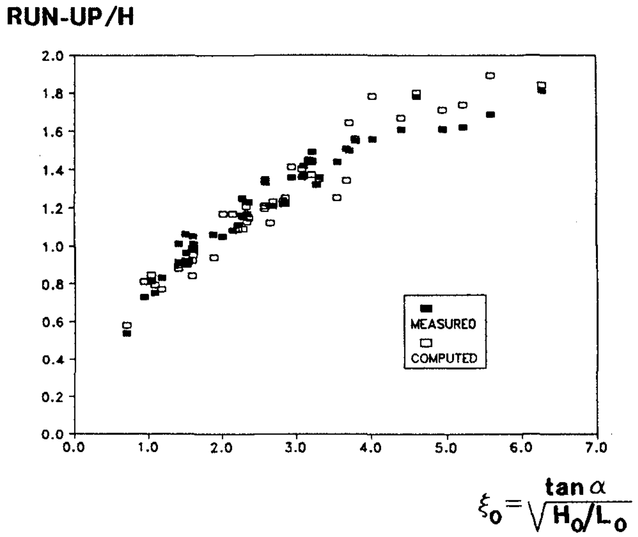

Figure 12 Run-up levels for breakwaters with permeable coverlayer

6 CONCLUSIONS

With MBREAK/ODIFLOCS a successful integration is realised of the mathematical modelling of the external flow on the slope of a rubble mound breakwater and the induced internal flow in the breakwater. Part of the success is due to the modelling of the disconnection between external and internal water surfaces. The sensitivity analysis made clear that many phenomena can be predicted qualitatively well. Run-up values can also be predicted fairly well. The further quantitative validation, however, is limited and requires more hindcasts to be made with the model for flume tests in which pore pressures have been measured.

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