CHAPTER 132

Roundhead Stability of Berm Breakwaters

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Abstract

Three-dimensional (3D) model tests were carried out for studying the stability of a berm breakwater roundhead and the adjacent trunk section. The present paper describes the influence of the wave incidence angle and wave steepness on the roundhead stability. The test results are described in terms of profile development, recession of the berm, eroded and deposited volumes and the transport of stones during reshaping. Results from analysis of the influence of wave obliquity on profile shape, initiation of longshore transport and longshore transport rate at the trunk section are presented in Alikhani et al (1996).

Introduction

For berm breakwaters as compared with traditional rubble mound breakwaters, special measures have to be taken for the breakwater roundhead. If stone displacements occur on a roundhead, the stones will be moved in the wave direction and will loose most of their stabilising effect. A point of special concern is whether, and under which conditions, a berm breakwater roundhead after some initial reshaping may develop into a stable shape that is not subject to continued erosion, or at least such slow erosion that it may be acceptable for a permanent structure.

The major part of the research on berm breakwaters has concentrated on the reshaping of the seaward side of the trunk under perpendicular wave attack. In 1988, van der Meer pre-

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sented results from a series of flume model tests with gravel beaches and rock slopes which led to a set of parameters equations for assessing the profile development of berm breakwaters. Also Kao and Hall (1990) presented results on various aspects influencing the stability of berm breakwaters. Analysis of flume tests concentrating on the rear side stability was presented by Andersen et al (1992).

Only a little research has been made to study the stability of berm breakwater roundheads. Burcharth and Frigaard (1987) described results from model tests with reshaping breakwaters exposed to head on waves and waves having a wave incidence angle of 15^o and 30^o. The analysis concentrated on the stability of roundheads and trunk erosion in oblique waves, and some preliminary recommendations for berm breakwater trunks and heads were given.

Jensen and Sørensen (1992) presented results from a 3D model study of a berm breakwater including trunk and roundhead. Comparison of the profile development on the trunk and head was made.

Van der Meer and Veldman (1992) made a discussion on roundhead stability based on analysis of results from a series of wave basin tests.

Description of Model Tests

Model Set-Up

The model tests were carried out in a 22 x 30 m wave basin at the Danish Hydraulic Institute, see Figure 1, which also shows the various positions of the two 5.5 m wide movable wave generators for generating long-crested irregular waves. A stone absorber was placed along the basin boundary in order to minimise wave reflections. The berm breakwater profile used for the trunk section is shown in Figure 2. The roundhead was constructed by rotating the profile around the centreline.

The berm breakwater was constructed from two stone classes, ie one for the core and the scour protection and one for the berm, the crest and the rear side protection. The core material had a nominal diameter of $D_{n,50}$=0.010 m. A relative wide stone gradation was used for the berm, ie $D_{n,85}/D_{n,15}$= 1.80 with a nominal diameter of $D_{n,50}$=0.023 m. The density of the stone material was ρ_s=2.68 t/m^3 and the density of the water was ρ_w= 1.00 t/m^3.

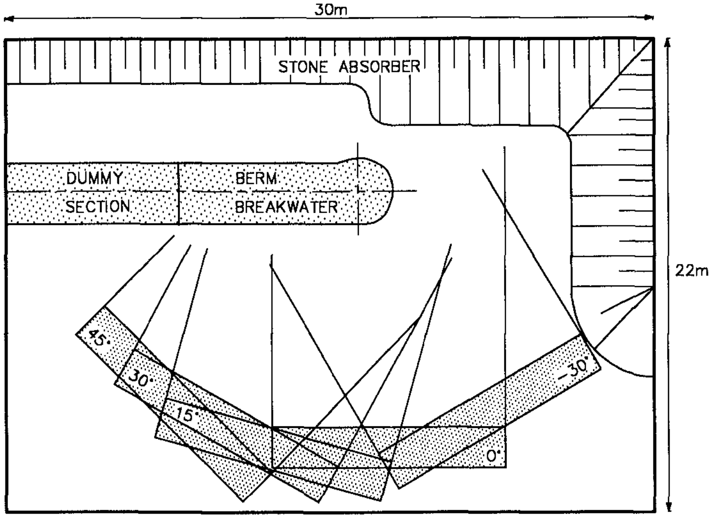


Figure 1. Model plan, including positions of the wave generators.

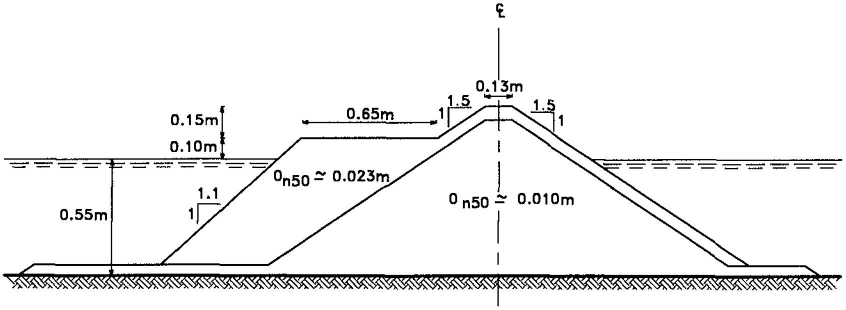


Figure 2. Cross-section of the initial profile for the trunk.
The roundhead was made by rotating the profile around the centreline

Test Programme

A total of six test series were carried out with irregular waves, covering five angles of incident waves with a wave steepness of S_m=0.05 (45°, 30°, 15°, 0° and -30°; where 0° is perpendicular to the trunk) and two wave steepnesses for -30° (S_m=0.03 and 0.05). The wave steepness, S_m, is given by $H_{m0}/L_{m0}=H_{m0}/(g/2\pi \cdot T_m^2)$, where H_{m0} is the wave height, L_{m0} is the deep water wave length, and T_m is the mean wave period.

Each test series consisted of five tests with a duration corresponding to 2,000 waves for reshaping of the berm breakwater ($H_0=H_{m0}/\Delta \cdot D_{n,50}$=2.0, 2.5, 3.0, 3.5, and 4.0; where Δ is the relative density, and $D_{n,50}$ is the nominal stone diameter) followed by four tests with a duration of 1,000 waves for studying the stone movements on the reshaped profile (H_0=2.5, 3.0, 3.5, and 4.0).

All waves were generated on basis of a Pierson-Moskowitz spectrum.

Measurements

The waves were measured in 14 positions in the wave basin by use of resistance type wave gauges. The incoming wave conditions were checked by five reference wave gauges placed in a way to minimise the effect of reflections. Spectral analysis and zero-crossing analysis were carried out.

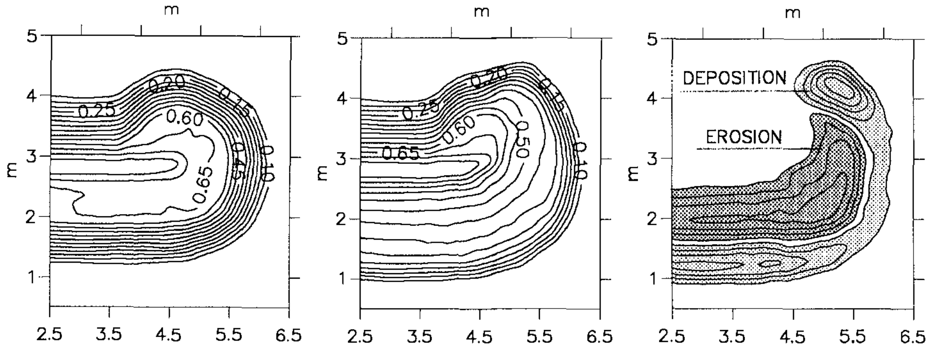
A total of 38 profiles along the 8.5 m long breakwater were measured after construction of the breakwater (initial profile) and after each test run. The profiling was made with a laser running on a beam across the breakwater trunk. The horizontal position of the laser running on the beam was measured by another laser, whereas the position along the breakwater was fixed manually. The profiles were measured for each 0.5 m along the trunk and for each 0.1 m at the roundhead.

The data from the 38 profile measurements were interpolated into a 3D representation of the breakwater from which it was possible to extract profiles in arbitrary cross-sections and to make contour plots of the breakwater as shown in Figure 3.

Definitions and Analysis

Sections and Wave Directions

The 3D representation of the test results was used to calculate the results for 10° sections on the breakwater head and 10 cm sections on the trunk with the convention as shown in Figure 4, which also shows the wave direction convention. This means that section 0 is the section covering 10° in continuation of the breakwater centreline and -90 is the section perpendicular to the centreline, where the trunk meets the roundhead.



Before testing

After testing (H_0=4.0)

Difference plot after testing (H_0=4.0)

Figure 3. Contour (m) plots of breakwater. Wave direction 0°

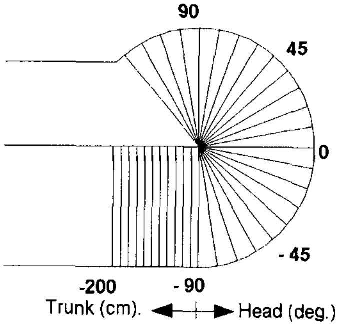
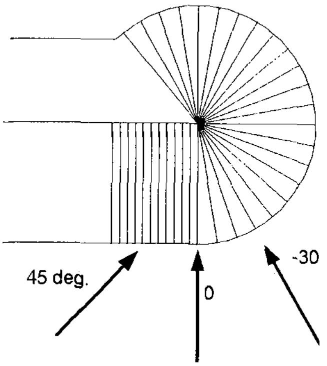


Figure 4. Profile definition.



Definition of wave direction

Relative Angle

When comparing results at the roundhead for different wave directions, a relative angle is introduced, defined as the angle between the incident waves and the considered section on the head, see Figure 5. For example, a relative angle of 0° corresponds to the section pointing directly towards the waves, whereas a relative angle of 90° corresponds to the section perpendicular to the wave direction.

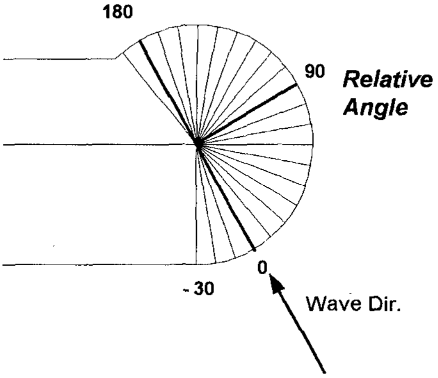


Figure 5. Definition of relative angle

Investigated Parameters

During the analysis, the following parameters have been investigated:

Recession

The recession is defined as the width of the berm eroded, see Figure 6. For the investigated breakwater profile with an initial berm width of 0.65 m, a recession of 0.65 m thus corresponds to a fully eroded berm with a directly exposed breakwater crest.

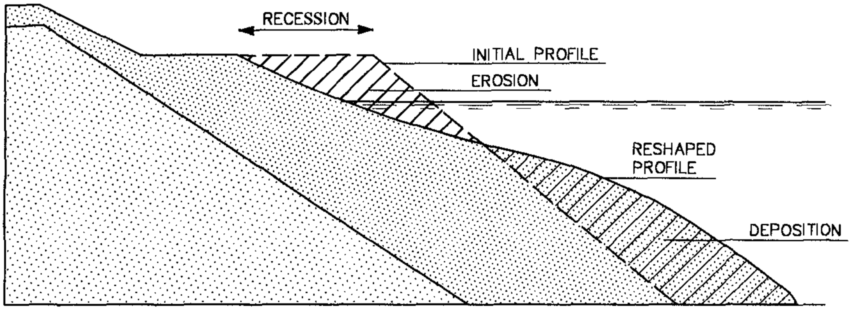


Figure 6. Definition of recession, erosion and deposition

Erosion

The erosion is defined as the volume eroded for the individual sections as shown in Figure 6. The erosion is presented as the eroded volume relative to the initial volume of berm material for the section. An erosion equal to 0.2 thus corresponds to the case where 20 per cent of the initial berm volume is eroded at the considered section. The erosion is presented as negative values.

Deposition

The deposition is defined as the deposited volume at the individual sections, as shown in Figure 6. As for the erosion, the deposition is presented as the deposited volume relative to the initial volume of berm material for each section. The deposition is presented as positive values.

Transported volume

This parameter is defined as the volume which has passed a given section since the start of the test series. The transport is defined positive in the anti-clockwise direction on the head (towards the rear of the head). On the trunk, the transport is positive towards the head. The volume is calculated directly from the measured profiles (ie including voids).

The transported volume is calculated by accummulating the volume changes from the rear of the roundhead - where no changes occur - clockwise around the head.

Stone transport

The stone transport is the estimated number of stones per wave passing a given section for a given H_0. The number of stones is estimated by correcting the calculated transported volumes for porosity and dividing by the average stone weight.

Presentation of Results

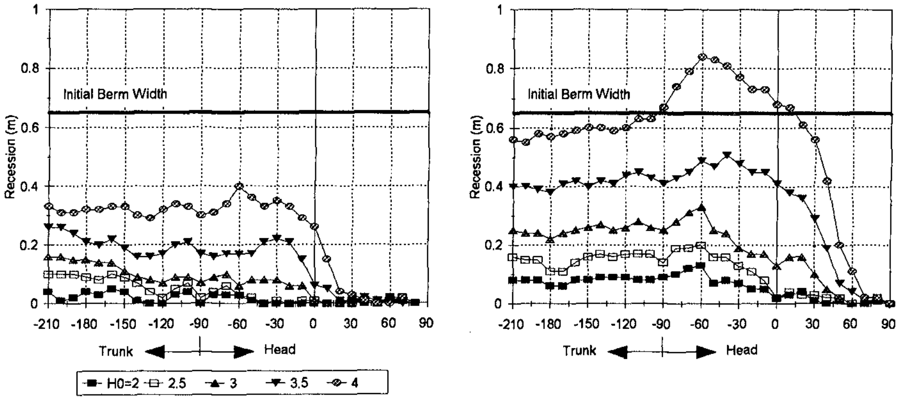
This section presents the results of the analysis of the profile measurements and concentrates on recession, erosion and deposition, transported volume and finally stone transport during the reshaping process.

Recession

Figure 7 presents the recession at the head found for wave direction 45°, respectively 0°, for increasing H_0.

It is seen that the recession for head on waves (wave direction 0°) is significantly higher than for 45°.

Plotting the recession measured after H_0 =4.0 for all wave directions as function of the relative angle, see Figure 8, shows that the recession pattern follows the wave direction, and that maximum recession occurs at an area directly exposed to the waves. It is found that the maximum recession on the head occurs for wave direction 0°, where the recession reaches the initial berm width for H_0 between 3.5 and 4.



Wave direction 45°

Wave direction 0°

Figure 7. Recession of head and adjacent trunk

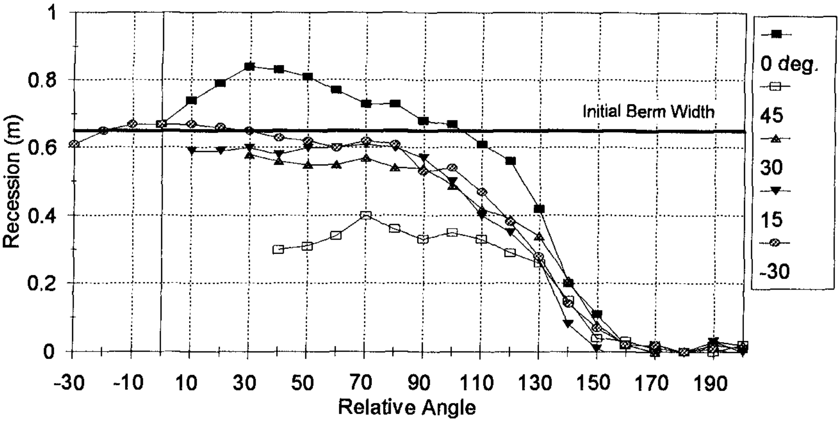
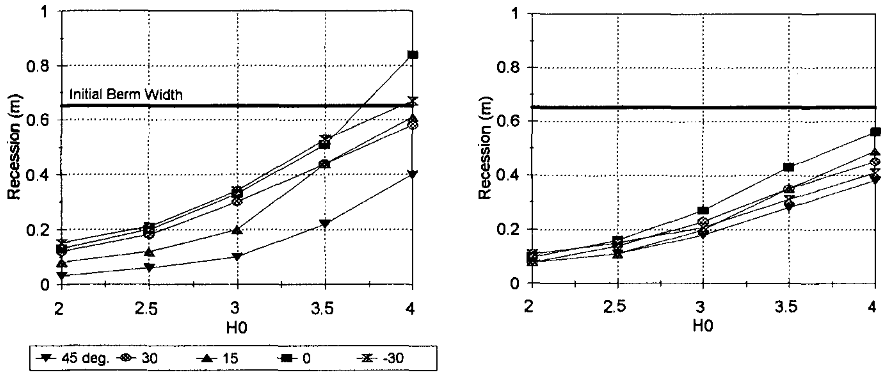


Figure 8. Recession. All wave directions. After H_0=4.0, S_m=0.05

Comparing the maximum recession found at the head with the recession on the trunk, see Figure 9, it is found that only in the case with wave direction 45° the maximum recession on the head is equal to or less than the recession on the trunk section. In the case with wave direction -30°, the recession on the head is up to 75 per cent higher than for the trunk section. For head on waves, the maximum recession on the head is 50 per cent higher than the recession on the trunk.



Head Trunk

Figure 9. Maximum recession on head, respectively trunk

When analysing the maximum recession as function of the wave direction, it can be seen that the maximum recession on the head is increased by a factor of up to 2 comparing the results for wave directions 45° and 0°, whereas the recession on the trunk is increased by a factor of about 1.4. The recession on the head is thus more sensitive to changes in the wave direction than the recession on the trunk. For comparison, a cosine (cos) and a cosine^2 (cos^2) distribution of the recession found for wave direction 0° for H_0=4 were compared to the results, showing that the variation of the maximum recession with the wave direction, on the head, can be approximated by a cos^2 distribution for the higher H_0's. At the trunk, the results show a distribution closer to a cos distribution.

The influence of the wave steepness was investigated for wave direction -30°. The results showed a strong influence by the wave steepness, as the maximum recession on the head for S_m=0.03 was almost twice the recession found for S_m=0.05. On the trunk, the influence was less pronounced. Analysis showed that a good agreement between the two data sets (S_m=0.03 respectively 0.05) was obtained when plotting the recession as function of H_0T_0, especially for the trunk section. T_0 is given by $T_0=T_m \sqrt{g / D_{n,50}}$.

Erosion and Deposition

Figure 10 presents the erosion and deposition pattern around the breakwater head, after H_0=4.0 for all wave directions as function of the relative angle, again showing that the reshaping pattern follows the wave direction closely. A pronounced deposition area at the rear of the roundhead and a relative wide area of erosion is found.

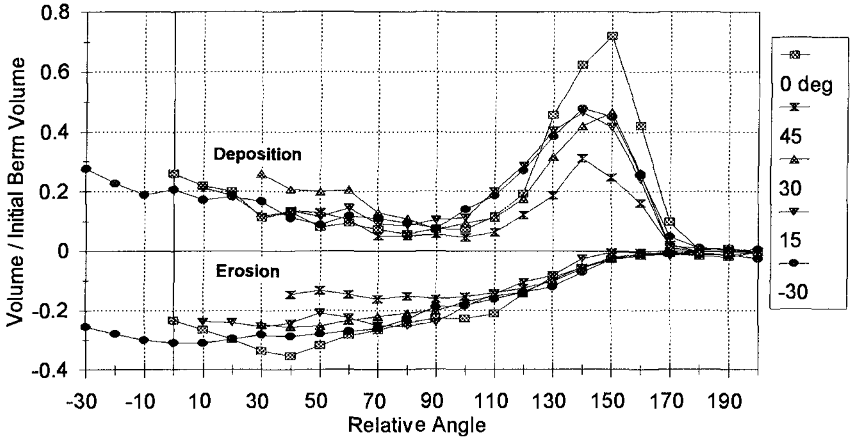
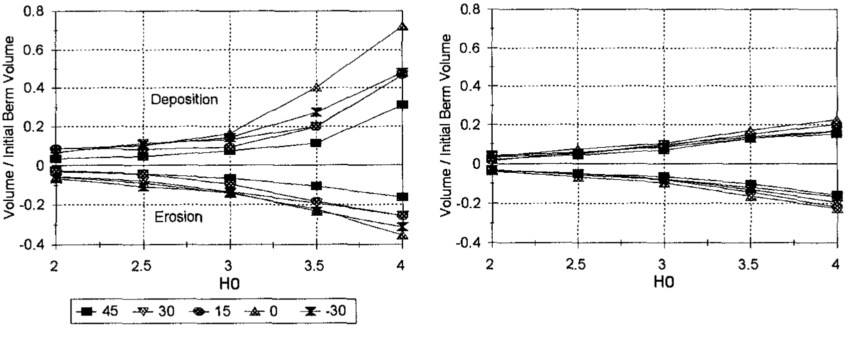


Figure 10. Erosion and deposition after H_0=4.0. All wave directions

For an infinitly long trunk, the erosion and deposition areas are equal (disregarding compaction), whereas for a roundhead stones will be transported towards the rear side of the roundhead. At the directly exposed part of the head, the erosion will be larger than the deposition, whereas the opposite will be the case at the rear of the head. This can also be seen from the contour plots presented in Figure 3 showing the height contours of the breakwater before and after the test series with wave direction 0° together with a difference plot.

As seen from Figure 11, the erosion at the head accelerates for H_0>2.5. The influence of the wave steepness can be seen from Figure 12 presenting the maximum erosion and deposition as function of both H_0 and H_0T_0 for the two wave steepnesses, S_m=0.03 and 0.05, respectively (wave direction -30°). Plotting the maximum erosion and deposition as function of H_0T_0 shows a better agreement between the two data sets than when plotting against the wave height parameter, H_0.



Head Trunk

Figure 11. Maximum erosion and deposition

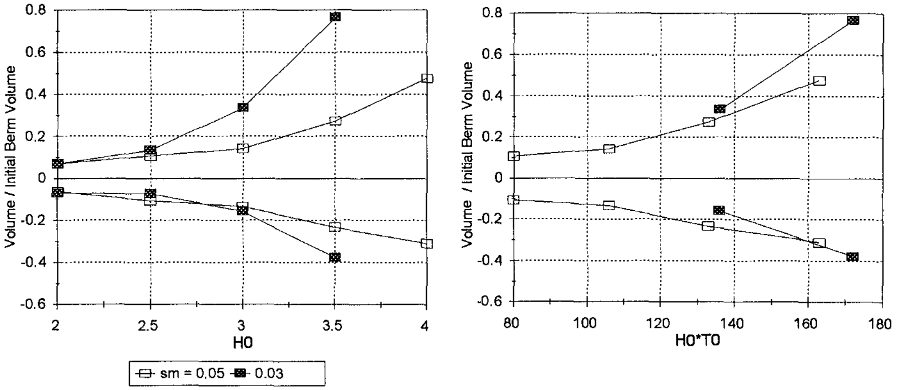


Figure 12. Influence of wave steepness on erosion/deposition. Wave direction -30^{o}

Transported Volume

Figure 13 presents the transported volume at the roundhead for all wave directions as function of the relative angle after H_0=4.0 (S_m=0.05), showing that the section which experiences the heaviest traffic during the test series is located 110°-130^{0} anti-clockwise from the angle of wave attack.

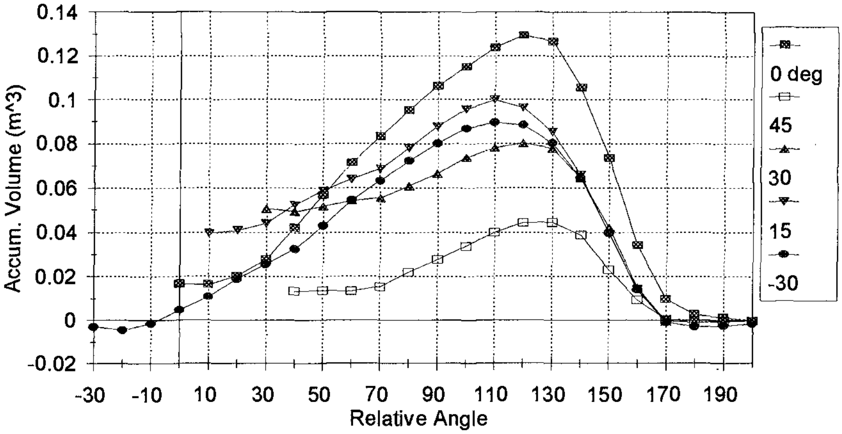


Figure 13. Transported volume on head after H_0=4. All wave directions

Figure 14 shows the maximum transported volume on the roundhead as function of H_0 revealing that the transport accelerates for H_0>2.5.

As for the recession on the head, the sensitivity to the wave direction can clearly be seen on the transport. The results indicate that the decrease in transported volume with the wave direction can be estimated by a $\cos^3$ distribution for the higher H_0's comparing with the transport for wave direction 0^o.

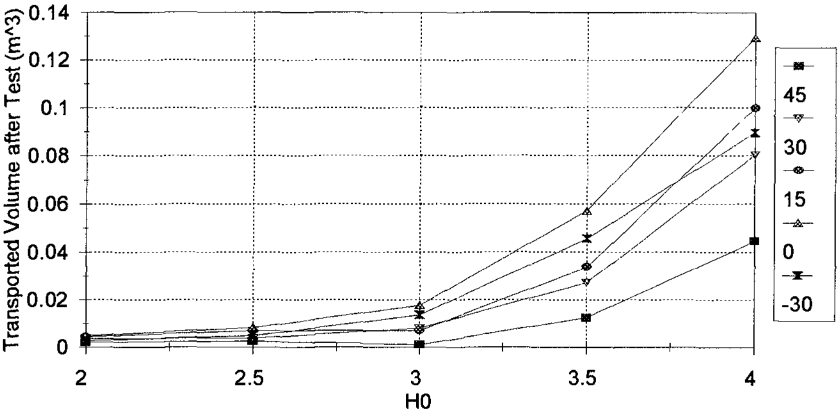


Figure 14. Maximum transported volume on head

Stone Transport

In Figure 15, the stone transport for H_0=4.0 is plotted for all wave directions as function of the relative angle, again showing that the maximum transport takes place at the sections 110°-130° relative to the wave direction. The maximum stone transport on the head occurs with head on waves (0°), being up to three to four times higher than for wave direction 45°.

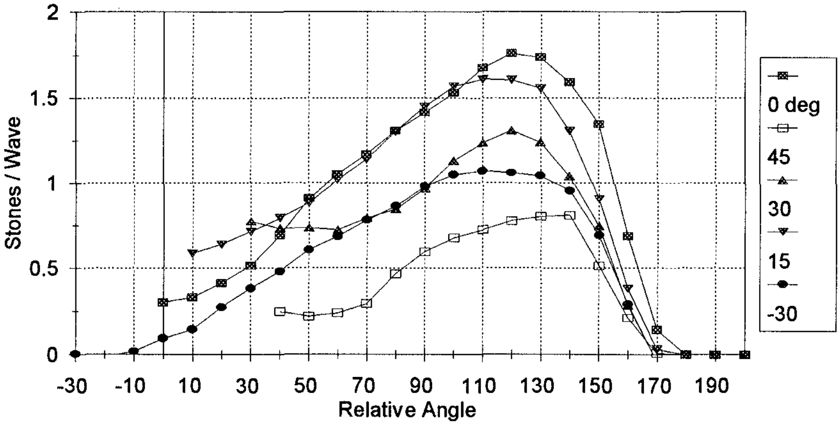


Figure 15. Stone transport for H_0=4.0. All wave directions

Conclusion

A total of six test series were carried out in a wave basin for studying the development of berm breakwater roundheads. Five wave incidence angles were tested together with two wave steepnesses All tests were carried out with irregular long-crested waves, and each test series consisted of five tests for reshaping of the breakwater (H_0=2.0, 2.5, 3.0, 3.5 and 4.0).

The measurements included a total of 38 profiles along the breakwater which were interpolated into a 3D representation of the breakwater. This formed the basis for detailed calculations of the profile development, recession of the berm, eroded and deposited volumes and transport of stones in arbitrary sections of the breakwater.

The main findings of the work are summarised below :

- The maximum recession occurs at the area directly exposed to the waves.
- The recession/erosion pattern follows the wave direction.
- On the head, the maximum recession was observed for head-on waves (0^o) being up to two times higher than for 45^o. For the trunk section, the increase was less than 1.5. The recession on the head is thus more sensitive to changes in the wave direction than on the trunk.
- For 45^o wave direction, the maximum recession on the trunk and on the head is of the same magnitude, whereas the maximum recession on the head is 75 per cent higher than on the trunk for wave direction -30^o. For 0^o, the maximum recession on the head is about 50 per cent higher than on the trunk.
- The results for the two wave steepnesses, $S_m = 0.03$ and 0.05, showed that the wave steepness is of paramount importance, and that H_0T_0 is a good parameter when comparing the results - better than H_0.
- The reshaping of the head accelerates for H_0>80-100.
- The maximum transport of stones takes place 100^o-130^o anti-clockwise from the angle of wave attack.
- The maximum stone transport rates were found for wave direction 0^o, being up to three to four times higher than for wave direction 45^o.

Acknowledgements

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