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EFFECT OF CORE POROSITY ON STABILITY AND RUN-UP OF BREAKWATERS

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Abstract—The commonly used formulae like Hudson's [(1959), Laboratory investigations of rubblemound breakwaters. WES report, Vicksburg], Iribarren's or Vander meer's [(1988), Rockslopes and gravel beaches under wave attack. Ph.D. thesis, Delft University of Technology, The Netherlands], do not give us the design cross section of a rubblemound breakwater for varying core porosity values. The paper presents the results of the experimental study carried out to compute the effects of core porosity on the stability and run-up characteristics of rubblemound breakwaters. Regular waves were made to attack the structure, with different core porosity values in a normal direction. The porosity of the armour and the secondary layers was neglected. It was observed that as core porosity increased the stability also increased considerably within the limits of the experimental data values. This may be due to large inflow and energy dissipation within the core of the structure. The run-up on the rubblemound slope was found to decrease with the increase in the porosity for the same reason.

NOMENCLATURE

A_e	Erosion area (m^2)
c1	Core 1
c2	Core 2
c3	Core 3
D_{n50}	Diameter exceeded by 50% of armour stones (m)
g	Acceleration due to gravity (m/sec^2)
H	Wave height (m)
H_0	Deep water wave height (m)
H_{zd}	Zero-damage wave height (m)
K_d	Hudson's stability coefficient
N_{zd}	Zero-damage stability number
N_Δ	Number of equivalent spherical stones eroded
R_u	Wave run-up (m)
S	Vander meer's damage level parameter
T	Wave period (sec)
ρ_a	Mass density of armour stones (kg/m^3)
ρ_b	Bulk density of armour stones (kg/m^3)
ξ	Surf similarity parameter
π	3.14 .

INTRODUCTION

A number of formulae have been in use for determining the safe weight of the armour unit to be used in a rubblemound breakwater. Unfortunately, none of them, except the recent Vander meer (1988) formula, include the core porosity (or permeability as it is popularly termed) as a variable, influencing the stability of the breakwater structure. (Vander meer uses permeability as applied to the structure and not just to the core.)

Logically speaking, core porosity should considerably affect the stability of the structure, because the inflow into the core of the structure increases with porosity, which in turn causes higher energy dissipation within the structure core making it more stable.

Run-up on the structure slope should decrease with an increase in core porosity due to the same reason. A study was undertaken to compute the magnitudes of these effects on a rubblemound breakwater model in a regular wave flume in the Coastal Engineering section of the department. It is assumed that the porosity of the armour and the secondary layer do not much affect the stability or run-up characteristics.

ABOUT THE FLUME AND BREAKWATER MODEL

The regular wave flume used has a length of 50 m, a width of 0.71 m and a depth of 1.1 m, with a 42 m long smooth concrete bed. About 25 m of the flume is provided with glass panels on one side to facilitate the observations. The flume at the generator end is smoothly widened to 1.5 m and deepened to 1.4 m.

The wave generating chamber is 6.3 m in length. Gradual transition is provided between the normal flume bed level and that of the generating chamber by a ramp with a length of 18 m. The wave filter adopted consists of a series of vertical asbestos cement sheets spaced at about 10 cm c/c parallel to the length of the flume.

The model was constructed of granite stones of specific gravity ranging from 2.71 to 2.82 with a mean value of 2.76. A pycnometer was used to determine the specific gravity of the stones. The breakwater model was designed for a zero-damage wave height of 10 cm using Hudson's (1959) formula with a K_d value of 3.5 for non-breaking conditions and for a side slope of 1:2 on the sea side. On the lee side of the structure the same side slope was used.

The design of the structure is a non-overtopping one and gave an armour weight of 72.3 g of granite stone. The weight of stones used varied from 55 to 91 g. This is in accordance with the Shore Protection Manual (1984), volume II. The cross section of the breakwater used is shown in Fig. 1.

TYPES OF CORE USED

Three cores were used, each with a different core porosity value. They are as follows: core 1. Jelly stones passing through I.S. 10 mm sieve and retained on 4.75 mm sieve. The porosity was 49.1% obtained as the average of three trials; core 2. Fine material passing through I.S. 4.75 mm sieve. Average porosity was 39.7% for three trials; core 3. Material used for core 1 and sand in the ratio of 2:1 by volume. Average porosity was 29.9% for three trials.

Core 1, core 2 and core 3 will be denoted by c1, c2 and c3 respectively.

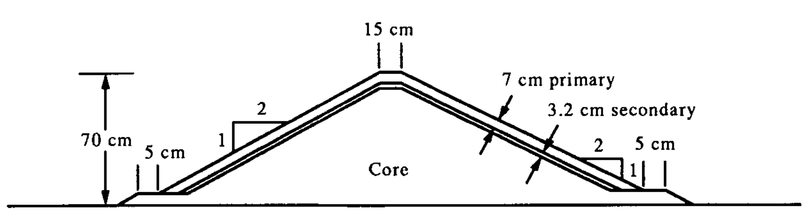

Fig. 1. Cross-section of the breakwater model.

MODEL CONSTRUCTION

The three models were constructed on the beach side of the flume, 33 m away from the generator blade. To help in the construction, a line sketch of the section of the breakwater denoting various layers was drawn on the glass sheet using white paint. Two galvanised iron pipes were placed on the bed along the section to keep the water level the same on both sides of the model. The materials were placed and formed to different levels in the proper order to obtain the cross section. The "fitted" method was used for placing the primary stones.

EXPERIMENTAL PROCEDURE

Experiments were conducted for the given 3 cores with wave heights ranging from 11 to 20 cm. Wave periods used were 1.2, 1.5, 2.0 and 2.5 sec. The depth of water was kept constant at 40 cm. Regular waves were generated by a bottom hinged flap type wave generator. Adequate copper sulphate was added to the water to control the growth of Algae.

The complete initial sea side profile was taken for each run using sounding rods spaced at 5 cm intervals. Each test was run for a minimum of 3000 waves. Tests were carried out in bursts of 10–20 waves at a time, depending on the wave period. This was required because after approximately this many waves, a complex undefined wave phenomenon occurred due to reflection and re-reflection from the generator blade. The next burst was started after obtaining calm conditions in the flume.

After each run soundings were again taken at the same points to obtain the final damaged sea side profile. The wave heights were measured 2 m ahead of the toe of the breakwater model. Run-up was measured as the maximum of first 25 run-up values. Both run-up and wave height were measured manually.
Damage was expressed by two methods:

- Vander meer's (1988) damage level parameter $S = A_e/(D_{n50})^2$.
- Damage parameter N_Δ defined by Thompson and Shuttler (1976) as $N_\Delta = (V_e \times \rho_b)/[\rho_a \times (D_{n50})^3 \times \pi/6]$.

Here, A_e is the average erosion area in m^2 and D_{n50} is the diameter exceeded by 50% of the armour units in m, V_e is the eroded volume in m^3, ρ_a and ρ_b are mass density and bulk density values of armour stones in kg/m^3.

RESULTS

Figure 2 shows the variation of damage with wave height for different cores. Clearly, as the wave height increased damage also increased non-linearly. The curve shows somewhat asymptotic behaviour to the damage axis, indicating rapid increase of damage without much increase in wave height after a particular value of wave height. A similar behaviour is reported by Bruun (1985).

For cores with lower porosity, damage was greater. This is due to more wave action on the armour, as the transmission of wave energy through the structure is less since porosity is less. Hedar (1986) has obtained a similar result.

Figure 3 shows the effect of porosity of the core on Hudson's zero-damage wave height H_{zd}. The trend, approximately, is an exponential increase of H_{zd} with an increase in porosity. The H_{zd} decreased by about 40% when porosity decreased to 29.9% from

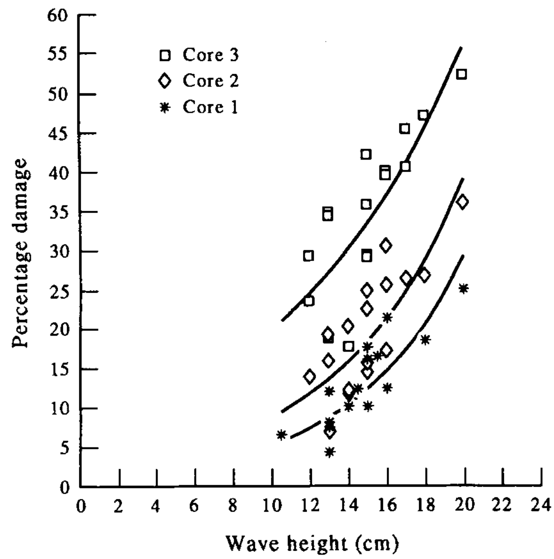

Fig. 2. Percentage damage vs wave height.

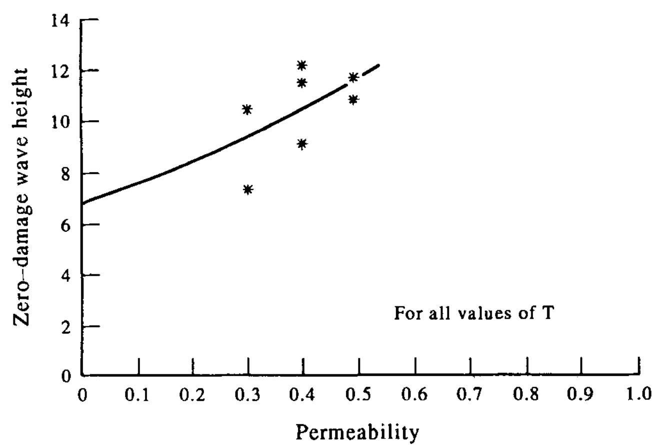

Fig. 3. Zero-damage wave height vs porosity.

49.1%. In other words, the damage significantly increases with decrease in porosity. Bruun (1985) also substantiates this result with permeability used rather than porosity.

To study the effect of core porosity on the run-up, graphs were drawn with deep water wave steepness H_0/gT^2 against relative run-up R_u/H_0 for the three cores tested. Here, H_0 is the deep-water wave height in m, $\mathbf{g}$ is acceleration due to gravity in m/sec^2, T is wave period in sec and R_u is wave run-up in m. It can be observed from the graphs that run-up values decreased with increasing deep water wave steepness—Figs 4–7.

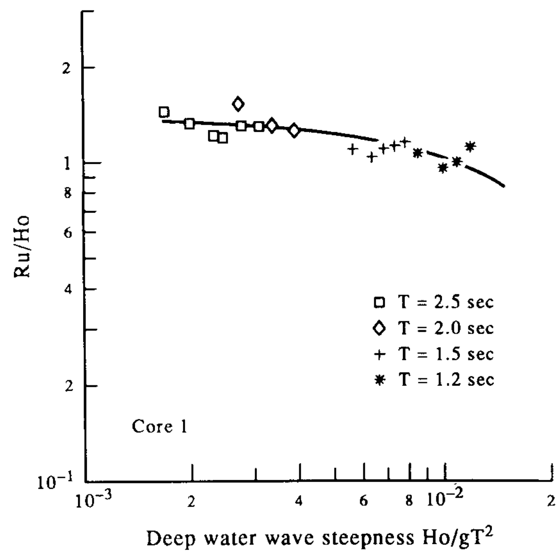

Fig. 4. Wave run-up vs deep water steepness.

Curves in Fig. 7 also indicate the effect of core porosity on run-up. Run-up decreases with increase in the value of core porosity for a given value of deep-water wave steepness.

In Fig. 8, the plots of observed and predicted values [Ahrens & McCartney (1975)] of R_u/H vs surf similarity parameter ξ is given for different cores. The plots indicate that observed run-up values increase as breaker type changes from plunging to collapsing, then decrease as breakers turn to surging ones.

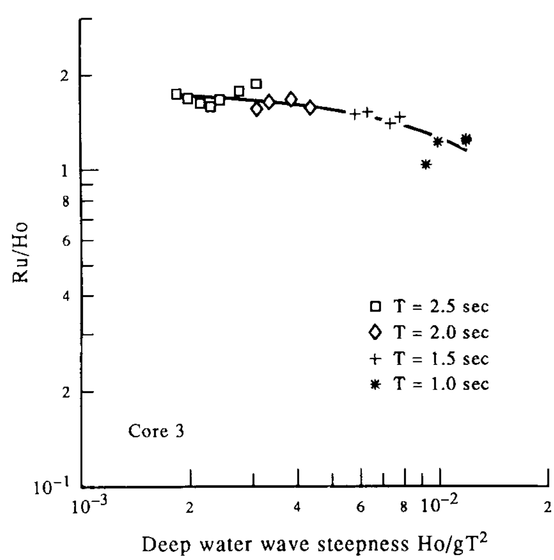

Fig. 5. Wave run-up vs deep water steepness.

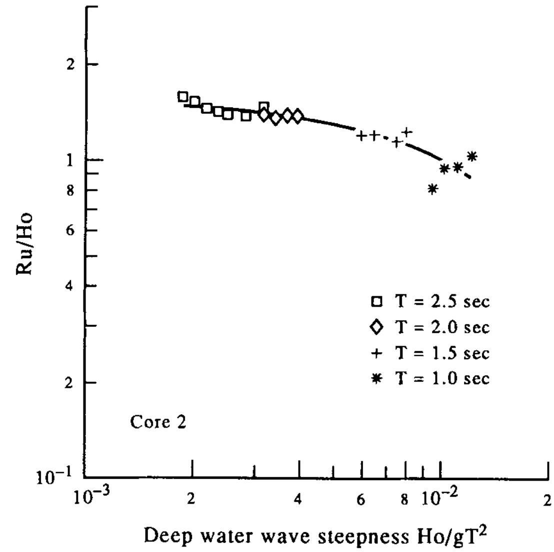

Fig. 6. Wave run-up vs deep water steepness.

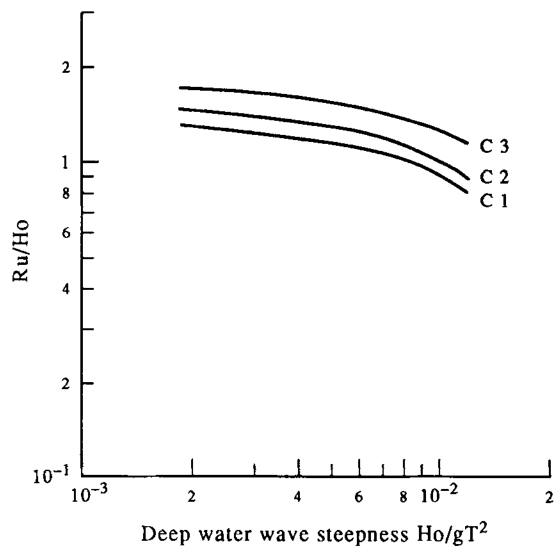

Fig. 7. Wave run-up vs deep water steepness.

It can be also noted from the same figure that the observed run-up values are lower than the predicted ones by about 12% for c1. For c2, both values are almost the same. For c3, observed run-up values are higher than the predicted ones by about the same magnitude. This indicates the possibility that predicted values as per Ahrens and McCartney (1975) agree well when the core has a porosity of around 39% (porosity of c2).

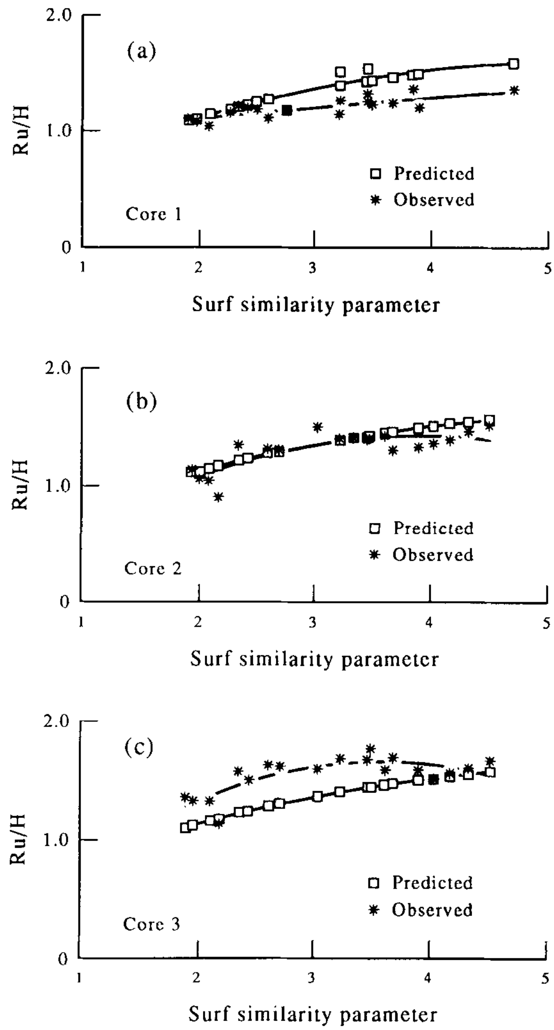

Fig. 8. Wave run-up vs surf similarity parameter.

Figure 9 shows the variation of zero-damage stability number N_{zd} with surf similarity parameter ξ for all the three cores. The stability is found to be the least for collapsing-type breakers in all three cases.

CONCLUSIONS

The effect of core porosity on the stability of the breakwater is considerable. The zero-damage wave height was 11.7 cm for core 1 (porosity 49.1%), 9.1 cm for core 2 (porosity 39.7%) and 7.3 cm for core 3 (porosity 29.9%), for a wave period of 1.5 sec. In other words, the damage increases with a decrease in core porosity. The same trend is observed for other periods. This stresses the need to consider the core porosity as a very important variable in the design formulae.

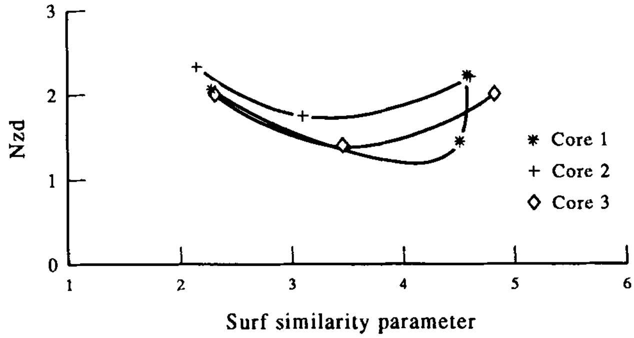

Fig. 9. Zero-damage stability number vs surf similarity parameter.

Damage also increases non-linearly with increase in wave height. Minimum stability is found for the collapsing type of breakers. Observed run-up values and predicted ones [Ahrens and McCartney (1975)] are the same for c2 (39.7% porosity), whereas they differed for cl and c3. Observed run-up values increased, then decreased with increasing wave steepness for all three cores.

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