

CHAPTER 129

Trends in Stability of Dynamically Stable Breakwaters

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Abstract

The reshaping of dynamically stable breakwaters was studied subject to variations in armour stone, (gradation and shape), wave characteristics and duration of wave attack from head on waves in a two dimensional wave flume. Tests were undertaken at the Coastal Engineering Research Laboratory of Queen's University, Kingston, Canada using irregular waves. Profiles of the structure during the various stages of reshaping were measured using a semi-automatic profiler developed for this study.

The volume of stones and the initial berm width required for development of a stable profile along with the extent to which the toe of the structure progressed seaward were chosen as the characteristic parameters of the reshaped breakwater. The results indicated that the toe width formed as a result of reshaping and the area of stones required for reshaping were dependent on the wave height, gradation of the armour stone and duration of the storm. The initial berm width required for reshaping was also found to be dependent on the wave height, armour stone gradation, percentage of rounded stones in the armour and the duration of the storm.

Introduction

Dynamically stable breakwaters are formed as a result of reshaping by wave action. Priest et al. (1964), Moutzouris (1978), Kogami (1978), Naheer and Buslov (1983), Hall et al. (1983) and Bruun (1985) reported the formation of S-shaped profiles to be superior in performance to statically stable breakwaters. Van der

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Meer and Pilarczyk (1987) provided design formulae for rock slopes and gravel beaches and extended them to apply to dynamically stable breakwaters. Breakwaters studied and reported here cover a range of instability number, $H_s/((S_r-1)D_{50})$, from 2 to 5, and utilize the total yield from quarries.

Present Tests

The studies were undertaken in a 1.4 m wide channel located within a 2 m wide wave flume, further details are provided in Hall and Kao (1990).

The rubble mound structure consisted of a core having a D_{50} of 1.2 cm and an armour layer having a D_{50} of 1.9 cm, where D_{50} is the diameter exceeded by 50% of the gradation. Four different gradations of the armour stones were used with D_{85}/D_{15} ratios ranging from 1.35 to 5.4 where D_{85} is the diameter of stone, that is larger by weight, than 85% of the sample and D_{15} is the diameter of stone, that is larger by weight, than 15% of the sample. In particular, gradation 2 has characteristics of quarries used for many previous breakwater projects (Hall et al. (1983), Baird and Hall (1984a, 1984b) and Hall (1987)).

Two other gradations of armour stones having a D_{50} of 1.9 cm and D_{85}/D_{15} ratio of 1.9 that were similar to gradation 2 but with differing percentages of rounded stones were also used in the tests, so that the percentage of rounded stones was varied from 0% to 30%. The characteristics of the armour stones used in the study are summarized in Table 1.

Tests were undertaken on a dynamically stable breakwater whose initial configuration is shown in figure 1. The basic geometry of the test structure was selected based on previous experience and taking into consideration practical aspects which make construction simpler.

Parameters Studied

Three parameters describing various aspects of the profile reshaping were chosen as dependent parameters. The three parameters, illustrated in figure 2, are the volume per unit length of armour stone required on the front slope, (A), the width of berm eroded, (B), and the distance from the control point to the outer extent of the toe following reshaping, (L), formed after the attack of 3000 waves. These parameters were made into

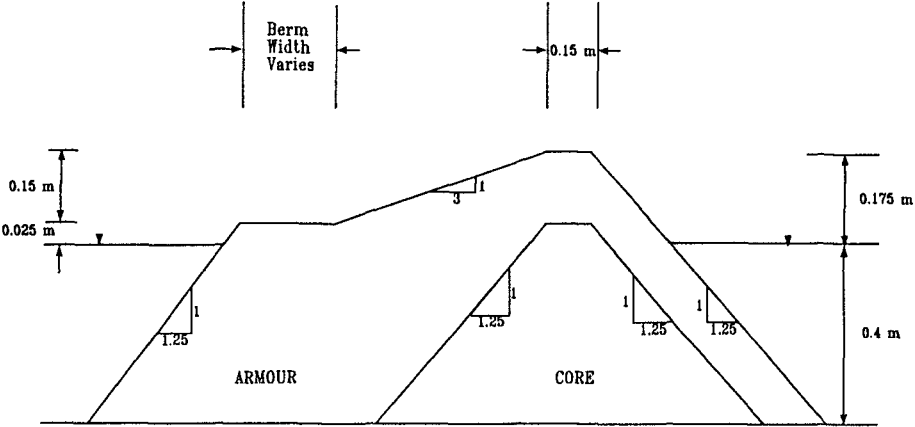


Figure 1 Layout of test breakwater

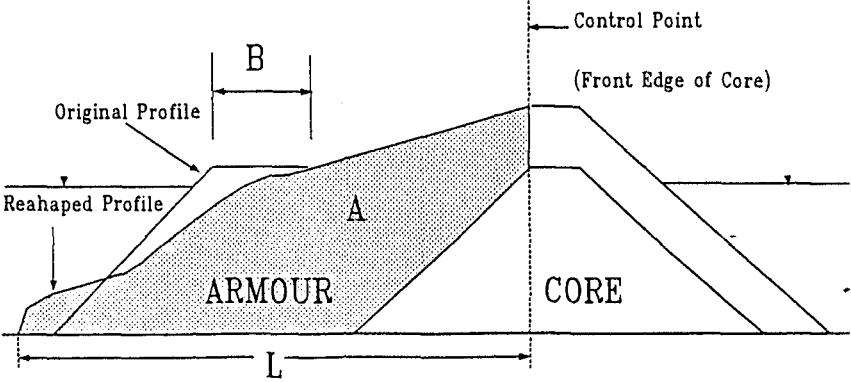


Figure 2 Definition of parameters

dimensionless quantities, A/D_{50}^2 , L/D_{50} and B/D_{50} .

Test Results

Effect of uniformity of stones

Figure 3 shows the relationship between L/D_{50} and the instability number, $H_s / ((S_r - 1)D_{50})$, (where H_s is the significant wave height and S_r is the specific density of armour stone) for the four gradation of stones having a D_{50} of 1.9 cm, and all containing 30% rounded stones. It is seen that gradation 1 is least susceptible to movement offshore indicating that the presence of substantial voids in the armour layer contributes to an efficient wave energy dissipation system. As the relative width of the gradation is increased, there are effectively less voids in the armour stone matrix. Figure 3 shows that the toe width developed increases for gradations 2 and 3. This trend, however, reverses for gradation 4. It appears that as the width of the gradation and thus the maximum stone size increases, the large quantity of stones exceeding a certain upper threshold size has a more dominant effect on stability than does the presence of voids. In gradation 4, a sizeable proportion (20%) of the armour stones exceed 100 gm in weight. The presence of these large stones no doubt had a considerable influence over the stability of the armour layer. Similar trends are observed parameters A/D_{50}^2 and B/D_{50} .

Effect of rounded stones in the gradation

No significant difference was observed regarding the influence of the percentage of rounded stones in the armour layer on L/D_{50} and A/D_{50}^2 following reshaping. Burcharth and Thompson (1983) indicated that in oscillatory flow, there was no appreciable difference in hydraulic stability between rock armour units and dolosse, that is for submerged units, the shape does not significantly influence stability. In the present case, although the berm width, B , of the structure was reduced as a result of wave action, the parameters A and L which are dominated by the underwater profile did not vary with shape. Such behaviour seems to confirm the results of Burcharth and Thompson that when the armour units are completely submerged the shape of the armour unit does not significantly affect the hydraulic stability. However, B/D_{50} was found to depend on the percentages of rounded stones in the armour. Gradation 2A (0% rounded) was found to be more resistant to erosion than gradation 2B (30% rounded), and gradation 2B more resistant to erosion than gradation 2 indicating that the proportion

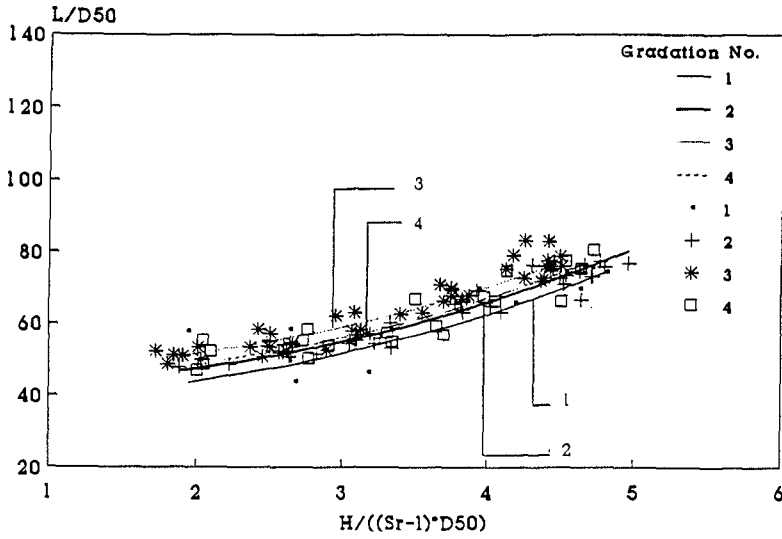


Figure 3 Dimensionless toe width versus instability number, with fitted curves, gradations 1, 2, 3 and 4

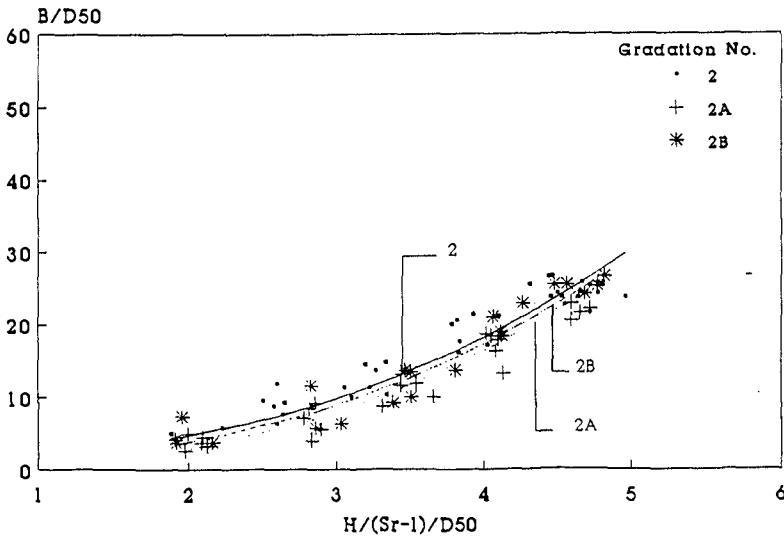


Figure 4 Dimensionless width of berm eroded versus instability number, with fitted curves, gradations 2, 2A and 2B

of rounded stones in the gradation affects initial movement, (stability decreases with increasing "rounding" of stones). Figure 4 shows the influence of the percentage of rounded stones on B/D_{50} .

Effect of duration of storm

Several sets of data were collected for storm durations ranging from 500 to 3600 waves. Such results would be important if there was uncertainty over the expected duration of the design storm. In analyzing these data, the respective areas, A , toe width, L , and width of berm eroded, B ; at any number of waves were divided by the corresponding values formed after the attack of 3000 waves and were called relative area, A_r , relative toe width, L_r , and relative width of berm eroded, B_r , respectively. The number of waves was also divided by 3000 to give the relative number of waves, N_r , (number of waves / 3000). Since relative values are involved, they are independent of wave height, wave period, wave groupiness, gradation and shape.

The relative toe width, $(L/D_{50})_r$, is plotted against the relative number of waves, N_r , in figure 5. The first 500 waves caused most of the reshaping (about 90 % of that of 3000 waves). After 3000 waves, the process of reshaping was found to slow down considerably, but actually never stopped. After the attack of 36000 waves, additional reshaping of about 10 % more than the total toe width formed after 3000 waves attack was observed.

The same trends were observed for A/D_{50}^2 and B/D_{50} .

Effect of other parameters

Wave period and groupiness factor were found to have no significant influence on the three dependent parameters under study. A typical diagram showing the relationship between L/D_{50} and peak spectral wave period T_p is shown in Figure 6. The relationship between L/D_{50} and groupiness factor $g.F.$ is shown in Figure 7.

Derived Relationships for A , B and L .

A multiregression analysis was undertaken using minimization techniques in order to determine the relationship between the three parameters of the reshaped profiles and characteristics of the stone gradations including D_{85}/D_{15} and the percentage of rounded stones (P_r), instability number and number of relative waves, N_r .

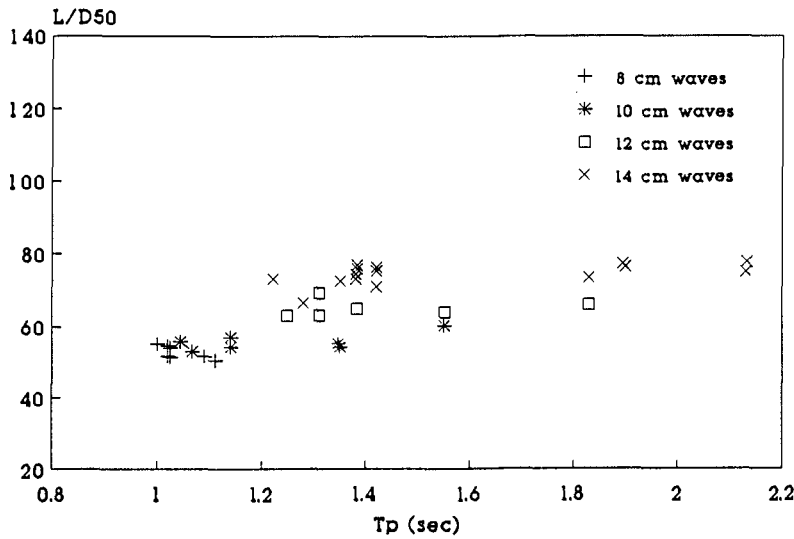


Figure 6 Dimensionless toe width versus spectral peak period, gradation 2

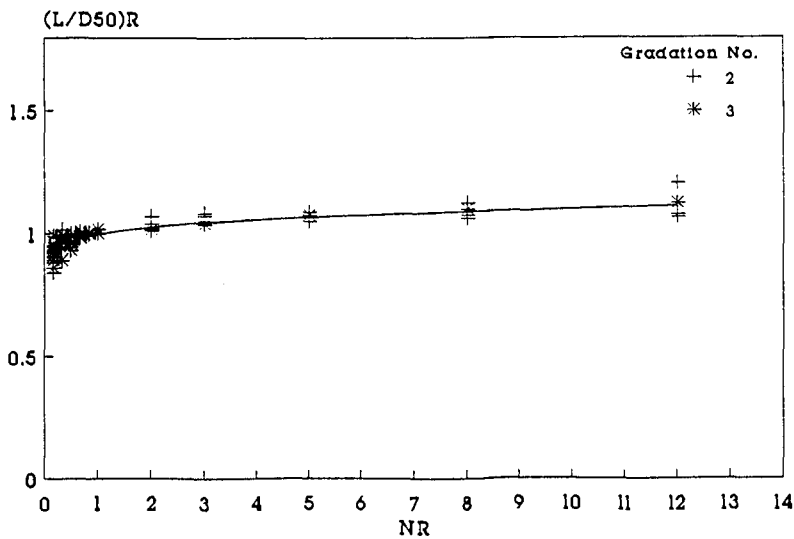


Figure 5 Relative toe width versus relative number of waves, with fitted curves, gradations 2 and 3, all waves

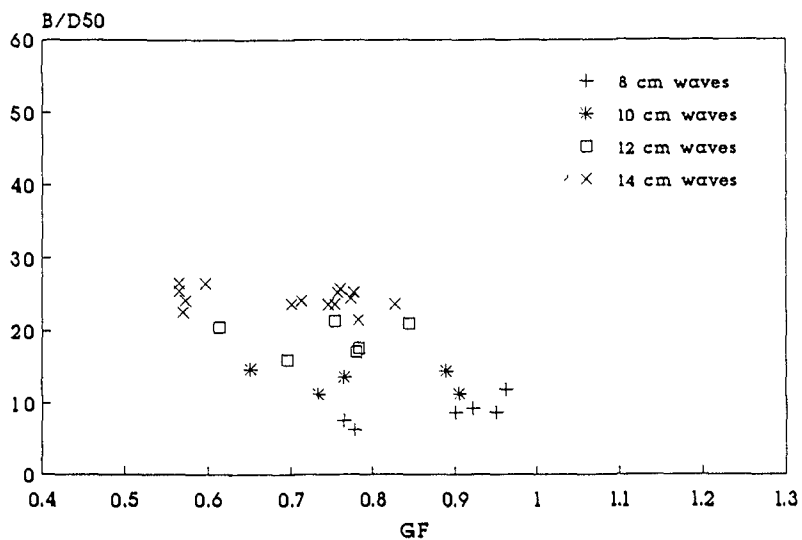


Figure 7 Dimensionless width of berm eroded versus groupiness factor, gradation 2

The relationship between $(L/D_{50})_N$, $(A/D_{50}^2)_N$ and $(B/D_{50})_N$ and N_R are given by

$$\left(\frac{L}{D_{50}}\right)_N = [26 + 1.15\left(\frac{H_s}{(S_r-1)D_{50}}\right)^{2.2} + 11\frac{D_{85}}{D_{15}} - 1.5\left(\frac{D_{85}}{D_{15}}\right)^2] N_R^{0.042}$$

$$\left(\frac{A}{D_{50}^2}\right)_N = [148 + 30\left(\frac{H}{(S_r-1)D_{50}}\right)^{1.9} + 194\frac{D_{85}}{D_{15}} - 27\left(\frac{D_{85}}{D_{15}}\right)^2] N_R^{0.043}$$

$$\left(\frac{B}{D_{50}}\right)_N = [-10 + 0.51\left(\frac{H}{(S_r-1)D_{50}}\right)^{2.5} + 7.5\frac{D_{85}}{D_{15}} - 1.1\left(\frac{D_{85}}{D_{15}}\right)^2 + 6.1P_R][1 + \ln N_R^{0.11}]$$

where,

$(A/D_{50}^2)_N$ = dimensionless reshaping area of breakwater after N waves attack

$(B/D_{50})_N$ = dimensionless width of berm eroded after N waves attack

$(L/D_{50})_N$ = dimensionless toe width after N waves attack

Conclusions

The present series of tests indicate that for armour stones having the same D_{50} values, the wave height is the single most important factor affecting the reshaping process. Both the porosity of the armour and the fraction of heavy stones in a gradation influence the reshaping of dynamically stable breakwaters. It appeared when the gradation of stones is not very wide ($D_{85}/D_{15} < 3$) narrowly graded armour stones are less prone to reshaping; however, when the gradation of the armour stones is sufficiently wide, the effect of the very large stones start to dominate the effect of the voids inside the armour stone layer. The percentage of rounded stones was found to have an influence only on the width of berm eroded. The other dependent parameters, A and L , are dominated by the submerged section of the structure, where it appears stone mass not shape is more significant. Wave period and wave groupiness were found to have no significant effect on either A , B , or L .

Acknowledgements

The authors would like to express their appreciation to Small Craft Harbours Branch, Department of Fisheries and Oceans, Canada for financial support of the study. The assistance of Mr. M. Mulcahy, Small Craft Harbours is gratefully acknowledged.

List of Symbols

A	volume per unit length of armour stones on the front slope following reshaping.
A/D_{50}^2	dimensionless reshaping volume per unit length of stones after 3000 waves attack
$(A/D_{50}^2)_N$	dimensionless reshaping area of breakwater after N waves attack
B	width of berm eroded
B/D_{50}	dimensionless width of berm eroded after 3000 waves attack
$(B/D_{50})_N$	dimensionless width of berm eroded after N waves attack
D_{15}	diameter of stone, that is larger by weight, than 15% of the sample
D_{50}	diameter of stone, that is larger by weight, than 50% of the sample
D_{85}	diameter of stone, that is larger by weight, than 85% of the sample
D_{90}	diameter of stone, that is larger by weight, than 90% of the sample
H_s	significant wave height
$H_s / ((S_r - 1) D_{50})$	instability number
L	width of the toe
(L/D_{50})	dimensionless toe width after 3000 waves attack
$(L/D_{50})_N$	dimensionless toe width after N waves attack

P_R	percentage of rounded stones in the armour
S_r	ratio of unit weight of armour unit to the unit weight of water

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