CHAPTER 135

Stability of Dolosse with Different Waist Thicknesses for Irregular Waves

A H Holtzhausen[1] and J A Zwamborn[2]

Abstract

Model tests were done to investigate the effect of waist thickness on the stability of dolosse under irregular wave attack. A comprehensive test programme resulted in a better understanding of dolos behaviour under a wide range of different conditions.

Irregular waves with Jonswap and Pierson-Moskowitz spectra were generated using a total of four different peak wave periods. Dolosse with five different waist ratios were tested. All the dolosse had a mass of about 80 g and were placed at a "normal" packing density of ϕ = 1,00. Tests were done on three different slopes namely 1:1,33, 1:1,5 and 1:2.

The test results showed that the stability of dolosse decreases as the waist ratio is increased. On average, K_D-values for 2 per cent displacement of dolosse with waist ratios of 0,36 0,38, 0,40 and 0,43 were approximately 22, 51, 49 and 69 per cent respectively smaller than the K_D-value of dolosse with a waist ratio of 0,33.

It was found that irregular waves cause more damage than regular waves. In the 2 per cent displacement range, regular waves (T=1,75 s) with wave height H, cause the same degree of damage to dolosse with waist ratios of

1 Research Engineer and 2 Programme Manager, Maritime and Hydraulic Structures, Division of Earth, Marine and Atmospheric Science and Technology, CSIR, P O Box 320, Stellenbosch, 7600, South Africa.

0,33, 0,38 and 0,43 as waves with a Jonswap spectrum (T_p=1,75 s) with wave heights $H_{mo} \approx 0,9$ H, $H_{mo} \approx 0,8$ H and $H_{mo} \approx 0,75$ H respectively. It was also found that the stability factor obtained with the Pierson-Moskowitz Spectrum (T_p=1,75 s) is on the average 16 per cent lower than that obtained with the Jonswap Spectrum.

There was a noticeable decrease in stability for shorter wave periods and the shortest wave period ($\xi \approx 3$) produced the lowest stability values.

Dolos stability appeared to decrease as the slope was increased from 1:2 to 1:1,33. This was more pronounced with the r = 0,33 dolosse than with the r = 0,38 dolosse. The difference in behaviour of these units can be ascribed to differences in their interlocking characteristics.

Introduction

A previous report on the effect of waist thickness on the stability of dolosse (Scholtz and Zwamborn, 1983) contained the results of model tests done with regular waves.

In that report, the results of tests with three different waist-to-height ratios, namely, 0,33, 0,38 and 0,43 were presented. Only regular waves which were produced by a translatory wave board were used. The wave period was kept constant at 1,75 s. The results showed a marked decrease in stability, especially when the waist-to-height ratio was increased to above 0,38.

Although the increased waist-to-height ratio showed a general decrease in stability, it was considered necessary to also test with units having waist-to-height ratios between 0,33 and 0,38 and between 0,38 and 0,43 to confirm this trend. It was also decided to use more realistic irregular waves instead of regular waves for these additional tests.

In addition, the effects of wave period and armour slope on dolos stability were tested to obtain a more comprehensive picture of dolos stability.

Description of Tests

Model layout and Dolos Characteristics

The tests were done in the 127 m long (effective length), 3 m wide and 1,1 m deep wind-wave flume in Stellenbosch.

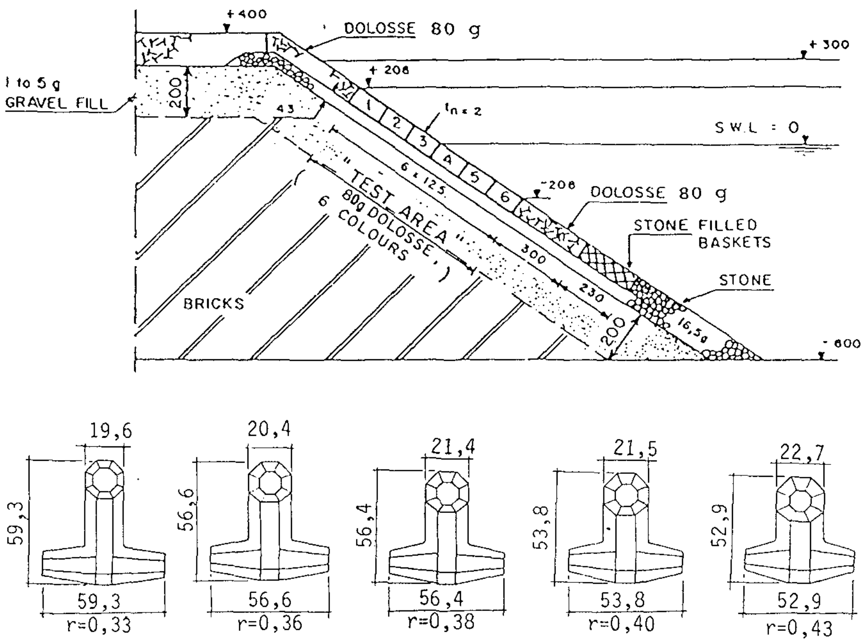

Figure 1. Cross Section of Test Configuration and Dimensions of Model Dolosse (Measurements in mm)

The flume was divided into three 750 mm wide test channels. Identical breakwater test sections (except for the test dolosse) were constructed in each of these test channels. The cross section of the test configuration is shown in Figure 1. The dolosse had a weight of 80 g and a density of 2,4 g/cm^3. Different slopes were used on the test sections, namely, 1:1,33, 1:1,5 and 1:2. The waves approached the dolos slope on a horizontal bottom with a depth of 0,8 m.

The test areas were 750 x 750 mm^2 and the dolosse were placed in six 125 mm (about 2 h where h is dolos height as shown in Figure 1) wide bands of different colours, with three bands above and three below still-water level, that is, 208 mm below to 208 mm above the water level (about 1,5 H_d, where H_d is the 'design wave height') (Zwamborn, 1980). A 'mean' packing of $\phi_{n=2}$ = 1,00 was used where (Zwamborn, 1980):

$$N_n = \phi_n V^{-2/3}$$

with N = number of dolosse per unit area
V = bock volume

A total of 538 dolosse were placed in each 750 × 750 mm^2 test area. Additional 80 g dolosse were placed above and below the 'test area' as shown in Figure 1, but these were not taken into account in assessing damage.

The underlayer consisted of 16,5 g selected stone and was 43 mm thick. The breakwater core was built of loose bricks covered with an approximately 200 mm thick layer of 1 to 5 g gravel.

Test Wave Conditions and Measurements

Waves were generated by Seasim irregular wavemakers placed near to the one end of the flume in 1,0 m deep water. The wavemaker is equipped with a wave absorption control unit which makes it possible to absorb reflections from the breakwater structure, thus minimizing unwanted re-reflections off the wavemaker paddles.

The following wave conditions were used for the tests: Jonswap spectrum with T_p-values of 1,25, 1,5, 1,75 and 2,0 s and Pierson-Moskowitz spectrum with T_p = 1,75 s.

Waves were measured by means of twin-wire resistance type probes coupled to the CSIR's model hall data acquisition system.

Three probes were positioned in each of the three channels at distances of 5,55, 5,80 and 6,20 m from the model slope. These three sets of three probes each were used to separate the incident from the reflected spectra. A three-point method using a least squares technique for decomposing the measured spectra from three known probe positions, developed by Mansard and Funke (1980), was used.

The wave data calculated from the recordings made during the actual tests at the three probes in each channel (9 probes altogether) were used to calculate the mean incident wave height for each test.

Test Procedures

After the underlayer stones had been smoothed out, the test area was profiled using the standard sounding technique on a 50 mm grid (Zwamborn, 1980). The dolosse were then placed in one operation, from the bottom upwards, and the surface was profiled on the same grid as the underlayer. The profiling of the underlayer grid as the underlayer. The profiling of the underlayer and the dolos surface was done for a number of tests only. The mean difference between the two soundings provided the average layer thickness, $t_{n=2}$ while the 'fictitious' porosity, P_f, was calculated using the following two equations:

$$t_n = \tau_n V^{1/3}$$

and $\phi_n = nC_n (1 - P_f/100)$

where
t = layer thickness
n = number of layers
$\tau_n = n C_n$ = 'relative' armour thickness
C_n = shape factor
$= \phi_n/n (1 - P_f/100)$
P_f = 'fictitious' porosity

Table 1 shows the average values of P_f, and $C_{n=2}$ that were determined for dolosse of five different waist ratios (r).

Waist ratio	r=0,33	r=0,36	r=0,38	r=0,40	r=0,43
P_f (%)	54,9	52,7	50,5	49,3	47,0
$C_{n=2}$	1,18	1,09	1,05	1,03	1,01

Table 1. Measured values of P_f (%) and $C_{n=2}$

A test series consisted of 60 minutes of wave action for each wave height starting from the smallest wave height and increasing the wave height in steps of about 20 mm until failure occurred or until the biggest wave was reached (normally about 5 to 8 steps).

The return period (55 to 80 minutes) of the input wave sequence used was mostly longer than the actual test period (60 minutes) used, with the result that the wave conditions varied throughout a test. All the repeat tests were started at the same position in the wave sequence, therefore the same section of the wave sequence was used for the different tests. Three 1,8 to 2,9 minute-long wave recordings were made in each test channel during each one-hour test.

Displacement of units were recorded by visual observation after each 60 minute test. Photographs were also taken at the start of a test series and after each 60 minute test. Rocking movements were recorded by

A test series was repeated from 3 to 8 times using the same wave sequence. The sublayer and the dolos cover were replaced after each test series.

Dolosse of different waist-to-height ratios were tested side by side in the flume. To eliminate the effect of small differences in wave conditions in the three channels, the positions of the test dolosse were alternated in the three channels.

Damage Criteria

In the analysis of the test results, the following damage criteria were used:

(1) displacement, movement of at least h
(2) continuous rocking or full roll-over (no displacement)
(3) intermittent rocking (about two-thirds) of the time
(4) occasional rocking (about one-third of the time)

At least three repeat tests were done for each test condition and the average damage was obtained for the different wave heights from these data.

Test Results and Interpretation

Effect of Irregular Waves

A comparison of the results obtained with regular waves and the results obtained with irregular waves are shown in Figure 2.

The results indicate that dolosse are less stable with irregular waves than with regular waves of height H_{mo}. For the r = 0,33, r = 0,38 and r = 0,43 dolosse, it is found that in the 2 per cent displacement range, regular waves with wave height H cause the same degree of damage as irregular waves with $H_{mo}\approx 0,9$ H, $H_{mo}\approx 0,8$ H and $H_{mo}\approx 0,75$ H.

Ouellet (1972) concluded from his model test results that "... the use of the significant wave height, $H_{1/3}$ for the design wave height of a rubble-mound breakwater is comparable to a constant periodic wave height ...", which contradicts the above results.

Brorsen *et al.* (1974) concluded from their model test results that irregular waves of H_s cause the same degree of damage as regular waves with the height $H\approx 0,8$ H_s. After checking the results presented by Brorsen, however, it was found that $H_s\approx 0,8$ H and not

H≈0,8 H_s as given in the paper (the same error is carried through in Burcharth *et al.* (1986)). Thus, after making this correction, these results are similar to the above ones.

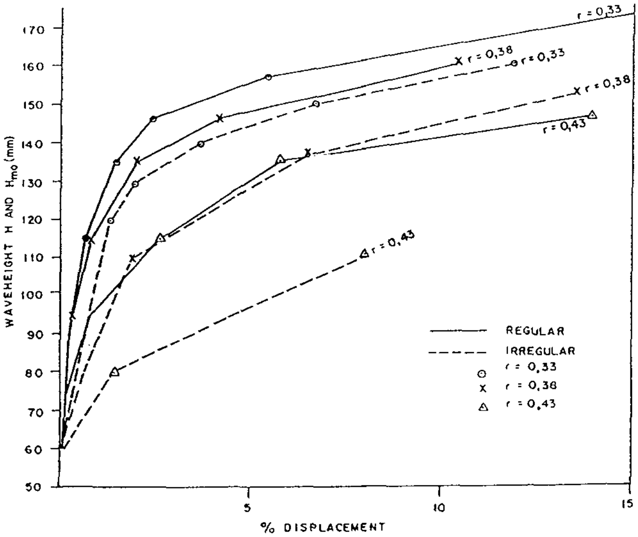

Figure 2. Irregular versus Regular Wave Results for Different Waist Ratios

Effect of Waist-to-Height Ratio

The 'relative' stability factor was used to describe the effect of waist ratio on stability. This is defined as the K_D value for a specific waist ratio devided by the K_D value of a waist ratio of 0,33 i.e. $K_D/K_{D(r=0,33)}$, where K_D is the Hudson stability coefficient:

$$K_D = \frac{\gamma_s \; H^3}{W \; \Delta^3 \; \cot \alpha}$$

where

W = weight of dolos
H = wave height

$$\Delta = \frac{\gamma_s}{\gamma} - 1$$

γ = specific density of water
γ_s = specific density of dolos
α = breakwater slope angle

Figure 3 shows the relative stability factor against waist ratio for a range of different test conditions including one condition tested by Burchart *et al.* (1986). All the results of the present tests show a very definite trend of decreasing stability with increase in waist thickness. This result is to be expected, considering the reduction of interlocking capability and decrease in porosity (Table 1) for the thicker-waist dolosse.

Surprisingly, the results of Burcharth show no clear influence of waist ratio on stability. Figure 3 shows that Burcharth's results are rather scattered and follow no clear trend with change in waist thickness. The reason for this is probably that the units tested were rather small (30,7 g). Also, the packing density was increased with increasing waist ratios, therefore variation in test results can not be attributed to waist ratio only.

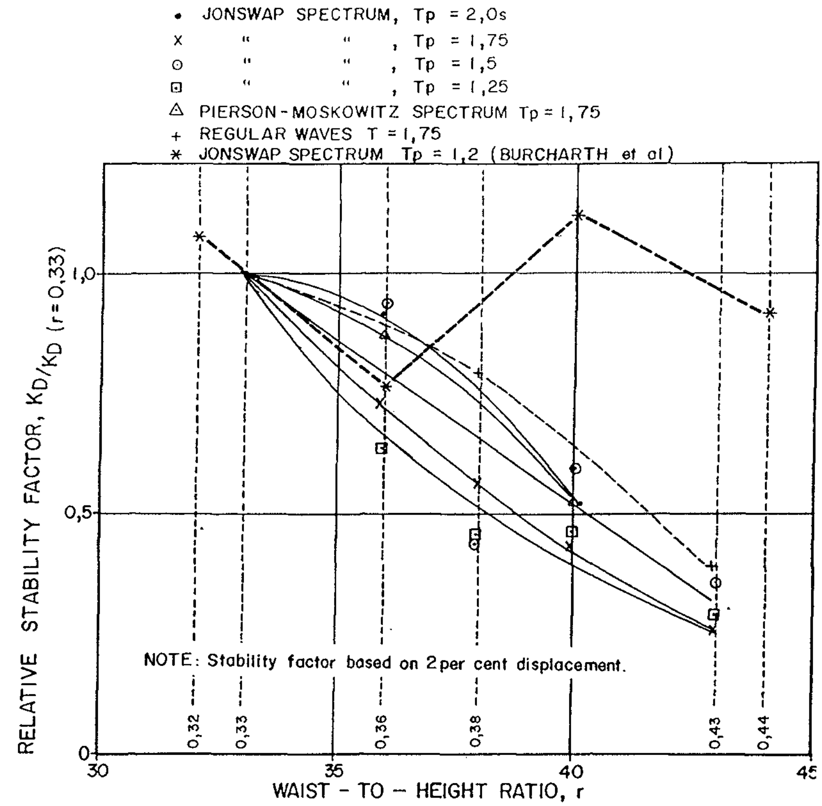

Figure 3. Effect of Waist Ratio on Stability

Effect of Wave-period and Wave Spectrum

The effect of wave period and spectrum shape on stability is shown in Figure 4. There is a noticeable decrease in stability with shorter wave periods except for T_p = 1,5 s when K_D is about equal to that for T_p = 1,75 s with r = 0,36, r = 0,40 and r = 0,43 dolosse.

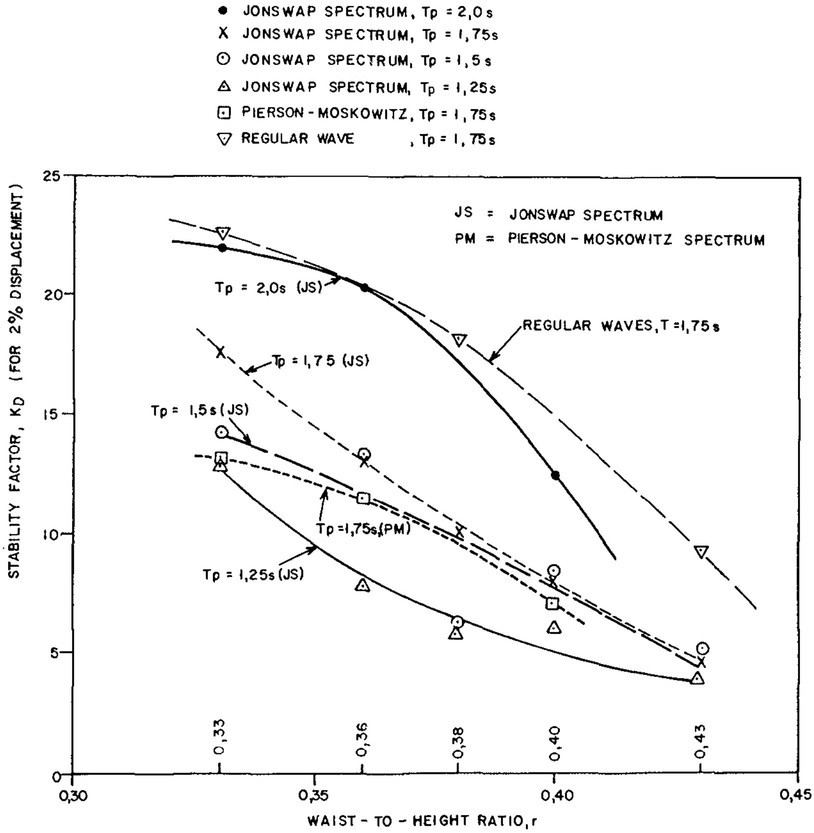

Figure 4. Effect of Wave Period and Spectrum Shape on Stability

For a displacement of 2 per cent for dolosse with r = 0,33; r = 0,36 and r = 0,40 respectively, waves with a Jonswap spectrum were approximately 9 per cent, 6 per cent and 4 per cent larger than waves with a Pierson-Moskowitz spectrum. Therefore the average stability factor obtained with the Pierson-Moskowitz Spectrum, T_p = 1,75 s is 16 per cent lower than that obtained with the Jonswap Spectrum, T_p = 1,75 s.

Effect of Armour Slope

For comparing the stability of units on different slopes, the stability number $N_s = H_s/(\Delta(W/\gamma_s)^{1/3})$ which equals $(K_D \cot\alpha)^{1/3}$, was used since (unlike K_D) it gives a direct indication of armour weight independent of the slope angle. Another important aspect of stability comparisons between different slopes, is the definition of wave attack. Comparison should be done when the destabilising forces produced by waves on different slopes are the same. Günbak (1979) showed that the Iribarren number $\xi = \tan\alpha/(H/L_o)^{1/2}$ may be used to describe the wave attack on a rubble mound structure. In this formula α is the slope angle, H is the wave height and L_o is the deep water wave-length.

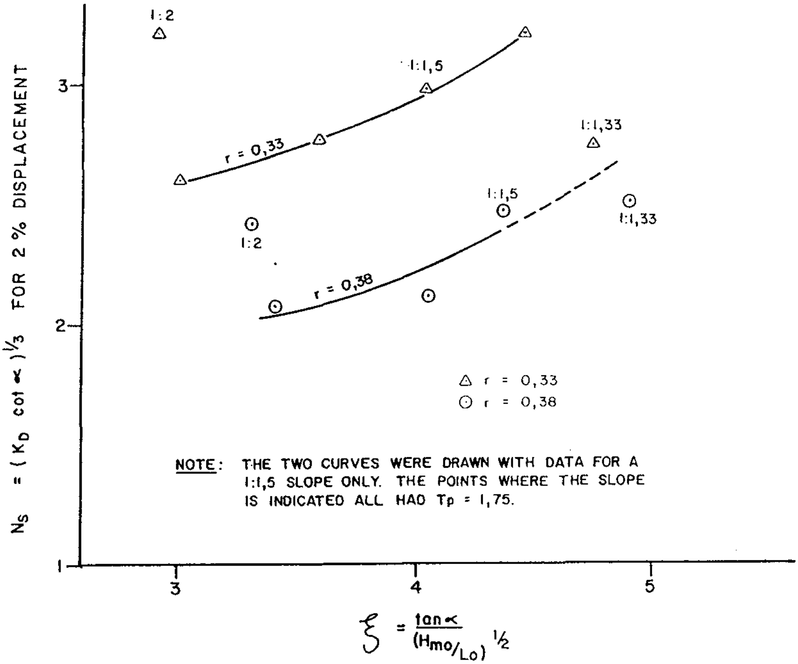

Figure 5. Effect of Armour Slope on Stability

Figure 5 shows the stability (defined by N_s) against the wave attack (defined by ξ) for three different slopes for dolosse with r = 0,33 and r = 0,38. For calculating ξ, the wave height was taken as H_{mo} just in front of the start of the dolos slope and L_o was calculated as: $L_o = (g/2\pi)\ T_p^2$ where T_p is the peak wave period. The 1:2 and 1:1,33 slopes were tested with

T_p = 1,75 s while the 1:1,5 slope was tested with four different peak wave periods.

From Figure 5 it is clear that the stability decreases as the slope is increased from 1:2 to 1:1,33 for both types of dolosse. However, this comparison was done at only one wave period and can therefore not be assumed to apply in general. The decrease in stability was more pronounced for the r = 0,33 dolosse than for the r = 0,38 dolosse. This seems to indicate that thicker units have better stability (for low displacement values) than more slender units on steep slopes. A possible explanation for this is that steep slopes cause the thicker units to pack close enough to utilize most of their interlocking capacity, while the slender units (with their higher porosity) require some initial settlement before optimum interlocking is achieved.

Design Curves

Based on the present test results, the relationships between the stability factor and the Iribarren number are as shown in Figures 6 and 7. For the range of Iribarren numbers used in the present tests (ξ approximately 3 to 5) the most critical wave conditions for the stability of dolosse have Iribarren numbers of approximately 3.

For the r = 0,38 dolosse all the data points (including the 1:1,33 and 1:2,0 slopes) fitted the design curve reasonably well. If the data points for the 1:1,33 and 1:2,0 slopes are included as data for the r = 0,33 dolosse, a very bad fit is achieved. These two data points were therefore excluded for the design curve of the r = 0,33 dolosse, and this curve is therefore strictly valid only for an armour slope of 1:1,5.

It is clear from the wide spread of data points in Figures 6 and 7 that the two parameters, K_D and ξ, do not fully describe the stability of dolosse under the various test conditions. However, these design curves can be used as a guide for a first design using Figure 6 for high quality strength-improved dolos projects while Figure 7 should be used for lower quality projects.

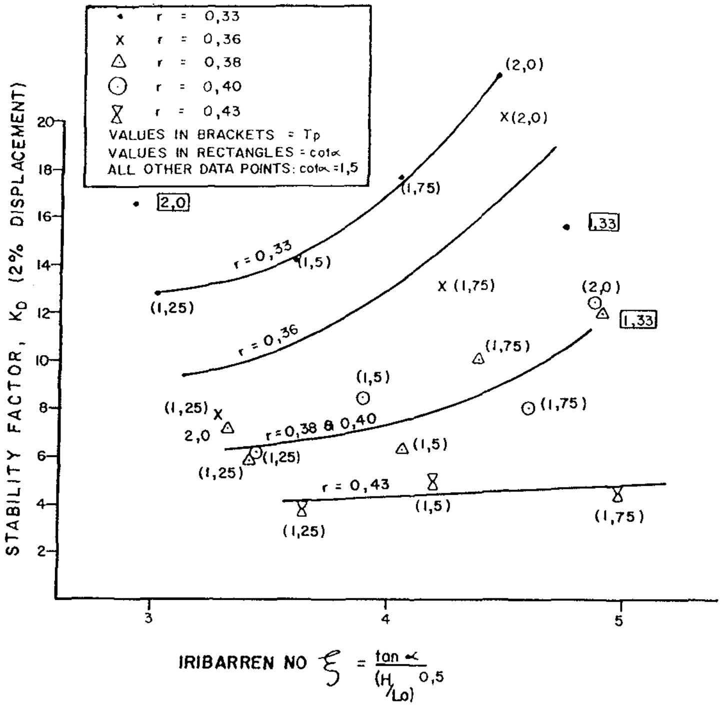

Figure 6. Design Curve for 2 per cent Displacement

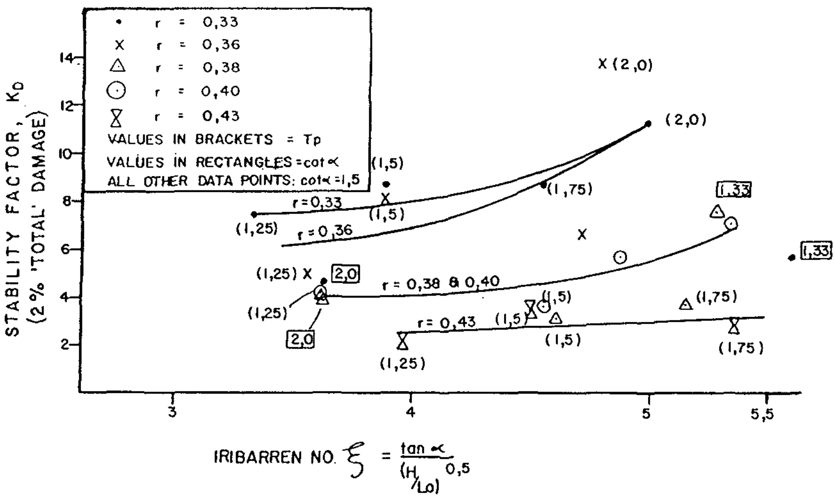

Figure 7. Design Curve for 2 per cent 'Total Damage' (displacement + continuous rocking +intermittent rocking)

Conclusions

Test results showed that the stability of dolosse decreases as the waist-to-height ratio increases. The results also showed that, for 2 per cent displacement, there is a noticeable decrease in stability with shorter wave periods down to $\xi \approx 3$ (minimum ξ value of tests).

It was also found that dolosse are on average 16 per cent less stable with Pierson-Moskowitz Spectra waves than with Jonswap Spectra waves of the same peak period.

It can further be concluded from the test results that irregular waves with a significant wave height equal to the wave height of regular waves, cause significantly more damage than the regular waves. The stability factors for dolosse with r = 0,33, r = 0,38 and r = 0,43, determined with irregular waves are respectively 23, 45 and 55 per cent smaller than the stability factors determined for regular waves. Although regular waves can be used to determine the relative stability of different types of dolos armouring, it is better to use irregular waves in tests where the stability of the armouring for a specific project is to be determined. If only regular waves can be used for these tests, allowance must be made for the expected greater damage by using a regular wave height, $H = 1,1\ H_{mo}$ for dolosse with r = 0,33, $H = 1,2\ H_{mo}$ for dolosse with r = 0,38, and $H = 1,3\ H_{mo}$ for dolosse with r = 0,43.

Tests with different breakwater slopes showed a decrease in stability as the slope was increased from 1:2 to 1:1,33. This decrease was less pronounced for dolosse with r = 0,38 than for the r = 0,33 dolosse.

Design curves are included in Figures 6 and 7 which show the dolos stability as a function of the Iribarren number and the waist ratio for two different damage levels. The data points in these figures show considerable scatter, indicating that these parameters do not fully describe the stability of the dolos armouring, particularly with regard to armour slope. However, the curves can be used as a guide for a preliminary design, taking into account the above limitations.

References

BRORSEN, M, BURCHARTH, H F and LARSEN, T (1974). Stability of dolos slopes. Proceedings of 14th ICCE. Copenhagen.

BURCHARTH, H F and BREJNEGAARD-NIELSEN, T (1986). The influence of waist thickness of dolosse on the hydraulic stability of dolosse armour. Proceedings of 20th ICCE Conference, Vol. II. Taipei, Taiwan.

GÜNBAK, A R (1979). Rubble mound breakwaters. The Norwegian Institute of Technology. Trondheim, Norway.

MANSARD, E P D and FUNKE, E R (1980). The measurement of incident and reflected waves in random wave experiments. Proceedings of 15th ICCE. Hawaii.

OUELLET, Yvon (1972). Effects of irregular wave trains on rubble-mound breakwaters. Journal of the Waterways, Harbors and Coastal Engineering Division. Proceedings of the American Society of Civil Engineers.

SCHOLTZ, D J P and ZWAMBORN, J A (1983). Effect of the waist thickness on stability of dolosse. CSIR Research Report 556. Stellenbosch.

ZWAMBORN, J A (1980). Measuring techniques, dolos packing density and effect of relative block density. CSIR Research Report 378. Stellenbosch.

ZWAMBORN, J A and VAN NIEKERK, M (1982). Additional model tests. Dolos packing density and effect of relative block density.