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Burcharth, Hans F.; Brejnegaard-Nielsen, Torben

Published in:
Proceedings of the 20th International Conference on Coastal Engineering : ICCE '86

Publication date:
1987

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Burcharth, H. F., & Brejnegaard-Nielsen, T. (1987). The Influence of Waist Thickness of Dolosse on the Hydraulic Stability of Dolosse Armour. In B. L. Edge (Ed.), *Proceedings of the 20th International Conference on Coastal Engineering : ICCE '86: Taipei, Taiwan, 9-14 November 1986* (pp. 1783-1796). American Society of Civil Engineers.

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CHAPTER 130

THE INFLUENCE OF WAIST THICKNESS OF DOLOSSE ON THE HYDRAULIC STABILITY OF DOLOSSE ARMOUR

by

Hans F. Burcharth *

Torben Brejnegaard-Nielsen **

ABSTRACT

The paper presents results from experiments with Dolosse having the same mass and volume but with different waist thickness to height ratios. The armour was exposed to irregular waves simulating one storm with increasing wave heights and the effect of waist to height ratio on the hydraulic stability was studied. A low packing density of approximately 0.65 was used corresponding to a two-layer armour with high porosity.

From the results it is concluded that the hydraulic stability of Dolos armour is not very sensitive to variations in the waist to height ratio. Only for damage levels exceeding displacement of approximately 5% of the armour blocks in the most exposed area there seems to be a significant decrease in hydraulic stability with increasing waist to height ratio. Thus the waist ratio only influences the residual hydraulic stability.

Based on a short discussion of stressed in armour units it is concluded that design criteria solely based on movements of armour units as observed in hydraulic models are not adequate for the assessment of structural integrity of the units.

The paper also presents the results of each stability test as well as the scatter and the distributions. The large scatter found underlines the need for adoption of more restrictive safety factors than generally used in rubble mound breakwater design. It also supports the idea of a probabilistic approach in the design process.

INTRODUCTION

The recent failures of major rubble mound breakwaters have demonstrated the need for developments in breakwater design and construction. The problem is highly complex as the loads on the breakwaters and the response to match are typical stochastic wide-banded processes. On that background all parameters involved in breakwater design certainly have to be considered and their relative importance evaluated. One parameter of great importance is the mechanical strength of concrete armour units.

* Professor of Marine Civil Engineering, University of Aalborg, Denmark.

** Consulting Engineer, London, UK.

It is evident and well documented that the relative strength of concrete armour units decreases with the size of the armour units (Burcharth, 1981a), (Burcharth, 1981b), and (Silva, 1983).

Generally in complex types of armour units the stress level due to flow forces and static (gravity) forces increases linearly with the characteristic length (e. g. the height of the armour unit) while the stress level due to impacting units increases with the square root of the characteristic length. The relative importance of these stresses depends on the geometry of the units and their position on the slope, cf. Fig. 1.

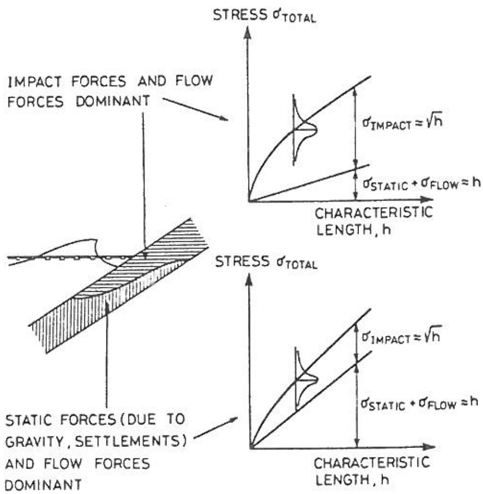


Figure 1. Qualitative representation of stresses in complex armour units as function of the size (length) of the units.

It follows from this that a design criterion solely based on movements of armour units in a hydraulic scale model is not adequate for the assessment of the structural integrity of the armour units.

Because of the size dependent stress level, one must either increase the strength of the units and/or apply a milder design criterion (e. g. a certain degree of rocking instead of displacements) when dealing with larger units.

In the case of complex types of armour units such as Dolosse, one way of increasing the strength is to increase the crosssections, i.e. apply a larger waist thickness to height ratio, r = d/h, see Fig. 3. However, by doing so the hydraulic stability will be changed too, which must be considered in the design. Thus, the relationship between the waist ratio and the hydraulic stability must be known. Scholtz et al. (1982) studied this relationship for Dolosse exposed to regular waves.

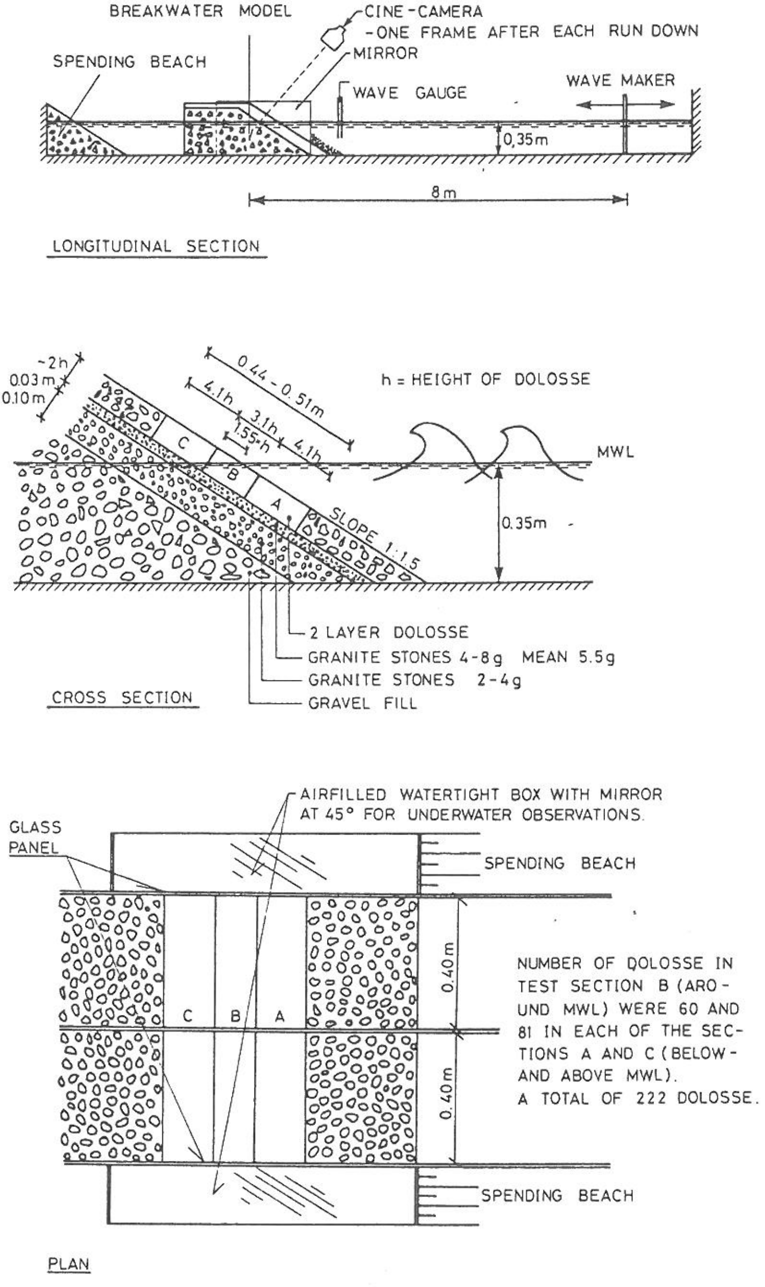


Figure 2. Test set-up.

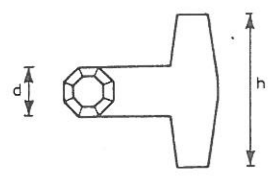
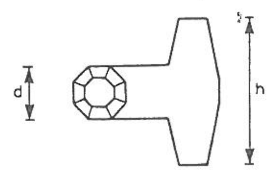
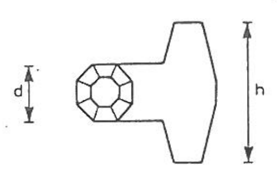
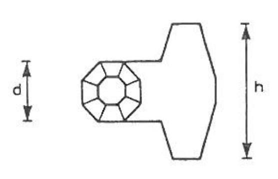
	TYPE	d(mm)	h(mm)	$r = \frac{d}{h}$
	1	14.4	45.0	0.32
	2	15.4	42.8	0.36
	3	16.4	40.9	0.40
	4	17.3	39.3	0.44

Figure 3. Geometry of model Dolosse.

In the present work the same hydraulic stability dependence is studied in irregular, two-dimensional waves for waist ratios of r = 0.32, 0.36, 0.40, and 0.44.

MODEL LAY-OUT

The tests were carried out in a 5 meter wide wavebasin, equipped with a spending beach, Fig. 2. As the total width of the model was only app. 1.6 meter, the wave reflection from the model was negligible.

The model was built in two separated sections to allow for a comparative study, where one section in all tests was armoured with Dolosse with a waist ratio of 0.32 used as a reference.

Each of the test sections was divided into three sub-sections called above, around and below mean water level. The Dolosse were placed randomly with a loose hand in two layers. For each test a total number of N = 222 Dolosse were applied in each section of 11.3 h x 0.40 m, where h is the height of the Dolos. Four types of Dolosse having the same volume and made of cement mortar with a mass density of ρ_a = 2.24 t/m³ were tested. The geometry is given in Fig. 3. The theoretical volume of the Dolos is 14.2 cm³, but pores in the surface made the actual volume V = 13.7 cm³.

The packing density of the armour, defined as $\varphi = N\ V^{2/3}$, where N is the number of blocks per unit area, was 0.61, 0.64, 0.67, and 0.70 for waist ratios, r = 0.32, 0.36, 0.40, and 0.44, respectively. This corresponds to a two-layer armour with loose packing and high porosity. The increase in φ with r compensates for the otherwise increasing openness (exposure of filter layer stones) with increasing r. This, however, also means increasing amount of concrete per unit area with increasing r.

Generally a larger packing density in the order of 1.0 is recommended, but here the low values were chosen deliberately to represent the worst conditions in a real breakwater situation where uneven distribution of Dolosse on the slope can occur.

Cement mortar was applied in order to represent the prototype surface roughness as closely as possible. The tests were performed with irregular waves generated with a piston type wave maker on basis of a 5 parameters JONSWAP-spectrum.

$$S(f) = \alpha g^2 (2\pi)^{-4}\, f^{-5} \exp(-\frac{5}{4}(\frac{f}{f_p})^{-4} \cdot \gamma^{\exp(-\frac{1}{2}(f-f_p)^2/\sigma^2 f_p^2)}$$

with the four parameters;

f_p = 0.83 Hz
σ = 0.07 for $f < f_p$
σ = 0.09 for $f \geqslant f_p$
γ = 3.3

The fifth parameter α was used as a gainfactor to establish the desired significant waveheight $H_s = 4\sqrt{m_o}$, where m_o is the variance of the surface elevation.

Five values of H_s were chosen such that rocking of single blocks and displacements of several blocks would appear for the smallest and the largest H_s values, respectively. The values of H_s are given in Table 1 together with the parameter $\zeta = (H_s/L_{H_s})^{-0.5}$ tanα, where L_{H_s} are the wavelength corresponding to H_s and tanα the slope.

Table 1. H_s and ξ values applied in the model tests.

Level	1	2	3	4	5
H_s (mm)	43	59	67	83	94
ξ	3.9	3.3	3.1	2.8	2.6

The duration of each test was 20 min. corresponding to approximately 1200 waves.

TEST PROCEDURES

Three series of tests were performed each containing the reference Dolosse (r = 0.32) and one of the other three block types. To evaluate the scatter each series consisted of five repeated (independent) tests, cf. Table 2, in each of which the wave height was increased corresponding to the above mentioned five levels of H_s.

Table 2. Test program.

Serie	1	2	3
Block type	r = 0.32, r = 0.44	r = 0.32, r = 0.40	r = 0.32, r = 0.36
No. of independent tests	5	5	5
No.of wave levels in each test	5	5	5

For each wave level in each test visual observations of the rockings and displacements in each of the sub-sections A, B, and C were made by 2 persons simultaneously by means of a special mirror system (Fig. 2). The mirror system allowed underwater observations throughout the running tests.

As a supplement single frames were taken by a cine-camera, which was activated when the water level during down-rush was approximately at the lowest level.

Two modes of movements were observed namely the rocking of the blocks (moving without translation) and the displacement of the blocks (moving with translation).

It was very clear from the testing that realistic information on the number of units rocking and being displaced cannot be obtained without the possibility of continuous underwater observations.

TEST RESULTS

In the Figures 4 to 7 the observed stability in terms of relative numbers of rocking and displaced units is depicted as functions of H_s, H_s/h and the stability number

$$N = \frac{\rho_a H_s^3}{M(\rho_a/\rho_w - 1)^3} = \frac{H_s^3}{V(\rho_a/\rho_w - 1)^3}$$

where ρ_a and ρ_w are the mass density of the Dolos and the water, respectively, and M and V are the mass and the volume of the Dolos, respectively.

N^3 can be derived from Hudson's formula as $K_D \cot\alpha$, where K_D is the Hudson stability factor. However, K_D should not be used for Dolos because the hydraulic stability is practically independent of the slope angle for $1 < \cot\alpha < 3$, which means that Hudson's formula is not valid for Dolos armour (Brorsen et al., 1974). However, to facilitate comparisons with the many published K_D values for Dolos also a K_D scale is shown in the figures.

To illustrate the scatter in the experimental results also the standard deviation over the mean value is shown for the various wave levels. Moreover, each test result is shown as a dot to visualize the actual distributions of the test results. It might be seen that these distributions can be fitted to the Poisson type distributions. It should be mentioned that these distributions, which represent the movements of the armour units, are different from the still unknown distributions related to the stresses in the units.

The figures illustrate the well known fact that the damage to the Dolosse armour is most severe in area B around the mean water level.

Despite its lack of consideration of the strength of the armour units, a design criterion corresponding to app. 5% of the units being displaced (within the levels SWL ± H_s) is often used. It is interesting to see that this compares to app. 10% of the units rocking and to H_s/h-values in the range 1.5-1.7 corresponding to K_D-values in the range 6.5-7.5. These K_D-values are lower than generally recommended. The reason for this discrepancy is probably that in many model tests the set-up did not allow underwater inspection of the movements of the armour units, which means that milder degrees of damage were recorded. Another reason might be lack of control of the reflected waves in some flume tests. Also the low packing density used in the present tests might have some influence on the K_D values, cf. the following conclusions.

Figure 8 shows a comparison of the stability of the four types of Dolosse. A decrease in stability with increasing waist ratio r is seen, but only for the more severe wave conditions, say $H_s/h > 1.5$ or $N^3 > 10$. For the smaller values of H_s/h there are only minor, non-systematical differences between the stabilities of the various shapes of Dolosse.

COMPARISONS AND CONCLUSIONS

Tests were performed on the hydraulic stability of Dolosse with waist thickness to height ratios of r = 0.32, 0.36, 0.40, and 0.44 exposed to irregular waves. It can be concluded that the hydraulic stability is decreasing with increasing waist ratios but only for high degrees of damage, i.e. damage levels exceeding displacements of approximately 5% of the blocks in the most exposed area. Thus the waist ratio only influences the residual hydraulic stability of the armour. The reduction in the hydraulic stability is probably due to the relatively quicker loss of effective permeability ("reservoir effect") and interlocking ability for units

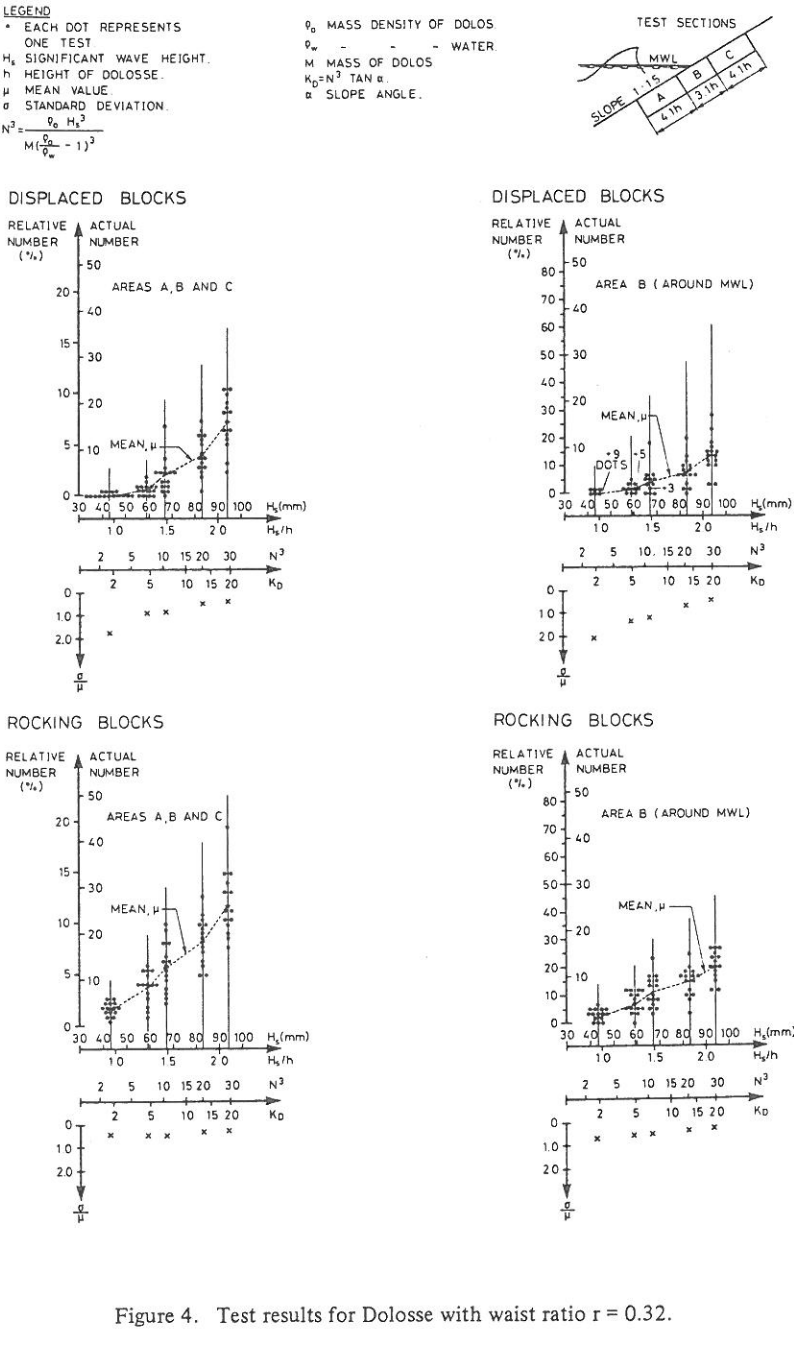


Figure 4. Test results for Dolosse with waist ratio r = 0.32.

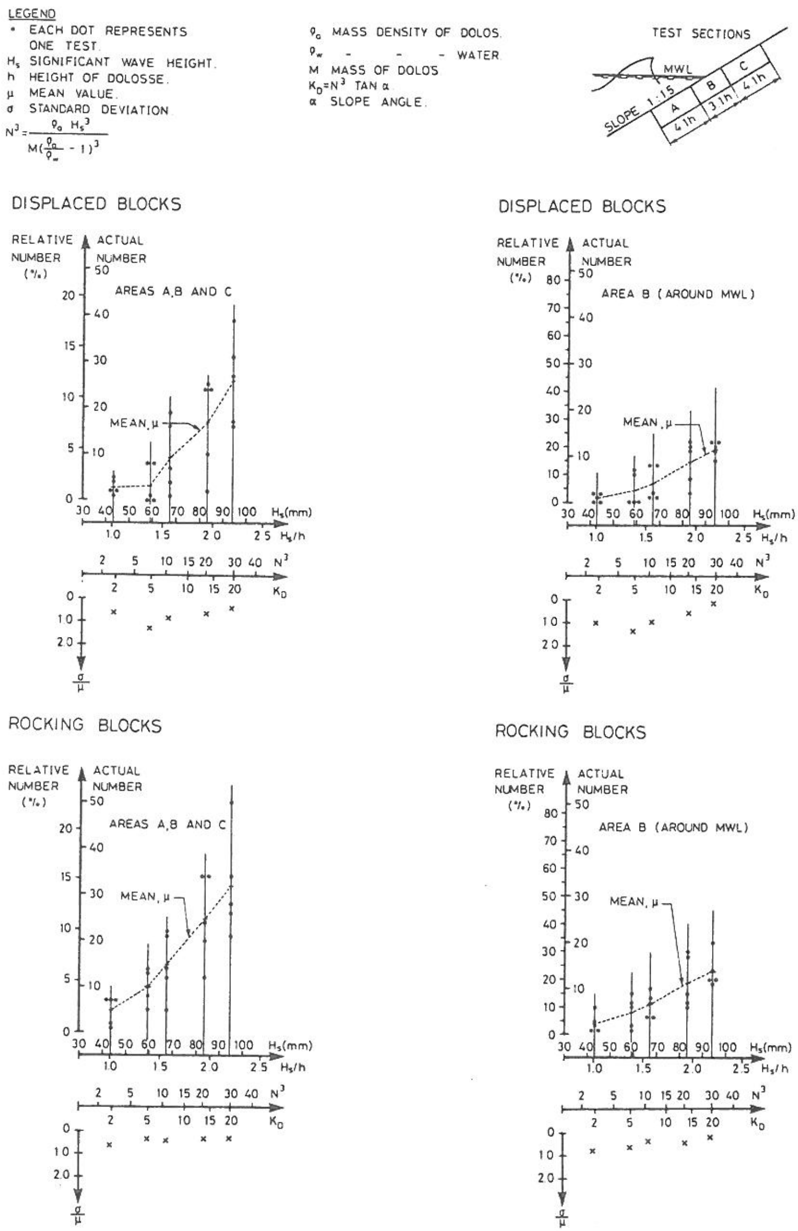


Figure 5. Test results for Dolosse with waist ratio r = 0.36.

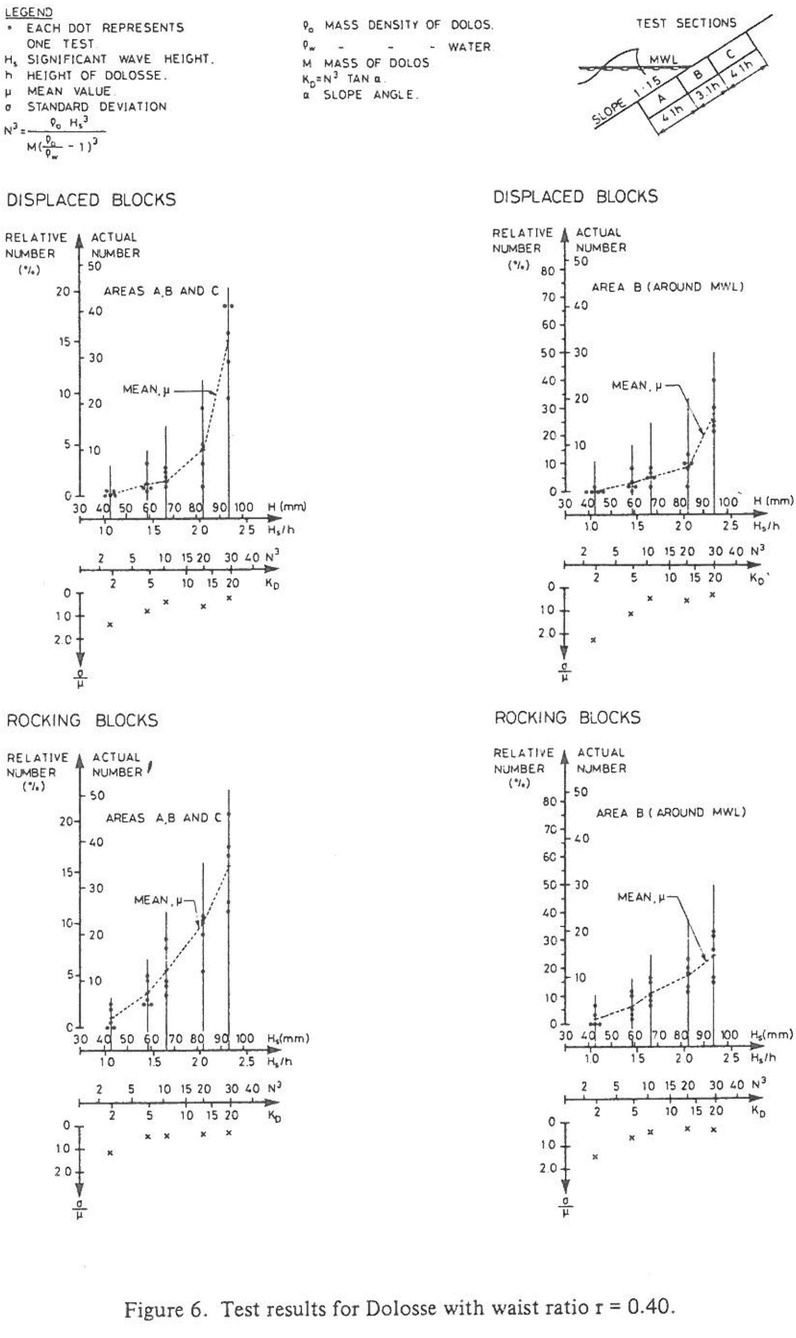
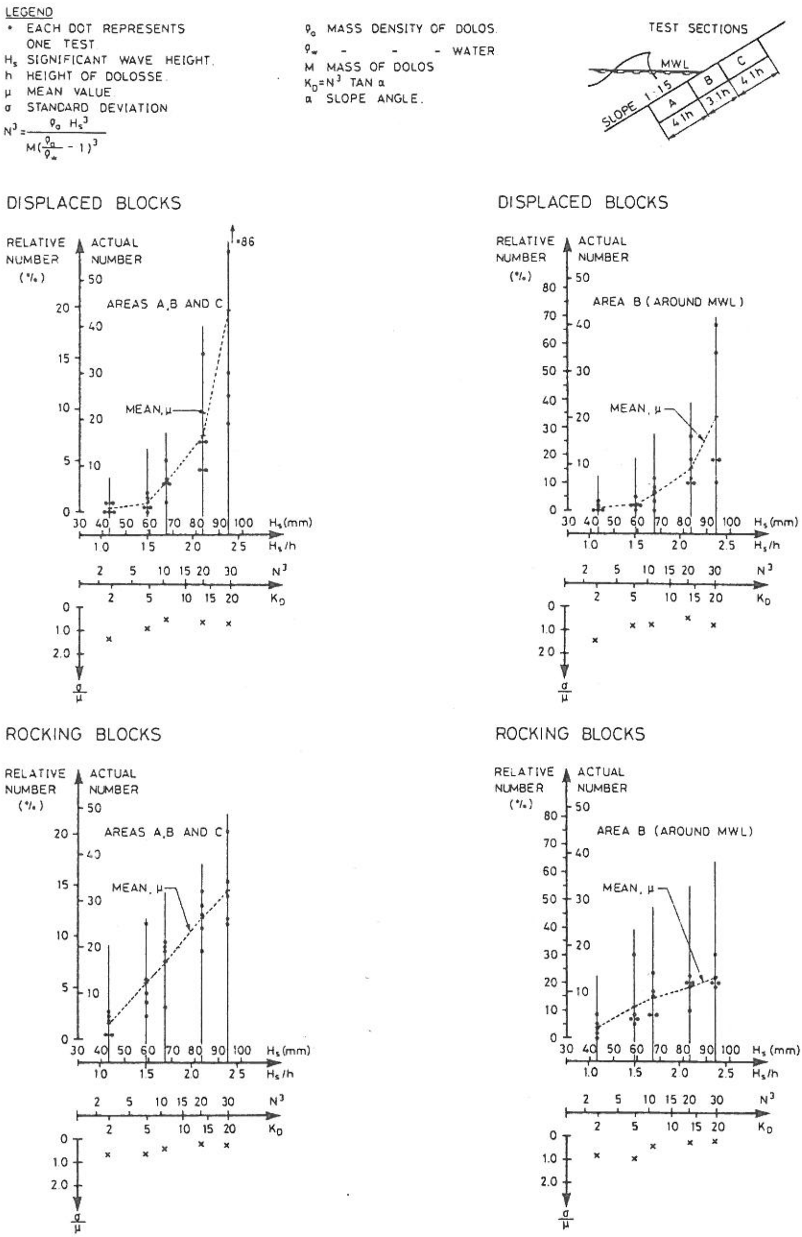


Figure 6. Test results for Dolosse with waist ratio r = 0.40.



$$N^3 = \frac{\rho_a H_s^3}{M(\frac{\rho_a}{\rho_w} - 1)^3}$$

Figure 7. Test results for Dolosse with waist ratio r = 0.44.

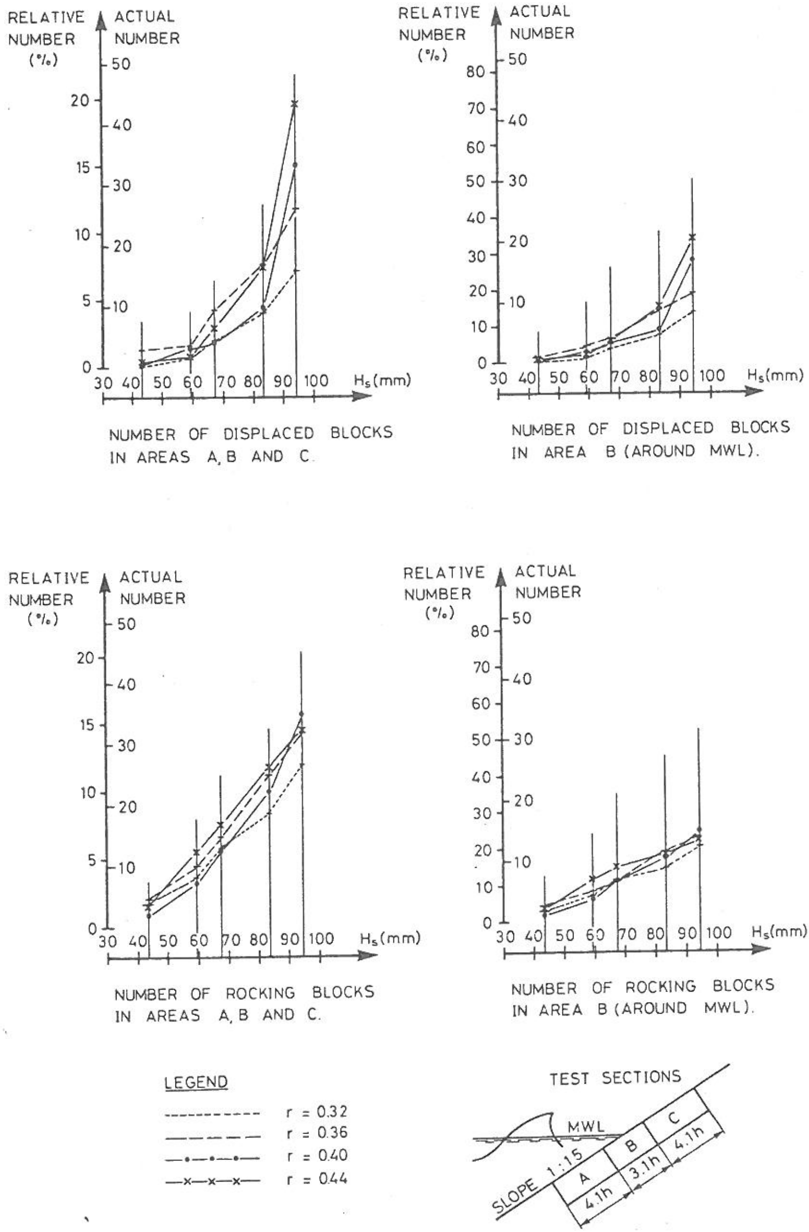


Figure 8. Comparison of hydraulic stability of Dolosse with waist ratios 0.32, 0.36, 0.40, and 0.44.

with large waist thicknesses (Burcharth et al., 1983).

The same trend but more pronounced was found by Scholtz et al. (1982). However, they used regular waves in the experiments such that a comparison cannot be made directly. Brorsen et al. (1974) found that irregular waves of H_s will cause the same degree of damage as regular waves with the height $H \cong 0.8 H_s$.

A comparison of the present results with the results of Scholtz et al. gives $H \cong 0.6 H_s$ for the same damages. An explanation for a part of this discrepancy is probably that Scholtz et al. did not use a technique which allowed underwater inspection of the movements of the armour units. This means that the present tests certainly will show a larger number of moving units (other things equal) and thus a lower stability of the Dolos armour, because all units are kept under observation during the tests.

Moreover, Scholtz et al. used a packing density of 1.00 for the Dolos armour while a range of 0.61-0.70 was used in the tests presented here. The difference should, according to tests in regular waves by Zwamborn et al. (1982), compare to a reduction in wave height of approximately 6% for the lower packing density.

It should also be noticed that damage levels expressed in terms of the relative number of moving units are dependent on the actual number of units in the section under observation, i.e. dependent on the size of the section and the packing density. For example by increasing the packing density from 0.65 to 1.0 the relative number of moving units will decrease by app. 50% but of course only if the actual number of moving units is independent of the total number of units in the section, which is not the case.

A similar comparison of the present results with the results obtained by Brorsen et al. (1974) and Burcharth (1979) for regular waves and Dolos packing densities of 1.0 shows approximately the same relationship $H \cong 0.6 H_s$ as mentioned above. This again is mainly due to the fact that the set-up of these tests did not allow continuous underwater inspections. It is believed that the relationship $H \cong 0.8 H_s$ is the more realistic although based on the tests by Brorsen et al. where underwater inspection was impossible. This is because these tests are a comparative study where exactly the same observation technique was used on both regular and irregular waves and because it is reasonable to assume the same proportionality between the total number of moving units and the observed number of moving units for both regular and irregular wave conditions.

The presented results indicate that in areas of the armour layer where impacts are the dominant loads it is possible to obtain a balance between the hydraulic stability and the structural integrity also for the very large Dolosse of say 40 t or more by increasing the waist ratio. However, because stresses due to static (gravity) forces and flow forces increases more rapidly with the size of the units than stresses due to impact forces it might well be that for the armour layer as a whole the structural integrity cannot be obtained.

The large scatter in the experimental results underlines the need for adoption of more restrictive safety factors than generally used in rubble mound breakwater design. It also supports the idea of a probabilistic approach in the design process (Nielsen et al., 1983).

REFERENCES

Brorsen, M., Burcharth, H.F., Larsen, T. (1974): Stability of Dolos slopes. Proc. 14th ICCE, Copenhagen, 1974.

Burcharth, H.F. (1979). The effect of wave grouping on on-shore structures. Coastal Engineering, 2, 1979, p. 189-199.

Burcharth, H.F. (1981a): A design method for impact loaded slender armour units. ASCE Int. Convention, New York 1981. Laboratoriet for Hydraulik og Havnebygning, Bulletin No. 18, University of Aalborg, Denmark, 1981.

Burcharth, H.F. (1981b): Full-scale dynamic testing og Dolosse to destruction. Coastal Engineering, 4, 1981, p. 229-251.

Burcharth, H.F., Thompson, A.C. (1983): Stability of armour units in oscillatory flow. Proc. Coastal Structures '83, Washington, 1983.

Nielsen, S.R.K., Burcharth, H.F. (1983): Stochastic design of rubble mound breakwaters. Proc. 11th IFIP Conf. on System Modelling and Optimazation, Copenhagen, 1983.

Scholtz, D.J.P., Zwamborn, J.A., van Niekerk, V. (1982): Dolos stability, effect of block density and waist thickness. Proc. 18th ICCE, Cape Town, 1982.

Silva, M.G.A. (1983): On the mechanical strength of cubic armour blocks. Proc. Coastal Structures '83, Washington, 1983.

Zwamborn, J.A., van Niekerk, M. (1982): Additional model tests, Dolos packing density and effect of relatively block density. CSIR Research Report 554, Stellenbosch, 1982.