WIND WAVES REFLECTIONS - A CASE STUDY

J. Rytkönen

Rakenteiden Mekaniikka, Vol 1
No 1 1988, s. 55...65

This study describes some of the wave reflection measurements conducted at the Hydraulic Laboratory of the Helsinki University of Technology. The main goal of this paper is to demonstrate the wave reflection pattern near rough and sloped rubble mound structure. The connections of the study to the harbour design and shore protection are briefly discussed, too.

1 INTRODUCTION

A subject of wind waves reflections is usually considered more to be associated with an open shore line than in conjunction of harbour design. In the latter the main importance is often directed to the structure stability problems and general harbour lay-out. Reflections itself, however, forms an essential parameter in breakwater and shore protection design.

In the sheltered harbour area, restricted by vertical wall caissons or seawalls a heavy oscillation phenomenon in a form of standing waves may develop. Inspite of harbour protection measures the directional wave spreading and an occurrence of long waves can lead to an oscillation of an entire harbour basin. This leads to an increase of downtime costs of the port facilities. Moreover heavy reflection pattern within the harbour causes high second order drift forces thus increasing the mooring forces, too.

An use of sloped rubble mound surfaces have been proved to increase the energy dissipation of oncoming waves, thus decreasing the part of wave reflections. Knowing the various parameters affecting wave transmission and reflection a proper design procedure can be carried out.

This paper describes mainly the reflection character of rubble mound shore protection prevention in head seas and in oblique waves. The ideas presented above are demonstrated with an aid of small scale hydraulic model tests.

2 WAVES REFLECTION

When wave front meets a shore line that part of wave energy which does not modify in the process to another form reflects. In the case of porous breakwaters the energies of reflected and transmitted waves depend on the oncoming wave amplitudes as follows:

$$Ea_1^2 = Ea_r^2 + Ea_t^2 + \text{losses} \qquad (1)$$

where Ea_i is oncoming wave energy for one wave amplitude
Ea_r is reflected energy for one wave amplitude
Ea_t is transmissed energy for one wave amplitude.

In a case of impermeable slope or porous construction having a significant width there is no transmission of energy and thus Eq. 1 simplifies to:

$$Ea_i^2 = Ea_r^2 + \text{losses} \qquad (2)$$

The part of reflected wave, ie. the wave dampening efficiency of the structure can be related using a reflection coefficient, R:

$$R = H_r/H_i = a_r/a_i \quad ; \quad 0 < R < 1 \qquad (3)$$

For R = 0 all wave energy transfers to the energy losses and the wave dampening is complete. The value R ˜ 1 can be reached in the case of vertical, smooth and impermeable wall thus a developing wave process is called standing waves, ie. clapotis phenomenon.

The bottom topography and the slope of the bottom in front of the sea wall or rubble construction affect the reflections, too. At steeper bottom slopes the wave breaking causes less flow turbulence than wave collapsing at shore line or wave breaking at constant water depth. This results in a reduction of reflections.

A dependance of wave breaking type on wave reflection characteristics can be pointed out with Iribarren- number, Ir:

$$Ir = \tan \alpha / (H/L_o)^{1/2} \qquad (4)$$

where α is slope inclination
H is wave height
L_o is deep water wave length

Some authors use the sk. 'surf similarity parameter, ' instead of Ir- number.

The roughness and the porosity of the slope of the shore line affect also the reflection intensity. For smooth slopes the reflection coefficient is greater than for rough slopes, which is clearly demonstrated in Fig. 1.

Generally R will increase with decreasing Ir- number. However for rough, impermeable slopes the decrease of Ir-number increases the R-value compared to the rough, but permeable slopes.

Wave reflection depeds strongly on the modes of wave run-up and run-down on the slope. When determining the R-value the various features of constructions with wave data should be taken into account. One practical solution then is to use hydraulic model tests where the effect of different pertinent parameters can be properly simulated.

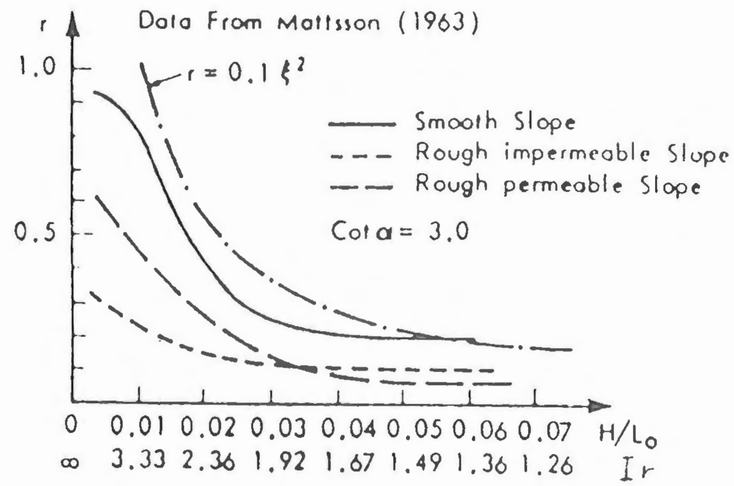

Fig. 1. The effect of roughness and porosity on reflection coefficient /2/.

2 TEST PROCEDURE AND RESULTS

The wave reflection measurements were conducted in a big flow/wave flume of the Hydraulic Laboratory of the Helsinki University of Technology. The test arrangement is shown in Fig.2.

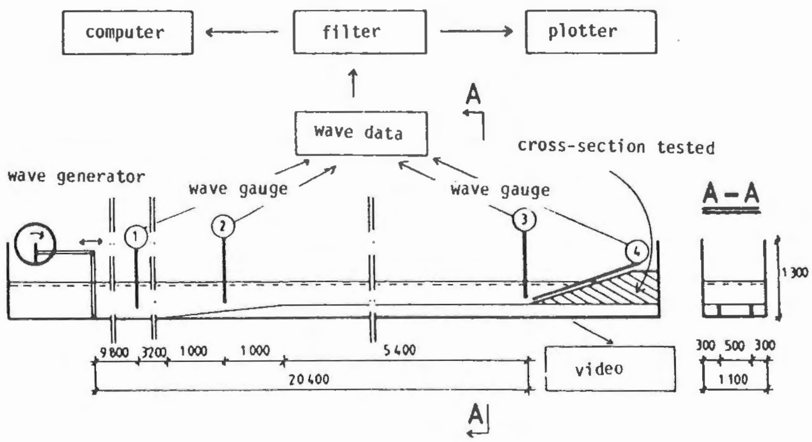

Fig. 2. Test arrangement.

The model scale used was 1 to 15. Regular waves with full scale periods 5 up to 10 seconds were simulated in 4 and 5 meter water depth in front of the rubble slope. The slope was constructed using 0.92 ton cubical blocks in full scale placed both randomly and regularily each by each. The angles of slope inclination tested were 1 to 3 and 1 to 2. Two angles between wave front and shore line were simulated, ie. 0 and 22.5 degrees. The former value holds in the case in head seas condition. Fig.3 represents the cross-section type tested.

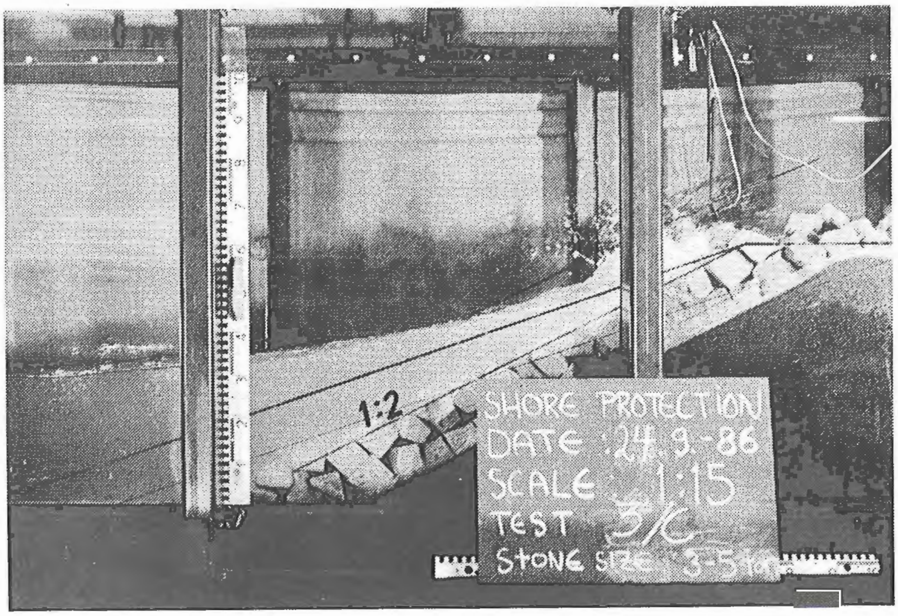

Fig. 3. Cross-section of tested construction.

The results of measurements are shown in Fig. 4 where the reflection coefficient is presented as a function of Ir-number. The lines are drawn using linear regression equation of form:

$$R = a + bIr \qquad (5)$$

The evaluated coefficients of fitted lines 1 and 2 are shown in Table 1.

cross-section	a	b	r
normal	-1.760E-02	5.900E-02	0.920
oblig.	-1.287E-03	2.621E-02	0.947

Table 1. Regression coefficient of linear form.

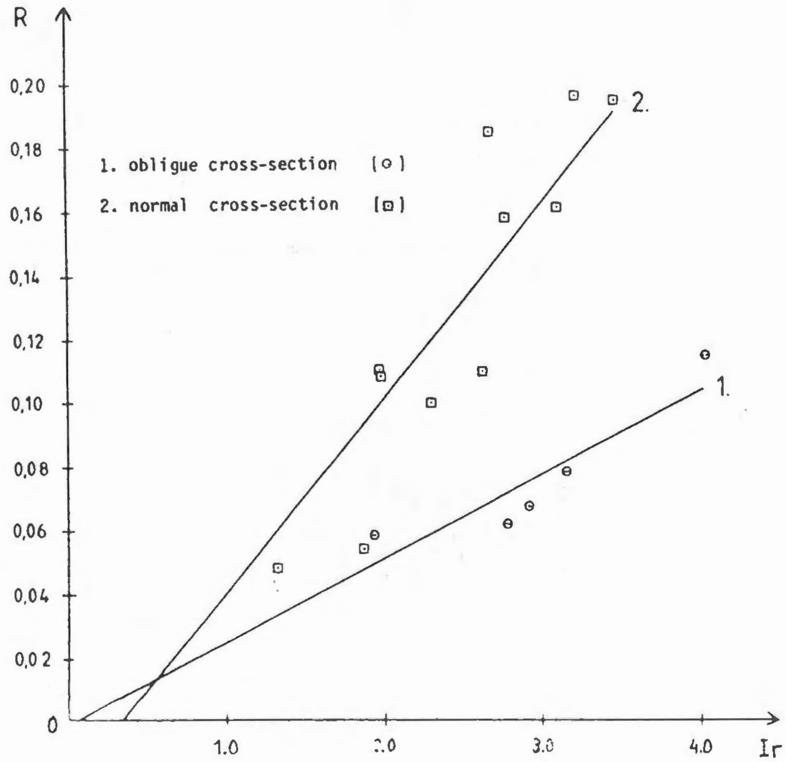

Fig. 4. Reflection coefficient as a function of Ir-number.

An increase of Ir-number increases linearly the magnitude of R-coefficient. This confirms the ideas of the reflection character presented in Ref./4/.

Measured maximum reflection coefficients are only up to 0.20 mainly due to a rough surface of rubble mound prevention, thus indicating high energy losses.

For the oblique waves attacking the rubble slope(line 1)measured R-coefficients are considerable smaller. When the angle between wave front and shore line increases from 0 to 90 degrees the part of reflected wave energy decreases. As a lowest limit we can imagine the case of 90 degrees when the shore line is parallel to the oncoming waves, thus R-coefficinet would practically be zero.

The reflection coefficient as a function of water depth versus deep water wave length is shown in Fig. 5.

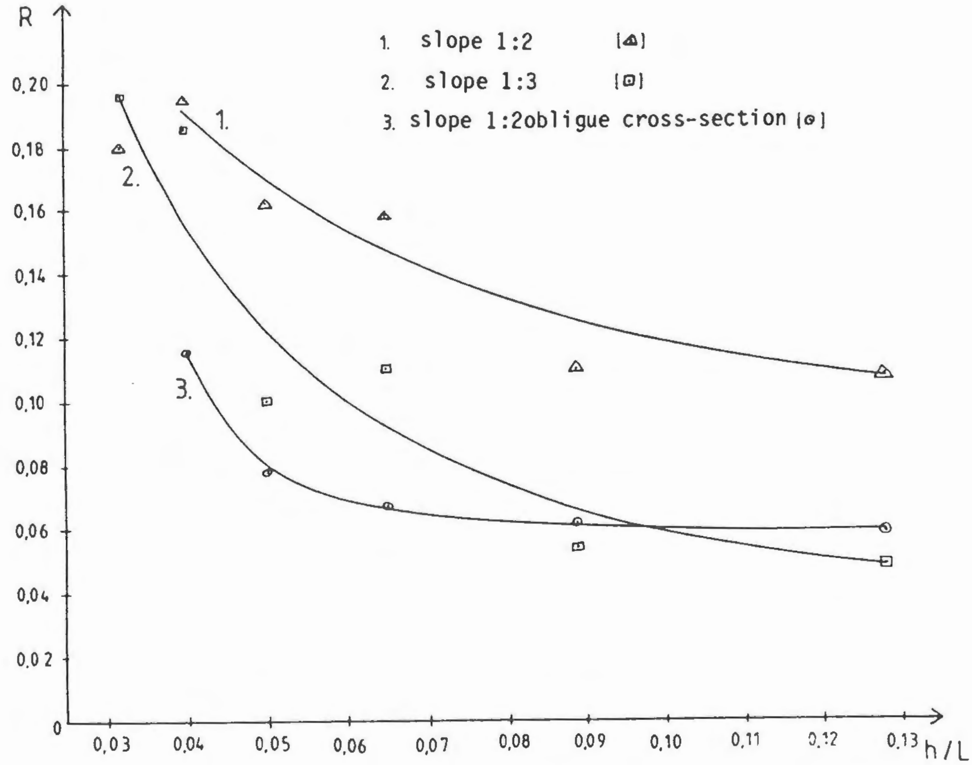

Fig. 5. Reflection coefficient as a function of water depth versus deep water wave length.

This figure shows the effect of slope inclination on reflected energy. Reflection rate is higher for steeper slopes which support the conclusion already presented. The maximum value of R for 1:2 and 1:3 slopes shows over 50 percentage higher value for 1:2 slope. Having constant wave length a decrease of water depth means an increase of reflection coefficient.

In the case of oblique waves the reflection coefficient is almost constant for h/l> 0.06. For longer waves ie. for greater wave periods, however, a considerable increase of reflection coefficient is noted.

A comparison between the measured reflections and the data of Ref./2/ for the slope 1:3 is shown in Fig. 6.

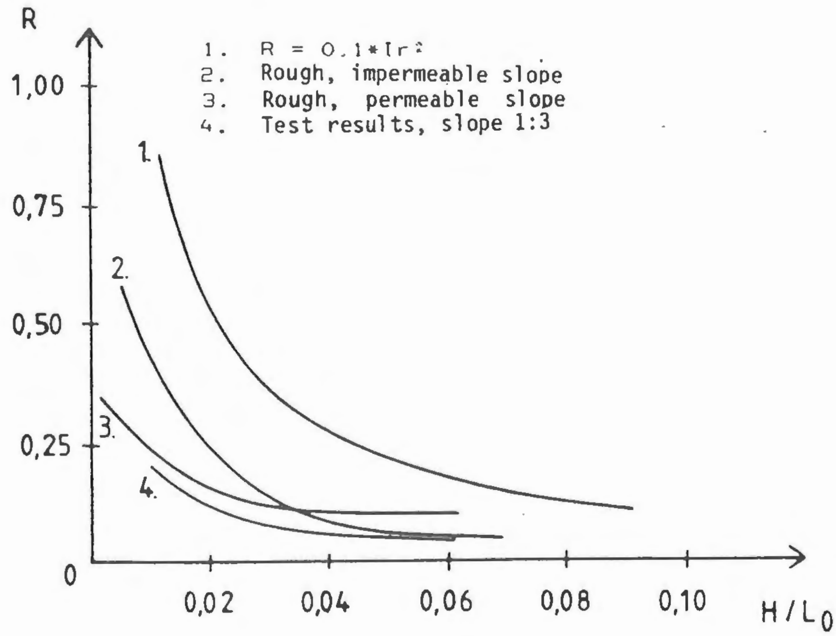

Fig. 6. Measured reflections compared to the literature data.

For shorter waves the measured values agree well with the reflection coefficient of Ref./2/ both for rough and permeable slopes.

However the measured values(line 4) seem to give generally lower R-values which indicates a higher rate of slope roughness and thus higher energy dissipation. Indeed the curves 2 and 3 represent more the rip-rap type slope protection while the curve 4 was found for 0.92 tons cubical blocks. The curve 1 is based on measurements carried out with smooth slopes(Battjes, 1974), thus giving very high reflected wave heights, especially for longer(h/L_o <0.05)waves.

4 CONCLUSIONS

One essential parameter describing the wave - structure interaction process ie. reflection, is presented.

Knowing the various parameters affecting the reflected wave energy the various shore preventions and breakwater constructions can be properly designed.

The following conclusions can be drawn from the reflection measurements presented above:

- The effect of wave period on wave reflections is of great importance when evaluating a suitable slope inclination of shore protection and harbour design. This conclusion holds also for the importance of roughness and permeability character of construction.

- A decrease of water depth increases the magnitude of reflection coefficient. An increase of wave length will increase the reflected part of wave energy.

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LIST OF SYMBOLS

a	amplitude
a, b	parameters
r	correlation coefficient
R	reflection -"-
H_i	incident wave height
H_R	reflected wave height
I_r	Iribarren number
α	slope inclination
L_o	deep water wave length
π	angle between shore line and wave front
h	water depth