CHAPTER 55

THE STABILITY OF RUBBLE MOUND BREAKWATERS AGAINST IRREGULAR WAVES

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INTRODUCTION

Through extensive model tests with rubble mound breakwaters conducted in many laboratories in recent years design criteria and stability data have been collected. To our knowledge such data have been based on tests with regular waves only. It has been more or less accepted that the destructive effect of a train of regular waves corresponds to a confused sea with a significant wave height equal to the height of the regular waves.

At the River and Harbour Research Laboratory at the Technical University of Norway a new wave channel has been equipped with a programmed wave generator which can produce irregular waves with any wanted wave spectrum.

This paper deals with model tests of the stability of rubble mound breakwaters against irregular waves as compared with regular waves.

THE WAVE CHANNEL

The wave channel is shown on Fig. 1. The channel is approximately 78 m long and 3.8 m wide, and the tests were run with a water depth of 1.0 m.

The wave generator consists in principle of a wave paddle operated by two hydraulic pistons, the movements of which are controlled by an electric signal from a sine-wave generator (regular waves) or a magnetic tape (irregular waves).

For use in three-dimensional tests with breakwater heads the test end of the channel is formed as a diffraction chamber into which reflections from a skew model is directed and absorbed.

For a general description of the channel the wind generating system must be mentioned; a 100 HP fan which can produce wind with a maximum velocity of 10 m/sec. Wind was not used in the described tests.

WAVE SPECTRA

Aside from sinusoidal waves irregular waves with two different spectra were used. (Fig. 2).

The B-spectrum is based on waves measured by a pressure activated wave gauge at the site of Berlevåg, exposed to waves from the Barents Sea.

The N-spectrum was designed to give a theoretical Neumann-spectrum.

The two spectra shown are the smoothed spectra based on recordings of 400 successive waves in the channel.

For a further illustration of the waves in the two spectra are on Fig. 3 and 4 shown scatter diagrams of wave heights and periods for 400 consecutive waves for both wave spectra as recorded in the wave channel. On Fig. 5 are shown examples of wave records in the channel. The recorded B-waves seem to include more wave groups than the N-spectrum.
On Fig. 6 is shown a sample of the pressure wave record from Berlevåg, on which the B-spectrum is based. A comparison of the B-waves and the pressure record from Berlevåg indicate that the wave group distribution seems to have been fairly well reproduced in the wave channel.

During the tests the wave height was increased in steps until failure in the armour layer. The stroke amplitude of the wave paddle, and hence the wave height, is controlled by the voltage reference signal from the magnetic tape and is easily varied by varying the amplification of the reference signal. The wave period distribution is determined by the taped program and the speed of the magnetic recorder and is fixed.

The energy in the model power spectrum will thus increase for all frequencies as indicated on Fig. 7 instead of an increase of energy with decreasing frequencies as will occur within a wave generating area in the nature.

BREAKWATER MODEL

The model was positioned adjacent to one wall in the wave channel as shown of Fig. 8. In order to obtain symmetrical reflections in the channel a dummy was constructed along the opposite wall of the channel. The rate of secondary reflected waves in the channel was insignificant.

The width of the model was 60 cm. The model cross section is shown on Fig. 9. Tests were done with a breakwater slope of

1:1.25 and 1.5. The model was non-overtopped for all waves occurring.

The water depth in front of the breakwater, 1.0 meter, gave a relative depth, d/L, sufficient to prevent waves from breaking due to shoaling.

The armour layer consisted of stones with weights in the range of 250-310 g, mean weight of 280 g and specific weight γ = 2.7 g/cm3. (Class A).

On the back side of the model and on the front side below -40 cm below still water level (SWL) the armour layer consisted of stones with approximately the same size as the above described Class A stones, but greater deviations from the mean weight were tolerated. No movements of stones in the Class B armour were observed during the tests.

TEST RESULTS

Stability tests were done for two different breakwater slope angles, cot α = 1.25 and 1.5, and for both slopes tests were run with two different test periods per wave step, 15 and 60 min.

In the following, Fig. 10-14, results from tests with cot α = 1.25 and 15 min. run period are first presented.

On Fig. 10. are shown damage curves for the three types of waves for the slope angle cot α = 1.25. The increase of wave height per wave step was 1 cm for the significant wave height. As shown the damage caused by the N-spectrum was, on the average, less severe than that caused by the B-spectrum.

On Fig. 11 is shown the wave height distribution of the two spectra for 2% damage, also illustrating less effect from the N- than from the B-waves.

On Fig. 12 is shown the wave height distribution of the two spectra for very nearly the same significant wave height; this to illustrate that the wave height distribution H/H_{mean} is very nearly identical for the two spectra.

On Fig. 13 is shown run-up distribution for the same significant wave height for the two spectra. It is seen that for the same wave height distribution, the run-up was less for the N- than for the B-spectrum.

On Fig. 14 is plotted the wave run-up distribution for the two spectra for the waves giving 2% damage and failure. It is seen that the run-up distribution for equal damage is

nearly identical for both wave spectra, and the test results indicate that the stability is correlated to wave run-up rather than to apparent wave height.

On Fig. 15-20 are shown damage curves and run-up distributions for the remaining of the mentioned tests. Also in these tests the wave attack from the N-spectrum seems to be less severe than for the B-spectrum. Again, the damage seems to be well correlated with run-up.

In order to illustrate the scatter in the tests results of run-up observations, Fig. 21 shows observations plotted with the continous line of run-up distribution.

COMMENTS

Most tests with regular waves (a.o. Hedar and Hudson, (1), (2)) are believed to have shown that the wave steepness has little influence on the stability of a breakwater armour layer.

Saville, (3), gives data of run-up versus wave steepness and slope angle on a smooth slope for regular waves. His curves show that for slope angles of 1:1.25 and 1:1.5 the run-up is practically independent of steepness in the range of H_o/L_o = 0.02-0.08.

A relation between stability and run-up, Q vs r, rather than Q vs H, would therefore not be apparent within the ranges of slope angles and wave steepness mentioned above.

The two spectra used in the tests differ considerably with respect to shape, the N-spectrum being wide and the B-spectrum narrow. The scatter diagrams of apparent wave height and -period reflect this difference. (Fig. 3 and 4). It is seen that the short period waves are much steeper in the N- than in the B-spectrum. This will have as a consequence that the waves, due to interference and reflections from the breakwater slope, more often will loose energy in the turbulence of spilling breakers in front of the breakwater in the N- than in the B-spectrum. This process should, finally, result in generally less uprush in the N-spectrum.

Observations of spilling breakers (whitecaps) within a distance of less than approximately 3 m from the breakwater were done. For the 1:1.5 breakwater slope spilling breakers were observed with a mean frequency of once per 22 waves in the N-spectrum and once per 500 waves in the B-spectrum, both at a significant wave height of 20 cm. Along the lenght of the wave basin where the waves practically unaffected by reflections from the model, a distance of approximately 50 m, spilling breakers during an observation period of 15 min. were observed 54 times for the N-waves, whereas no breaker was observed for the B-waves.

It seems therefore reasonable to assume that the higher steepness of the N-waves compared to the B-waves is at least partially responsible for the observed shorter uprush of the N-waves.

CONCLUSIONS

The described tests are few and have been run for conditions which are limited as compared with the range of conditions to be handled in practice.

In consideration of the few tests with the seemingly unavoidable scatter inherent in stability tests, conclusions are as follows:

The tests have indicated a relation between stability and run-up rather than apparent wave height, the run-up being a function of the spectrum.
The spectrum with the highest run-up was observed to have the lowest number of whitecaps in front of the breakwater.

As one could expect, there does not seem to exist one single relation which describes the effect of regular waves compared with irregular waves valid for all shapes of wave spectra.
The substitution in model tests on breakwater stability of a confused sea with a wave train of significant waves is not a safe procedure for all wave spectra.

The test results point out a need for further investigation of run-up distribution for various spectra and reflection conditions. However, for the design of a breakwater armour layer on a particular location, the spectrum of the waves attacking the structure will be determined by a great number of factors specific for the local conditions; typical wind systems, fetch dimensions, bottom topography, reflections from the coast etc. The test results can therefore be said to have given some new information about factors relevant for the stability, however of a nature which still calls for model tests and in particular model tests with irregular waves.

REFERENCES

Hedar, P. A. (1960) "Stability of Rock-Fill Breakwaters". Akademiförlaget-Gumperts, Göteborg, Sweden.

Hydson, R. Y. (1958) "Design of Quarry-Stone Cover Layers for Rubble-Mound Breakwaters". Waterways Experiment Station, Research Report No. 2-2.

Saville, T. (1961) Shore Protection, Planning and Design, Beach Erosion Board, Technical Memorandum No. 4.

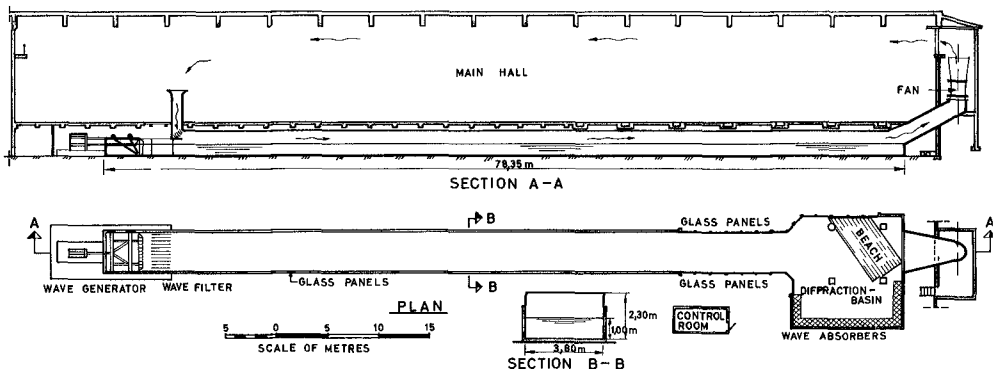

Fig. 1. Wave channel.

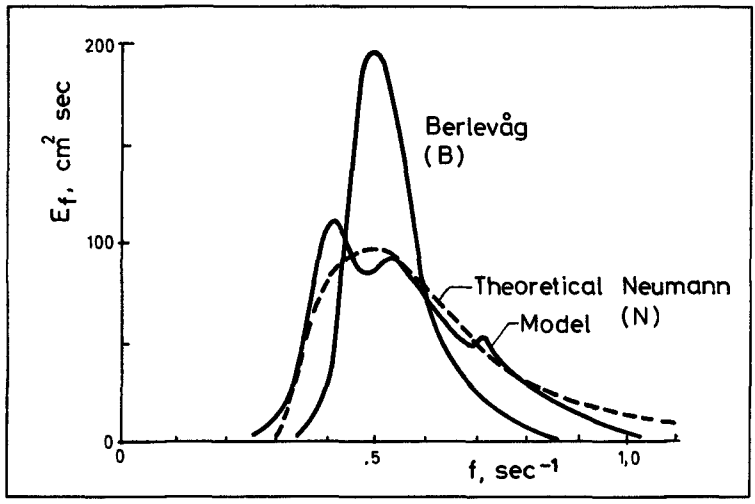

Fig. 2. Model wave spectra. $H_{1/3}$ = 18.5 cm.

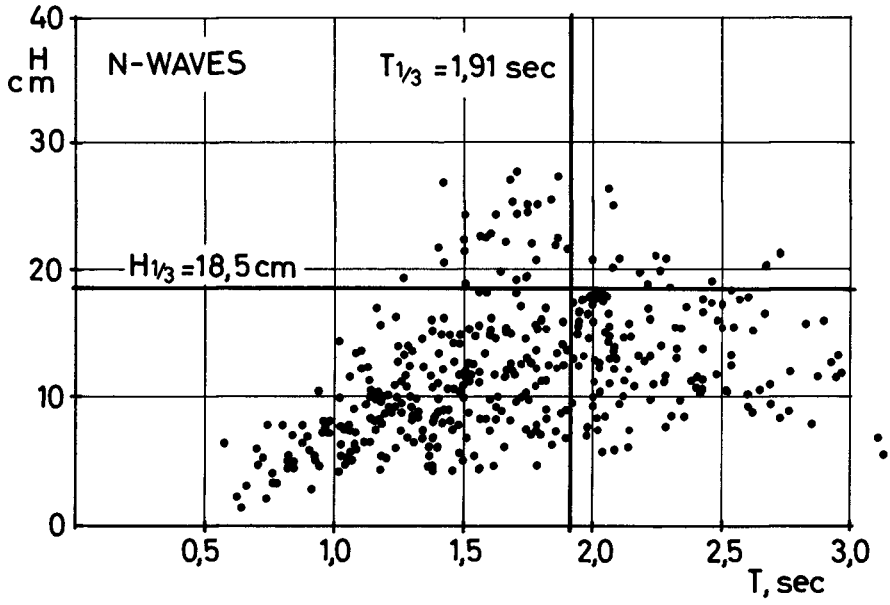

Fig. 3. N-waves. Apparent wave heights and periods.

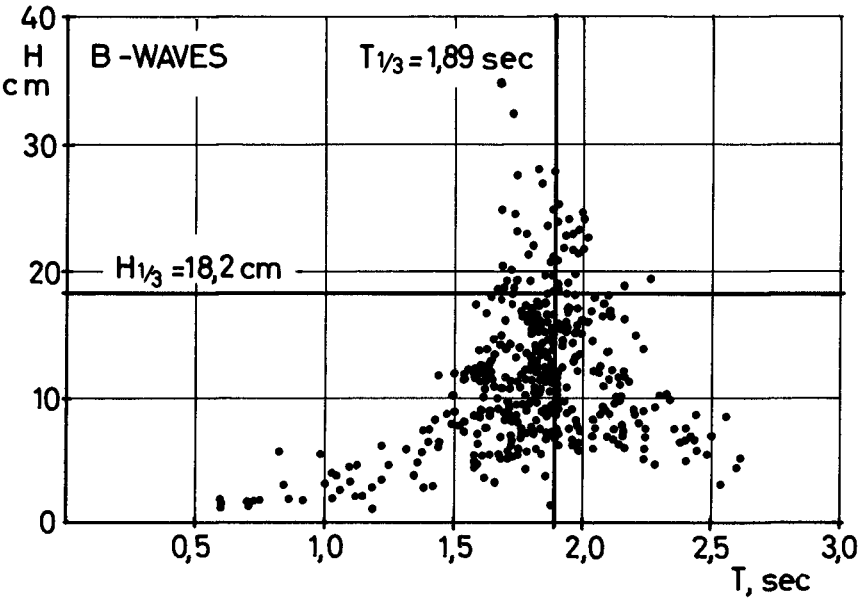

Fig. 4. B-waves. Apparent wave heights and periods.

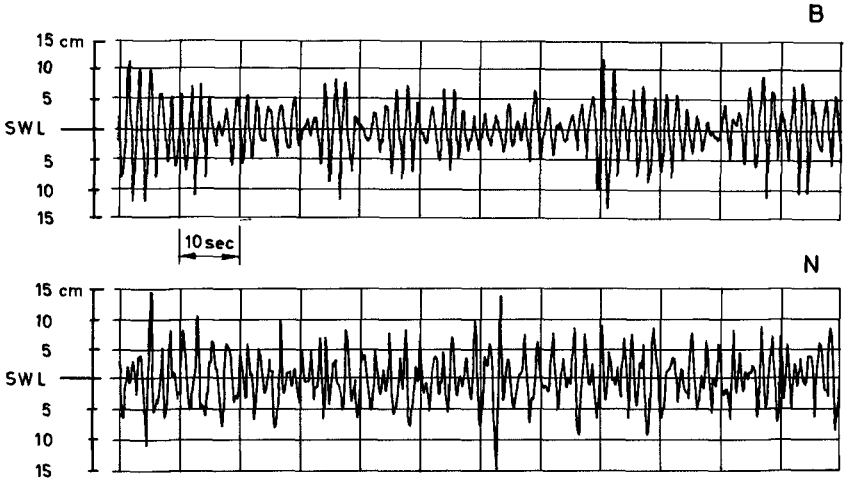

Fig. 5. Example of wave records, B- and N-waves. $H_{1/3}$ = 18 cm.

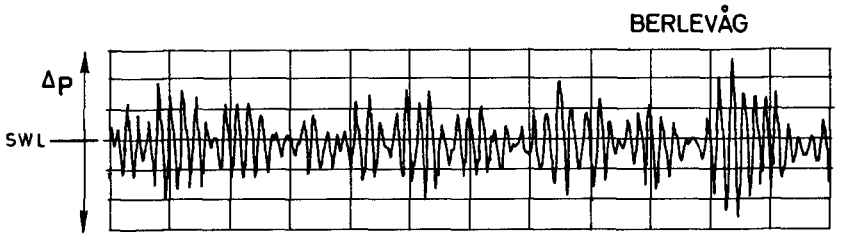

Fig. 6. Example of pressure gauge record from Berlevåg.

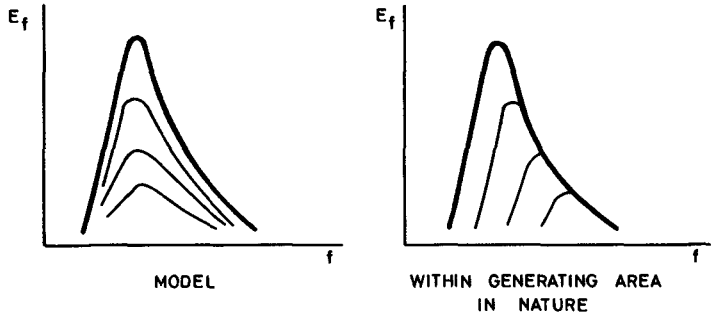

Fig. 7. Spectra for increments in wave height.

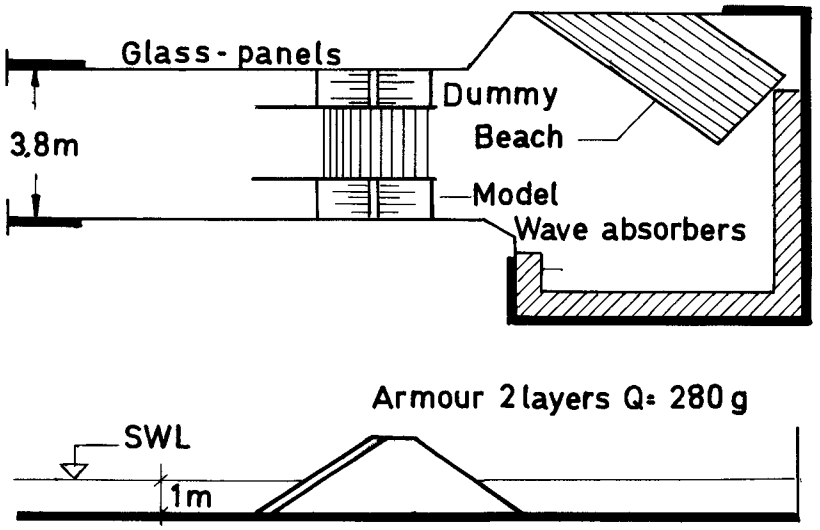

Fig. 8. Wave basin, test section.

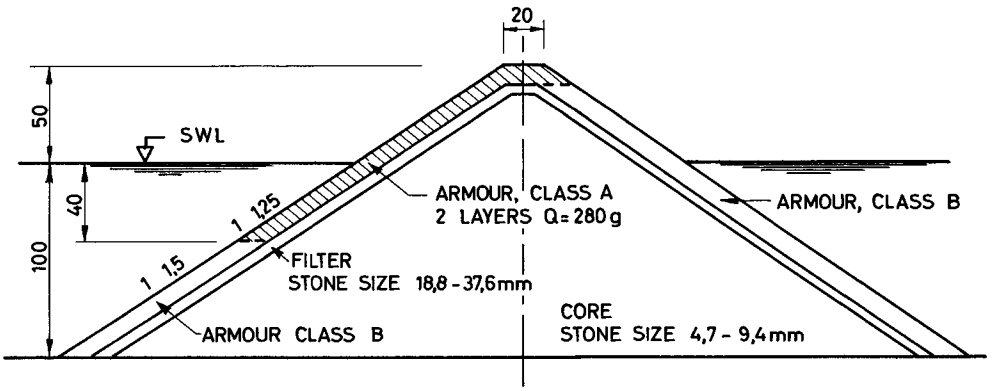

Fig. 9. Cross section of model.

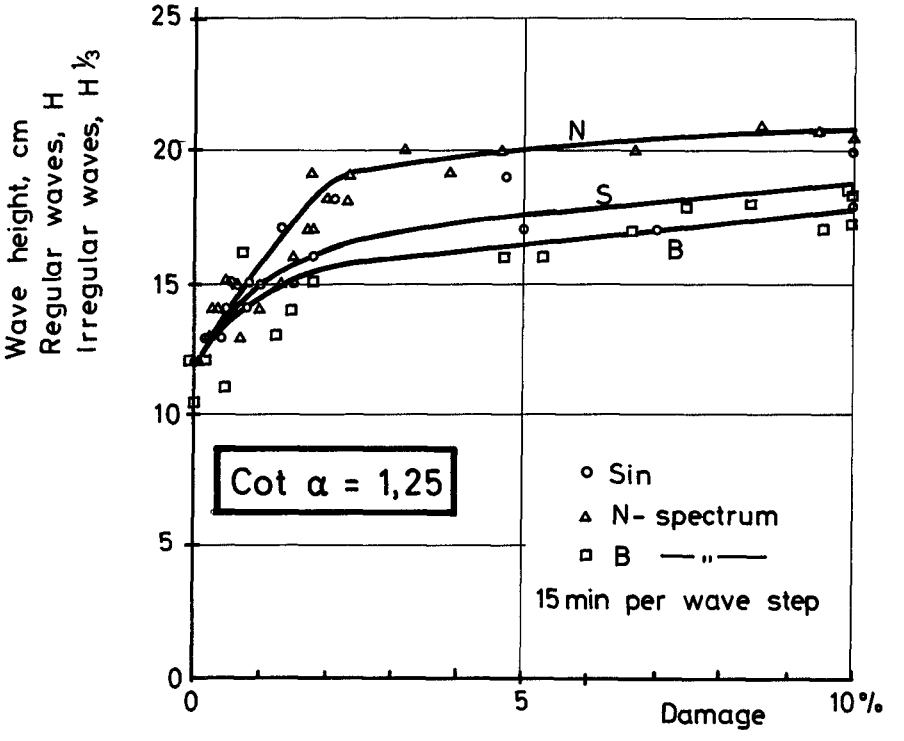

Fig. 10. Damage curves.

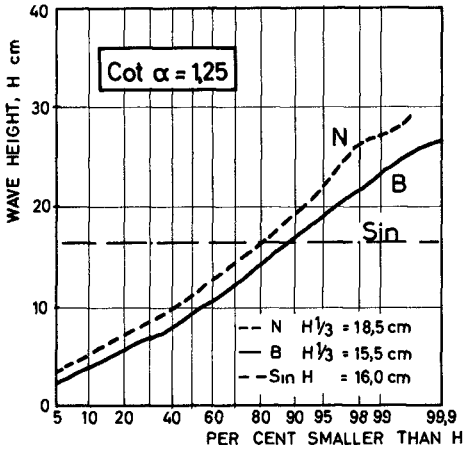

Fig. 11. Wave height distribution 2% damage

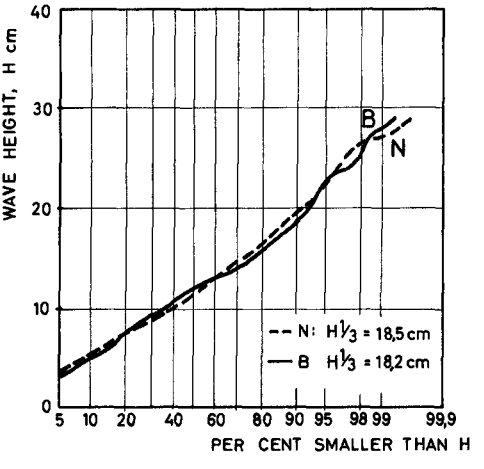

Fig. 12. Wave height distribution of B- and N-spectrum for equal $H_{1/3}$.

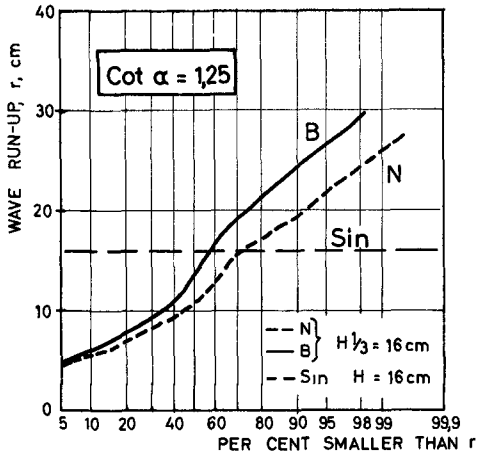

Fig. 13. Wave run-up distribution for equal wave height.
H and $H_{1/3}$ = 16 cm

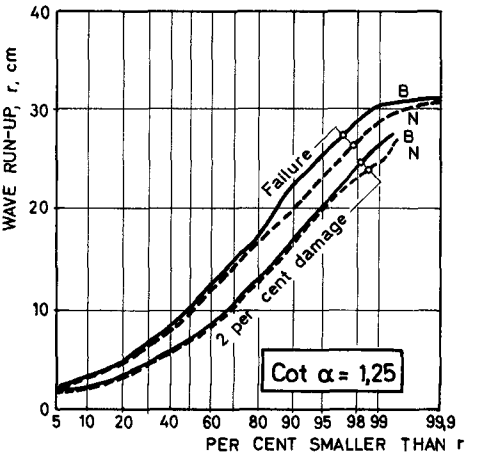

Fig. 14. Run-up distribution for equal damage.
15 min per wave step

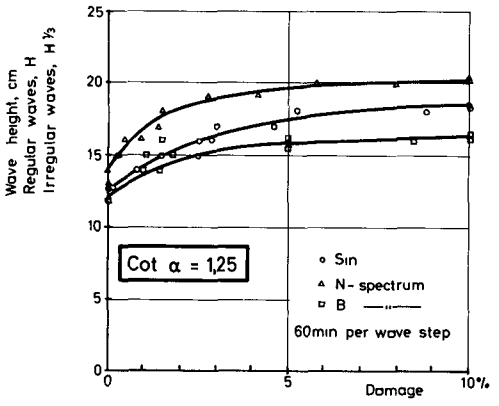

Fig. 15. Damage curves.

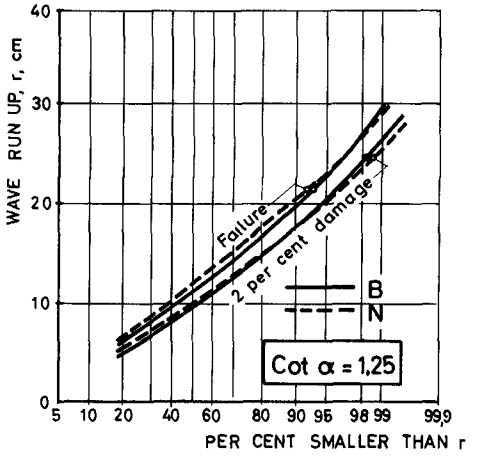

Fig. 16. Run-up distribution for equal damage.
60 min per wave step

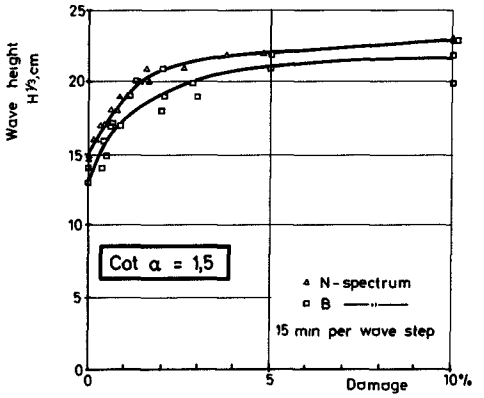

Fig. 17. Damage curves.

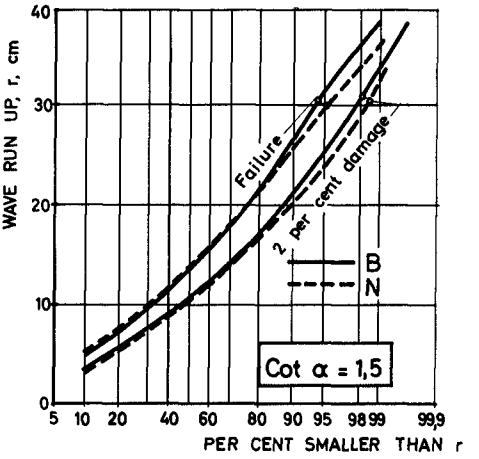

Fig. 18. Run-up distribution for equal damage
15 min per wave step

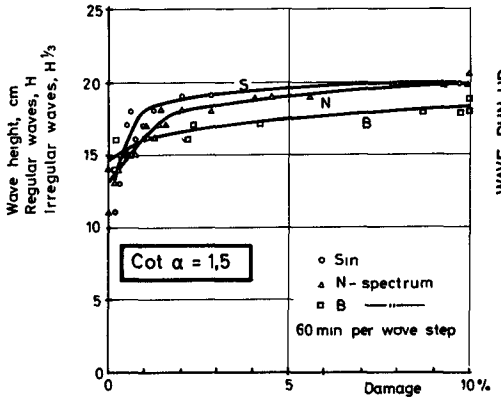

Fig. 19. Damage curves.

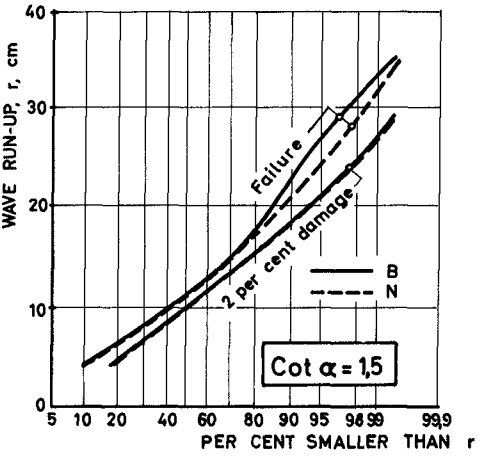

Fig. 20. Run-up distribution for equal damage
60 min per wave step

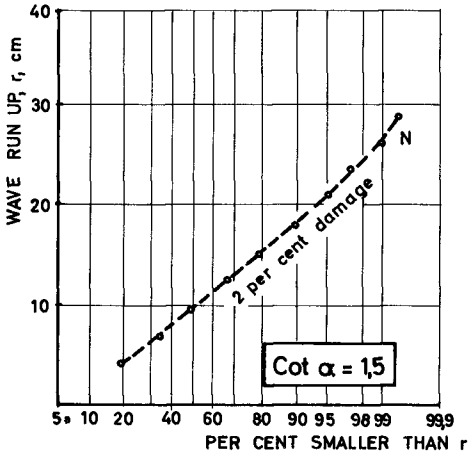

Fig. 21. Scatter in run-up observations.