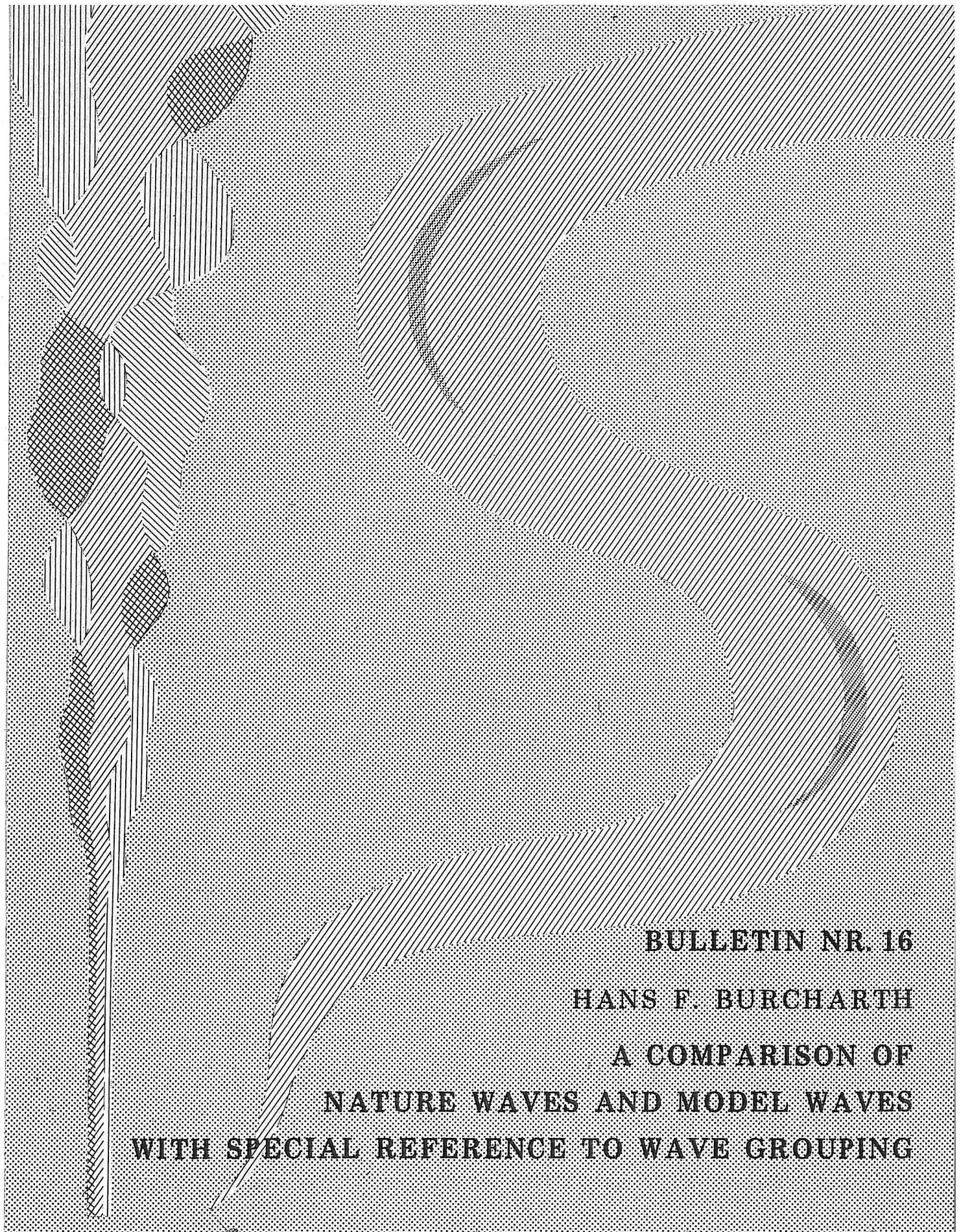
A Comparison of Nature Waves and Model Waves with Special Reference to Wave Grouping

Burcharth, Hans F.

Publication date:
1980

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



BULLETIN NR. 16

HANS F. BURCHARTH

A COMPARISON OF NATURE WAVES AND MODEL WAVES WITH SPECIAL REFERENCE TO WAVE GROUPING

AALBORG UNIVERSITETSCENTER
LABORATORIET FOR HYDRAULIK OG HAVNEBYGNING
SOHNGARDSHOLMSVEJ 57 DK-9000 AALBORG DANMARK

INSTITUTE OF CIVIL ENGINEERING
AALBORG UNIVERSITY
Sohngårdsholmsvej 57 DK-9000 Aalborg DENMARK TEL (08) 142333

Hans F. Burcharth

A COMPARISON OF NATURE WAVES AND MODEL WAVES WITH SPECIAL REFERENCE TO WAVE GROUPING

APRIL 1980

(presented at the 17th International Conference on Coastal Engineering, 1980)

CONTENTS

A COMPARISON OF NATURE WAVES AND MODEL WAVES WITH SPECIAL REFERENCE TO WAVE GROUPING

by

Hans F. Burcharth*

1. ABSTRACT

This paper represents a comparative analysis of the occurrence of wave grouping in field storm waves and laboratory waves with similar power spectra and wave height distribution.

Two wave patterns - runs of waves and jumps in wave heights - which have significant influence on the impact on coastal structures were included in the analysis of storm wave records off the coasts of Cornwall, U.K. and Jutland, Denmark. Two different laboratory wave generator systems, based on random phase distribution of component waves, were used. Within the limitations given by the relatively small number of analysed records it is shown that wave group statistics can be satisfactorily reproduced by random phase generators that are not based on a limited number of component waves, but for example based on filtering of white noise. It is also shown that the statistics of large waves and wave groups containing large waves depend on whether the waves are defined from zero-upcrossings or zero-downcrossings. Although very similar seas were chosen for the analysis it was found that significant differences in the wave group statistics from the two locations existed. Also a considerable scatter in the wave group statistics throughout the storms was found.

---

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

2. INTRODUCTION

Very few quantitative data are available on the differences in stochastic nature of wave groups in model and prototype wave records. This in spite of the fact that it has been shown by authors like Johnson et al (1978) and Burcharth (1977), that certain sequences of waves - or wave groups - are important to the impact of waves on structures. For example, the stability of rubble mound breakwaters and also run-up are affected by wave grouping. It is therefore important that the statistics of wave grouping in model waves are the same as those in nature.

It may be argued that a safe method in model testing is a direct reproduction af recorded natural wave trains, but accepting this statement we are left with the problem of selecting the typical or say critical records, especially when the number of available records is limited. This is so because very often there is a considerable scatter in the wave group statistics throughout storms on a given location. Also, it is not possible to make a statistical analysis of any impact from waves if the model waves are reproduced - and maybe repeated - from a time limited wave record. This problem can, however, be overcome if the phase spectrum can be found and the model waves reproduced accordingly, for example as done by Funke et al. (1980). But to get it right, we need a good deal of knowledge and understanding of the variation of the phase spectrum - which we normally do not have. If, however, we are so lucky that a further analysis shows that the phase spectra do not vary too much during storms on a given location the method may be useful.

Another problem is that very few laboratories have facilities for a direct reproduction of natural wave trains or a reproduction based on a given phase spectrum. Most laboratories use wave generators which can reproduce waves in accordance with the shape of any power spectrum, but with phases of component waves more or less equally distributed.

The question is, therefore, can these random phase wave generators be used without introducing too big errors in the many cases where wave grouping has a significant influence on the impact from waves?
In order to answer this question a comparative study of wave groups in field waves and laboratory waves was performed.

3. METHOD

3.1 Wave Patterns

A relevant comparison between wave patterns in field waves and laboratory waves must be related to large waves if we are thinking in terms of wave impact on fixed structures and if we are not dealing with fatique problems. Runs of large waves were included in the study because it has been demonstrated by Johnson et al. (1978) that such wave groups are dangerous to armour layer block stability. The definition of a run, which is shown in Fig. 1, is the same as previously used by Goda (1970) and Rye (1974). Only runs of waves bigger than or equal to the significant wave height were considered.

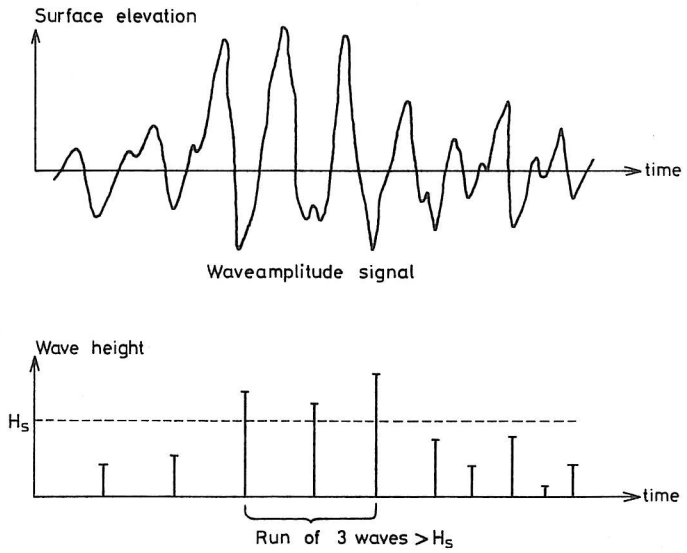


Fig. 1. Definition of runs.

Besides runs of large waves, another dangerous wave pattern in form of big jumps in wave height between successive waves was investigated. The definition of the jump is shown in Fig. 2. It consists of a small wave with the height a constant C times the mean wave height, followed by a large wave with a height bigger than or equal to the significant wave height. Only sizes of jumps corresponding to values of C of 0.5, 0.75 and 1 were considered.

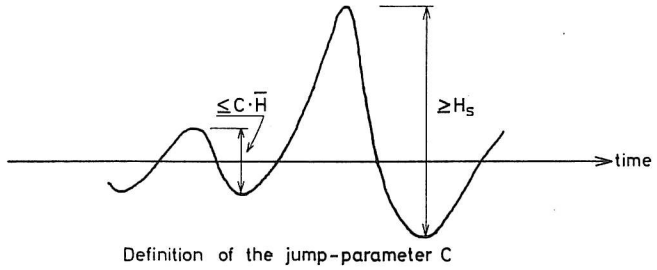


Fig. 2. Definition of jumps.

The jump pattern was included in the analysis because Burcharth (1977) found, from a series of experiments, that of the three wave patterns shown in Fig. 3 (regular waves, runs of waves, and jumps - all containing the same max. waveheight) the jump was the most dangerous to rubble mound breakwater stability and caused the highest run-up on slopes.

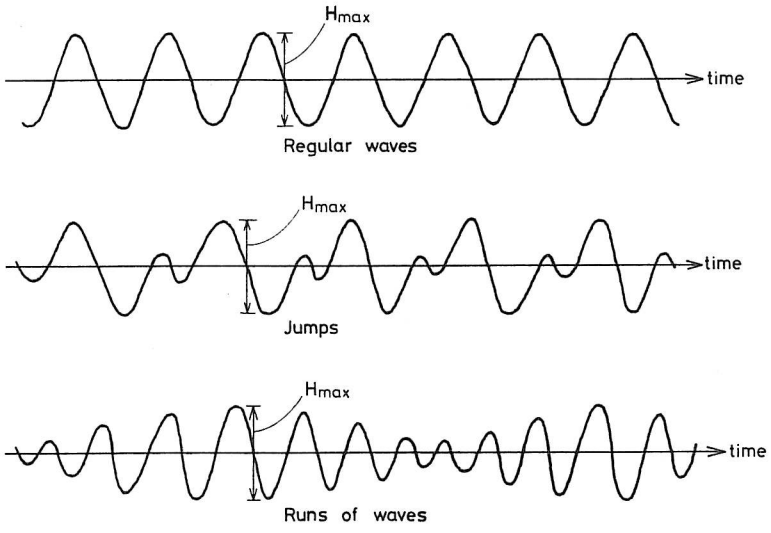


Fig. 3. Wave patterns.

Besides the physical relevance of the two described wave patterns it is important to mention that by including two different patterns in the comparative analysis a very strong proof of idendity of the statistics of wave patterns in general is obtained.

3.2. Field Waves

The basic principle of the study was to analyse the statistics of runs and jumps in real sea and in laboratory waves, both with the same power spectra. The field data were collected from Waverider buoys at two rather exposed locations, see Fig. 4.

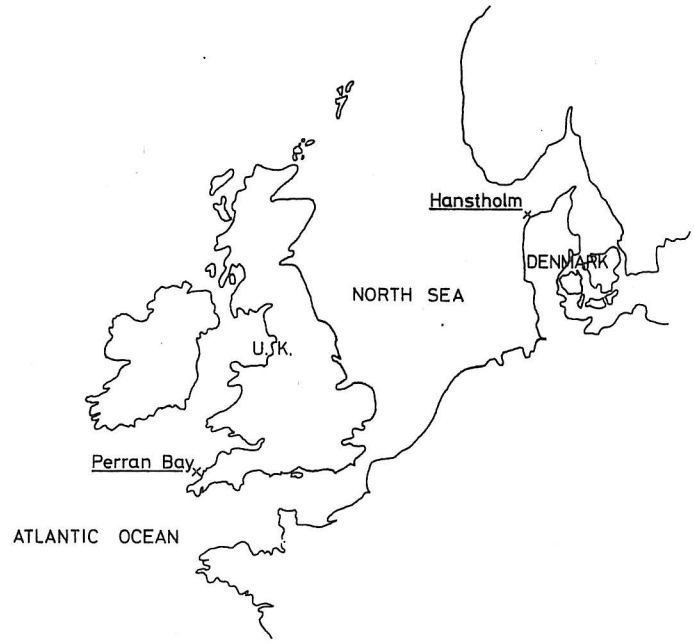


Fig. 4. Location of wave recording sites.

The one is Perran Bay on the north west coast of Cornwall in U.K., which is exposed to Atlantic waves. The other is Hanstholm, the north west corner of Denmark, which is exposed to North Sea waves. The Water depth at the Perran Bay buoy is approximately 22 m and at the Hanstholm buoy 20 m.

Two storms from Perran Bay and one from Hanstholm were analysed. Situations,where no or very little swell was present, were deliberately chosen in order to avoid the complicated

mixture of swell and storm waves. A total of 20 records was analysed. In both places waves were recorded during 20 minutes every 3 or 4 hours. The number of waves in each record varied from 115 to 300.

The variation in significant wave height during the storms is shown in Fig. 5. It is not extreme storm situations, but rather rough sea situations, which set in a couple of times every year.

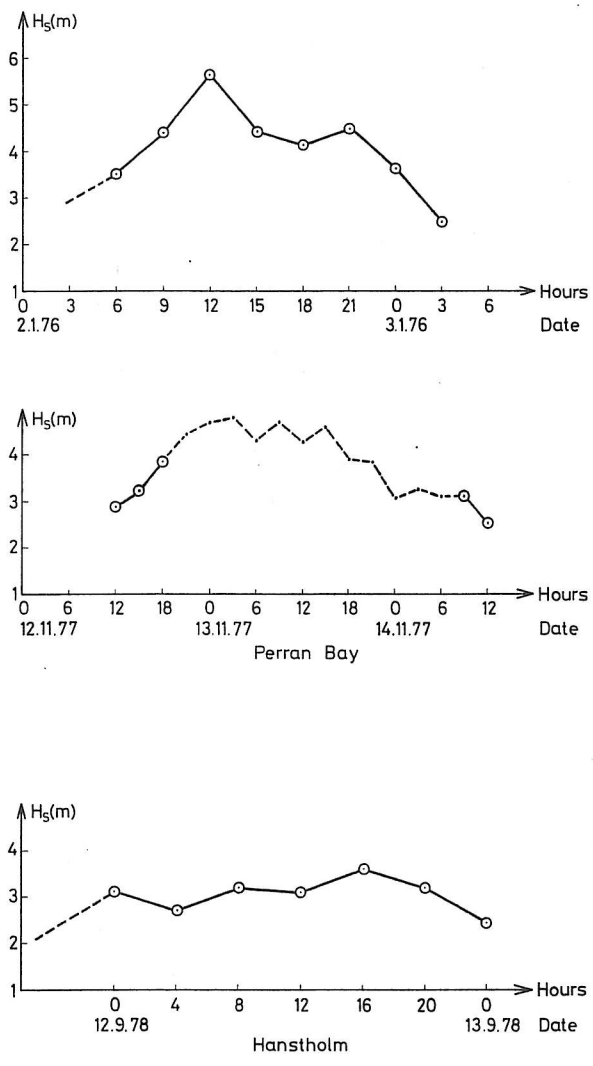


Fig. 5. Histories of analysed storms.

Fig. 6 shows some typical power spectra from two of the storms. It is seen that the spectra vary from fairly wide-band spectra to fairly narrow-band spectra.

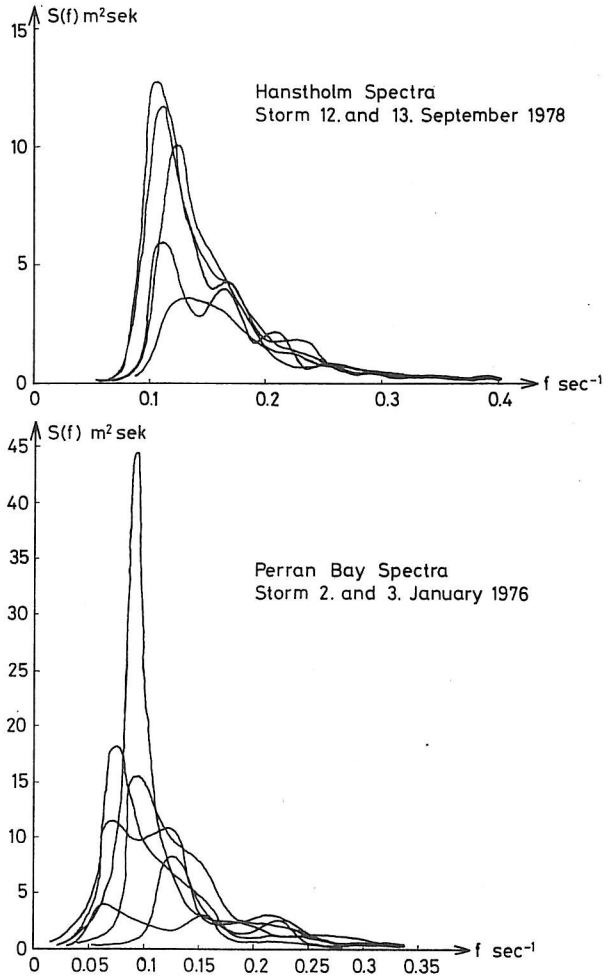


Fig. 6. Typical power spectra from analysed storms.

The wave height distribution in the field records was found to be fairly close to the Rayleigh distribution although the distributions showed a dependence on the applied wave height difinition, see chapter 4.1. The waves on the most energy containing frequencies correspond to waves in the transition between deep-water waves and shallow-water waves.

3.3 Laboratory Waves

Modelwaves with the same power spectra as for the real sea records were generated in two laboratories.

The Perran Bay waves were generated at the Hydraulics Research Station, Wallingford, in a waveflume at a length scale of 1 in 25. The paddle was a hydraulic operated piston type controlled by a synthesizer, which operated on the basis of equally distributed phase angles. The synthesizer which is described in detail in a paper by Fryer et al. (1973) works on the principle of filtering white noise by means of a digital method.

The Hanstholm waves were generated at the Hydraulics Laboratory, Aalborg University, Denmark, in a small wave basin at a length scale of 1 in 70. Also this paddle was a hydraulic operated piston type, which could be controlled in different ways, but for this study the most simple way of generating irregular sea, namely that of adding sinewaves of different frequencies and amplitudes, was deliberately chosen. In order to make it as rough as possible, only 10 different frequencies were used. The phases of the component waves were random and different in each test.

For each field wave record batches of 4 or 5 records were generated in the laboratories. Each laboratory record contained approximately the same number of waves as the corresponding field record. It was found that the wave heights in the lab. waves were Rayleigh distributed and it was checked that the lab. wave spectra corresponded to the field wave spectra.

4. ANALYSIS AND RESULTS

4.1 Influence of Wave Height Definition

In the analysis two different definitions of waves were used, the zero-upcrossing definition and the zero-downcrossing definition, both of which are shown in Fig.7. The zero-downcrossing analysis uses the wave trough and the proceeding wave crest in the definition of a single wave and defines the wave height as the difference between these water levels.

The conventional zero-upcrossing analysis defines the wave height from a wave crest and the following wave trough.Generally it is difficult to say which of the two definitions gives the best representation of the physical conditions, but in cases where - for example - impact from breaking or almost breaking waves is important, the zero-downcrossing definition must be the most relevant.

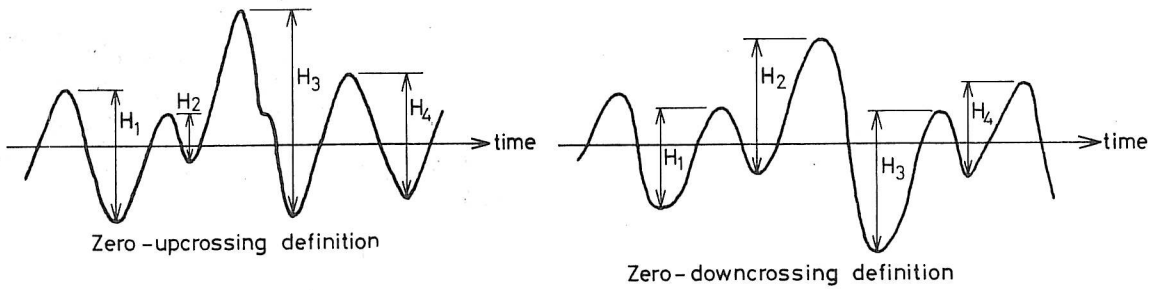


Fig. 7. Definitions of wave height.

The first interesting result that appeared from the analysis was that in the field wave records a zero-upcrossing definition gave significantly more high waves than a zero-downcrossing definition. In the Perran Bay records the upcrossing definition gave on an average 13% more waves bigger than significant wave height, and in the Hanstholm records it was 12%. Fig. 8 shows as an example the wave height distributions in some of the Perran Bay records.

In the lab. wave records no such difference was found. Eight Perran Bay records of typical swell situations were also analysed, and here again there was no difference. So it was only in the field storm wave records that the phenomenon was found, which then might be explained by the asymmetry of the waves caused by the wind. Fig. 9 shows the sort of asymmetry that would lead to differences in wave heights.

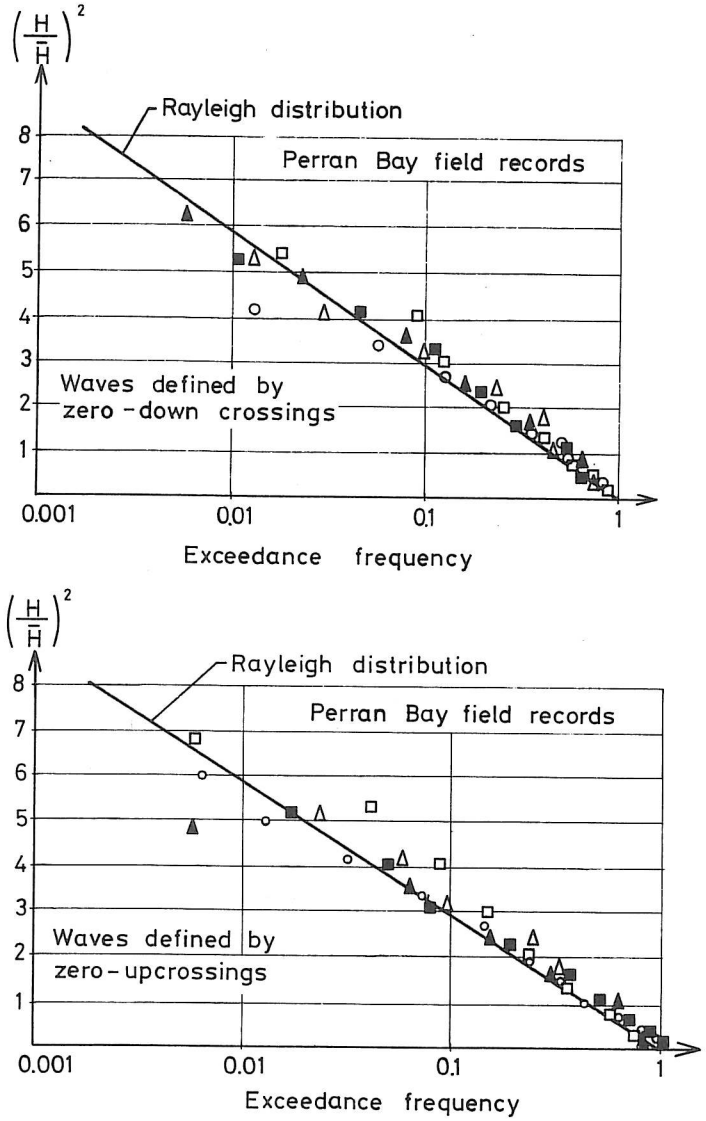


Fig. 8. Example of the influence of wave height definition on the wave height distribution in natural waves.

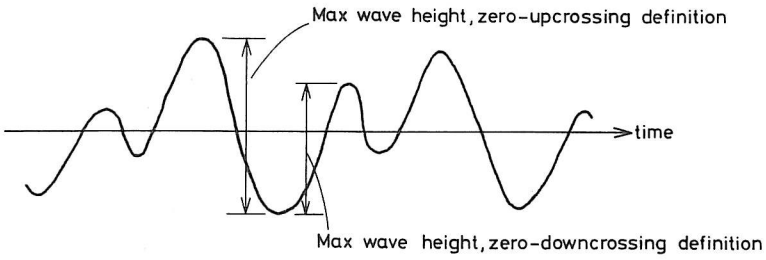


Fig. 9. Influence of zero-crossing definition on wave heights.

Field wave records from other near-shore areas than the two included in this project should be analysed in order to see if the wave definition influences the number of big waves. If it be so, a standard definition must be agreed.

4.2. Wave Grouping Analysis

The results from the comparative analysis of the occurrence of wave grouping in field waves and laboratory waves are shown in Fig. 10 and Fig. 11.

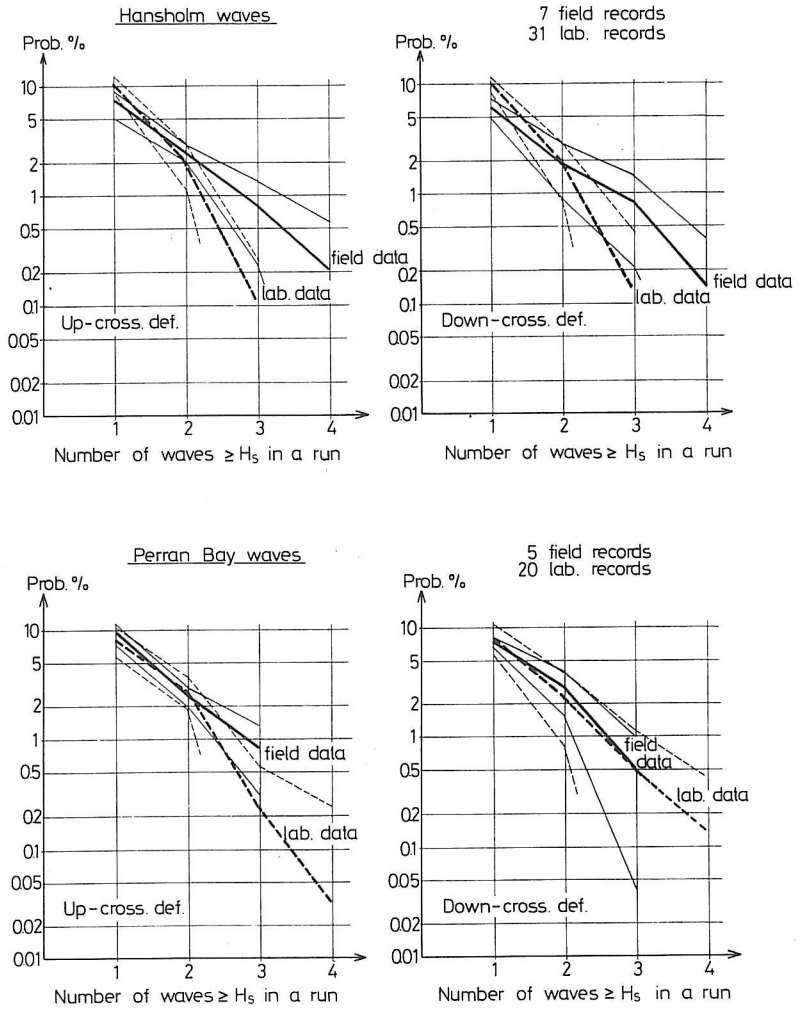


Fig. 10. Probability of runs in field storm wave records and laboratory records with the same power spectra. Graphs are mean values ± standard deviation.

The vertical axes are the absolute probability of the wave patterns, which means that the events are related to the total number of analysed waves in the record. The graphs represent the mean values plus minus the standard deviation.

Fig. lo shows the probabilities of the formation of runs of different lengths. Hanstholm data and Perran Bay data based on both zero-upcrossing and zero-downcrossing wave definition are represented. It is seen that in the case of the Perran Bay waves there is a good agreement between the field wave graphs and the lab. wave graphs if the zero-downcrossing definition is applied.

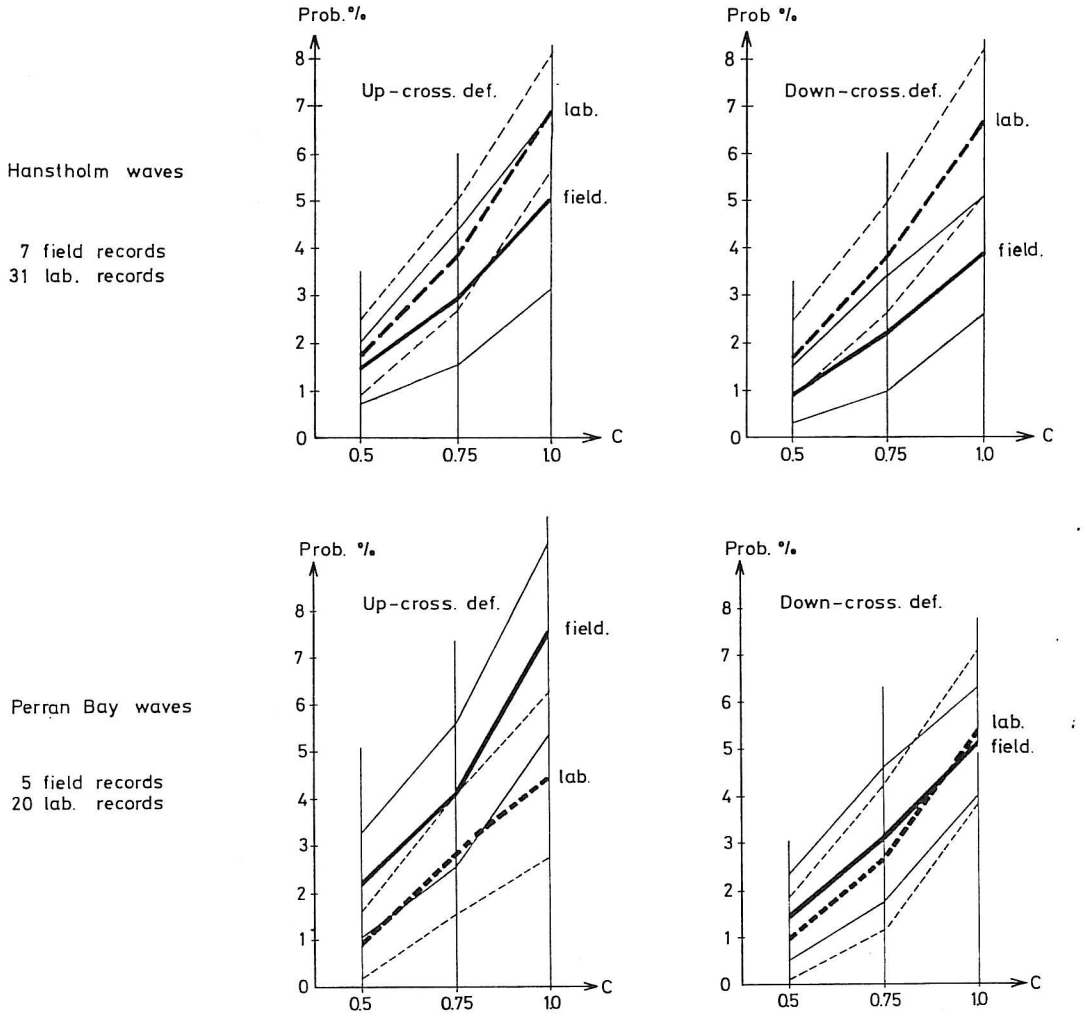


Fig.11. Probability of jumps in field storm wave records and laboratory records with the same power spectra. Graphs are mean values ± standard deviation.

For the Hanstholm waves there is considerable discrepancy between field waves and lab. waves. The number of long runs in the lab. waves is much too small.

Fig. 11 shows the probabilities of the formation of jumps defined by the jump parameter C, see Fig. 2. Small values of C correspond to big jumps in successive wave heights. For the Hanstholm waves there is actually no acceptable agreement between the lab. and the field data results. For the Perran Bay waves, however, it is seen that the agreement is very good if, again, the downcrossing definition is used.

From Fig. 10 and Fig. 11 it is seen that in the Hanstholm case the lab. simulations of both runs and jumps are so bad that it can be concluded - as also expected - that the very simple wave generator used in this case is far from satisfactory, whereas the much more sofisticated generator or synthesizer, used for the Perran Bay waves, seems to be good if the downcrossing definition is applied. The last part of this conclusion must be regarded as a preliminary conclusion since the wave group statistics for the Perran Bay waves and the Hanstholm waves are different (see chapter 4.3) and a reproduction of the Hanstholm waves by means of the more complicated generator has not been tried.

4.3 Variations in The Wave Group Statistics

From the field data graphs in Figures 10 and 11 it is seen that the Perran Bay records contain considerable more jumps and fewer long runs than the Hanstholm records. So the wave-group statistics are different for the two sets of records.

If the group statistics for a single field wave record are compared with the group statistics for the corresponding batch of lab. wave records the agreement is generally not very good. Only approximately half of the field wave results will be well inside mean plus minus standard deviation for lab. wave results.

This is understandable since the group statistics for the field records vary considerably, and since each of the records contains a very limited number of waves. Because of this scatter in the field wave group statistics one has to be very careful if a model test procedure based on a direct reproduction of natural waves is applied. The selection of the wave records is difficult and can only be done properly if based on the analysis of many field records.

4.4 Comparison with Random Theory

From the field wave records it was found, as also reported by Wilson et al. (1972) and Rye (1974), that the formation of runs of big waves is more pronounced than would be expected from a random distribution of the wave height successions. Corresponding to this, fewer jumps than given by random theory were recorded. This is illustrated in Fig. 12 where graphs representing the theoretical distribution for jumps and runs are shown. The graphs are based on the assumption of independence between successive waves and Rayleigh distributed wave heights.

The theoretical expression for the graph representing runs is,

$$P(n) = (1 - P\ [H > H_s])\ P\ [H > H_s]^{n-1}, \qquad (1)$$

where P(n) is the relative probability of the occurrence of a run of n waves that are bigger than H_s, and P $[H > H_s]$ is the probability of occurrence of a wave bigger than H_s, which, in the case of a Rayleigh distribution, is exp(-2).

The expression for the graph representing jumps is,

$$P = P\ [H > H_s]\ P\ [H < C\bar{H}], \qquad (2)$$

where P is the absolute probability of the occurrence of a jump from a wave height smaller than or equal to C times the mean wave height to a wave height bigger than H_s.

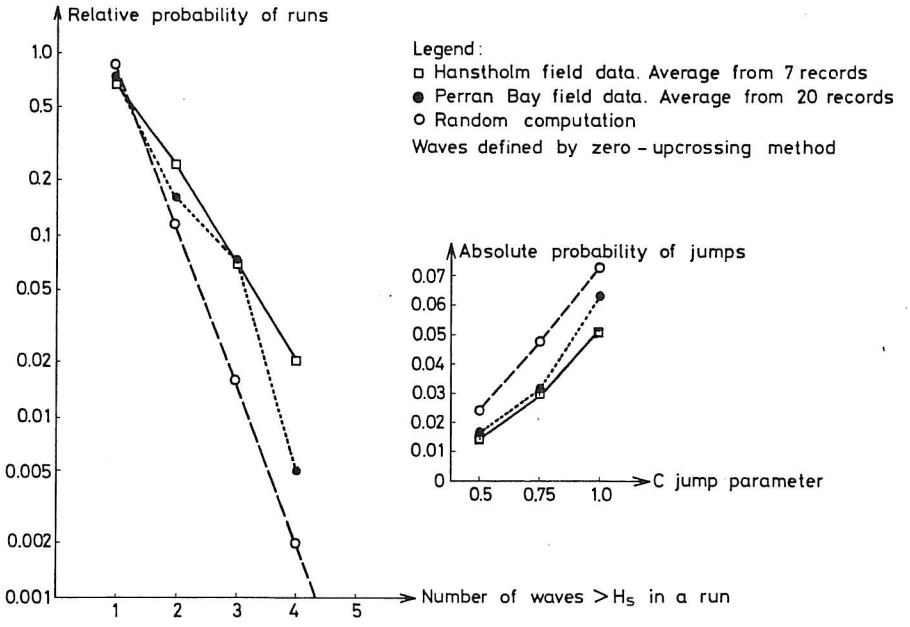


Fig. 12. Comparison of wave group formation with random theory.

Fig. 12 confirms that a correlation between successive wave heights exists. The lab. waves are not shown in the figure, but this conclusion also holds for the Perran Bay model waves.

4.5 Comparison with other Field Wave Records

The statistics of runs in the field waves have been compared with the results presented by Rye (1974). Rye's results are based on 60 storm wave records from a Waverider buoy outside Utsira on the west coast of Norway, where the water depth is approximately 100 m. In Fig. 13 the two sets of results, which both represent the average from many records, are compared. It is seen that the agreement between these averaged data is good.

Rye and other authors found that the formation of runs of large waves tends to be more pronounced for a growing sea than for a decaying sea and that growing seas have more sharply peaked spectra than decaying seas.

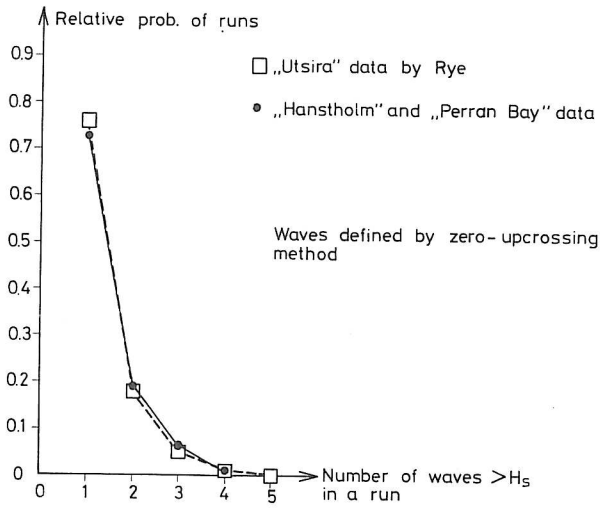


Fig. 13. The avarage probability of occurrence of runs of waves for field data from Utsira and from Hanstholm and Perran Bay

However in the Perran Bay and the Hanstholm data no significant correlation was found between the sea state and the occurrencies of runs and jumps. But as to the spectral peakedness it was found - but only for the Hanstholm records - that there was a correlation between spectral width and sea state, as Rye also did. Many more records are needed, especially from near-shore areas, before a conclusion about the correlation between sea state and groupiness can be made.

5. CONCLUSIONS AND RECOMMENDATIONS

The main conclusion of this study is that if only pure storm waves in near-shore areas are considered, it seems possible to generate laboratory waves with a fairly good reproduction of nature wave trains by using random phase wave generators, but the very simple type of generators based on a limited number of pre-set sine components can not be used. It is important to stress that since the number of analysed records is little, much more work has to be done before a general

conclusion on the generation of wave patterns by means of random phase generators can be made.

It was found that the wave group statistics in the field records from the two locations are different. Further analysis from other near-shore areas could clarify if a general correlation between wave grouping and location exists.

The analysis of field wave records from a given location shows a considerable scatter in the wave group statistics. A model test procedure based on a direct reproduction of natural wave records might therefore imply unsafe results if not based on knowledge about the variations in the wave grouping.

The statistics of high waves in the field records were found to be influenced by the wave height definition. A zero-upcrossing definition gave significantly more high waves than a zero-downcrossing definition. If this holds for other near-shore areas a standard definition must be agreed. But in any case, the zero-downcrossing definition seems to be the most relevant if impacts on structures are considered.

In this study only wave grouping with respect to wave heights has been considered. However, since the dynamics of the waves are very important the wave period or the wave steepness should also be included in the wave grouping analysis. Work in this field has already been done by Cavanie et al. (1976), Ezraty et al. (1977) and Arhan et al. (1978) but more work has to be done before an applicable method is obtained.

6. ACKNOWLEDGEMENTS

Most of the work on which this paper is based was done during the author's stay at the Hydraulics Research Station, Wallingford in 1977 - 78. I would like to thank the Director and his staff for their kind assistance.

7. REFERENCES

Arhan, M., Ezraty, R. Statistical relations between successive wave heights. Oceanologica Acta 1978. Vol. 1, No. 2

Burcharth, H.F. The effect of wave grouping on on-shore structures. Annual Report 1977, Hydraulics Research Station, Wallingford, England and Coastal Engineering, 2 (1979), pp. 189 - 199.

Cavanie, A., Arhan, M., Ezraty, R.A. Statistical relationship between individual heights and periods of storm waves. Proc. Boss'76 Conference, Trondheim, Norway. Vol. II pp. 354 - 360.

Ezraty, R. et al. Comparison with observation at sea of period or height dependent sea state parameters from a theoretical model. Proc. OTC Conference, Houston 1977, Paper No. 2744.

Fryer, D.K., Gilbert, G., Wilkie, M.J. A wave spectrum synthesizer. Journal of Hydraulics Research, 11 (3), 1973.

Funke, E.R., Mansard, E.P.D. On the synthesis of realistic sea states. Proc. Int. Coastal Eng. Conf., 17th, 1980.

Goda, Y. Numerical experiments on wave statistics with spectral simulation. Report of the Port and Harbour Research Institute, Vol. 9, No. 3, 1970, Japan.

Goda, Y. On wave groups. Proc. Boss'76, Trondheim, Norway. Vol. I, pp. 115 - 128.

Johnson, R.R., Ploeg, J. Effects of wave grouping on breakwater stability. Proc. Int. Coastal Eng. Conf., 16th, 1978, Pap. No. 175.

Rye, H. Wave Group formation among storm waves. Proc. Int. Coastal Eng. Conf., 14th, 1974, pp. 164 - 183.

Wilson, J.R., Baird, W.F. A discussion of some measured wave data. Proc. Int. Coastal Eng. Conf., 13th, 1972, pp. 113 - 130.