PORT AND OCEAN ENGINEERING UNDER ARCTIC CONDITIONS
TECHNICAL UNIVERSITY OF NORWAY

LONG-TERM WAVE HEIGHT DISTRIBUTIONS AT SEVEN STATIONS AROUND THE BRITISH ISLES

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ABSTRACT

Instrumental measurements of significant wave height and mean zero up-crossing period are analyzed. The data were obtained from the National Institute of Oceanography, Wormley, England, which made ten-minute records with ship-borne wave recorders every three hours for a period of one year, in locations in the North Atlantic, in the Irish Sea and in the North Sea. Each record yields an estimate of the significant wave height (H_s) and of the mean zero up-crossing period (T_z). The measured joint distributions of H_s and T_z formed the basis for the analysis, from which two conclusions are:

(1) The long-term distribution of H_s appears to be well described by a Weibull function at all of the seven stations.

(2) The long-term distribution of individual wave heights (H), calculated from the joint distribution of H_s and T_z, is approximately exponential at all of the seven stations.

Details can be found in N.I.O. Internal Report A44, July 1970, and in a paper to be published in the "Journal of Coastal Marine Science", Vol. 1, No. 1, January 1972, both with the title given above.

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WINTER WAVES IN THE NORTHERN NORTH SEA AT 57°30'N 3°00'E RECORDED BY M. V. FAMITA

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Waves have been recorded by a Shipborne Wave Recorder (Tucker, 1956) placed on M. V. FAMITA, a Norwegian rescue and meteorological vessel which is stationed in the North Sea in 40 fathoms of water 160 miles east of Peterhead at 57°30'N 3°00'E. The records from one winter's operation, from October 1969 - March 1970 have been analyzed, mainly following the method of analysis developed by Tucker (1961) from theoretical studies by Cartwright and Longuet-Higgins (1956). The method of presentation is that recommended for data for engineering purposes (Draper 1966).

Records were taken at three-hourly intervals, and the analysis yields the following parameters:

(a) H_1 = The sum of the distances of the highest crest and the lowest trough from the mean water level.

(b) H_2 = The sum of the distances of the second highest crest and the second lowest trough from the mean water level.

(c) T_z = The mean zero-crossing period.

(d) T_c = The mean crest period.

From these measured parameters the following parameters have been calculated, after allowing for instrumental response:

(e) H_s = The significant wave height (mean height of the highest one-third of the waves): this is calculated separately from both H_1 and H_2, and an average taken. The relationship between the parameters is $H_1 = f(H_s)$ where f is a factor related to the number of zero-crossings in the records (Tucker 1963). A similar relationship is used for the calculation of H_s from H_2.

(f) $H_{max\ (3\ hours)}$

= The most probable value of the height of the highest wave which occurred in the recording interval (Draper, 1963).

(g) ϵ = The spectral width parameter, which is calculated from T_z and T_c (Tucker, 1961):

$$\epsilon^2 = 1 - (T_c/T_z)^2$$

The results of these measurements are expressed graphically divided into two seasons thus:

Autumn:	October	November	December
Winter:	January	February	March

For each season a graph (Figures 1 & 2) shows the cumulative distribution of significant wave height H_s, and of the most probable value of the height of the highest wave in the recording interval, $H_{max\ (3\ hours)}$.

The distribution of zero-crossing period is given for each season (Figure 3 & 4).

The distribution of the spectral width parameter is given for the six months (Figure 5).

Figure 6 is a scatter diagram relating significant wave height to zero-crossing period, for the six months.

Figure 7 is a persistence diagram for the six months.

Figures 8 & 9 are 'Lifetime' wave height prediction graphs.

Discussion of Results

From Figures 1 & 2 may be determined the proportion of time for which H_s or $H_{max\ (3\ hours)}$ exceed any given height. For example, in the Winter the significant height exceeded 10 feet for 43 percent of the time, which is somewhat rougher than the winter data (1962) from the Sevenstones, off Land's End (Draper and Fricker, 1965). It is considerably rougher than wave conditions at Smith's Knoll in the southern North Sea (Draper, 1968). The highest measured wave (H_1) of 61 feet with a zero-crossing period T_z on the record of 13.3 seconds occurred about 1500 hr on either 27 or 28 November 1969. The uncertainty in date is caused by inadequate labelling of the chart and discontinuities in the sequence of records. The record showing the high wave is a good one and its validity is not in doubt. There is little seasonal variation in either the wave period or spectral width parameter. The scatter diagram of Figure 6 relates the significant wave height to zero-crossing period, with the numbers of occurrences expressed in parts per thousand; for example, the most common wave conditions were those with a significant height of between 4 and 5 feet and a zero-crossing period of between 6.0 and 6.5 seconds, which occurred for 33 thousandths, or 3.3 percent, of the time. The rapid attenuation of the shorter waves with depth means that the pressure units, which are necessarily situated at about 3.7 feet below mean water level, do not record the lower period waves; this is a cause of the cut-off below that period.

A parameter which is sometimes of interest is the wave steepness, expressed as wave height: wave length; it may also be expressed as a decimal number. It should be noted that the steepness of a wave is not the same as the maximum slope of the water surface during the passage of a wave. Lines of constant steepness of 1 : 20 and 1 : 40 are drawn on Figure 6. (In this case, steepness relates to significant wave height : wave length calculated from the zero-crossing period.)

A fairly well-defined limit of steepness is observed at approximately 1 : 16 (0.06); this occurs in all stormy areas. There is a theoretical limit for a progressive wave of 1 : 7 (0.14). From the persistence diagram, Figure 7, may be deduced the number and duration of the occasions between October and March on which waves persisted at or above a given height. For example, if the limit for a particular operation of a vessel is a significant height of 8 feet, it would have been unable to operate for spells in excess of 10 hours on 46 occasions, or spells in excess of 20 hours on 32 occasions.

Figure 8 enables an estimate to be made of the most probable value of the height of the highest wave likely to occur in various time intervals up to 100 years. For example the most probable value in a 50-year interval is 90 ft.

Figure 9 shows an alternative method of extrapolating wave data to yield estimates of extremes. It is based on the scatter diagram (fig.6.) of significant height and zero-crossing period, and has been calculated following an example by Battjes 1970. The authors are indebted to their colleague Mr. J. A. Ewing for the calculations on which this graph is based. The values of extreme-wave heights yielded by this method are the highest of several different methods of estimating this parameter for this site.

Wind Conditions

The mean wind speed for the six months during which wave measurements were made has been compared with the appropriate ten-year mean speed. Two stations, Lerwick, Shetland and Bell Rock, off the Firth of Tay were investigated by Mr. H. C. Shellard of the Meteorological Office. At Lerwick the mean speed for the 1969-70 winter was 15.1 knots whilst the 10-year mean was 15.3 knots. At Bell Rock the figures are 17.9 and 18.1 respectively. The difference from the 10-year mean were quite small, being less than 1.5% in wind speed. The higher values at Bell Rock are due to the winds being recorded at the top of a tall lighthouse, and not at a standard height above a land station.

It could be argued that to achieve 'average' conditions the measured wave heights quoted in this report should be increased by between 2 and 3 percent, depending on whether in this area wave heights are related to the wind speed to the power of 1.5 or 2. However, these differences are quite small and are well within the errors inherent in the measuring system. It is recommended that the heights (and periods also) be used without modification.

Acknowledgements

The authors wish to express their appreciation to Norsk Selskab til Skibbrudnes Redning, and Kåre Misje and Co. for permission to operate the equipment on the vessel, and to the Officers and Crew for operating the equipment, and to the authors' colleagues for help in the analysis. The authors are very grateful to the North Sea Environmental Study Group, which has given financial assistance to expedite the analysis.

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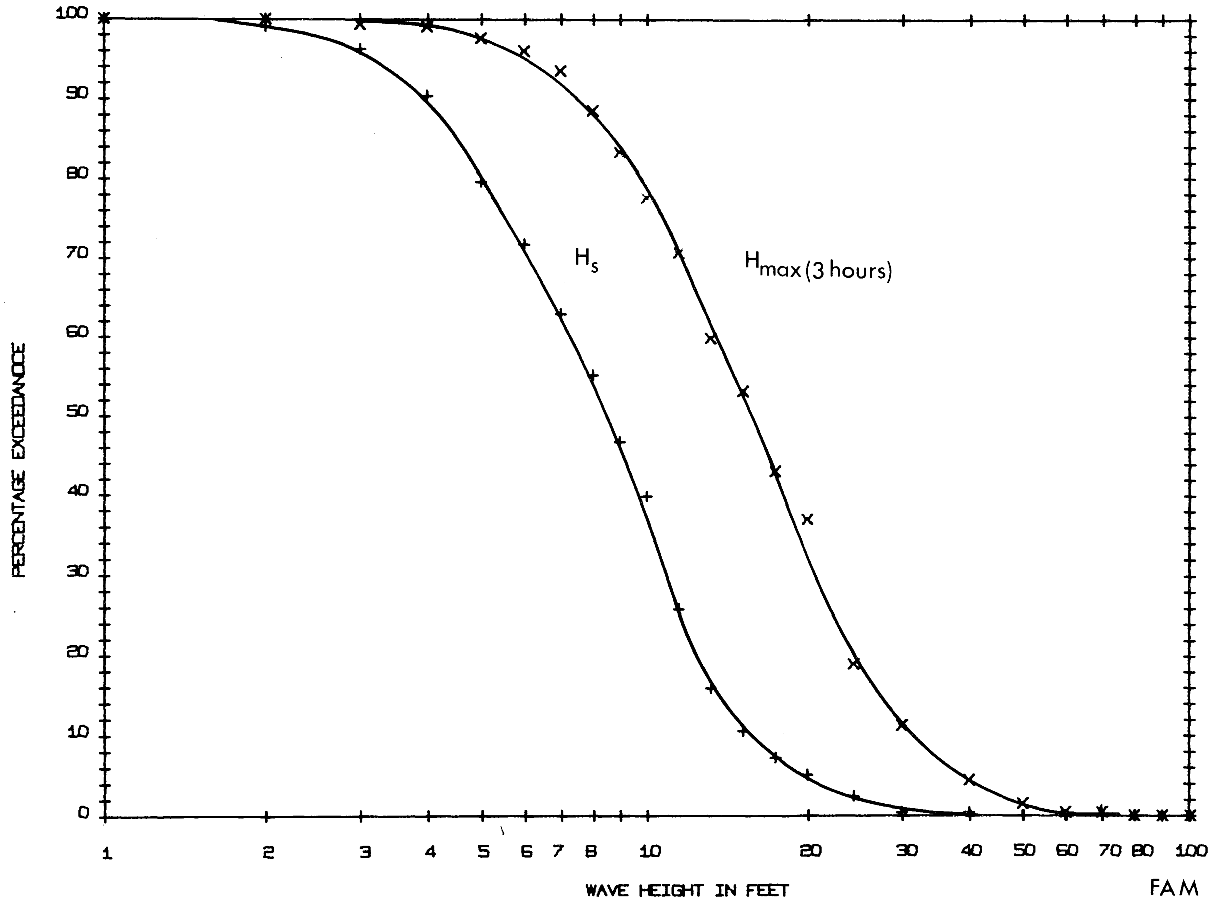
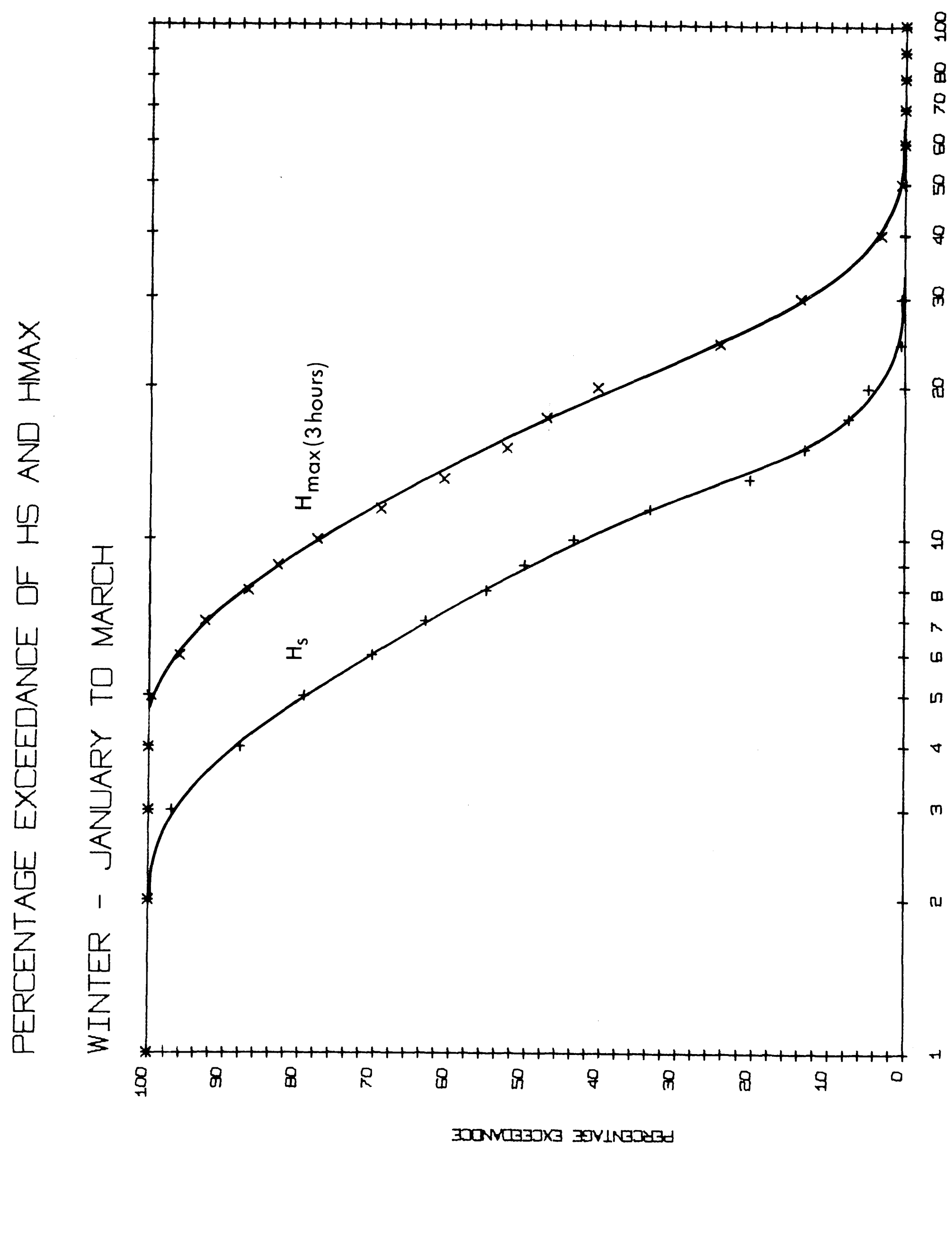
PERCENTAGE EXCEEDANCE OF HS AND HMAX

AUTUMN - OCTOBER TO DECEMBER



FAM
Fig.1

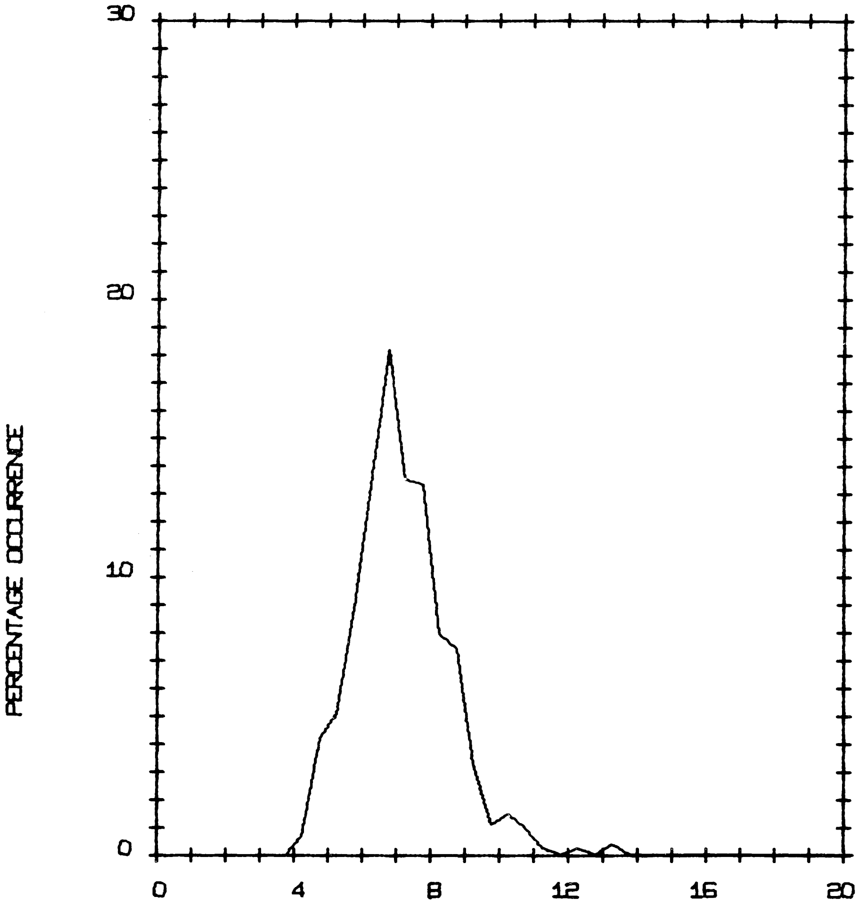

PERCENTAGE EXCEEDANCE OF HS AND HMAX
WINTER - JANUARY TO MARCH
H_{max}(3 hours)
H_s
PERCENTAGE EXCEEDANCE
WAVE HEIGHT IN FEET
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
10
20
30
40
50
60
70
80
100

FAM
Fig.2

GRAPH OF PERCENTAGE OCCURRENCE OF TZ

WITHIN HALF-SECOND INTERVALS

AUTUMN - OCTOBER TO DECEMBER



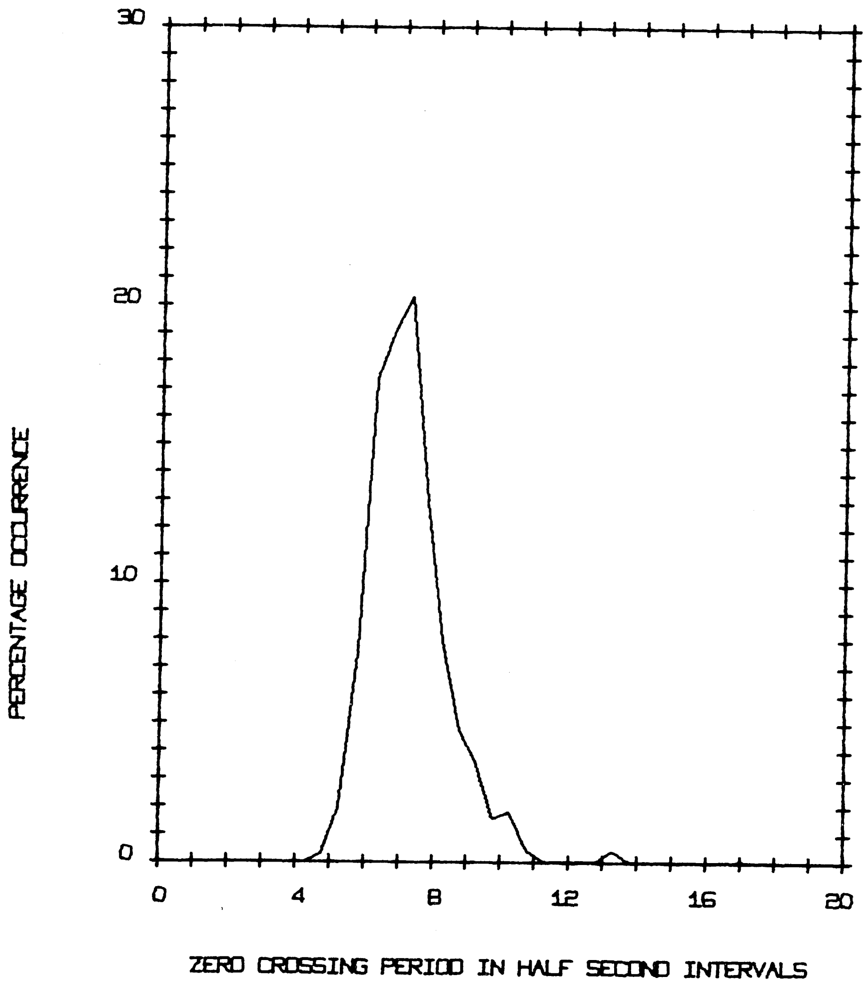
CALM = 0.00 PER CENT

FAM
Fig.3

GRAPH OF PERCENTAGE OCCURRENCE OF TZ

WITHIN HALF-SECOND INTERVALS

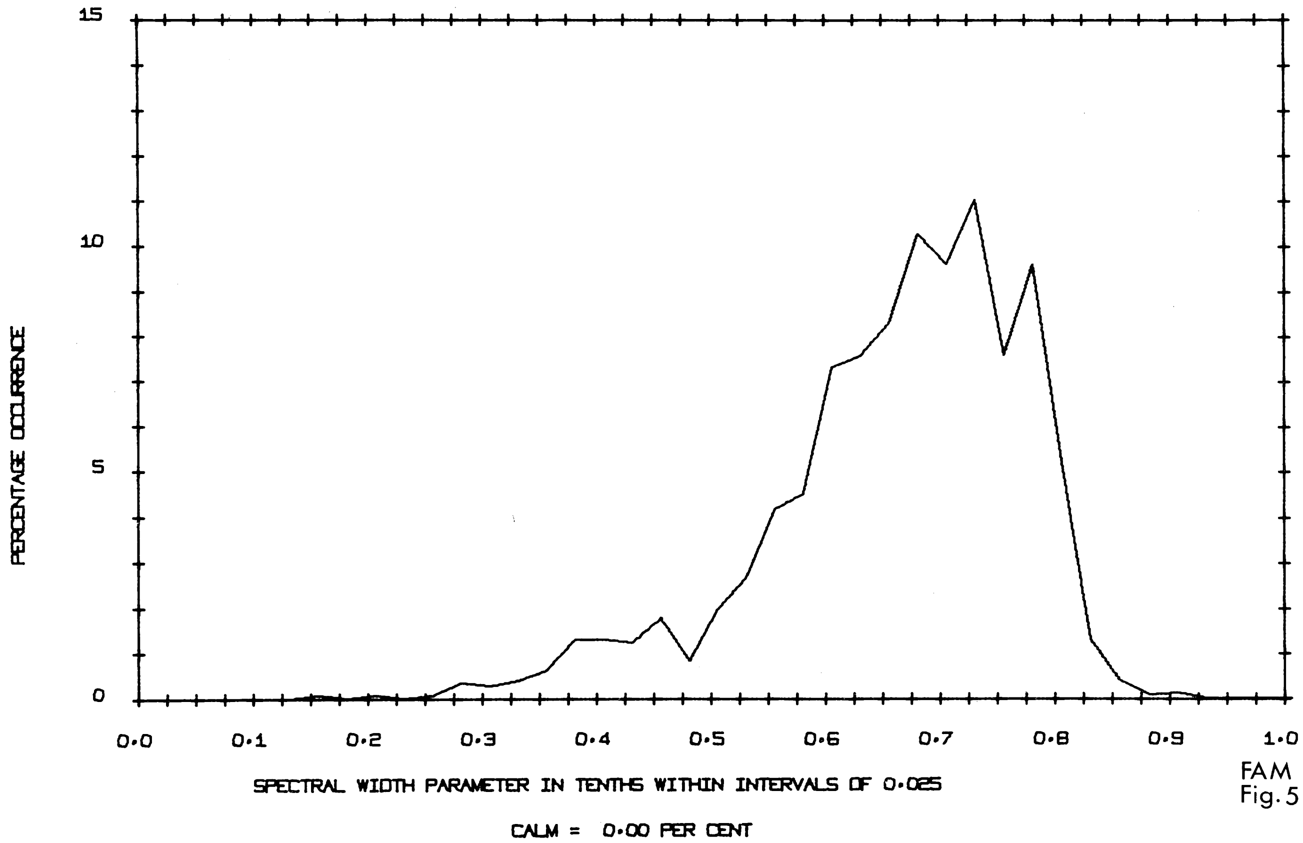
WINTER - JANUARY TO MARCH



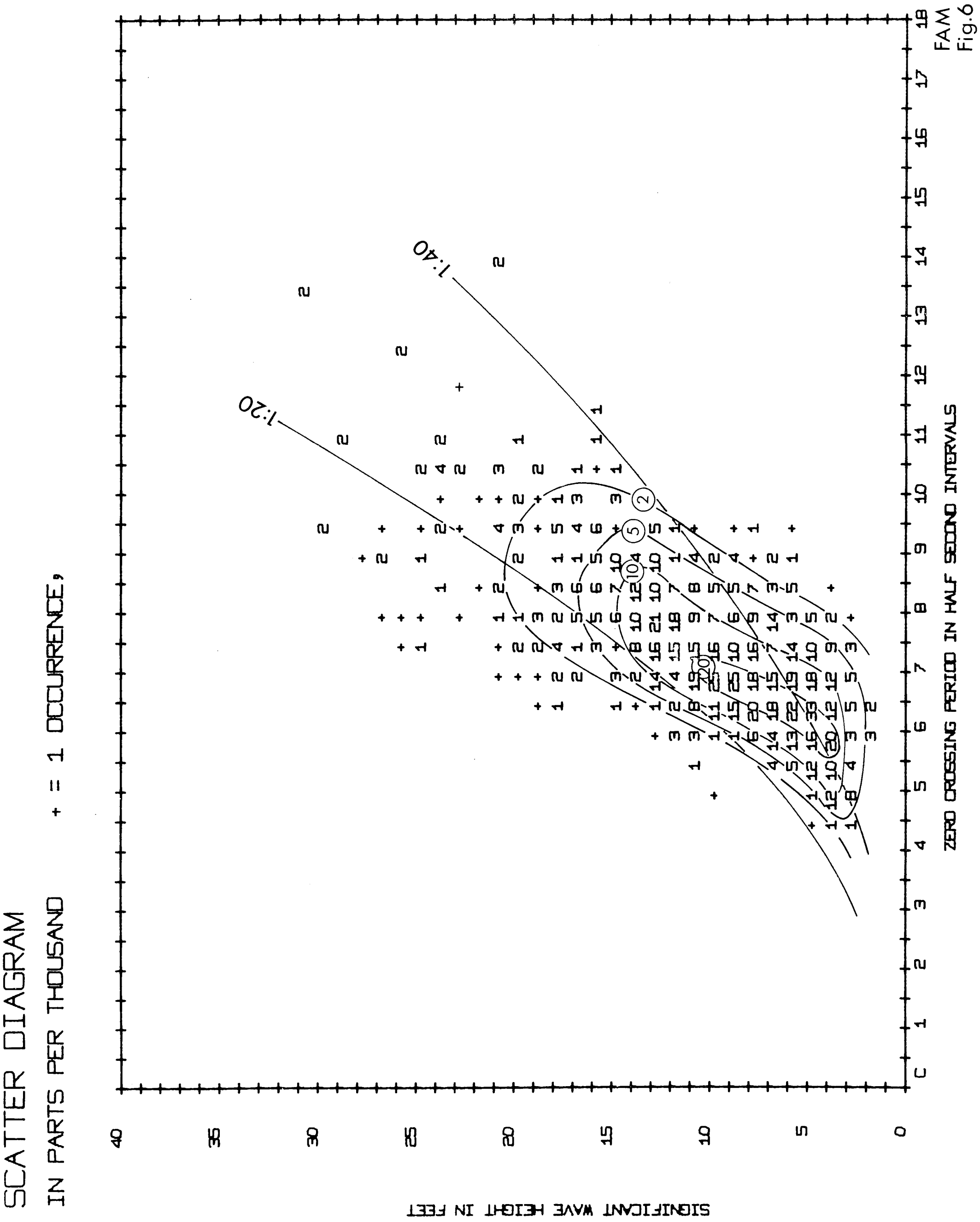
CALM = 0.00 PER CENT

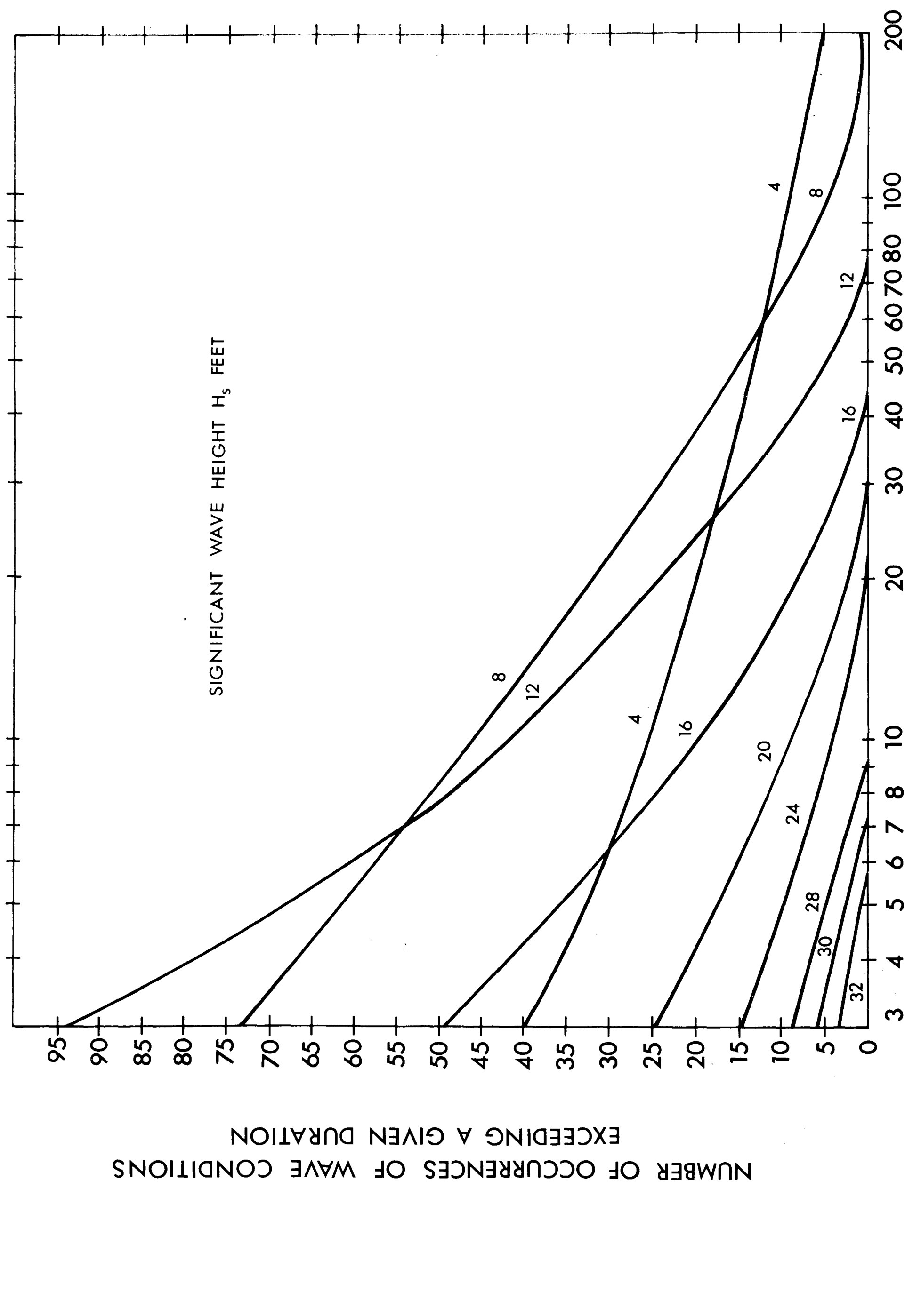
FAM
Fig.4

GRAPH OF SPECTRAL WIDTH PARAMETER

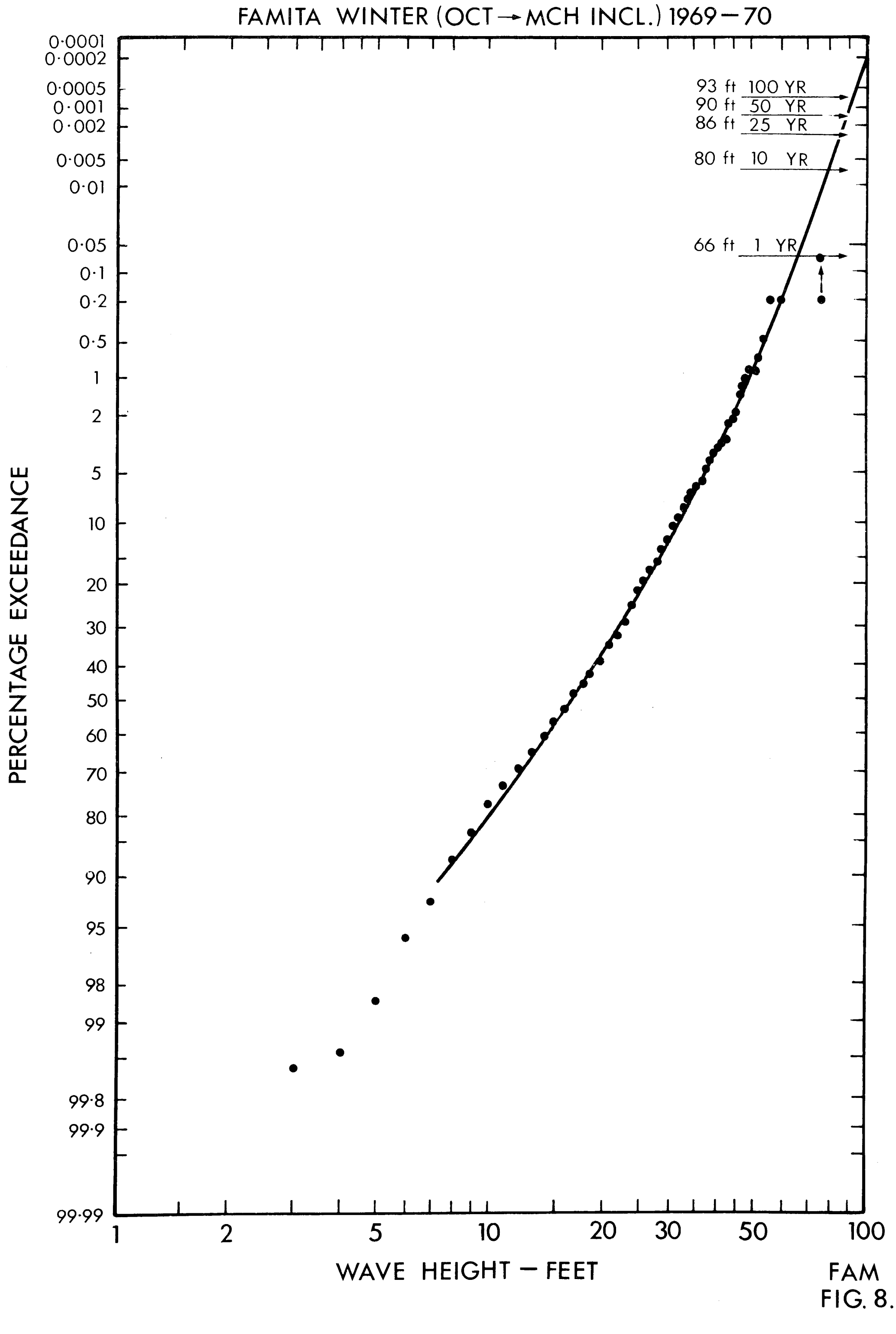


FAM
Fig. 5

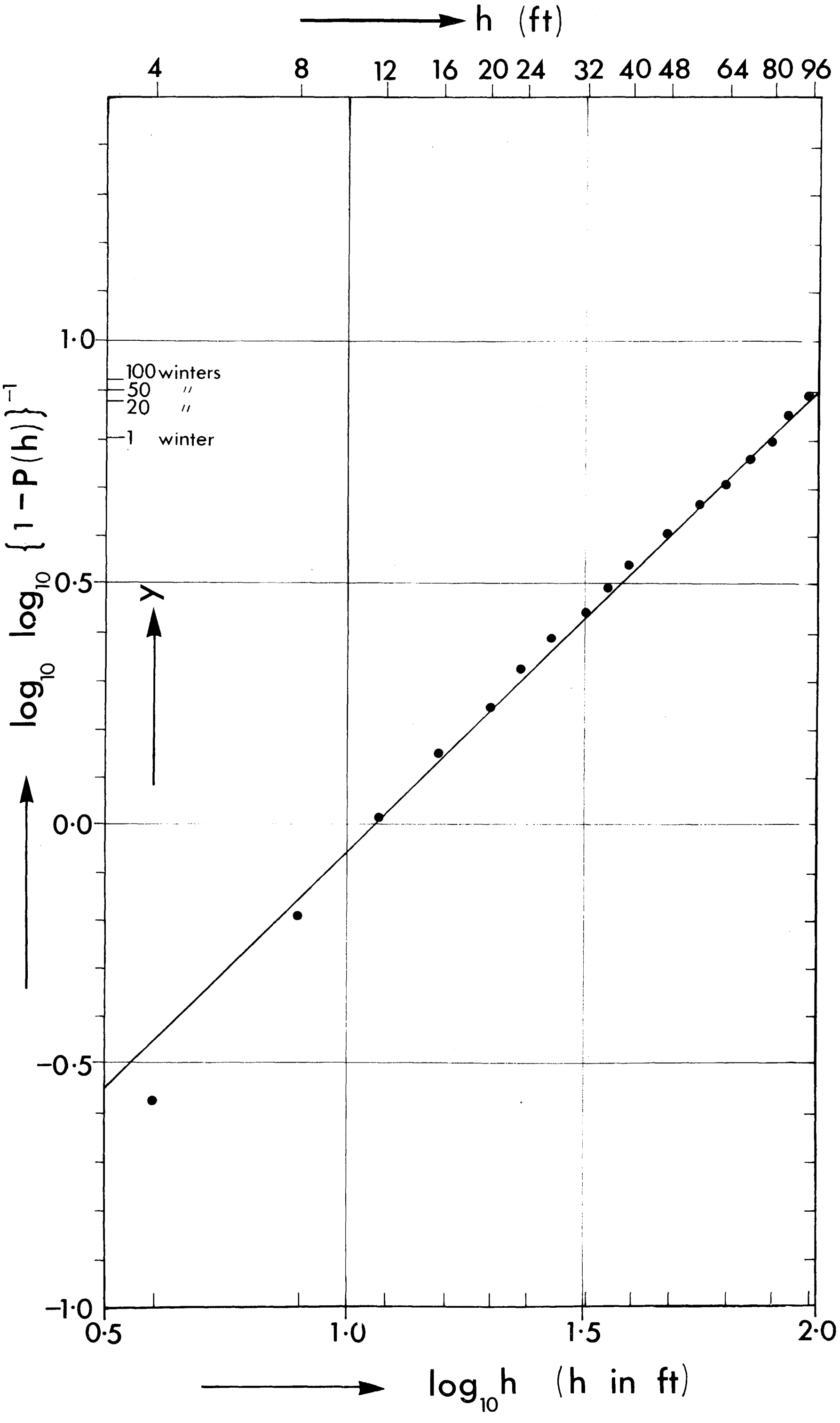

SCATTER DIAGRAM
IN PARTS PER THOUSAND
+ = 1 OCCURRENCE,
SIGNIFICANT WAVE HEIGHT IN FEET
ZERO CROSSING PERIOD IN HALF SECOND INTERVALS
1:20
1:40
FAM
Fig.6


SIGNIFICANT WAVE HEIGHT H_s FEET
DURATION IN HOURS
NUMBER OF OCCURRENCES OF WAVE CONDITIONS EXCEEDING A GIVEN DURATION
3
4
5
6
7
8
10
20
30
40
50
60
70
80
100
200
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
4
8
12
16
20
24
28
30
32

FAM
Fig. 7


FAMITA WINTER (OCT → MCH INCL.) 1969 – 70
PERCENTAGE EXCEEDANCE
WAVE HEIGHT – FEET
93 ft 100 YR
90 ft 50 YR
86 ft 25 YR
80 ft 10 YR
66 ft 1 YR
0·0001
0·0002
0·0005
0·001
0·002
0·005
0·01
0·05
0·1
0·2
0·5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99·8
99·9
99·99
1
2
5
10
20
30
50
100

FAM
FIG. 8.



FAMITA WINTER Fig. 9