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WAVE DIMENSIONS IN THE NORTH AND BALTIC SEAS

The following translated paper first appeared, in limited issue, as Technical Report HE-116-150, Fluid Mechanics Laboratory, University of California. The paper is reproduced here to bring the findings to the attention of a larger group of research workers and others having an interest in ocean waves. The original paper "Beitrage zur Frage der Grossee der in Nord-und Ostsee vorkommenden Wellen" was prepared by E. Mewes of the Deutsche Versuchsanstalt fur Luftfahrt, E. V. Institut fur Seeflugwesen, Berlin - Adlershof, October 1937.

Introduction

a. Purpose of report. - The engineer designing ocean going craft requires a knowledge of the conditions produced by the state of the sea. Important are the specification of wave heights, wave length, and wave periods. This report is to contribute to the knowledge of these wave dimensions by reporting observations made in specific areas of the North and Baltic Seas (along German coast).

b. Type of data used. - In the winter of 1936-37 observations of the state of the sea were made and recorded by the captains of a number of German lightships. The project was sponsored and directed by the Hydrographic Section of the Lilienthal-Gesellschaft for aeronautical research (Arbeitsgruppe fur Seegangsforschung, Lilienthal-Gesellschaft fur Luftfahrtforschung). The information required by this organization included estimation of wave dimensions and periods. A large part of these observations are used in this report.

Also the marine-aviation section of another German aeronautical research organization, Deutsche Versuchsanstatt fur Luftfahrt (DVL) has measured wave motion by instrument continuously since September 1936. These measurements were made with instruments developed by this research group in the Baltic Sea from the lightship FEHMARNBELT and for short periods from the lightships BORKUMRIFF and AMRUMBANK in the North Sea. This recorded data has only partially been reduced and, consequently, limited use is made of it here.

Evaluation of Accuracy

a. Relative value of measurement and observation. - Generally the results of measurements, with DVL apparatus must be considered more reliable than visual observations which essentially are estimations. But usable information may be obtained from such observations of wave dimensions since the relative ease of procurement and evaluation permits the collection of such observations on a greater scale. The greater part of the data used in this report was observed rather than measured.

Care must be taken in evaluating such observed data since often estimates are not too accurate and conditions often do not permit accurate observations. For example, it is quite difficult to estimate wave heights from a moving point of observation. On the other hand, it is quite possible to make accurate estimates from an anchored lightship. On the basis of this, observations of lightship captains are considered quite accurate. Since not all seagoing personnel are equally capable in this direction, a careful selection is necessary. Most of the data used here has been collected by a small number of experienced captains.

b. <u>Comparison of recorded and estimated wave dimensions</u>. - To be able to evaluate the accuracy of the wave dimensions based upon observation, the results of comparison between measured and observed data are given. First, the data collected by observer I, lightship FEHMARNBELT during the period, 22-30 September 1936 are compared to data obtained with tested DVL apparatus recorded during the same period. Data was taken only when conditions of observation were perfect. The dimensions required from the observer were the maximum vertical differential (wave height) in meters. While observations were made at certain specific times (8 a.m. noon, and 4 p.m.) the recording instrument operated continuously over the 8-day period. The ten highest waves were determined from all waves recorded during a period starting one-half hour before the time of observation and ending one-half hour after the time of observation.

Figure 1 shows the observed value of the greatest difference in height and the measured wave height which was surpassed 10 times during one hour. This corresponds to the value given for the evaluation of measurements which were carried out to establish a scale for the relative state of the sea (DVL report covering periods measurements in the LUEBECKER BUCHT). In most cases, the agreement between measured and observed values is good; e.g., for two-thirds of all cases differences are less than 20 cm. In individual cases, the estimated wave heights are lower than those measured. In the extreme case, a wave measured to be 92 cm. in height was estimated to be 40 cm. It must be borne in mind that because of the irregularity of storm waves, the value for the height surpassed 10 times per hour is not altogether identical to the maximum height observed during the time of observation.

In figure 2 a comparison is shown of wave lengths measured and observed concurrently. No observed values are available for certain periods of time, probably because unfavorable observation conditions made accurate estimates impossible. Wherever possible wave lengths were estimated; also a count was taken of the number of crests moving past the point of observation per minute. From this frequency coefficient n, the mean period, $T = 60/n$, in seconds and consequently, the wave length is computed, i.e., the corresponding value for the wave length from the trochoid theory

$$L = \frac{g}{2\pi} T^2 = 1.56\ T^2 \text{ in meters.}$$

The computation of the wave length from the recorded data is accomplished in a similar manner. It differs merely in the determination of T which is obtained by dividing the time elapsed by the number of waves (k) of relatively even height ($T = t/K$).

From previous investigations (3, pp. 24-27) it may be assumed that the given relation between the mean values of T and L is sufficiently accurate. The wave length thus determined from measurements can then be regarded as the actual mean value for the wave length to which estimated wave length should correspond. Figure 2 indicates that the observed wave length is considerably smaller than those obtained by measurement. On the other hand, the wave lengths estimated by counting the number of passing waves are in better agreement with respect to order of magnitude. In two-thirds of all cases, deviations are less than 5 meters or below 40 per cent. The directly estimated wave lengths in figure 2 show the same tendency for increase and decrease as the values obtained from measurement, only the latter are four to five times as great.

The estimates of observer II of lightship FEHMARNBELT made in the period, 3-17 October 1936, were checked in the same manner as those observations described above. The comparison between observed, measured, and calculated data is presented in figures 3 and 4. The picture is essentially the same and occasionally this observer, too, has over estimated the wave height. In the extreme case here a wave measured to be 0.85 meters was estimated at 1.50 meters. Both observers were informed of the results of comparison of measured and observed wave heights and lengths, whereupon subsequently reported wave lengths increased. Figure 6 indicates better agreement between measured and observed wave lengths during the period 24 October to 13 November 1936, and according to figure 5 wave heights for this period are in good agreement; only at very high seas were estimated heights greater than those measured. The observer noted that the buoy of the recorder undercut due to the high sea and it is not to be assumed that the measured values are the more accurate ones in this case.

The estimates of observer III of lightship BORKUMRIFF were also checked for a short period by means of measurements. The result of the comparisons was about the same as in the case of the estimates of observers I and II on the lightship FEHMARNBELT. Figures 7 and 8 show the comparison between observed and measured wave dimensions for the period, 4-10 November 1936 at the lightship BORKUMRIFF. The wave heights are generally in good agreement and deviations are only appreciable in the case of very high estimated values. The estimated wave lengths were too short but the values calculated from the counted number of waves passing are in fairly good agreement with the measured wave length.

The lack of measured data prevented comparison of the values estimated by observer IV of the same lightship. It appears, nevertheless that the estimates of this observer followed the same trend as the rest.

Observations from the lightship AMRUMBANK during the period 20 November to 10 December 1936, were also checked by measurements. Observer V is responsible for data up to December 3 and observer VI for data thereafter. Figure 9 indicates that the wave heights estimated by observer V generally are of the right order of magnitude. The estimated values of low waves nearly always were below the measured values while in the case of higher waves, agreement was better. Only in the case of exceptionally high estimated waves do these values run appreciably higher than those values computed from measured data by the method outlined above. The observer reported that the buoy of the recording apparatus did not completely follow the motion of the water surface at such high seas and that consequently the measurements were not exact. Figure 10 gives a comparison of wave lengths based upon observations of observer V whose values for the wave length and frequency were approximately the same for wind waves and swells. Observer VI did not give frequency values for the period checked by measurement, but noted that it was not possible to distinguish wave crests due to wind and swells. During this period wind waves and swells crossed over one another. Observed wave lengths for wind waves and swells are compared to measured values in figure 12. Figure 11 indicates a great discrepancy in the estimates of observer VI of the wave heights in high seas.

Comparison of Results of Observations from Various Lightships

The results for the estimated wave heights from all points of observation in the North Sea were compared. Figure 14 represents the data for the period 18-31 January 1937, during which continuous observations were made from all points. Observations came from the lightships BORKUMRIFF, NORDERNEY, WESER, AUSSENJADE, MINSENER SAND, BREMEN, AUSSENEIDER AND AMRUMBANK. The location of these observation stations is given on the map, figure 13.

The wave height curves in figure 14 indicate the uniform tendency for increase and decrease at all points of observation (note rise of curves on the 23/1/37). Some of the changes in height are displaced along the time axis and the relative ratios between heights show some differences. On 19 January, the maximum value occurred at the lightship BORKUMRIFF which was farthest out at sea. On the other hand, the highest values occurred on the 25, 26, 28, and 29 January at the lightship NORDERNEY where the maximum wave reaches a height of 3.5 meters. During this period all lightships in the mouth of the Weser (with the exception of the AUSSENJADE) reported wave heights between 2 and 3 meters. It is noteworthy that wave heights up to 3 meters were also reported from the lightship BREMEN which was closest to shore, while during calmer weather wave heights at the position were always lower. Observed wave-height data from these lightships which were not checked by measurement cannot be used as a basis for the evaluation of the effects of wind at the various observation points, and a corresponding comparison of wave length is even less feasible.

Largest Waves at Three Lightships

The results of observation are reported from the following lightships:

(1) FERMARNBELT	Western Baltic
(2) BORKUMRIFF	Western North Sea
(3) AMRUMBANK	Eastern North Sea

The winter 1936-37 during which the following observations were made, was particularly stormy. Figure 15 which represents wave heights observed at the lightship FEHMARNBELT (1-10-36 to 31-3-37) in the western part of the Baltic Sea, show a general picture of the effects of the storm. Generally, observations were made three times a day, 8 a.m., noon, and 4 p.m. Data is missing for certain periods because the ship left its position to escape danger of freezing in. According to observations from the lightship FERMARNBELT during the winter 1936-37 a wave height of 2 meters was reached or surpassed nine times, while the 3-meter mark was exceeded only once. The strongest effect of the storm was observed on 1 December 1936. The highest wave was estimated by observer II of the lightship FERMARNBELT to be 3.10 meters in height. On 27 October 1936, the day when the lightship ELBE 1 capsized, maximum wave heights given by observer I of lightship FERMARNBELT were 2.5 - 3.0 meters. The same observer gave 2.7 meters for the maximum value on the 19 January 1937. Wave lengths evaluated from the observed data indicate that on 1 December 1936 the wave steepness, H/L was equal to 1:10 and on 19 January 1937 for wave heights of 3.1 and 2.7 respectively.

From the lightship BORKUMRIFF observer III reports for the afternoon of 1 December 1936 "the highest sea observed in the North Sea." The maximum wave height was estimated at 8-9 meters. This estimate must be judged on the basis of the previously made statement that the heights of very high waves are readily overestimated. Measurements were not possible on this day; in fact the lightship had torn itself loose from the anchor chain. During this high sea observer III counted six passing crests per minute which corresponds to an average period of 10 seconds and a mean wave length of about 150 meters. The wave length was visually estimated at 60 meters but this value must be ruled out since the wave lengths at this point of observation were consistently underestimated.

The highest waves given by observer V of lightship AMRUMBANK in the winter 1936-37 (December 1936) were 5 meters in height while observer VI gave the maximum height for 4 December 1936. Here the average period was equivalent to a frequency of eight crests per minute or T = 7.5 seconds. This corresponds to about L = 90 meters and, on the basis of the estimated wave height to a ratio H/L = 1:18.

Frequency of Various Wave Heights and States of the Sea

Observed maximum values of wave dimensions are a matter of contingency and represent singular values which occur relatively seldom. Knowledge of the frequency at which different states of the sea occur is required for craft of limited seaworthiness, such as seaplanes, etc. For this reason the collected observation data from lightship FEHMARNBELT, BORKUMRIFF and AMRUMBANK was used to construct diagrams indicating the frequency of different states of the sea and wave height.

All results are based upon data collected during the stormy winter 1936-37 and must consequently be considered the most unfavorable conditions which could be expected over a period of 6 months. Observations were fairly regular (3 times daily) but were interrupted several times so that instead of 546 possible entries there were 443 entries from lightship FEHMARNBELT, 345 entries from lightship BORKUMRIFF and 348 entries from lightship AMBUMBANK.

The frequencies are expressed in percentage of actual observations carried out at the respective stations. Two type of frequency curves are represented, type 1 and type 2 (figures 16-21). Frequencies designated type 1 represent the number of occurrences of values in a fixed range. Type 2 represents the percentage of values exceeding fixed limits (accumulative frequency). Convenient ranges of wave heights were chosen for the evaluation of frequencies of type 1. In the case of the data from lightship FEHMARNBELT these ranges comprise the wave heights 0 to 10 cm, 20 to 30 cm, 40 to 50 cm. etc. The frequencies are plotted as the respective ordinates of the mean values, i.e., at 5, 25, 45, ... cm. and represent the ranges 0-15, 15-35, 35-55 ..cm. in wave height. In the case of data from lightships BORKUMRIFF and AMRUMBANK the ranges were chosen somewhat larger, i.e., 0-25, 25-55, 55-85,...cm.

Direct comparison of the plotted values for type 1 frequency of wave heights at lightships in the Baltic and North Seas is not practicable. The type 2 frequency curves for the three lightships were used as a means of comparison. Figure 22 shows such a comparison for the relative states of the sea and figure 23 for the wave heights. The diagrams (figure 22) indicate the similarity of the frequency curves for the relative states of the sea as observed at three widely separated positions in the Baltic and North Seas. On the other hand, there is considerable variation among the curves (figure 23) representing the frequency of particular wave heights. High seas were observed as frequently from the lightship FEHMARNBELT anchored in the Baltic Sea as from the other lightships in the North Sea but the waves were not as high as those observed in the North Sea. The following table can be constructed from the diagrams.

TABLE I

Accumulative Frequency of Wave Height and State of the Sea

Accumulative frequency	Wave height not exceeding			State of the Sea not exceeding
	Fehmarnbelt	Borkumriff	Amrumbank	
Percent	Meters	Meters	Meters	
25	0.34	0.66	0.58	2
50	0.60	1.08	1.20	3-4
75	1.05	1.60	2.00	4-5
90	1.60	2.10	2.80	5-6
95	2.00	2.50	3.20	
Maximum	3.10	8.50	5.00	8-9

A determination of the wave-length frequencies were attempted but great discrepancies were found. A plotting of frequencies of type 2 has been omitted. Figure 24 shows the frequency percentage of the number of wave crests passing per minute and or the wave lengths for the lightship FEHMARNBELT. In the case of these observations, frequencies varied between 28 and 10 waves per minute and the wave lengths between 7 and 56 meters.

Wave Dimensions for Different States of the Sea

a. Relation between wave dimensions and states of the sea. - The differentiation between sea disturbances on a scale (Douglas Sea Scale) 0-9 is generally based upon the impressions of the observer who bases his judgment upon tradition and experience (4, p. 33). On several occasions it was found that the estimated relative states of the sea were not always associated with the same appearance of the water surface (1). For this reason there are no generally applicable fixed relations between wave dimensions and states of the sea nor can definite degrees of sea disturbance (Douglas Sea Scale) be associated with fixed wave dimensions for definite positions (2).

For evaluation of the state of the sea, it is desirable to know the wave dimensions associated with the respective states of the sea. For this purpose mean values and degree of scatter can be given. Mean values are utilized in the correlation of states of the sea to wave heights in frequency diagrams.

b. Wave heights for different states of the sea. - The relation between wave heights and states of the sea was investigated by utilizing a number of diagrams and tables. Figure 25 represents data compiled by observer VII from lightship AUSSENEIDER, who reported that he estimated the state of the sea on the basis of wave dimensions, unlike the methods of other mariners. Each dot on the graph represents a recorded observation and the signs adjacent to these dots denote the presence of swells. Figure 25 indicates that the values of wave heights for particular states of the sea are greatly scattered and variations are as follows:

State of the Sea	Wave height meters
1	0.10 - 1.50
2	0.20 - 1.75
3	0.30 - 2.00
4	0.75 - 3.00

If, on the other hand, one omits those cases where swells were present then the ranges of wave heights for different states of the sea overlap to a much lesser degree. One thus obtains from figure 25 for wind waves without swells, a revised tabulation:

State of the Sea	Wave height meters
1	0.10 - 0.25
2	0.20 - 0.40
3	0.30 - 1.00
4	0.75 - 1.75
5	1.75 - 2.25
6	2.00 - 3.00

These relations cannot be applied to the estimates of other observers.

Arithmetic mean values were found from all wave heights at different states of the sea; they were observed during the winter at fixed positions of the lightships. The resultant mean wave heights are shown in Table 2 below and presented in figure 26.

TABLE 2

State of the Sea and Corresponding Wave Heights at Lightships

State of the Sea	Mean Wave Heights		
	FEHMARNBELT	BORKUMRIFF	AMRUMBANK
1	0.15	0.35	0.35
2	.30	.60	.55
3	.50	.95	1.00
4	.75	1.40	1.50
5	1.25	1.80	2.25
6	1.75	2.50	3.15
7	2.15	3.40	3.70
8	2.75		

It is evident here (figure 29) as in the frequency diagrams that in the case of the higher values, the wave heights reported from lightship AMRUNBANK were greater than those reported from lightship BORKUMRIFF. At each individual state of the sea, the mean wave heights of the lightships in the North sea are greater than those of lightship FEHMARNBELT. The fact that in the case of the lightships in the North Sea, the wave heights do not reach zero with decreasing disturbances of the sea, is due to the influence of swells which is negligible only in the case of lightship FEHMARNBELT.

To get an idea of the spread of the values for wave heights associated with particular states of the sea, the values in the following table represent the number of times particular wave heights were observed at different states of the sea. The wave heights are tabulated (table 3) in 10 cm. intervals. Where intermediate values were estimated (H = 0.25) they were listed alternately with the next higher and next lower values.

TABLE 3

Frequency of Wave Heights at States of the Sea - Lightship FEHNARMBELT

Wave height meters	State of the Sea						
	2	3	4	5	6	7	8
0.10	1						
.20	18	1					
.30	33	10					
.40	16	23	8				
.50	5	36	2				
.60	1	19	14	2			
.70	1	10	11	2			
.80		2	22	5			
.90			9	1			
1.00			9	16			
1.10		1	1	9	1		
1.20				10	2		
1.30				11	1		
1.40				7	7		
1.50			1	2	2		
1.60				3	2	1	
1.70				1	4		
1.80				3	4		
1.90					2	3	
2.00				1		5	
2.10						3	
2.20					2	1	
2.30					2	1	
2.40							1
2.50							3
2.60							1
2.70							1
2.80							1
3.10						1	

The wave height ranges for particular states of the sea overlap considerably. Observations from lightship FEHMARNBELT can be summarized as follows:

State of the Sea	Wave Height Meters
2	0.10 - 0.70
3	0.20 - 1.10
4	0.40 - 1.50
5	0.60 - 2.00
6	1.10 - 2.30
7	1.60 - 3.10

If only 70 to 90 per cent of all observed cases are taken into consideration observations from lightship FEHMARNBELT would fall into the following scheme:

State of the Sea	Wave Height Meters
1	0.10 - 0.20
2	0.20 - 0.40
3	0.40 - 0.60
4	0.60 - 0.90
5	0.90 - 1.40
6	1.40 - 1.90
7	1.90 - 2.40
8	2.40 - 2.80

The mean values of these ranges approximately correspond to the arithmetic mean value obtained from all wave heights reported from this lightship (table 2).

c. Representation of wave dimensions associated with different states of the sea in three separate regions. - Subsequent diagrams (figures 27-30) represent the relationship between wave height and lengths where wave lengths were calculated from the counted wave frequencies. Each dot represents an observation and the adjacent numbers denote the estimated state of the sea. Where two numbers were given in the observation data, e.g., state of sea 2-3, the mean value (2.5) is shown.

Figure 27 represents a plot of the results of a series of observations made during the period 9 January to 6 April 1937, from lightship BORKUMRIFF stationed in 25 meters of water in western North Sea. For tranquil states of the sea no values are plotted because observers reported that reliable estimates of wave frequencies could not be made. The most turbulent states of the sea did not occur during this period. Entries vary from 2 to 6 of the Douglas Sea Scale. The graph indicates that in general the more turbulent states of the sea occur more frequently with increasing wave dimensions but that considerable overlapping of ranges of wave dimensions associated with particular states of the sea is encountered. The ratios between wave height and wave length (wave steepness) scatter considerably from 1:12 to 1:55 and in 20 percent of all observations the ratio is less than 1:20.

In figure 28 the results of observations made in December 1936 and January 1937 from lightship AUSSENEIDER (western North Sea) in a 13-meter water depth are plotted. Data from this lightship are of particular significance since they were observed in a relatively shallow region. Here the seas due to wind from land and from the open sea are indicated separately. The most turbulent states of the sea were caused by winds from the open sea, but land winds also caused considerable turbulence. Maximum estimated values due to land wind were a state of the sea, 6, and a wave height of 3 meters. The observed wave dimensions here were not checked by measurements. According to the reports of the observers the wave steepness was between 1:9 and 1:114. For a state of the sea, 3 and less (Douglas Sea Scale), H/L is always less than 1:20. During the period in which the observations were made, a particularly great number of high seas were encountered. Numerical values may shift considerably if other periods of observation are chosen.

Figure 29 represents the corresponding results of observations made from the lightship FEHMARNBELT in the Baltic Sea in a 27-meter depth. In this case the wave steepness values are less scattered. All values lie in the sector between 1:10 and 1:35. The flattest waves (1:35) occurred with very small wave heights (H = 0.30 m) and the steepest waves occurred with the greatest wave height 3.10 meters in which case the state of the sea was given at 7. On several occasions the state of the sea was estimated at 8, where the wave heights were smaller (about 2.5 meters), but the wave lengths had their maximum value (50-60 m).

In figure 30 values of wave dimensions measured at lightship FEHMARNBELT are plotted in the same manner as above. The values here are not the greatest in each case, but the characteristic values mentioned in section II b. The data used was taken over various periods of time during the months of September, October and November 1936. They include very tranquil states of the sea up to wave heights of 0.1 meter. At these tranquil states of the sea even the shallowest waves have steepness up to H/L = 1:50 while the steepest wave with H/L = 1:14 occurred at a state of the sea 4. The mean wave steepness is about H/L = 1:25. Figure 30 illustrates the manner in which wave dimensions increase with increasing values of the Douglas Sea Scale.

VII. Summary

According to observations of the captains of German lightships, the highest waves in the southwest region of the North Sea are 8 to 9 meters high, in the eastern part 5 to 6 meters, and in the Baltic Sea a good 3 meters. The estimates of the observers were checked and verified as to order of magnitude by means of instrument measurements, but only for relatively tranquil states of the sea.

If a marine craft is to be operated 75 per cent of the time during a stormy winter wave 1 meter high can be anticipated in the Baltic Sea and waves 2 meters high in the North Sea. If a marine craft or seaplane can operate only in waves up to 1 meter, operation in the North Sea during a stormy winter will be limited to 50 per cent of the time.

Values for wave dimensions at different states of the sea are considerably scattered. Mean values based upon observation and measurement from lightship FEHMARNBELT in the Baltic Sea are:

State of the Sea	Wave Height Meters
2	0.30
3	0.50
4	0.80
5	1.25

Observations from three lightships in the North Sea at a state of the sea 3 indicate a mean wave height of about 1 meter. The ratios between wave heights and wave lengths vary considerably. Shallow waves with H/L = 1:20 were more frequently encountered than steep waves, both in the Baltic and North Seas.

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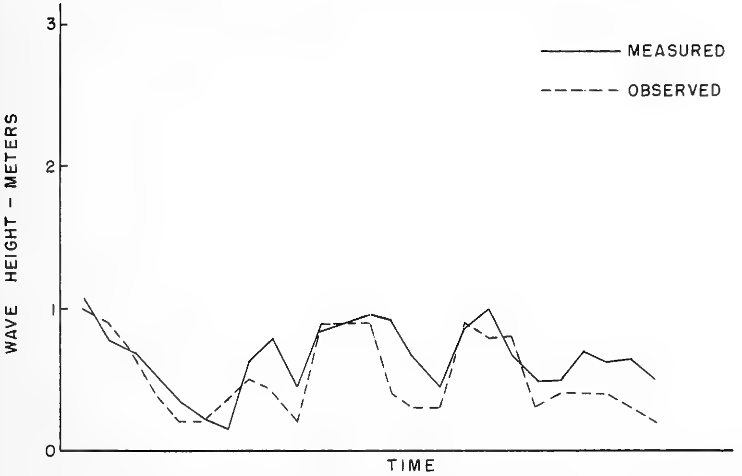


FIGURE 1.
COMPARISON OF MEASURED AND OBSERVED WAVE HEIGHTS. OBSERVER 1 OF THE LIGHTSHIP FEHMARNBELT, SEPT. 22-30, 1936.

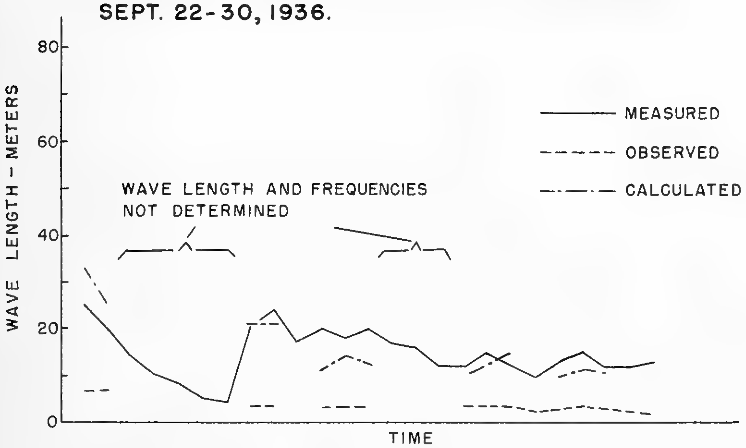


FIGURE 2.
COMPARISON OF WAVE LENGTHS. OBSERVER 1 OF THE LIGHTSHIP FEHMARNBELT, SEPT. 22-30, 1936.

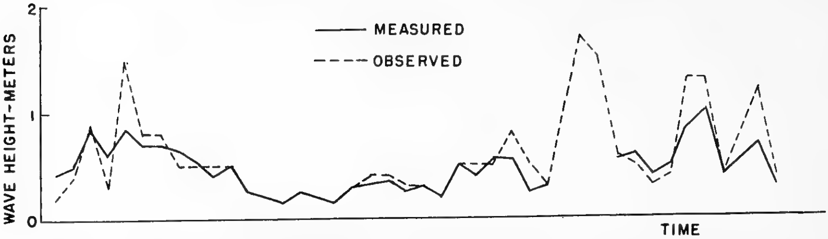


FIGURE 3. COMPARISON OF MEASURED AND OBSERVED WAVE HEIGHTS. OBSERVER 2 OF THE LIGHTSHIP FEHMARNBELT, OCT. 3-17, 1936

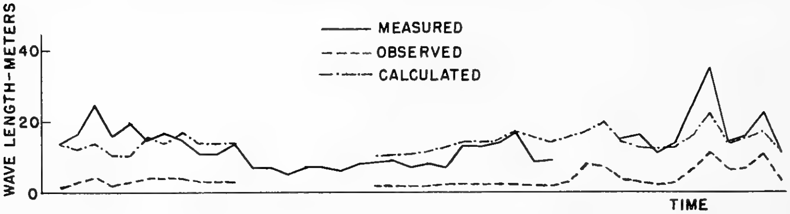


FIGURE 4. COMPARISON OF WAVE LENGTHS. OBSERVER 2, OCT. 3-17, 1936.

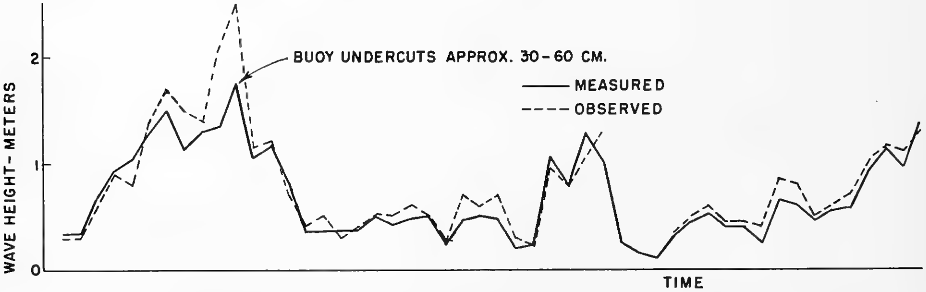


FIGURE 5. COMPARISON OF MEASURED AND OBSERVED WAVE HEIGHTS. OBSERVER I, OCT. 24-NOV. 13, 1936

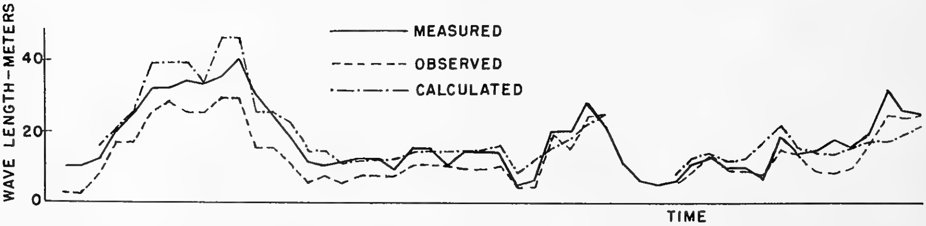


FIGURE 6. COMPARISON OF WAVE LENGTHS. OBSERVER I, OCT. 24-NOV. 13, 1936.

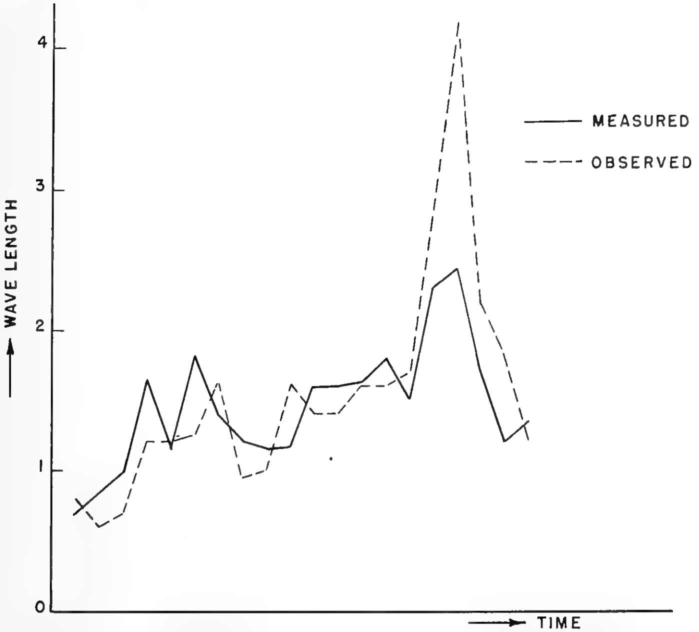


FIGURE 7 - COMPARISON OF MEASURED AND OBSERVED WAVE HEIGHTS; OBSERVER III OF THE LIGHT SHIP BORKUMRIFF NOV. 4-10, 1936

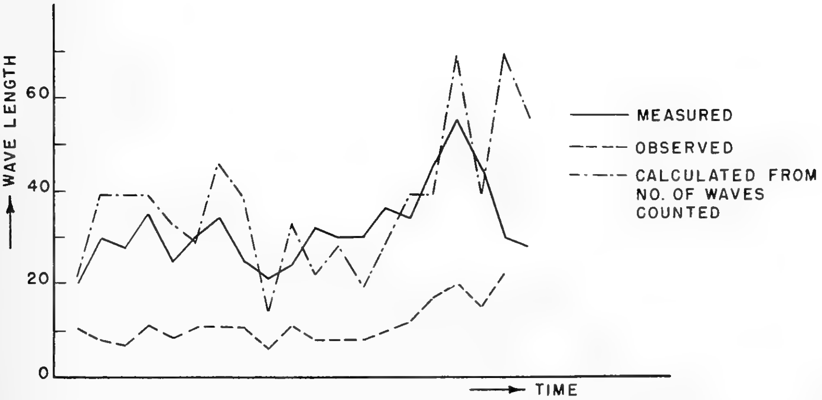


FIGURE 8 - COMPARISON OF WAVE LENGTHS; OBSERVER III OF THE LIGHT SHIP BORKUMRIFF NOV. 4-10, 1936

FIGURE 9.

COMPARISON OF MEASURED AND OBSERVED WAVE HEIGHTS.
OBSERVER 5, LIGHTSHIP AMRUMBANK, NOV. 20-DEC. 12, 1936

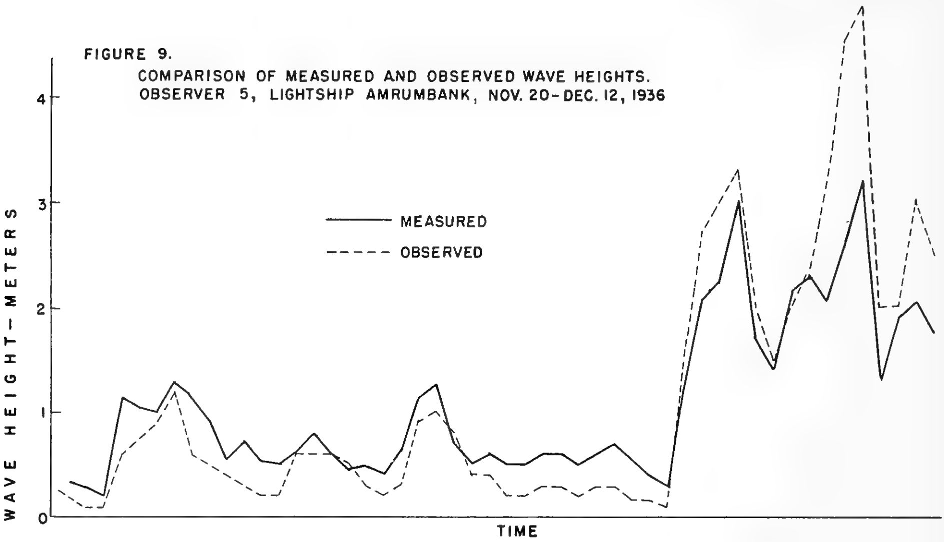
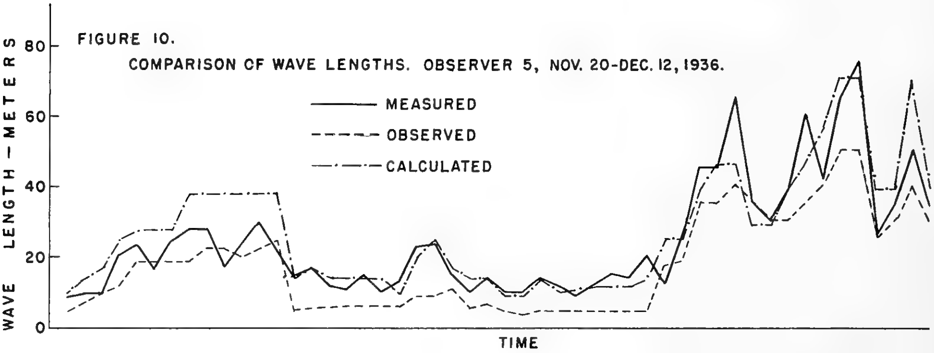


FIGURE 10.

COMPARISON OF WAVE LENGTHS. OBSERVER 5, NOV. 20-DEC. 12, 1936.



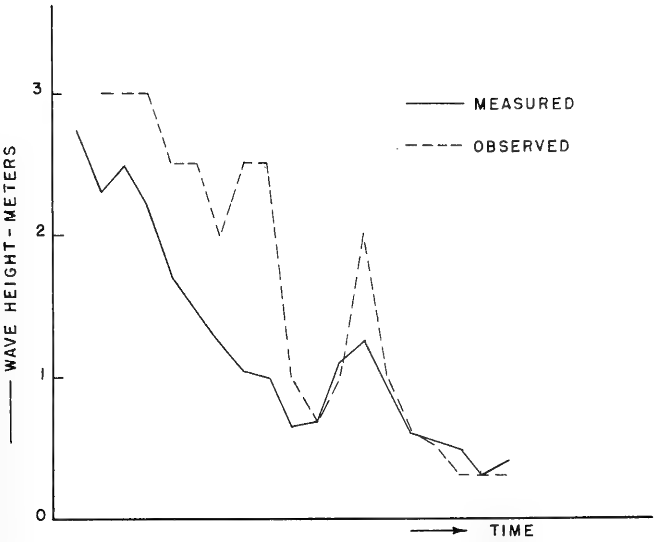


FIGURE 11.- COMPARISON OF MEASURED AND OBSERVED WAVE HEIGHTS OBSERVER VI LIGHT SHIP AMRUMBANK DEC. 4-10, 1936

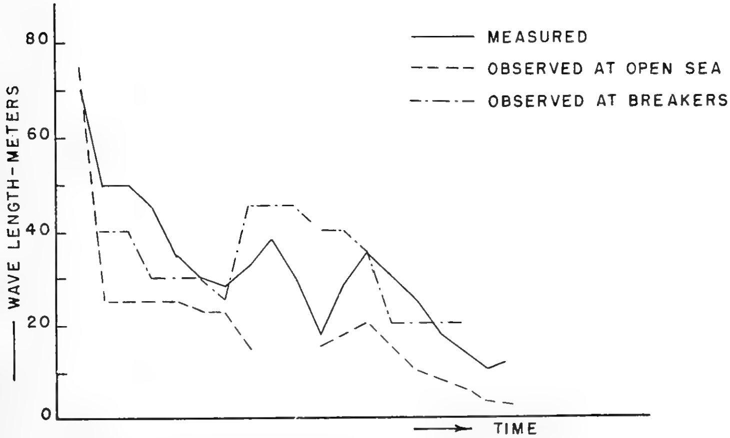


FIGURE 12.- COMPARISON OF WAVE LENGTH OBSERVER VI DEC. 4-10, 1936

FIGURE 13.- LOCATION NORTH SEA OBSERVATION STATIONS
DOUBLE UNDERLINED: LIGHTSHIPS, WHERE MEASUREMENTS AND OBSERVATIONS WERE MADE.
SINGLE UNDERLINED: LIGHTSHIPS, WHERE OBSERVATION MATERIAL WAS COLLECTED.

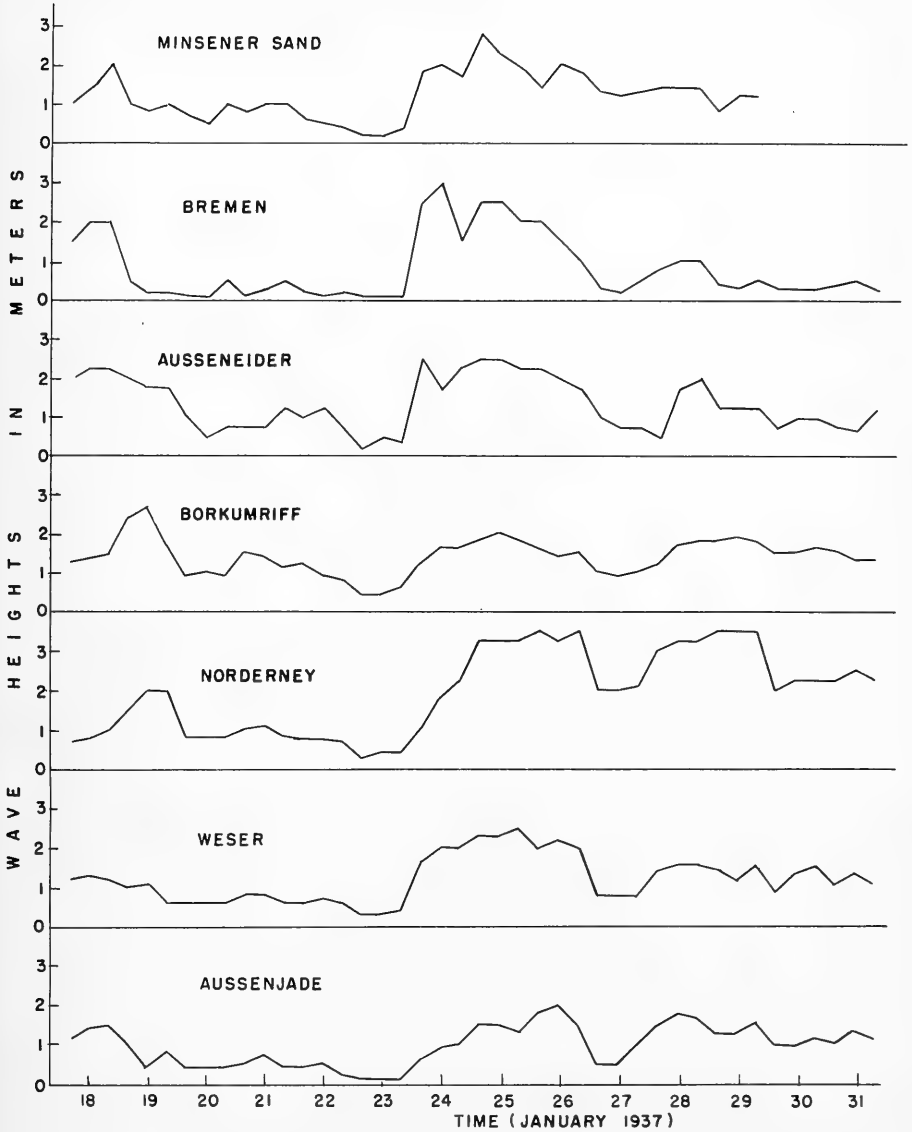


FIGURE 14. COMPARISON OF WAVE HEIGHTS OBSERVED ON DIFFERENT LIGHTSHIPS IN THE NORTH SEA (SEE MAP, FIG. 13)

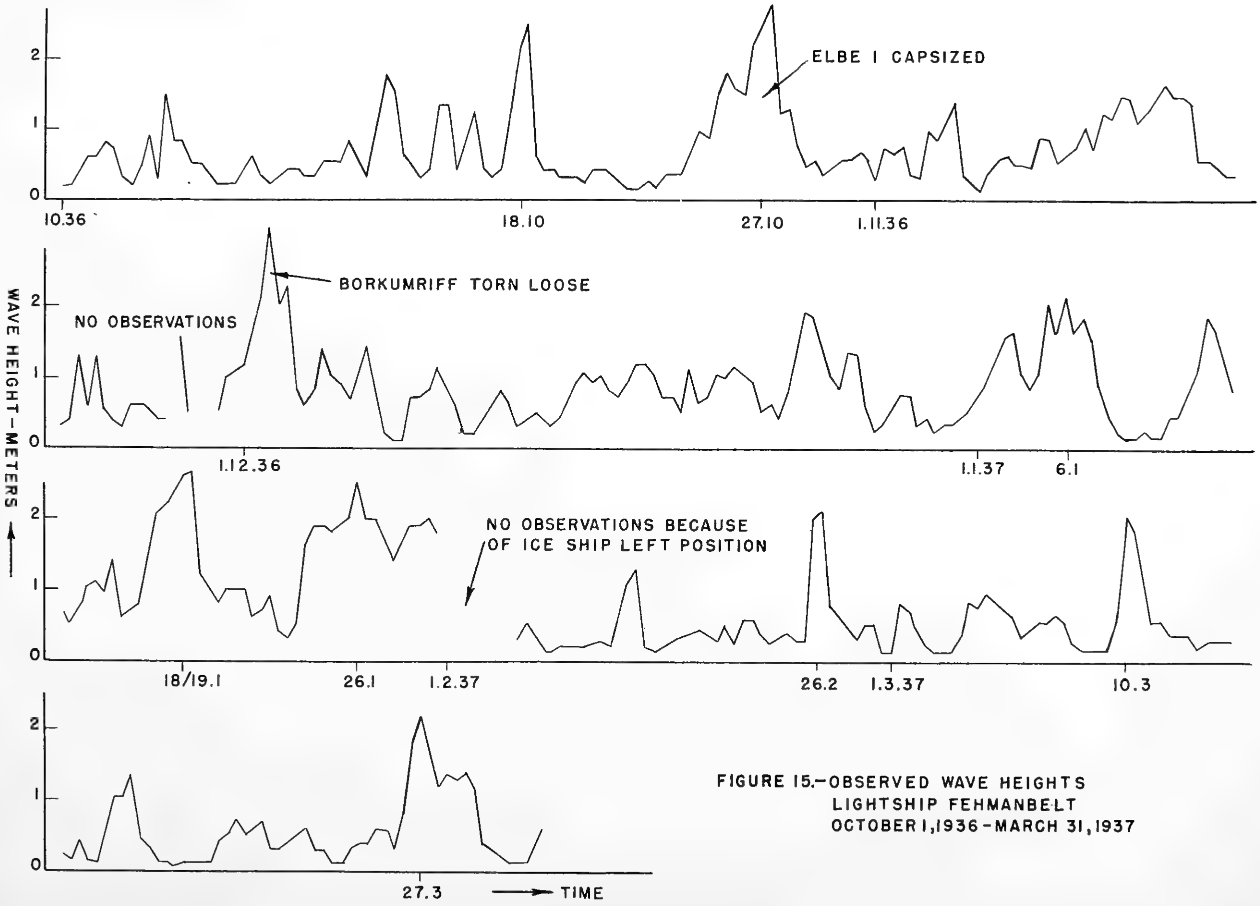


FIGURE 15.-OBSERVED WAVE HEIGHTS
LIGHTSHIP FEHMANBELT
OCTOBER 1,1936-MARCH 31,1937

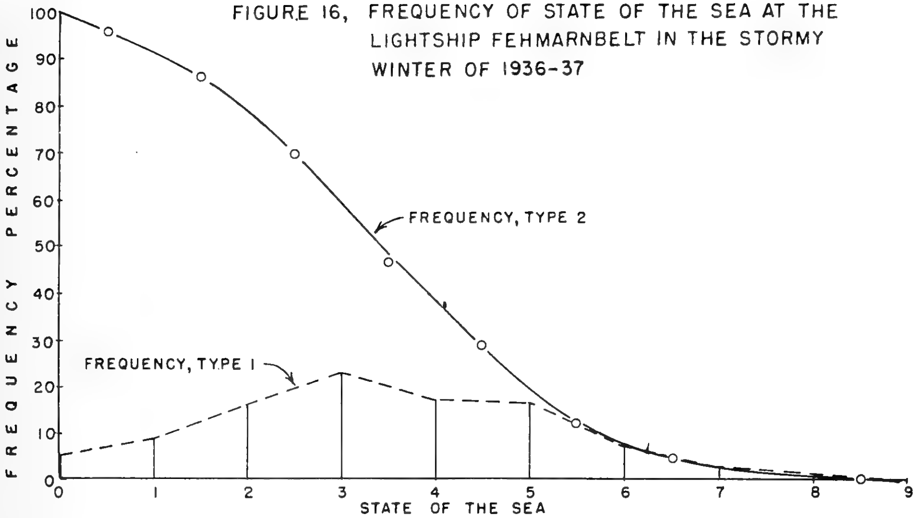


FIGURE 16, FREQUENCY OF STATE OF THE SEA AT THE LIGHTSHIP FEHMARNBELT IN THE STORMY WINTER OF 1936-37

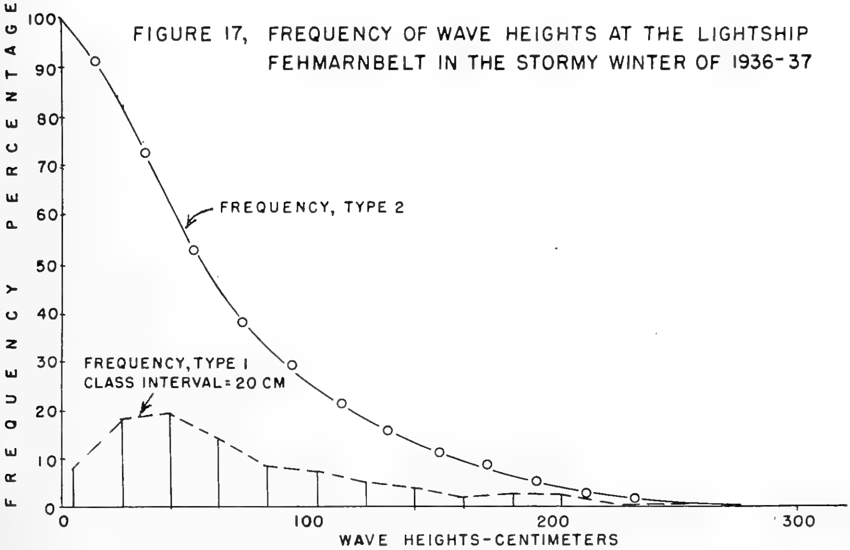


FIGURE 17, FREQUENCY OF WAVE HEIGHTS AT THE LIGHTSHIP FEHMARNBELT IN THE STORMY WINTER OF 1936-37

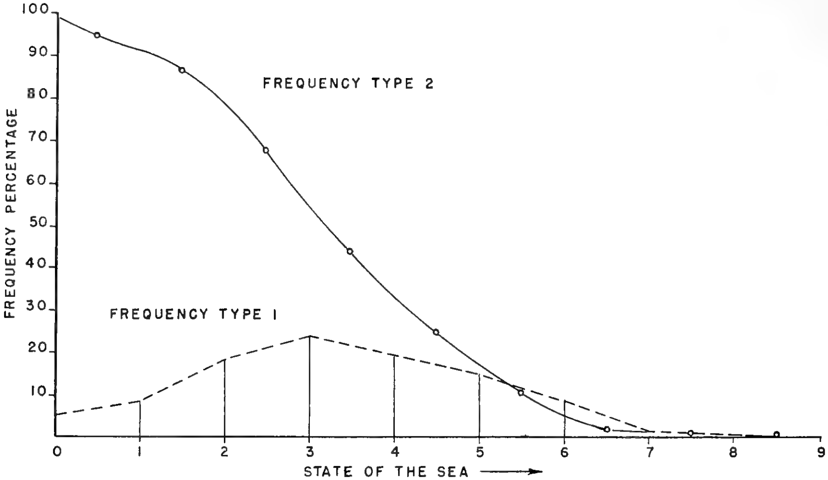


FIGURE 18.– FREQUENCY OF STATE OF THE SEA AT THE LIGHTSHIP BORKUMRIFF, WINTER 1936–37

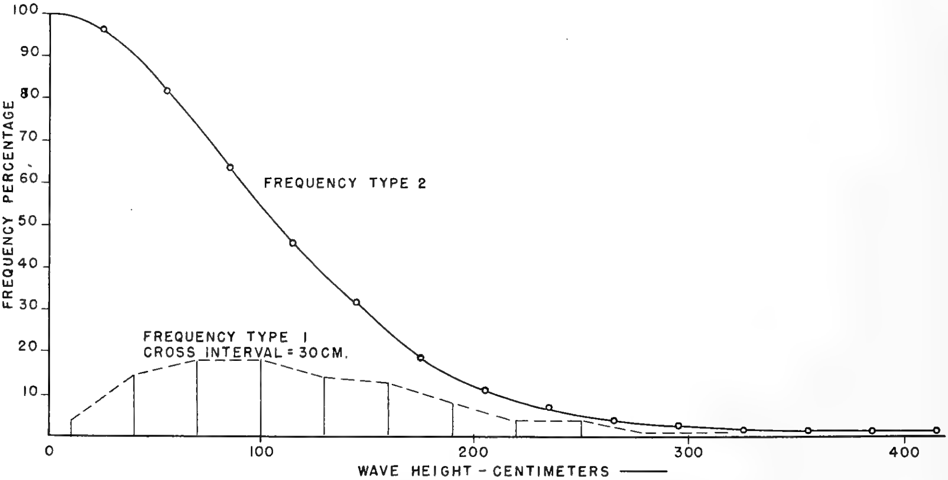


FIGURE 19.– FREQUENCY OF WAVE HEIGHTS AT LIGHTSHIP BORKUMRIFF IN THE STORMY WINTER 1936–37

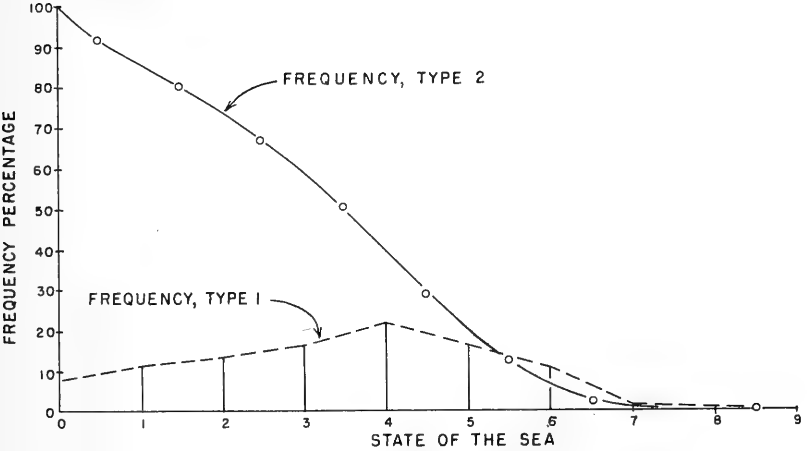


FIGURE 20. FREQUENCY OF STATE OF THE SEA AT THE LIGHTSHIP AMRUMBANK IN THE STORMY WINTER OF 1936-37.

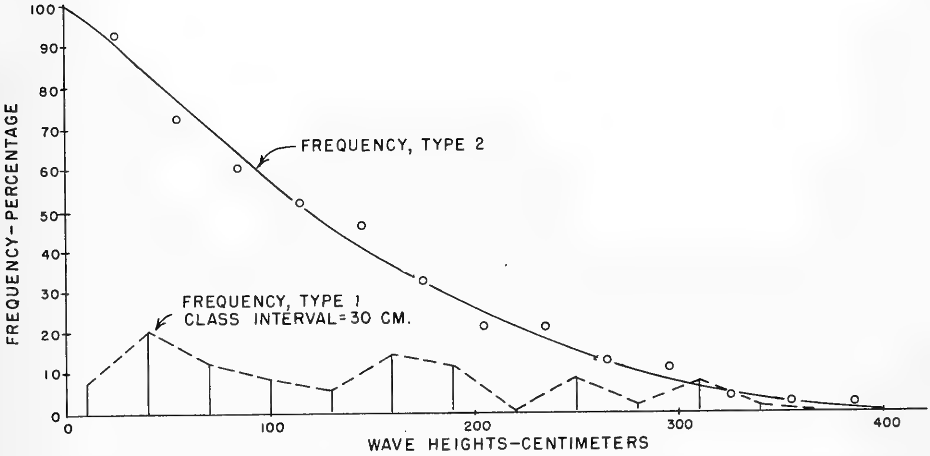


FIGURE 21. FREQUENCY OF WAVE HEIGHTS AT THE LIGHTSHIP AMRUMBANK IN THE STORMY WINTER OF 1936-37.

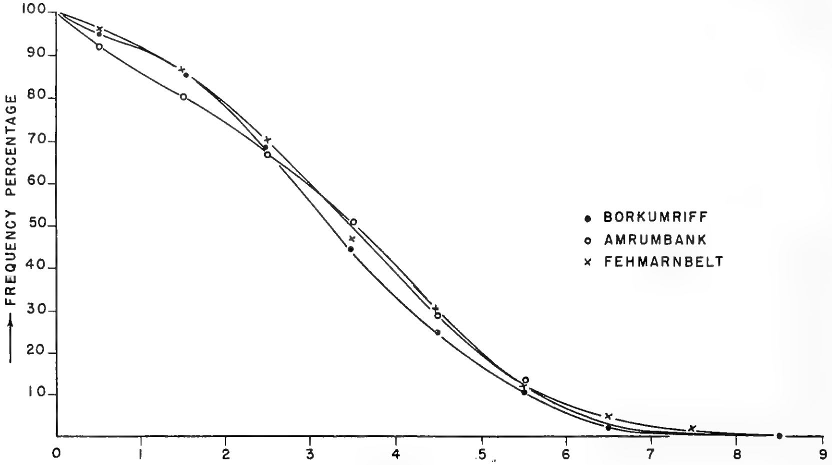


FIGURE 22 — COMPARISON OF FREQUENCY OF STATES OF THE SEA.

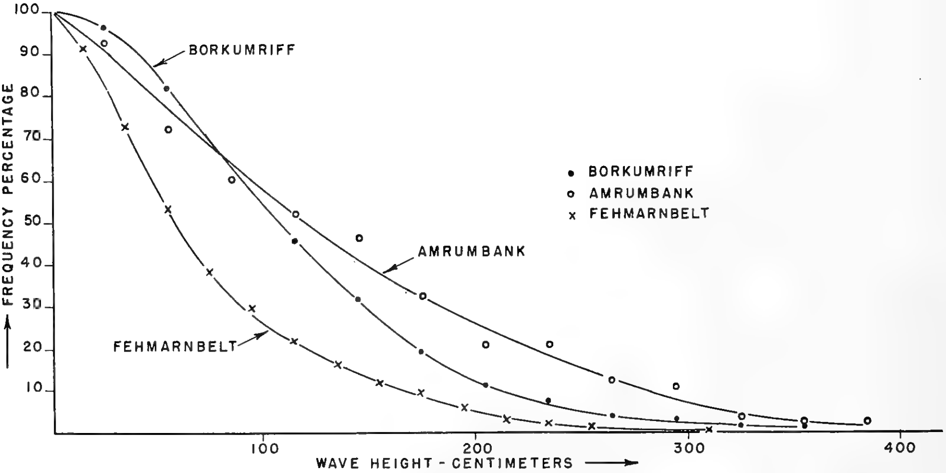


FIGURE 23.— COMPARISON OF FREQUENCY OF WAVE HEIGHTS.

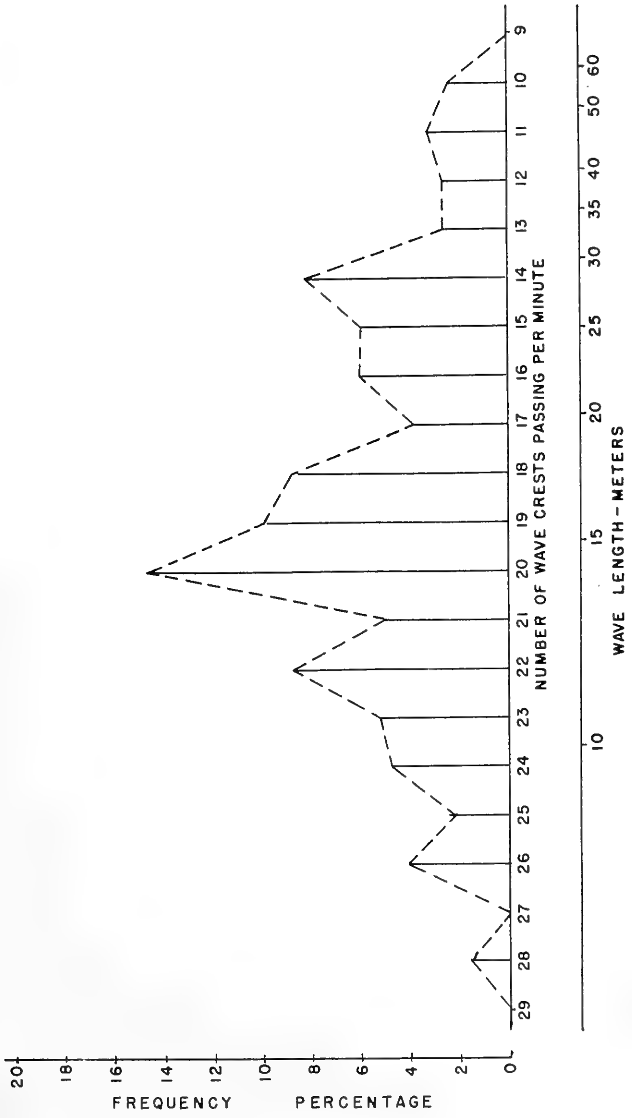


FIGURE 24. FREQUENCY OF WAVE LENGTH AT THE LIGHTSHIP FEHMARNBELT, WINTER 1936-37

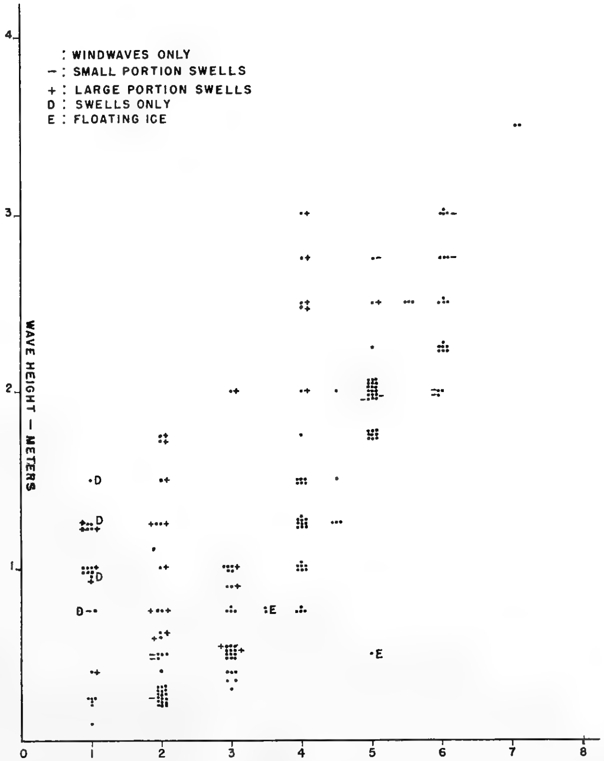


FIGURE 25.– RELATION OF WAVE HEIGHTS TO STATES OF THE SEA OBSERVER VII LIGHTSHIP AUSSENEIDER

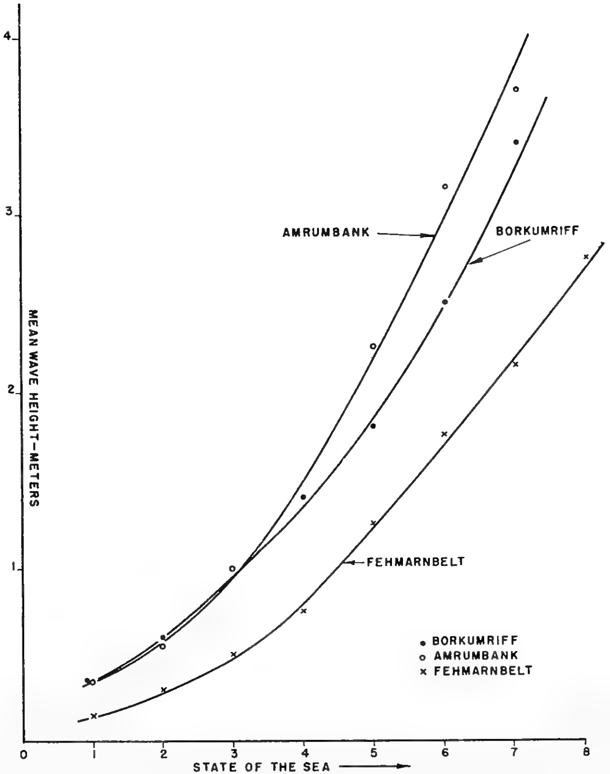
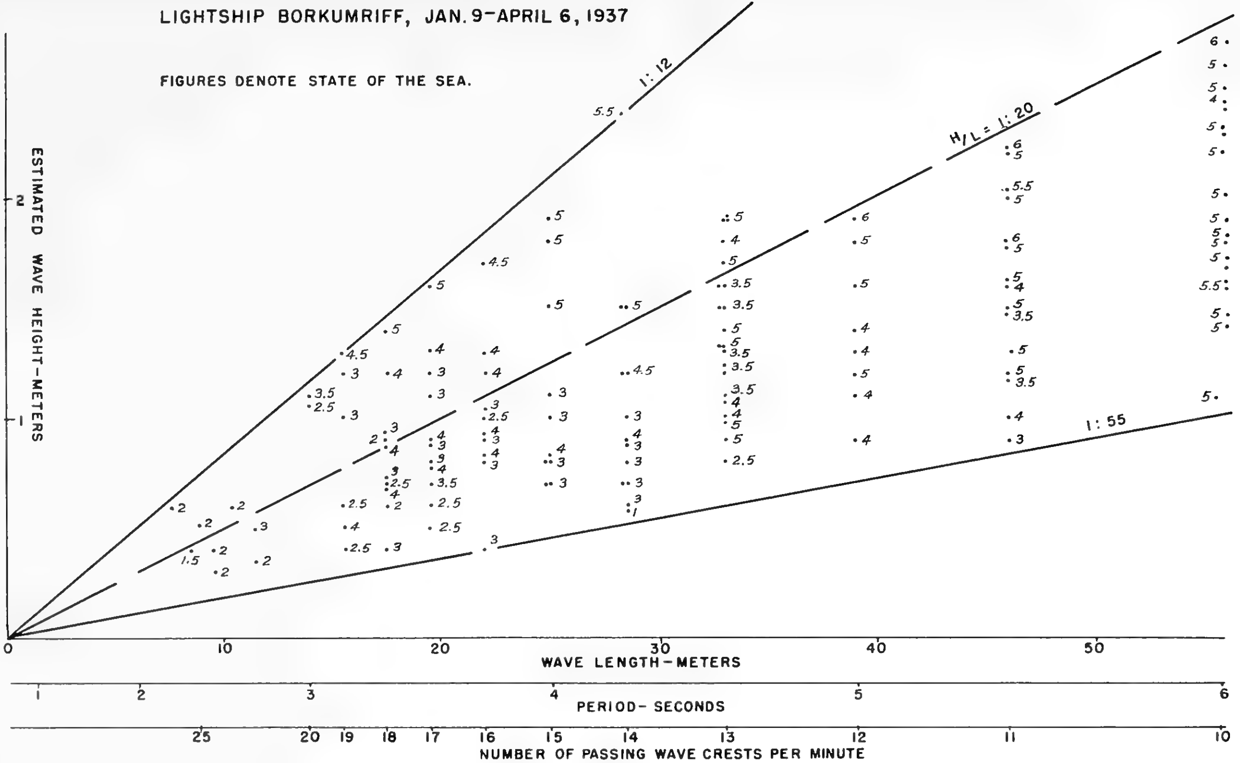


FIGURE 26.– RELATION OF WAVE HEIGHTS TO STATES OF THE SEA, WINTER 1936-37

FIGURE 27. WAVE DIMENSIONS AND RELATIVE STATES OF THE SEA LIGHTSHIP BORKUMRIFF, JAN. 9–APRIL 6, 1937



FIGURES DENOTE STATE OF THE SEA.

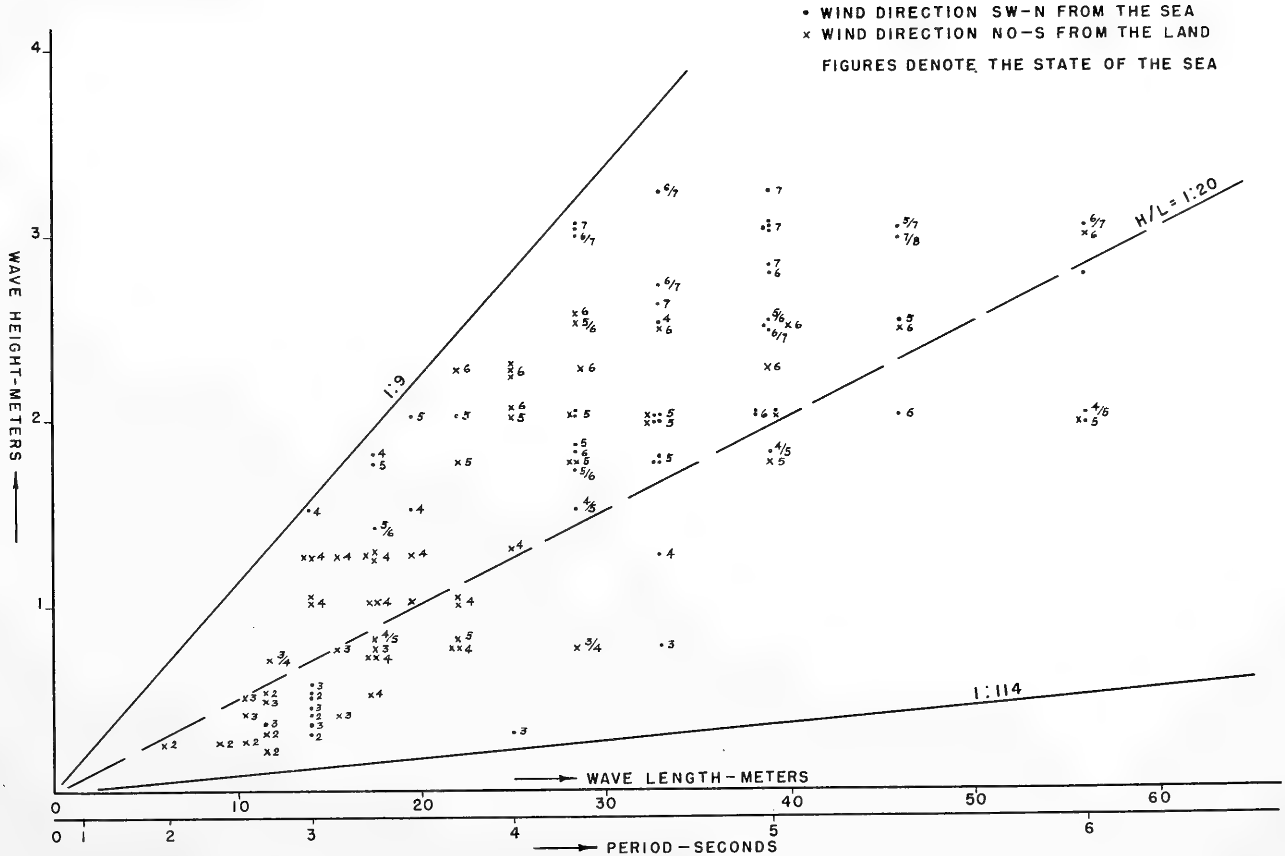
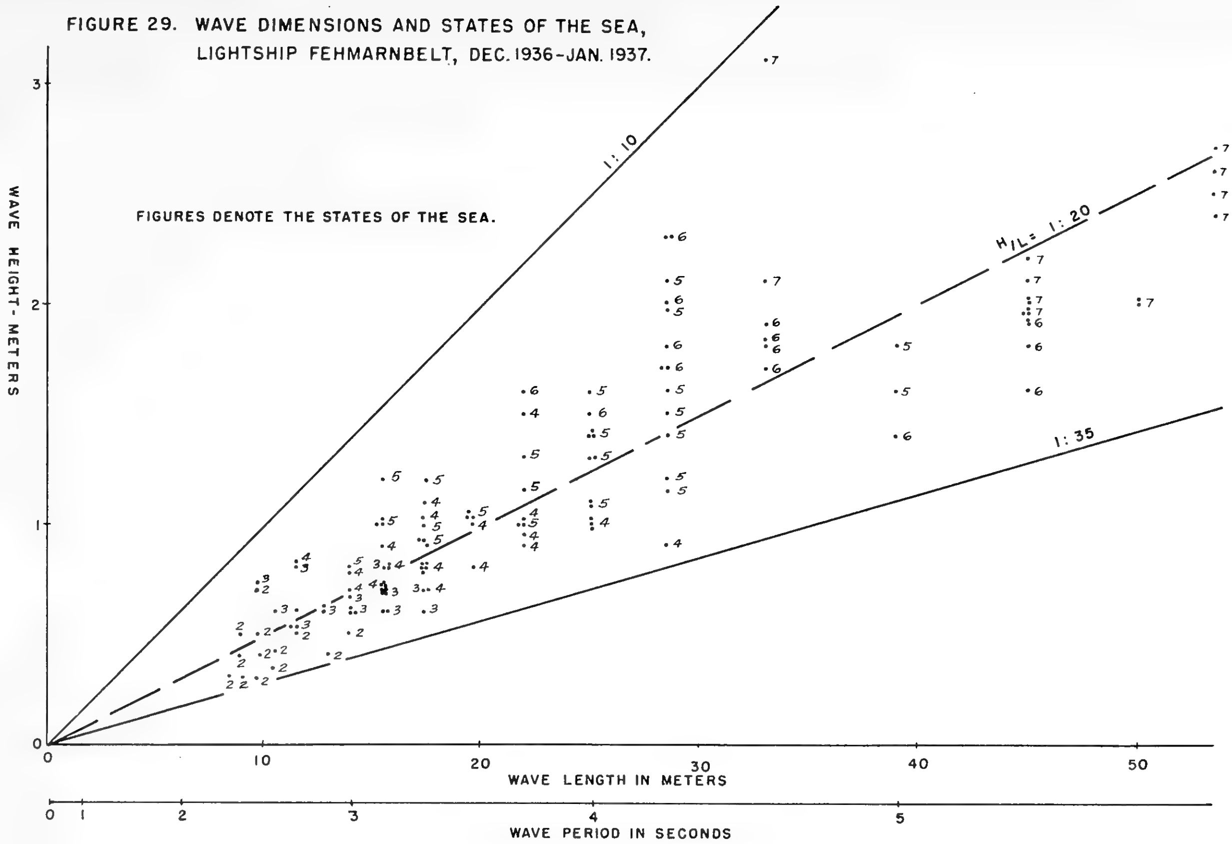


FIGURE 28.- WAVE DIMENSIONS AND RELATIVE STATES OF THE FOR DIFFERENT DIRECTIONS OF THE WIND; DEC., 1936-JAN., 1937 LIGHTSHIP AUSSENEIDER.

FIGURE 29. WAVE DIMENSIONS AND STATES OF THE SEA, LIGHTSHIP FEHMARNBELT, DEC. 1936-JAN. 1937.



FIGURES DENOTE THE STATES OF THE SEA.

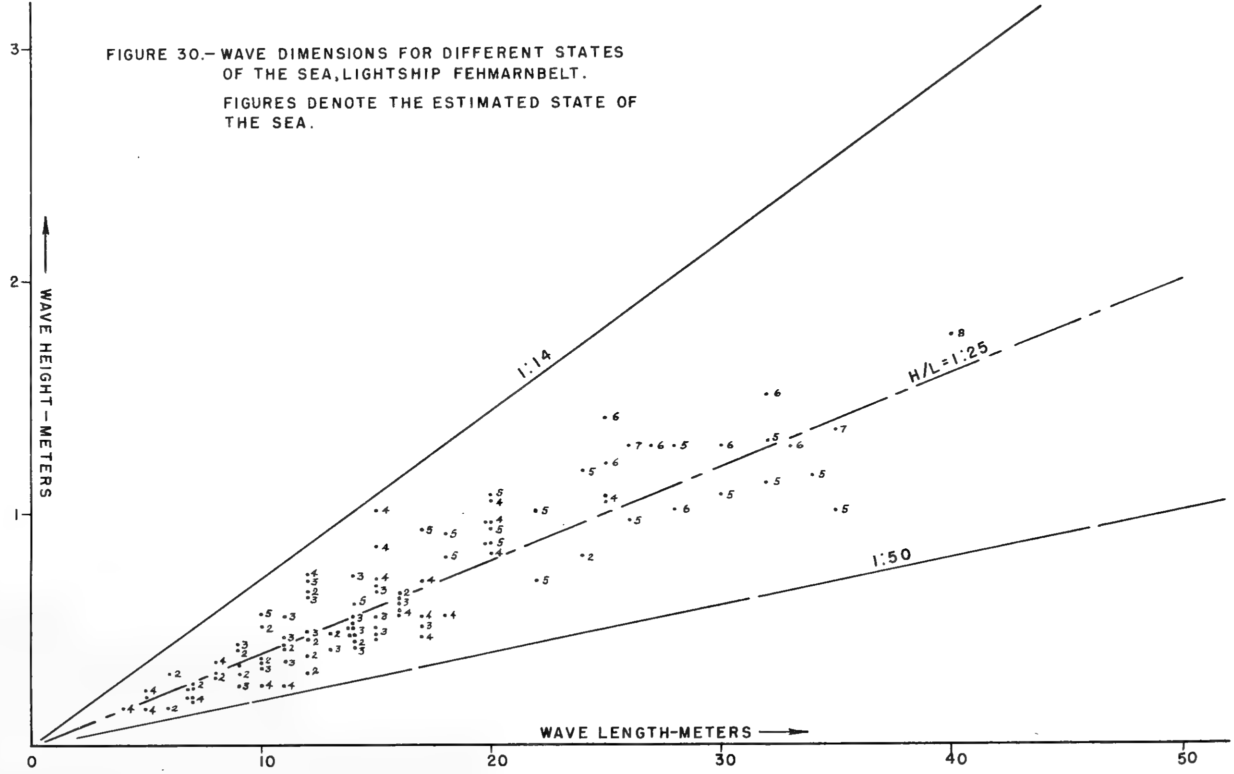


FIGURE 30.—WAVE DIMENSIONS FOR DIFFERENT STATES OF THE SEA, LIGHTSHIP FEHMARNBELT.

FIGURES DENOTE THE ESTIMATED STATE OF THE SEA.

A METHOD OF ESTIMATING WAVE DIRECTION

D. R. Forrest, Project Engineer
Beach Erosion Board

For the past several months a field research group of the Beach Erosion Board has been engaged in making hydrographic surveys and daily observations at Mission Bay, San Diego, California. The daily observations consist of estimating wave period, height and direction, local wind direction and velocity, and littoral drift direction and velocity.

Of the several observations, a satisfactory method of estimating wave direction has presented the greatest problem. This has been overcome to some extent by using a sighting bar (figure 1) and auxiliary sights attached to an ordinary engineer's transit (figure 2). An automatic recording device would be superior but lacking such a device the sighting bar has yielded generally acceptable results.

The sighting bar consists of a 3/16-inch diameter brass rod 8 inches long, one end of which is threaded to fit in the place of the end cap of the transit's horizontal spindle. Several such rods have been procured from a local machine shop at a nominal cost. In order that the rod accurately extends the horizontal axis of the transit, the rod must be straight and the threads cut to a square shoulder.

The rod is attached to the transit only at the time of use but the small aluminum auxiliary sights, to aid in pointing the telescope, have been permanently installed. These sights are held in place by the capstan adjusting nuts of the level tube, with line of sight made parallel to the optical axis of the transit telescope. They are inconspicuous and do not interfere with any other use of the transit.

To measure wave direction, the transit is set up over a point of known location and elevation and oriented on a distant point of known direction. Since the sighting bar, when attached, revolves in a horizontal plane approximately parallel to the sea surface, it is possible to align the bar visually with a wave crest and read the orthogonal azimuth on the plate of the transit directly. When the sighting bar is in alignment or parallel with the sighted wave crest, the telescope will be oriented perpendicular to the wave crest extended or in the direction of the orthogonal. The telescope will not be pointing toward the position of the sighted wave, unless the particular wave chosen is traveling directly toward the observer. An observer may obtain best results in aligning the bar to the wave crest, by sighting with one eye closed (figures 3 and 4). To obtain the position of the wave which was sighted, the transit is simply pointed

FIGURE I.- THE SIGHTING BAR

FIGURE 2.-THE SIGHTING BAR AND AUXILIARY SIGHTS ATTACHED TO A TRANSIT.

FIGURE 3.-METHOD OF OBSERVING WAVE DIRECTION

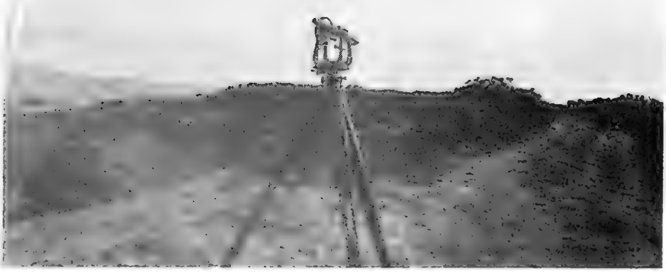


FIGURE 4.- THE OBSERVER'S VIEW.

at it, using the auxiliary sights, and the azimuth and vertical angle read. Sighting through the telescope is unsatisfactory since the field of view is too small and the magnification undesirable.

The higher the observation station the better, provided it is not too distant from the sea area where the wave direction is to be measured. At Mission Bay two stations are in use. The one most used is U.S.C. and G.S. triangulation station "Jolla" which provides a height of instrument of elevation 535.6 msl and is located approximately 4,000 feet from the beach. A chart (figure 5) has been plotted showing the relation of vertical angle to distance from the observation stations. The maximum distance which can be determined with reasonable accuracy is about 20,000 feet for station "Jolla". The chart has been corrected for the earth's curvature and refraction. The maximum distance from an observation station that swell direction can be measured with the sighting bar seems to be that obtained by a vertical angle of about $1\frac{1}{2}^{\circ}$. For smaller angles the errors in locating a wave and measuring its direction become excessive. The larger the vertical angle the more accurate is the position and direction of the wave determined. However, it appears desirable to make observations as far from shore as practicable and a compromise is thus required, with some sacrifice in accuracy. With the azimuth and distance to the observed point of the wave crest thus known, the point is plotted and the orthogonal azimuth drawn. This may or may not be the deep-water direction, depending upon the wave period. At Mission Bay, for periods of 10 seconds or more, comparison with wave refraction diagrams is necessary in order to obtain deep-water direction.

A test of the accuracy of the method was made by making observations at the same time aerial photos were being flown. A controlled mosaic (figure 6) was made and the observed wave directions plotted thereon. Though the photography left much to be desired, several satisfactory comparisons were possible. At the time of observation three separate wave patterns existed. One had a very short period and was not identifiable from shore. The other two had estimated wave heights of about 2 feet and had relatively long periods. Of 10 shore observations which plotted in areas on the photos in which swell could be identified, the average error in wave direction appeared to be about 3° with a maximum error of 5°.

There are several features which limit the usefulness of the sighting bar in measuring the direction of wave fronts, namely:

1. It is nonrecording and requires an observer.
2. Observation can be made only during daylight and when fog, rain, or haze conditions are not prohibitive.
3. A high observation station close to the sea is desirable.

4. A very flat sea or a confused one with much wind chop results in inaccurate directions.

5. The relative position of the sun may cause an observer to fail to identify a swell.

The advantages of the device are as follows:

1. The direction is obtained visually and directly.

2. For well-defined wave crests average errors of about five or six degrees may be expected.

3. It is simple to operate.

4. Its cost is nominal assuming possession of a transit.

* * * * *

ANNOUNCEMENT OF PUBLICATIONS

The Beach Erosion Board announces the publication of Technical Memorandum No. 13, "Longshore Current Observations in Southern California," and Technical Memorandum No. 14, "Report on Beach Study in the Vicinity of Mugu Lagoon, California." Copies are being mailed to those individuals and institutions on the mailing list for technical publications.

The memoranda are contributions from the Scripps Institution of Oceanography and report the results of shore studies conducted along the coast of California.

Investigations of longshore currents measured in the surf zone at frequent intervals throughout a year at a series of stations along the southern California Coast are described and discussed in Technical Memorandum No. 13. The study indicates that dominant currents in the area are to the south in response to the direction of approach of the principal wave trains, while north currents indicative of southern hemisphere storms prevail during a large part of the summer and fall.

Investigations to determine the relative stability of the beaches and sand spits bordering Mugu Lagoon are reported in Technical Memorandum No. 14. The effect of spring tides, high waves, and direction of longshore transport of sand on the spits is discussed.

A limited number of copies are available for distribution upon request to the President, Beach Erosion Board, Corps of Engineers, 5201 Little Falls Road, N. W., Washington 16, D. C.

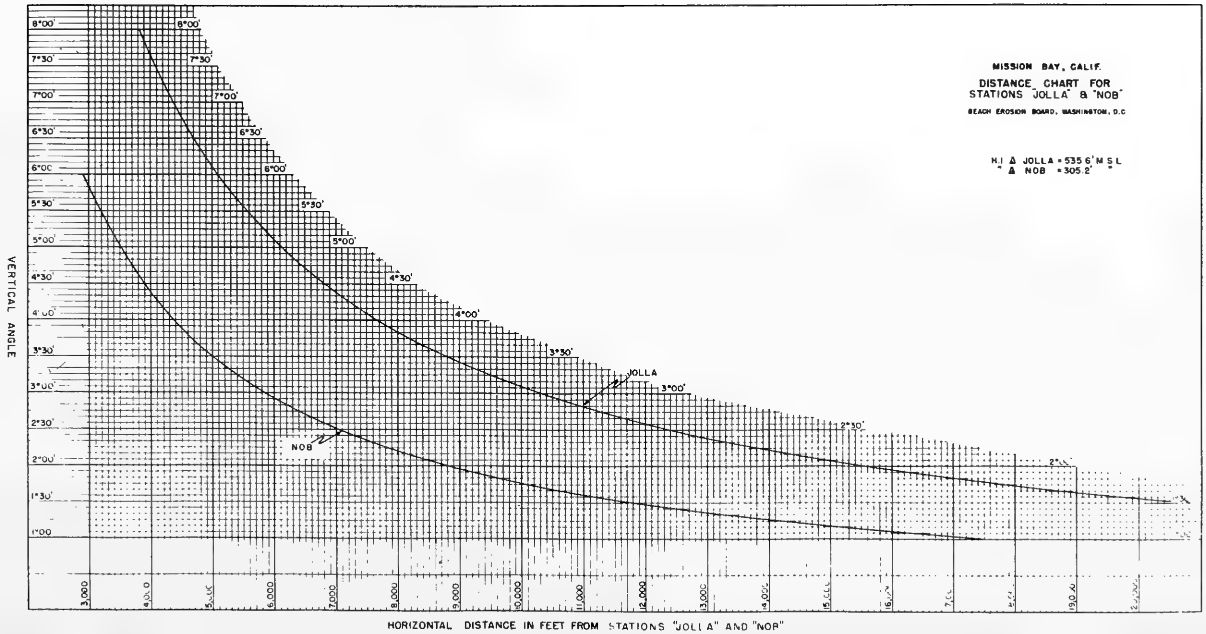

MISSION BAY, CALIF.
DISTANCE CHART FOR STATIONS "JOLLA" & "NOB"
BEACH EROSION BOARD, WASHINGTON, D.C.
H.I Δ JOLLA = 535.6' M.S.L.
" Δ NOB = 305.2' "
JOLLA
NOB
8°00'
7°30'
7°00'
6°30'
6°00'
5°30'
5°00'
4°30'
4°00'
3°30'
3°00'
2°30'
2°00'
1°30'
1°00'
VERTICAL ANGLE
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
11,000
12,000
13,000
14,000
15,000
16,000
17,000
18,000
19,000
20,000
HORIZONTAL DISTANCE IN FEET FROM STATIONS "JOLLA" AND "NOB"

FIGURE 5.

FIGURE 6.– MOSAIC OF AERIAL PHOTOS SHOWING COINCIDENT SHORE OBSERVATIONS

EXPANSION OF BEACH EROSION BOARD RESEARCH FACILITIES

The expansion of the Beach Erosion Board research facilities by the construction of a large wave tank and a coast model test basin is in progress adjacent to the Board's offices and laboratory. The wave tank will be 635 feet long, 15 feet wide, and 20 feet deep. In plan the test basin will be 300 feet by 150 feet and inclosed by a 3-foot perimeter wall. Contract work is about 90 per cent complete at the time this publication goes to press.

Excavation work for the wave tank and coast model basin has been completed and concrete work is on schedule and practically complete. Photographs of the construction operations on the wave tank and coast model basin are shown in figures 1-5.

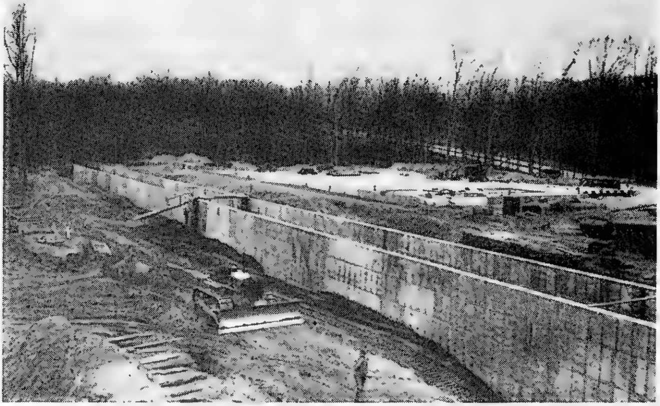


FIGURE I. GENERAL VIEW OF AREA, WAVE TANK IN FOREGROUND AND MODEL TEST BASIN IN BACKGROUND

FIGURE 2. WAVE TANK INTERIOR AND CONSTRUCTION OF WAVE GENERATOR SUPPORTING STRUCTURE IN THE BACKGROUND

FIGURE 3. INTERIOR VIEW OF ENTIRE LENGTH OF WAVE TANK LOOKING TOWARD WAVE GENERATOR

FIGURE 4. GENERAL VIEW OF THE COAST MODEL TEST BASIN.

FIGURE 5. COAST MODEL TEST BASIN PERIMETER WALL AND FLOOR SLAB.

BEACH EROSION STUDIES

The principal types of beach erosion reports of studies at specific localities are the following:

a. Cooperative studies (authorization by the Chief of Engineers in accordance with Section 2, River and Harbor Act approved on 3 July 1930).

b. Preliminary examinations and surveys (Congressional authorization by reference to locality by name).

c. Reports on shore line changes which may result from improvements of the entrances at the mouths of rivers and inlets (Section 5, Public Law No. 409, 74th Congress).

d. Reports on shore protection of Federal property (authorization by the Chief of Engineers).

Of these types of studies, cooperative beach erosion studies are the type most frequently made when a community desires investigation of its particular problem. As these studies have, consequently, greater general interest, information concerning studies of specific localities contained in these quarterly bulletins will be confined to cooperative studies. Information about other types of studies can be obtained upon inquiry to this office.

Cooperative studies of beach erosion are studies made by the Corps of Engineers in cooperation with appropriate agencies of the various States by authority of Section 2, of the River and Harbor Act approved on 3 July 1930. By executive ruling the cost of these studies is divided equally between the United States and the cooperative agency. Information concerning the initiation of a cooperative study may be obtained from any District Engineer of the Corps of Engineers. After a report on a cooperative study has been transmitted to Congress, a summary thereof is included in the next issue of this bulletin. A list of cooperative studies now in progress follows the summary.

SUMMARIES OF REPORTS TRANSMITTED TO CONGRESS

SOUTH SHORE, STATE OF RHODE ISLAND

The shore area studied is located mainly on the Atlantic Ocean and Block Island Sound. It includes the shores of the Towns of Narragansett, South Kingstown, Charlestown, and Westerly, extending from the mouth of Narrow River to the Rhode Island - Connecticut State line. The shore area is generally low ground with many ponds and marshes. The major exception is the shore between Narragansett Pier and Point Judith which includes bluffs of glacial till and moderately high rocky cliffs.

The area is primarily a summer resort area. The permanent population is centered principally in the villages of Narragansett Pier, Wakefield, and Westerly. Summer colonies are scattered throughout the shore area and the influx of summer residents greatly increases the population of the area. Good highways connect the area with population centers in northern Rhode Island and adjacent States.

Except for the rocky shores between Narragansett Pier and Point Judith, almost the entire shore area has sandy beaches. The more accessible beaches are developed for recreational use. Public recreational beaches are owned and operated by the State and towns. Some private beaches are also open to the public at a reasonable fee.

The purpose of the Beach Erosion Board's study was to determine the best methods of (a) restoring and protecting the shore lines against damage from storms and hurricanes, and (b) maintaining openings into certain salt water ponds. The Board reviewed the geological history of the area and studied the tides, currents, winds, and wave action, effects of storms on the shore, movement of beach material, effects of existing structures and changes in the shore line and offshore depth contours, and pursuant to statutory requirements, analyzed the public interest involved in protecting and improving the publicly owned beaches.

The Board found that protection of the entire length of the shore line under study is neither practicable nor essential. The Board also found that openings within the area covered that require consideration of continued maintenance are Narrow River (inlet to Pettaquamscutt River), Charlestown Inlet, Quonochontaug Inlet, and Weekapaug Breachway (inlet to Winnapaug Pond). The Board concluded that the best method of accomplishing the objectives of the study comprise the following: For the inlets named above, maintenance by periodic removal of material as required; for the Narragansett Pier beach, widening of the beach by direct placement of sand and construction of groin system and a barrier to landward sand movement; for Point Judith Harbor, widening of the beach by direct placement of sand, providing a barrier to landward sand movement and, if experience indicates the necessity thereof, providing a groin system as deferred construction; for Jerusalem, provision of a barrier to landward sand movement; for the beach east of Matunuck Point, artificial replenishment of the beach and construction of a groin system and dunes; for Matunuck Point, grading and revetting the slope; for Misquamicut and East Beaches, stockpiling of sand on East Beach and providing a barrier to landward sand movement; for Napatree Beach, widening the beach by direct placement of sand, providing a barrier to landward sand movement and, if later found necessary, a groin system as deferred construction. The Board further concluded that the public interest justifies adoption of a Federal project for improvement and protection of the Narragansett Pier, Point Judith Harbor, and Napatree Beaches.

The Planning Board of the Town of Narragansett proposed a modification of the plan for Narranganset Pier beach providing for a jetty at each end of the beach and a single groin about midway of the beach, the latter only if loss of fill is excessive, in lieu of the seven groins proposed by the Beach Erosion Board. The Beach Erosion Board did not consider the modification as effective as the recommended plan. However, the Board considered the alternative a permissible substitute provided satisfactory methods for maintaining the beach are adopted.

The Board recommended that a project be adopted by the United States authorizing Federal participation by the contribution of Federal funds in an amount equal to one-third of the cost of the following proposed works for shore protection and improvement:

a. At Narragansett Pier, widening the beach between Upper Pier and Narrow River an average of about 125 feet by direct placement of sand and constructing seven impermeable groins and a barrier to landward sand movement;

b. At Point Judith Harbor, widening the beach for a length of about one mile west from the east limit of the State beach an average of about 65 feet by direct placement of sand, constructing a barrier to landward sand movement, and if experience indicates the necessity, construction of ten impermeable groins;

c. At Napatree Beach, constructing a barrier to landward sand movement, and, if experience indicates the necessity, construction of three impermeable groins. The proposed artificial replenishment of Napatree Beach has been accomplished in connection with the disposal of dredged material from a navigation project.

The Board recommended contribution of Federal funds subject to the conditions that responsible local interest will: (1) adopt the recommended projects, or in the case of Narragansett Pier, adopt the plan for artificial beach building with such maintenance methods as they desire in lieu of the groin system, subject to approval thereof by the Chief of Engineers; (2) assure maintenance of the improvement and protective measures during their useful life, as may be required to serve their intended purpose; (3) provide at their own expense, all necessary lands, easements, and rights-of-way; (4) hold and save the United States free from all claims for damages that may arise either before, during or after prosecution of work; (5) assure that water pollution that would endanger the health of bathers will not be permitted; (6) assure continued public ownership of the beach and its administration for public use only.

In addition the Board recommended that the adequacy of work proposed by local authorities, detailed plans, specifications, assurances that the requirements of local cooperation will be met and arrangements for prosecuting the entire project be approved by the Chief of Engineers prior to commencement of work.

The estimated costs of the work recommended by the Beach Erosion Board for the publicly owned shores are as follows: Narragansett

Pier (Beach Erosion Board Plan) $136,500; Point Judith Harbor, $190,500; and Napatree Beach, $75,000. The estimated amounts of Federal participation are $45,500 for Narragansett Pier, $63,500 for Point Judith Harbor, and $25,000 for Napatree Beach.

* * * * *

STATE OF CONNECTICUT

Area 1 - Ash Creek to Saugatuck River

Area 1 of the State of Connecticut study comprises the shore of Long Island Sound between the mouths of Ash Creek and Saugatuck River, and includes the shore of the Town of Fairfield and part of the Town of Westport, a total length of about 9.2 miles. This shore area is adjacent to and west of Bridgeport, Connecticut, and is about 40 to 50 miles east of New York City. It is extensively developed as a resort and residential area, with improvements ranging from small cottages to large estates. Sherwood Island State Park comprising 1.2 miles of shore, and a number of small town-owned beaches are included in the area.

The eastern portion of the study area consists of low barrier beaches in front of extensive marsh areas. To the west several headlands of glacial material with some rock outcrops extend to the shore. Between these headlands wave-built bars have been formed and the shoreward areas generally have filled and become marshy. The headlands formerly supplied ample material to the intervening beaches, but seawalls constructed in connection with the development of the area now protect the headlands and reduce the supply of beach material. Consequently the beaches have slowly deteriorated, although Long Island affords considerable protection and wave action in the sound is generally not severe.

The Division Engineer considered the desires of the cooperating agency, studied the sources and movement of beach material, the changes in the shore line and offshore bottom, the effects of winds, storms, and of existing structures, developed a plan for protecting and improving the shores of the area, and made an economic analysis of proposed protective and improvement measures for publicly owned shores. He found that prospective benefits warrant construction of these measures and that the public interest therein justifies Federal participation to the extent of one-third of the total cost of recommended work, in accordance with the policy established by Public Law 727, 79th Congress. The Division Engineer recommended, subject to certain conditions of local cooperation, adoption of separate projects by the United States authorizing Federal participation in an amount equal to one-third of the costs of the improvements for the public beaches at Jennings Beach and Ash Creek, Sasco Hill Beach, Southport Beach, Burial Hill Beach, Sherwood Island State Park and Compo Beach.

The Board carefully considered the report of the Division Engineer and concurred generally in his views and recommendations. The Board recommended that projects be adopted by the United States authorizing Federal participation by the contribution of Federal funds in an amount equal to one-third of the first cost of the following measures for the protection and improvement of the shores of the Towns of Fairfield and Westport, Connecticut as follows:

a. Jennings Beach and Ash Creek. Construction of an impermeable west jetty about 800 feet long and, if experience indicates the necessity thereof, dredging of an inlet channel through the outer bar;

b. Sasco Hill Beach. Widening to 100-foot width about 900 feet of beach by direct placement of sand, and construction of one impermeable groin 400 feet long at the west end of the improvement;

c. Burial Hill Beach. Contingent upon the construction under the project for Sherwood Island State Park as set forth below, of a 400-foot training wall on the east bank of Burial Hill Creek, widening to a 100-foot width about 500 feet of beach by direct placement of sand;

d. Southport Beach. Widening to 100-foot width about 700 feet of beach by direct placement of sand, and construction of one impermeable groin 400 feet long at the west end of the improvement.

e. Sherwood Island State Park. Widening to a 150-foot width about 6,000 feet of beach by direct placement of sand, the creation of a stockpile by direct placement of sand for an additional width of 100 feet for a distance of 1,000 feet each side of Sherwood Point, the construction of two training walls 400 and 500 feet long at Burial Hill Creek, and the construction of an impermeable groin 500 feet long at the west end of the improvement;

f. Compo Beach. Widening to 100-foot width beaches east and west of Cedar Point about 2,600 and 1,100 feet long respectively, by direct placement of sand, construction of two impermeable groins 500 feet long, one at Hills Point and one at the west end of the improvement.

The Board recommended Federal participation subject to the conditions that responsible local interests will: (1) adopt the recommended plans of protection and improvement; (2) assure maintenance of the improvements for their useful life as may be required to serve their intended purpose; (3) provide, at their own expense, all necessary lands, easements, and rights-of-way; (4) hold and save the United States free from all claims for damages that may arise either before, during, or after prosecution of the work; (5) assure that water pollution that would endanger the health of bathers will not be permitted; and (6) assure continued public ownership of the beaches and public lease of the Sasco Hill Beach, and the administration of these beaches for public use only.

The Board further recommended that the adequacy of work proposed by local authorities, detailed plans, specifications, assurances that the requirements of local cooperation will be met and arrangements for prosecuting the entire project be approved by the Chief of Engineers prior to commencement of work.

The estimated amounts of Federal participation in accordance with the Board's recommendations are as follows:

Jennings Beach and Ash Creek	$22,000
Sasco Hill Beach	14,000
Southport Beach	10,000
Burial Hill Beach	5,500
Sherwood Island State Park	114,000
Compo Beach	38,000
Total	203,500

The Board also concurred in the recommendation of the Division Engineer on the methods of protection and improvement developed for privately owned shores, for which no policy of Federal participation has been established.

Area 2 - Hammonasset River to East River

Area 2 of the State of Connecticut study comprises the shore of Long Island Sound between the mouths of the Hammonasset and East Rivers, and includes the shore of the Town of Madison and small portions of the adjoining Towns of Clinton and Guilford, a total length of about 10 miles. The area is about 100 miles east of New York City, about 25 miles east of the metropolitan area of New Haven and the same distance west of New London, Connecticut. The shore area is generally developed with summer cottages and a few larger estates. The surrounding area is generally of a rural nature. The permanent population of Madison is about 2,000, but the summer population is about four times that number. Hammonasset State Park, comprising 3½ miles of shore, and a number of smaller town-owned beaches are included in the area.

The shore area under consideration is generally low, flat and sandy. Numerous small outcrops of ledge rock have contributed materially to the stability of the shore. Erosion of glacial islands and headlands has supplied considerable quantities of material in the past, forming bay-mouth bars and tombolos. The small creeks running to the shore have narrow openings and valleys have filled and become marshy. The headlands, which formerly supplied ample material to the intervening beaches, have generally been protected by seawalls which reduce the supply of material. Consequently the beaches have deteriorated, although Long Island affords considerable protection and wave action generally is not severe.

The Division Engineer considered the desires of the cooperating agency, studied the sources and movement of beach material, the changes in the shore line and offshore bottom, the effects of winds, storms and of existing structures, developed a plan for protecting and improving the shore of the area, and made an economic analysis of proposed protective and improvement measures for publicly owned shores. He found that prospective benefits warrant construction of these measures and that the public interest therein justifies Federal participation to the extent of one-third of the recommended work, in accordance with the policy established by Public Law 727, 79th Congress. The Division Engineer recommended, subject to certain conditions of local cooperation, adoption of separate projects by the United States authorizing Federal participation in an amount equal to one-third of the costs of the improvements for the public beaches at Hammonasset Beach and Middle Beach.

The Board carefully considered the report of the Division Engineer and concurred generally in his views and recommendations. The Board recommended that projects be adopted by the United States authorizing Federal participation by the contribution of Federal funds in an amount equal to one-third of the first cost of the following measures for the protection and improvement of the shores of the Town of Madison, Connecticut, as follows:

a. Hammonasset Beach. - Widening of 50 feet at the east end increasing to 100 feet at the west end, about 10,000 feet of beach by direct placement of sand, construction of two impermeable training walls at Toms Creek, 320 and 400 feet long, and an impermeable groin at Hammonasset Point, 800 feet long;

b. Middle Beach. - Revetment of 700 feet of sea wall by placement of riprap for a width of 20 feet, or contingent upon evidence satisfactory to the Chief of Engineers that facilities for public use will be provided by local interests, widening to a 100-foot width 700 feet of beach by the direct placement of sand and construction of an impermeable groin 300 feet long, all in lieu of the revetment.

The Board recommended Federal participation subject to the conditions that responsible local interests will: (1) adopt the recommended plans of protection and improvement, (2) assure maintenance of the improvements during their useful life as may be required to serve their intended purpose; (3) provide, at their own expense, all necessary lands, easements, and rights-of-way; (4) hold and save the United States free from all claims for damages that may arise either before, during or after prosecution of the work; (5) assure that water pollution that would endanger the health of bathers will not be permitted; (6) assure continued public ownership of the shore and its administration for public use only.

The Board further recommended that the adequacy of work proposed by local authorities, detailed plans, specifications, assurances that the requirements of local cooperation will be met and arrangements for prosecuting the entire project be approved by the Chief of Engineers prior to commencement of work.

The estimated amounts of Federal participation in accordance with the foregoing recommendations are as follows:

Hammonasset Beach	$128,000
Middle Beach (Revetment method)	11,000
Middle Beach (Alternative protective beach method)	17,000

The total estimated Federal participation is therefore $138,000 or $145,000 depending upon the plan adopted for Middle Beach.

The Board also concurred in the recommendation of the Division Engineer on the methods of protection and improvement developed for privately owned shores, for which no policy of Federal participation has been established.

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ATLANTIC CITY, NEW JERSEY

Atlantic City is located on the coast of New Jersey about 45 miles northeast of Cape May, the southern tip of the State at the entrance to Delaware Bay. It comprises nearly one-half of the length of the barrier beach island known as Absecon Island. Absecon Inlet is the northeastern boundary of the city and island.

Atlantic City is approximately 60 miles from Philadelphia, Pa., and 125 miles from New York City. The extensive development and dense population of the area within a few hundred miles of Atlantic City make it the most popular resort of its kind in the country. The total patronage of the resort is estimated at 13,000,000 annually. The summer residents are estimated at 800,000 compared to the permanent population of 70,000. Summer week-end vacationists are estimated at 360,000. Visitors are drawn from all parts of the country and also from foreign countries. In addition to the summer patronage, there is considerable patronage during the remainder of the year. Many conventions are held there, attracted by the large convention hall and excellent hotel facilities. The assessed valuation of property in the city in 1948 was nearly $94,000,000.

The ocean front beaches in Atlantic City are generally wide and flat. However in recent years the beach adjacent to Absecon Inlet has deteriorated until the high water line was shoreward of the Boardwalk. In 1948 the city and State restored the beach in this area by artificial fill and constructed a jetty at the inlet and a groin south thereof to retain the fill. The inlet beaches are steep and subject to erosion by the strong inlet tidal currents. A groin system retards the erosion, but the beaches have been unsatisfactory. A timber bulkhead protects the street behind the beach. At the throat of the inlet a heavy riprap revetment and a concrete wall are threatened with undermining. Fill was placed on the inlet beaches in 1948. Practically the entire shore frontage is publicly owned. The purpose of the study was to determine the causes of the erosion and remedial measures to present further erosion and to restore the beaches.

The District Engineer considered the desires of the cooperating agency, studied the sources and movement of beach material, the changes in the shore line and the offshore bottom, the effects of winds, storms and of existing structures, developed a plan for protecting and improving the shores, and made an economic analysis of proposed protective measures. He found that the recreational and other benefits of the proposed work warrant the adoption of a comprehensive plan of protection and improvement. He concluded that the public interest therein warrants Federal participation to the extent of one-third of the total cost in accordance with the policy established by Public Law 727, 79th Congress.

The District Engineer recommended adoption of a project for control of beach erosion and for restoration and protection of the shore lines along Absecon Inlet and the Atlantic Ocean in Atlantic City, New Jersey, the work thereunder to comprise the removal of the damaged portion of the retaining bulkhead on the city park frontage west of the inlet gorge and substitution therefor of a steel sheet pile wall; the construction of a stone jetty extending seaward from Brigantine Island northeast of the inlet channel; construction of 2 new stone groins and stone extensions to 6 existing groins along the inlet frontage; the placing of stone riprap revetment at the toe of the bulkhead on the Maine Avenue frontage on the inlet; restoration of the ocean and inlet beaches by artificial deposit of sand; extension of the stone jetty at Oriental Avenue; and the extension of one stone groin and construction of five timber groins on the ocean frontage. The District Engineer recommended Federal participation to the extent of one-third of the cost of the foregoing work subject to certain conditions of local cooperation. The Division Engineer concurred in the recommendations of the District Engineer.

The Board carefully considered the reports of the reporting officers. It concurred generally in their views and recommendations. The Board recommended that a project be adopted by the United States authorizing Federal participation by the contribution of Federal funds in an amount equal to one-third of the cost of the following measures for the protection and improvement of the shores of Atlantic City, New Jersey: (a) removal of damaged concrete wall at the city park and replacement by a steel sheet piling wall; (b) a stone jetty extending from Brigantine Island to be built in stages to a point in prolongation of the Boardwalk in the vicinity of Massachusetts Avenue (approximately 4,800 feet long from the existing high water line) parallel to and about 2,300 feet from the Main Avenue bulkhead, the exact design, location and length of each stage of construction to be subject to approval by the Chief of Engineers prior to construction; (c) two new groins and stone extensions of existing groins along Maine Avenue; (d) revetment at toe of bulkhead along Maine Avenue; (e) artificial placement of fill on the ocean and inlet beaches to widen the beaches, to an amount not to exceed 1,200,000 cubic yards, to be secured by dredging to widen the channel on its east side; (f) extension of the Oriental Avenue jetty; (g) a groin system on the ocean frontage consisting of 5 new timber groins and extension of the groin at Vermont Avenue.

The Board recommended Federal participation subject to the conditions that responsible local interests will:

a. Adopt the recommended plan of improvement;

b. Assure maintenance of the protective measures during their useful life, as may be required to serve their intended purpose;

c. Provide at their own expense all necessary lands, easements, and rights-of-way;

d. Hold and save the United States free from all claims for damages that may arise either before, during or after prosecution of the work;

e. Assure that water pollution that would endanger the health of bathers will not be permitted;

f. Assure continued public ownership of the beach and its administration for public use only.

The Board further recommended that the adequacy of work proposed by local authorities, detailed plans, specifications, assurances that the requirements of local cooperation will be met and arrangements for prosecuting the entire project be approved by the Chief of Engineers prior to commencement of work.

The amount of Federal participation in accordance with the Boards recommendation is estimated to total $1,579,000.

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CLEVELAND AND LAKEWOOD, OHIO

Cleveland, the largest city in Ohio, is an important manufacturing and shipping center, and in 1940 had a population of 878,336. Cleveland is located on the south shore of Lake Erie about 100 miles east of Toledo, Ohio, and 180 miles west of Buffalo, New York. The shore line in the study area extends generally in a northeasterly to southwesterly direction.

The study area, comprising the lake frontage between the west city limit of Lakewood and the east city limit of Cleveland, is 18 miles in length. The most westerly 3 miles are located in Lakewood. The Lakewood frontage and an additional 2½ miles in Cleveland to Edgewater Park consist of almost vertical shale bluffs, 30 to 60 feet high, which rise directly out of the lake except for short sections where they are fronted by narrow sand and gravel beaches. At Edgewater Park the beach of fine sand is about ½ mile long. East of Edgewater Park, Cleveland Outer Harbor is formed by a breakwater about 5 miles long located 1,600 to 2,400 feet offshore. The waterfront inside the harbor is generally developed for commercial purposes; the Cuyahoga River empties into this harbor. Just east of the Outer Harbor, Gordon Park has a lake frontage of about 3/4 mile. Most of this frontage is bordered by a highway and is protected by stone walls. The remainder consists of a rapidly eroding clay bluff. The next 2½ miles of shore lie in the village of Bratenahl and are mostly protected by private sea walls. The shore line between Gordon Park and Cleveland east city line consists in general of low, easily eroded silt and clay bluffs fronted by a few short stretches of narrow sand and gravel beaches. Many breakwaters, groins, sea walls and bulkheads are located along this shore. East of Bratenahl are located the White City Park and Wildwood Park public beaches and Euclid Beach, a privately owned amusement park. The remainder of the shore line is privately owned and is developed mainly for residential purposes. The publicly owned bathing beaches at Edgewater, Gordon, White City and Wildwood Parks are accessible without charge.

Pollution from nearby sewers impairs the attractiveness and usability of all the beach areas, but the City of Cleveland is taking all reasonable steps to make available for bathing purposes satisfactory beaches within its city limits. The U. S. Public Health Service cooperated in the investigation of sanitary conditions at the beaches. It concluded that there is reasonable assurance that beaches satisfactory from a sanitary standpoint for bathing purposes will be available in Cleveland and that in its opinion Federal participation in shore improvement and protection at Cleveland should not be dropped for reasons connected with the sanitary quality of bathing beach waters.

The District Engineer considered the desires of the cooperating agency, studied the sources and movement of beach material, the changes in the shore line and offshore bottom, the effects of winds, storms, ice and of existing structures, determined the most suitable methods of protecting the shore against erosion, and made an economic analysis of proposed improvement and protective measures for the publicly owned shores. He found that there is no problem of development of public recreational areas or protection of publicly owned property on the shore of the City of Lakewood, and that the most economical and effective method of protection of the shale bluffs in Lakewood would be the construction of a rock wall at the toe of the bluff. For the clay and silt bluffs in Cleveland, he found that rock sea walls combined with slope grading and revetment would be the most effective means of protection. With respect to the public beaches in Cleveland, he concluded that:

a. The best plan of improvement for Edgewater Park and adjoining Perkins Beach Would be the construction of five new groins, the alteration of four existing groins, the relocation of the storm overflow sewer, and placement of sand fill.

b. The most suitable plan for stabilization of the beach at White City Park would be the construction of a wall at the east end of the beach to prevent eastward sand movement into the harbor area, a groin at the west end of the beach, and widening the beach by the redistribution of sand from the dune area at the rear of the beach.

c. In view of the land reclamation and harbor development plans of the city of Cleveland for Gordon Park and the probability of pollution at that locality,consideration of a project for shore protection or beach development is not advisable at this time; and the shore protection considered for the east end of this park is not economically justified.

d. In view of the proposed breakwater construction at Wildwood Park in connection with the construction of a water intake, adoption of a project for Federal participation in the development of a beach at that location is not advisable at this time.

The District Engineer recommended that projects be adopted authorizing Federal participation in the improvement and protection of Edgewater and White City Parks to the extent of one-third of the initial cost of the work. The Division Engineer concurred in the views and recommendations of the District Engineer.

The Board carefully considered the reports of the reporting officers. It concurred generally in their conclusions and recommendations. The Board recommended that a project be adopted by the United States authorizing Federal participation by the contribution of Federal funds in an amount equal to one-third of the first cost of the improvement and protection of the shores of Edgewater Park and White City Park, Cleveland Ohio, in accordance with the following plans. The plan for Edgewater Park comprises the construction of five new groins, alteration of four existing groins, and placement of about 600,000 cubic yards of suitable fill. The Board considered that local authorities should be given the opportunity to prevent pollution at Edgewater Park by any suitable method. The plan for White City comprises the construction of a cut-off wall, and of one groin for the stabilization of the existing beach, and the redistribution of sand within the area. Federal participation was recommended subject to the conditions that the City of Cleveland will: (1) assure maintenance of the improvement and protective measures, during their useful life as may be required to serve their intended purpose; (2) abate pollution of waters in the vicinity of these beaches so that the health of bathers will not be endangered during the useful life of the project; (3) provide at its own expense all necessary lands, easements and rights-of-way; (4) hold and save the United States free from all claims for damages that may arise either before, during or after prosecution of the work; (5) assure perpetual public ownership of the beaches and their administration for public use only. The Board further recommended that the adequacy of work proposed by local authorities, detailed plans, specifications, assurances that the requirements of local cooperation will be met and arrangements for prosecuting the work be approved by the Chief of Engineers prior to the commencement of work.

The estimated amounts of Federal participation in accordance with the Board's recommendation are $809,200 for Edgewater Park and $42,700 for White City Park, a total of $851,900.

COOPERATIVE BEACH EROSION STUDIES IN PROGRESS

NEW HAMPSHIRE

HAMPTON BEACH. Cooperative Agency; New Hampshire Shore and Beach Preservation and Development Commission.

Problem: To determine the best method of preventing further erosion and of stabilizing and restoring the beaches; also to determine the extent of silting and erosion in the harbor.

MASSACHUSETTS

METROPOLITAN DISTRICT BEACHES. Cooperating Agency: Metropolitan District Commission (for the Commonwealth of Massachusetts).

Problem: To determine the best methods of preventing further erosion, of stabilizing and improving the beaches, and of protecting the sea walls of Quincy Shore Reservation.

SALISBURY BEACH. Cooperating Agency: Department of Public Works (for the Commonwealth of Massachusetts).

Problem: To determine the best methods of preventing further beach erosion. This will be a final report to report dated 26 August 1941.

CONNECTICUT

STATE OF CONNECTICUT. Cooperating Agency: State of Connecticut (Acting through the Flood Control and Water Policy Commission).

Problem: To determine the most suitable methods of stabilizing and improving the shore line. Sections of the coast will be studied in order of priority as requested by the cooperating agency until the entire coast is included.

NEW JERSEY

OCEAN CITY. Cooperating Agency: City of Ocean City.

Problem: To determine the causes of erosion or accretion and the effect of previously constructed groins and structures, and to recommend remedial measures to prevent further erosion and to restore the beaches.

VIRGINIA

VIRGINIA BEACH. Cooperating Agency: Town of Virginia Beach.

Problem: To determine the methods for the improvement and protection of the beach and existing concrete sea wall.

SOUTH CAROLINA

STATE OF SOUTH CAROLINA. Cooperating Agency: State Highway Department.

Problem: To determine the best method of preventing erosion, stabilizing and improving the beaches.

LOUISIANA

LAKE PONTCHARTRAIN. Cooperating Agency: Board of Levee Commissioners, Orleans Levee District.

Problem: To determine the best method of effecting necessary repairs to the existing sea wall and the desirability of building an artificial beach to provide protection to the wall and also to provide additional recreational beach area.

TEXAS

GALVESTON COUNTY. Cooperating Agency: County Commissioners Court of Galveston County.

Problem: a To determine the best method of providing a permanent beach and the necessity for further protection or extending the sea wall within the area bounded by the Galveston South Jetty and Eight Mile Road.

b To determine the most practicable and economical method of preventing or retarding bank recession on the shore of Galveston Bay between April Fool Point and Kemah.

CALIFORNIA

STATE OF CALIFORNIA. Cooperating Agency: Division of Beaches and Parks, State of California.

Problem: To conduct a study of the problems of beach erosion and shore protection along the entire coast of California. The initial studies are to be made in the Ventura- Port Hueneme area and the Santa Monica area.

WISCONSIN

RACINE COUNTY. Cooperating Agency: Racine County.

Problem: To prevent erosion by waves and currents, and to determine the most suitable methods for protection, restoration and development of beaches.

KENOSHA. Cooperating Agency: City of Kenosha.

Problem: To determine the best method of shore protection and beach erosion control.

ILLINOIS

STATE OF ILLINOIS. Cooperating Agency: Department of Public Works and Buildings, Division of Waterways, State of Illinois.

Problem: To determine the best method of preventing further erosion and of protecting the Lake Michigan shore line within the Illinois boundaries.

OHIO

STATE OF OHIO. Cooperating Agency: State of Ohio (Acting through the Superintendent of Public Works).

Problem: To determine the best method of preventing further erosion of and stabilizing existing beaches, of restoring and creating new beaches, and appropriate locations for the development of recreational facilities by the State along the Lake Erie shore line.

TERRITORY OF HAWAII

WAIKIKI BEACH. Cooperating Agency: Board of Harbor Commissioners, Territory of Hawaii.

Problem: To determine the most suitable method of preventing erosion, and of increasing the usable recreational beach area, and to determine the extent of Federal aid in effecting the desired improvement.

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BEACH EROSION LITERATURE

There are listed below some recent acquisitions to the Board's library which are considered to be of general interest. Copies of these publications can be obtained on 30-day loan by interested official agencies.

"The Distortion of Scales in Models with Loose Beds," Herbert Chatley, Report on Second Meeting of International Association for Hydraulic Structures Research, Stockholm, 7-9 June 1948, pp. 107-111.

An examination of the distortion of scales in models is made and discussed for conditions in regime channels in incoherent alluvium, in empirical rules for flow in alluvial channels, in models fed by natural rainfall, and in tidal models. The author states that investigators frequently express opinions that distortion should be less than a certain value; however, he concludes that, (1) a distortion may be as high as two times the square root of the vertical model scale if side slopes in the model are steep, (2) a distortion equal to the square root of the vertical scale is often applicable, and (3) values of distortion as high as 100 are not compatible with true similarity.

"The Formation and Movement of Sand Bars by Wave Action," C. A. M. King and W. W. Williams, Geographical Journal, Vol. 113, June 1949 pp. 69-85.

This interesting paper describes studies on the formation and movement of two types of natural sand bars, the submarine bars of a tideless sea and the ridge and runnel beaches of tidal seas. Model wave tank experiments showing the effect of wave height and period, beach gradient, wave steepness, and onshore winds; on sand movement, break-point bar formation, and swash bar formation are discussed and illustrated. The correlation of tank experiments and field observations are described for bars in tideless seas, and ridge and runnel beaches. The authors conclude that one important question is unanswered; namely the exact mode of sand movement under surf waves because of the difficulty in simulating surf conditions in wave tanks, and observations are difficult to make in nature. They suggest that the solution may be found only in a larger laboratory tank.

"The Behavior of Waves on Tidal Streams," N. F. Barber, Proceedings of the Royal Society, Series A, Vol. 198, No. 1052, 22 July 1949, pp. 81-93.

The paper reports on the changes in wave characteristics which take place when the waves encounter regions where the water has a streaming motion. Mathematical treatment applied to tidal streams, the velocity of which depends on time and position, is given and some observational evidence supporting the theory is analyzed. The author states that in deep water the average length of waves appear to expand or contract at the same rate as the general surface of the water on which they are moving. He concludes that; fluctuations in tidal cycles of the periods of recorded waves can be satisfactorily attributed to the action of tidal streams; and the change in period will be proportionately small when the tidal streams are weak or where the waves complete their passage through the tidal area in a small fraction of a tidal cycle.

"Model Experiments on the Belgian Ports of the North Sea," L. Bonnet and J. Lamoen, Dock and Harbour Authority, Vol. XXX, Nos. 348-350, October-November-December 1949.

This article is a detailed review of the book, "Etude des Ports Belges de la Mer du Nord," by L. Bonnet and J. Lamoen. It describes model experiments for the Belgian ports of Zeebrugge and Ostend separated by a distance of only twelve miles, but presenting two widely different problems. Zeebrugge is a single curved mole enclosing a single area of the sea and encroaching upon the natural flow of the coastal currents; Ostend is a canalized outlet debouching on the sea with no appreciable interference of the littoral currents. At Zeebrugge the problem was to provide remedial measures for the silting up the harbor, while at Ostend the problem was to investigate proposed entrance channel improvements. The progressive series of experiments conducted in the harbor models under various projected improvements are discussed and illustrated in detail. Test results of the wave reduction within the harbor modelled on the various projects are given. The outstanding features of these model experiments are the practical methods adopted to achieve results related to the actual phenomena.

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