CHAPTER FIFTY THREE

ESTIMATES OF LONG WAVES IN THE WESER ESTUARY

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ABSTRACT

Long waves of small amplitudes can excite harbour oscillations as well as the motion of floating structures or vessels. Field data from the Weser Estuary, German Bight of the North Sea were analysed with respect to waves with periods greater than 8 s. After preprocessing of the mostly noisy data records, special analysis incorporated the reconstruction of incorrectly recorded frequency components below .03 Hz and bivariate distributions of heights and periods. Results suggest that long wave activity increases towards the inner estuary. Grouping properties are dependent on wind direction and on directionality of the sea state. Further investigations and model studies for the response of travelling vessels to this wave climate are recommended.

1.0 INTRODUCTION

It has been frequently suggested and generally accepted that long waves with a small amplitude can excite harbour oscillations. Pinkster (7) and Mansard and Pratte (6) demonstrated that significant motions of moored vessels can be induced as a result of these same waves. It is also being speculated that large vessels navigating with small underkeel clearance in restricted channels can hit bottom in response to these long waves. It is therefore important to know about and to understand long wave activity in coastal areas and estuaries.

Long waves in estuaries can appear as

(a) free long waves, which are generated far from shore and travel at free wave velocity.

(b) group-bound long waves, which represent a set-down under the wave group and travel at group velocity.

(c) free long waves, which result from the shoaling process of bounded long waves.

(d) reflected long waves, which derive from a reflection process of free or bounded long waves.

The existence of second order group-bound long waves as a result of the variation of radiation stress under a group of waves has already been shown by Longuet-Higgins and Stewart (5). Dependent on the amount

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of wave grouping the bounded long wave appears as a set-down under a group of larger waves and a set-up in between groups (Fig. 1). That this phenomenon is really present in nature can be shown by a low-pass filtering process presented in Figure 2 where the thick line superimposed on the measured wave train represents the second-order low frequency surface elevation. The encircled low frequency part of the variance spectral density is shown enlarged on the upper left part of the figure.

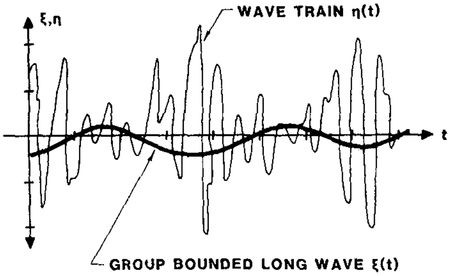


FIGURE 1: GROUP BOUNDED LONG WAVES - DIAGRAMMATIC SKETCH -

Long waves in deep water are typically considered to have periods longer than 30 seconds. However, as waves propagate into the shallower water of an estuary, there is a significant transformation of spectral energy towards the higher as well as the lower frequency part of the spectrum. As a result, long waves in estuaries may reasonably be considered as being those of periods longer than eight to ten seconds. This

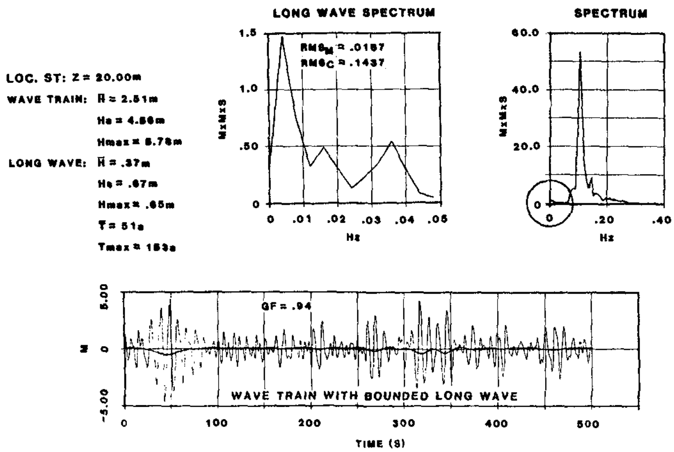


FIGURE 2: BOUNDED LONG WAVES IN NATURAL WAVE TRAINS

investigation was also undertaken in support of navigation services in the Weser Estuary, part of the German Bight of the North Sea, for which a specific interest in wave activity beyond a certain threshold had been expressed. Discussions taking estimated or well-established response frequencies of different types of vessels into consideration resulted in a cut-off frequency of 8 s. For the purpose of this analysis long waves - in deviation from a conventional definition - shall be considered as those which exceed this given threshold.

The behaviour of long waves propagating in a uniform channel at constant water depth is well known (Barthel et al., 1983) (2). However, when approaching the shore with progressively decreasing depth of water, these waves change due to shoaling, refraction, diffraction and reflection in a manner which is not yet understood. It is suspected that, e.g. bounded long waves depart from the wave groups and proceed as free long waves in the shoaling process. To complicate matters, some long wave components tend to follow deep channels into the inner estuary without much change in characteristics.

2.0 Field Data

Field investigations were carried out in the Weser Estuary, German Bight of the North Sea, between 1975 and 1981 and results were partly reported by Barthel (1). This study was to provide sufficient wave climate information for the prediction of waves and form the basis for design of coastal structures. Waverider buoys were deployed in seven

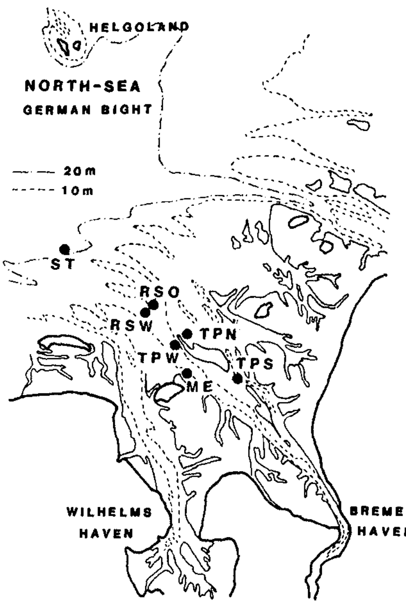


FIGURE 3: WESER ESTUARY WITH LOCATIONS OF MEASUREMENTS

different locations in the estuary, covering specific areas like the open sea, the edge of deep channels and the protected areas behind submerged bars (Fig. 3). This data set was also made available for the present investigation.

Data had been acquired for the conventional 20 minute periods and transmitted to shore for recording on digital magnetic tape. However, for reasons of cost, it had not been possible to record data from all buoys concurrently. Instead, data channels were selected consecutively for 20 minute periods. During different periods, different buoys participated in wave monitoring activity. Sometimes two, three or four buoys were selected consecutively so that the same buoy recorded every 40, 60 or 80 minutes. At other times a two-buoy sequence repeated every 60 or 80 minutes if one or two of the buoys in the sequence were inoperative.

3.0 INSTRUMENTATION

When the wave climate study was started in 1975 it could not be anticipated that the data might be used for long wave analysis. Consequently, the instrumentation selected which was most suitable for short wave measurements at that time, proved to be not ideal for this investigation.

The Waverider buoy has a dynamic response which starts dropping off at wave periods of 16 seconds. As Figure 4, which originates from the

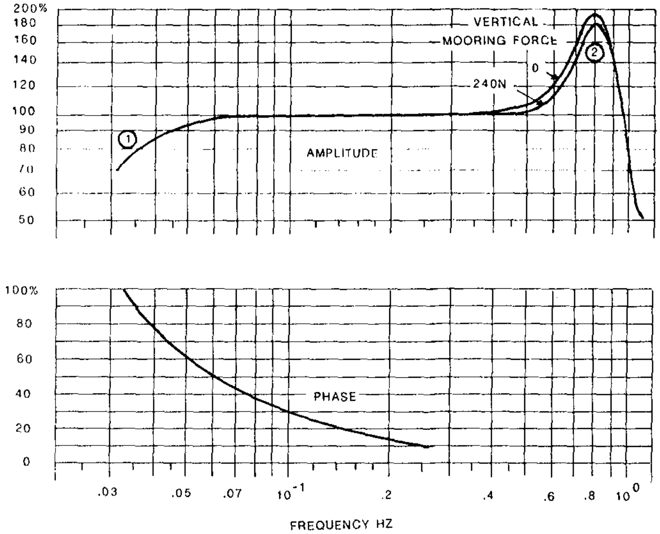


FIGURE 4: WAVERIDER TRANSFERFUNCTIONS (WAVERIDER MANUAL)

Waverider Manual, shows, the buoy is totally incapable of recording periods greater than 50 seconds. Typically, measurements of periods longer than 30 seconds should not be relied upon.

A further disadvantage stems from the fact that the radio transmission is susceptible to corruption by radio interference. The buoys and their receiver station had to be located in the vicinity of harbour services which were using short wave communication systems. CB-amateur activity in the region is very high. Hence, many of the records are influenced by interferences which lead to statistical "outliers" or "glitches". In order to make use of as many of the limited number of records as possible, programs had to be developed to detect and correct these erroneous portions of records.

4.0 PREPROCESSING OF DATA

The procedure GLTFX which was created to recognize and repair noise records can be summarized as follows: The data vector is being differentiated by simple differencing. The resultant derivative is subjected to statistical analysis for the definition of a threshold which permits the separation of derivatives contributed by noise spikes on the one hand and those contributed by the uncorrupted signal on the other. The derivative record is then searched and on the basis of this threshold, a noise derivative is identified with the additional proviso that the derivative of the noise spike must be shorter than a given period and that the noise spike must be associated with a derivative exceedence of one polarity followed immediately by another derivative exceedence of the opposite polarity.

Figure 5 shows an example of a noisy record with its derivative and

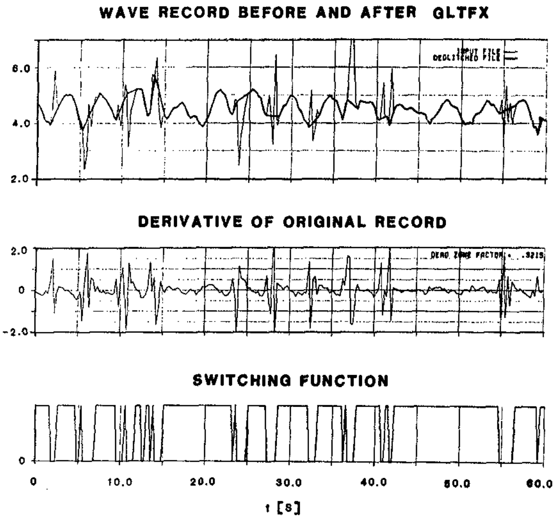


FIGURE 5: PREPROCESSING OF DATA

the switching function. The upper part shows the repaired wave record as a thick line superimposed on the original recorded time series of "surface elevations". As may be seen, the method can significantly improve the viability of wave data.

Another program was developed which can process erroneous prototype records and replace them by the best fitting quasi-synthetic time series. By using Fourier techniques, sinusoidal components are systematically removed from the original record until the variance of the extracted sum of sinusoids is greater than 90-95% of the RMS value of the original record. The superposition of all sinusoids at their computed amplitude and phase approximates the original function quite well.

By this method "glitches" and statistical "outliers" can be removed. However, since the process requires a comparatively long computation time, it can only be justified for very valuable records which cannot be recovered otherwise.

5.0 ANALYSIS OF WAVE DATA

5.1 Conventional Analysis

In order to assess the quality of data records after preprocessing, conventional analysis is applied on all records. This procedure incorporates:

(a) Zero-downcrossing analysis, resulting in statistical parameters like H_s, H_{max}, T, etc.

(b) Variance spectral density analysis giving peak frequency and RMS-values.

(c) SIWEH-analysis as per Funke and Mansard (4) from which the groupiness factor GF is obtained.

(d) Wave height probability distribution analysis including a comparison with model distributions.

After a visual control and selection process, data are subjected to a second analysis procedure.

5.2 Extended Long Wave Analysis

Since waves with a period longer than 33 s could not have been recorded correctly, all frequency components smaller than the given boundary were removed and replaced by a theoretical bounded long wave component. These second-order components were calculated using the method described by Ottensen-Hansen (7) and had been extensively tested for laboratory conditions (Barthel et al.) (2). The program uses Fourier techniques combining every possible combination of frequency pairs and their respective Fourier components. The second order surface elevations are given by

$$\eta_{nm}(t) = G_{nm}(f,\Delta f) \left[\left(a_n a_m + b_n b_m\right) \cos\left(\Delta\omega_{nm} t\right) + \left(a_m b_n - a_n b_m\right) \sin\left(\Delta\omega_{nm} t\right)\right]$$

$G_{nm}(f,\Delta f)$ is the transfer function, the properties of which were extensively described by Sand (9). In order to save computational time the program lets the user remove all frequency pairs with an energy content below a defined threshold.

This procedure effectively reconstructs the long period portion of the energy spectrum which could not be correctly measured by the Waverider buoy. The low frequency part of the spectrum shown in Figure 2 is, in fact, a reconstructed, theoretical bounded long wave which adds remarkably to the energy content in this range. However, it accounts only for those long waves which belong to the category of "bounded long waves". It does not include any free long ave activity which may also be present in the natural sea state but has not been correctly recorded. Consequently the long wave activity computed and presented here represents an underestimation of the true situation.

Because of the specific interest in all "long wave" activity for wave periods longer than eight seconds, a special time series was constructed. The measured wave train was band-pass filtered between the low cut-off frequency of 0.03 Hz and the given boundary value of 0.125 Hz ($T = 8$ s). The filtered time series was then superimposed with the "theoretical bounded long wave" and the resulting "long wave" subjected to the following analysis:

(a) Zero-crossing analysis results in heights and periods of this artificial wave train. The effect of a wave field on a floating structure or travelling vessel can only be obtained by physical or mathematical modelling. However, certain boundary values (e.g. periods) are considered to initiate a - very often serious - response of a vessel. The RAO (response amplitude operator) of a vessel can be for example 0.6 for a frequency of .2 Hz and 1.0 for a frequency of 0.125 Hz. Therefore, a wave height H_R obtained from a measured wave train, which in Figure 6 as an example only consists of two superimposed frequencies, may not mean too much for a travelling vessel. The filtered, lower frequency component attached to a significantly smaller height H_F, however, can be of more consequence to its movement.

(b) To evaluate the frequency of occurrence of pairs of height and period obtained from the zero-crossing analysis data are subjected to a bivariate distribution analysis resulting in a scatter diagram of heights and periods of the "long wave train". This procedure is performed on the data records of each station separately for a whole measurement period and results are accumulated in one data file to show the distribution of this specific period. Figure 7 shows the bivariate distributions of stations ST and RSW (42 records each) for the period of November 15-17, 1978. Leakage during the filtering process still lets waves appear in the region $T < 8$ s. Due to the same filtering process, the asymmetry of a joint distribution as shown by Cavanie et al. (3) is not very distinct in this representation. As can be seen from the example, the maximum numbers of events occur within the periods of 8-10 s with heights from 0.4-1.0 m. These "long waves" may well

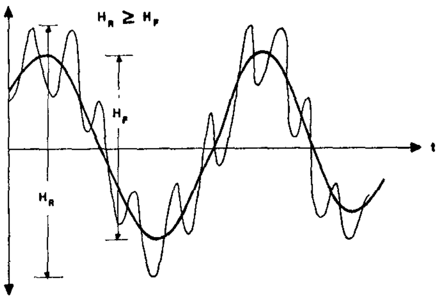


FIGURE 6: SUPERPOSITION OF LOW AND HIGH FREQUENCY COMPONENTS - SCHEMATIC PRESENTATION -

excite a travelling vessel to an extent which could cause dangerous situations. Multiple events in that period range go up to 3.6 m whereas very long waves (T > 22 s) occur more than once with a height of .4-.6 m. However, it still remains to be accurately defined how these results have to be interpreted with respect to the behaviour of a certain type of vessel.

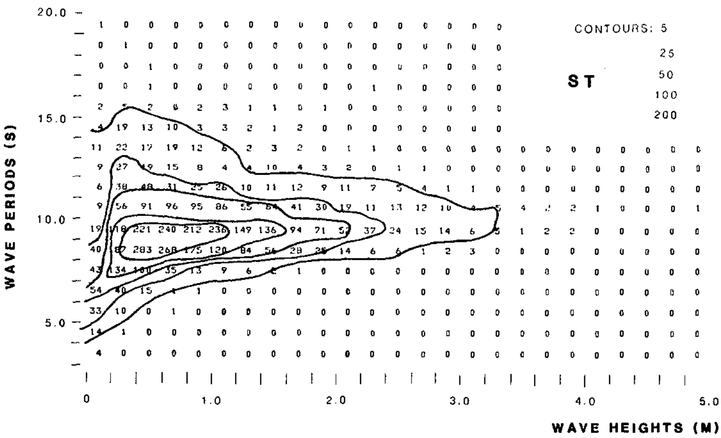
5.3 Distribution of Energy

Another method of showing the energy which is attached to certain frequency ranges is given with Figure 8. The cumulative distribution of spectral energy (RMS-value) for the frequency bands 0-0.05, 0.05--0.125, 0.125-0.25 and 0.25-0.5 Hz gives a very good indication of what is happening, e.g. in a storm. In the presented example the energy of "long waves" increases substantially with increasing wind velocity in both locations. However, real long wave activity for frequencies below .05 Hz (T > 20 s) is much larger towards the inner estuary (RSW) than it is in deep water. This process of transfer of energy towards lower frequencies in storm situations could be observed quite often and appears to be enhanced with decreasing water depths. It implies that vessels moving into the estuary can expect more "long wave activity" and therefore possibly heavier motion towards the inner estuary where water depths normally provide less underkeel clearance.

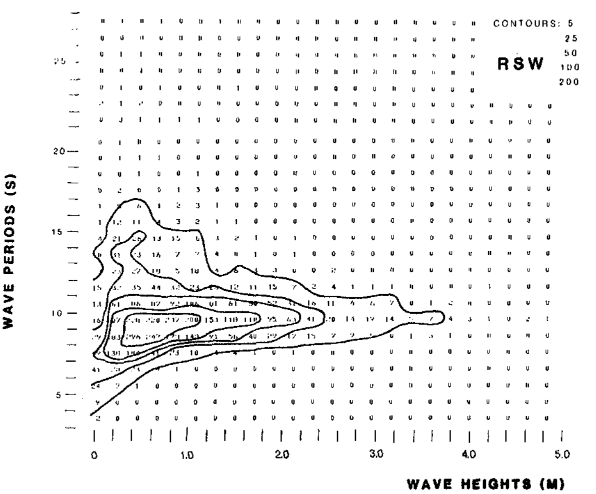
5.4 Grouping Properties

The concentration of energy in a group of higher waves in superposition with a second-order slow drift oscillation of a ship due to very long waves can affect its stability especially if it starts to respond in a resonant rise. Grouping properties of the sea state in terms of the groupiness factor

$$GF = \frac{\sqrt{m_{0\varepsilon}}}{m_0}$$



JOINT FREQUENCY OF OCCURENCE DIAGRAM



JOINT FREQUENCY OF OCCURENCE DIAGRAM

FIGURE 7: BIVARIATE DISTRIBUTION OF H AND T

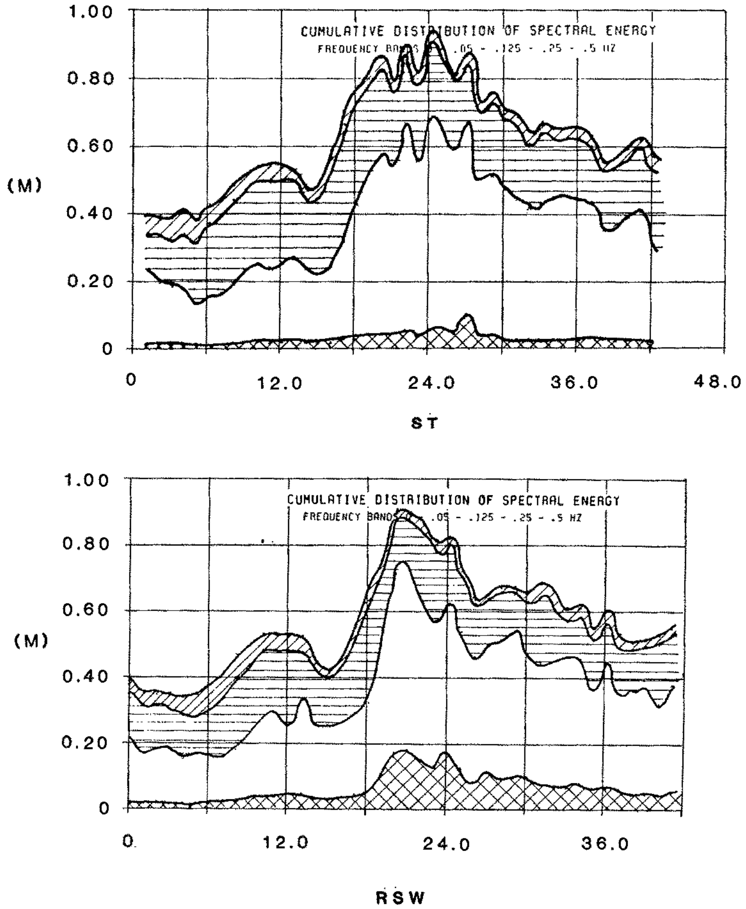


FIGURE 8: CUMULATIVE DISTRIBUTION OF SPECTRAL ENERGY

$m_{0\varepsilon}$ = zeroth moment of the SIWEH spectral density

m_0 = zeroth moment of the SIWEH variance spectral density

SIWEH = Smoothed Instantaneous Wave Energy History

as defined by Funke and Mansard (4), were determined for all records. The groupiness factor GF is the standard deviation of the SIWEH function about its mean normalized by its variance and gives a good indication of the concentration of higher and smaller waves in deviation from the Gaussian process. Table 1 presents the results of this specific analysis for different wind directions and the three main locations which were being looked at for navigation safety purposes. It appears that unusually high GF values only occur with certain prevailing wind directions (SE).

WIND DIRECTION	ST			RSW			TPW (TPN)		
	GF_{ave}	GF_{max}	H_{sig} (m)	GF_{ave}	GF_{max}	H_{sig} (m)	GF_{ave}	GF_{max}	H_{sig} (m)
SW	0.64	0.66	1.6	0.56	0.70	1.6	—	—	—
WSW	0.61	0.73	2.4	0.63	0.74	2.1	—	—	—
SW-WNW	—	—	—	0.60	0.66	3.3	0.63	0.72	1.4
WSW-NE	—	—	—	0.59	0.75	1.4	0.62	0.63	0.7
SW-SE	—	—	—	0.56	0.66	2.0	0.60	0.75	0.6
SE	0.64	0.69	1.3	0.66	0.63	0.6	—	—	—
SE-SW	—	—	—	0.80	0.66	1.4	0.61	0.66	0.6
SE-SSW	0.65	0.63	1.6	0.63	0.62	0.9	—	—	—
NE-ESE	—	—	—	0.63	0.73	1.6	0.60	0.70	1.0
WNW	0.65	0.76	2.6	0.63	0.73	2.6	0.66	0.79	1.4
WNW	0.67	0.63	1.6	0.67	0.66	1.4	0.67	0.95	1.2

TABLE 1: GF AND H_{sig} FOR DIFFERENT WIND DIRECTIONS FOR THE LOCATIONS ST, RSW AND TPW

Figure 9 shows the groupiness factors for only three wind directions. Interpretation of these results suggests that waves, generated by easterly winds, are not very much affected by topography and therefore only obey the boundary process of energy transfer from wind to water surface, which seems to govern or influence the grouping properties the most. On the other hand, waves penetrating the estuary are being affected by bottom-wave-interaction and superimposed by locally generated wind waves. Therefore, the grouping-process is disturbed and interrupted. Interaction of the group-bound long wave, which feels the bottom very early, and its constituent group could lead to a decay of the group. Finally, superposed wave fields coming from different directions can suppress grouping behaviour of the combined sea state.

Therefore, wave data used for groupiness analysis should be seleted and treated very carefully. If superposed sea states like those shown in Figure 10 are being recorded, a separation of the two (or in some

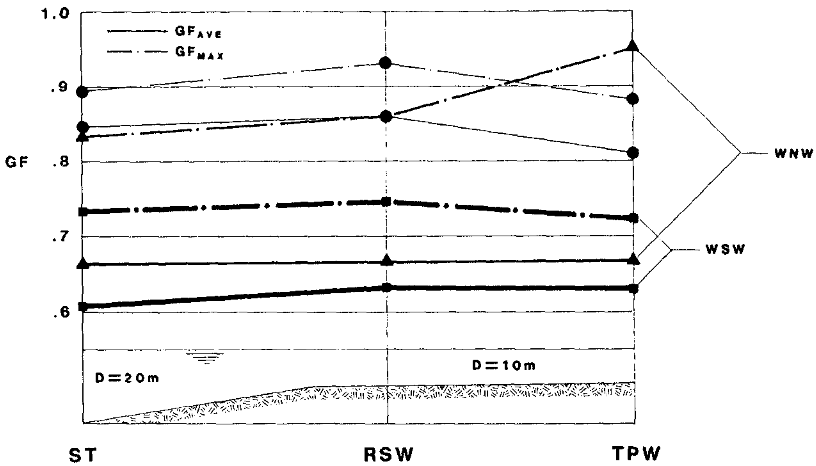


FIGURE 9: AVERAGE AND MAXIMUM GF - VALUES FOR 3 WIND DIRECTIONS

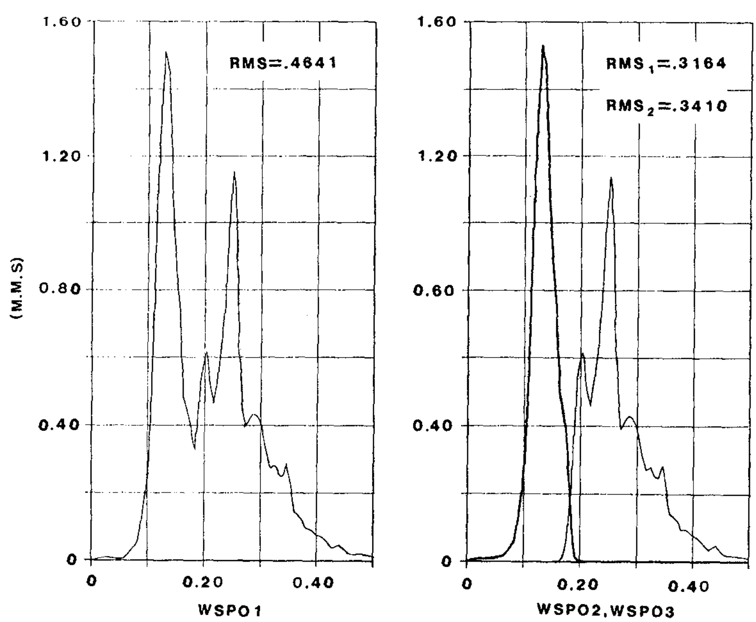
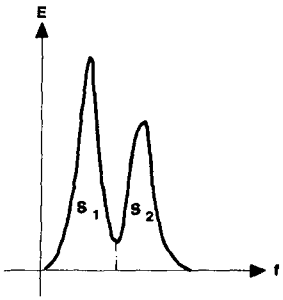


FIGURE 10: DOUBLE - PEAK - SPECTRUM - RW 609

cases even three) partial spectra is necessary to obtain valid grouping properly results. For a series of twelve records for four locations double-peak spectra were separated by filter techniques. Combined and separated time series were subjected to a grouping analysis, the results of which can be seen in Table 2. The GF value is generally much higher for the partial wave fields than for the combined record. Moreover, bounded long wave energy in terms of RMS-values of the bounded long wave is up to 25% higher if determined for the separated wave fields rather than for the superimposed and recorded sea state. This shows very much the need for directional information for further investigations if also groupiness properties are to be determined.



LOC.	GF	GF1	GF2	BLW (RMS1 +RMS2)/RMS
ST	0.82	0.82	0.73	1.23
TPW	0.58	0.88	0.80	1.18
RSO	0.57	0.83	0.80	1.18
RSW	0.88	0.83	0.82	1.25

TABLE 2: GROUPINESS OF DOUBLE - PEAK - SPECTRA
AVERAGE OF 12 RECORDS

5.5 Parameter Sampling

To show the collected parameters of each measurement series consisting of more or less consecutive recordings of participating buoys over the course of a strong wind episode, analysis results were plotted for each location showing the time series of

- wind direction and velocity
- significant and maximum height of the measured wave train
- groupiness factor GF
- significant and maximum height of the "long waves" with T>8 s

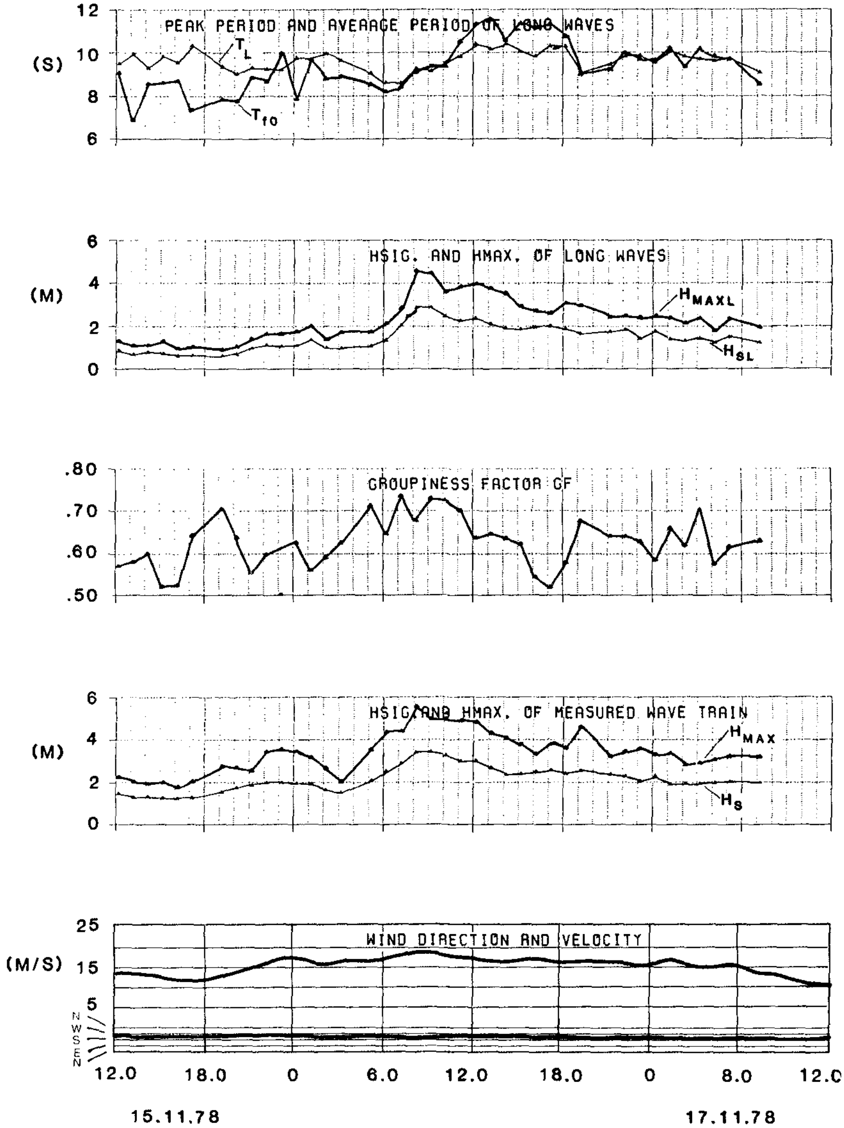


FIGURE 11: WESER WAVE PARAMETER - STATION RSW

- and the peak period (derived from spectral analysis) and average period (derived from zero-crossing analysis) of the "long waves".

Figure 11 presents the results for location RSW for the period of November 15-17, 1978.

6.0 CONCLUSIONS

Analysis indicates that

- long waves with periods exceeding 8 s may well be in excess of 5 m in height.
- those waves of periods greater than 33 seconds, which provide only an underestimation of real long wave activity (theoretical bounded long wave) can reach .5 m in height.
- grouping of waves can be very much affected by decreasing water depth. With only wind-wave interaction groupiness is quite high, if waves travel offshore.
- grouping properties described by the groupiness factor GF, as defined by Funke and Mansard (4), are much more distinct for the directional components of a superimposed state than for the original record itself. This reflects on the theoretical energy content of the group bounded long wave as well.

It is recommended to perform further wave investigations in that area deploying measurement devices which are capable of recording the required range of frequencies. In addition to that, gustiness recordings and directional information are essential for a detailed analysis.

The response of different types of travelling ships to the existing wave climate has to be investigated in laboratory experiments.

7.0 REFERENCES

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