CHAPTER 2

WAVE CLIMATE ANALYSIS FOR ENGINEERING PURPOSE

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ABSTRACT

The North Sea (Fig. 1) is known as a random sea with depths in the southern part between 40 m and 100 m so that in contrary to the Atlantic and Pacific coastlines deep sea wave conditions do not exist. After four years of comprehensive wave measurements in the offshore area of the Island of Sylt near the Danish border a general analysis of the wave climate in that region was possible. In this paper results and suggestions will be presented under the aspect of replacing qualitative judgements by quantitative statements which are derived from the knowledge of the adjacent wave climate. Because the wave action varies from year to year a general time unit is not advisable for the evaluation of shore processes; therefore the time scale should be substituted by the integral of incoming wave energy occurring after a certain time. The investigated method of expressing the total energy of one season or one year in the electrical unit Kilowatthour (kWh) per meter (m) width of shoreline could prove in future as a feasible way of classifying the irregular seasonal and yearly wave intensities.

It is further shown that wave measurements over a period of several years can be sufficient for the investigation of correlations between the wind velocities occurring from all directions and the resulting wave heights. In case of satisfying correlation factors it will then be possible to carry out feedback operations for periods from which only records of wind velocities and directions are available and even to hindcast the wave heights for certain not yet measured wind velocities.

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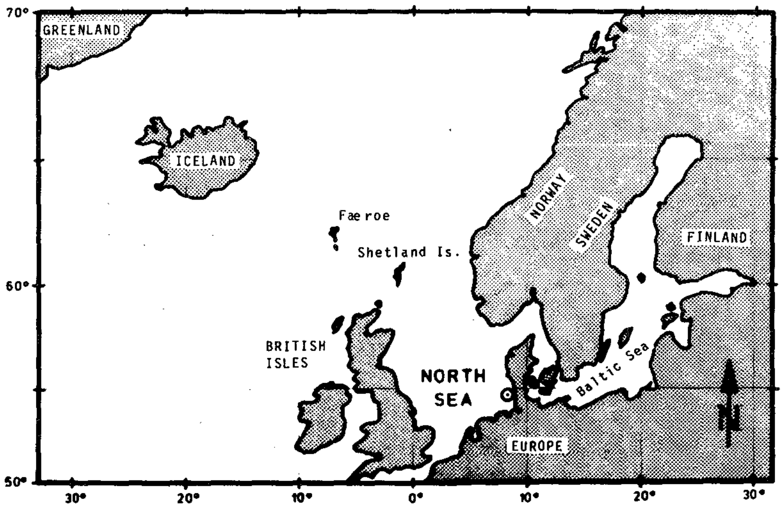

Fig. 1: Location of the North Sea with the region of wave climate analysis

INTRODUCTION

The analysis of the wave climate at a certain location by means of longterm measurements is usually aimed at the investigation of extreme wave parameters and the exceedance frequencies of the maximum or significant wave heights. These informations are needed for the design of offshore structures and coastal protection works. Besides it is often desirable to get some further information about the wave pattern which will normally have to be expected or taken into consideration during certain months or seasons within the year. This is of interest for the determination of the execution time.

Another point of interest is the knowledge of the wave intensity during a certain period or after the completion of an activity. Such informations are especially needed with regard to the feasibility of mobile coastal protection works - e. g. beach nourishments in which sand is used in large amounts as material of construction. As such measures do not grant a protection for ever they will have to be repeated from time to time depending upon the intensity of waves in that region. For this purpose it is necessary to find quantitative statements as it has been for example suggested by the definition of a "half decay time" of a nourishment (FÜHRBÖTER 1974) as that point when a nourishment should be renewed.

WAVE RECORDS AND ANALYSIS

With regard to the above mentioned necessities and in order to evaluate an artificial beach nourishment with more than 1.000.000 m^3 of sand dumped in 1972 at Sylt through an extensive surf zone a comprehensive wave measuring program was carried out from 1971 to 1974. Four ultrasonic wave recorders were laid out up to a distance of 1.3 km from the shoreline; from which three stations were located seaward of a longshore bar extending at a distance of 300 m from the shoreline, whereas the fourth was placed in the trough between longshore bar and the beach (Fig. 2).

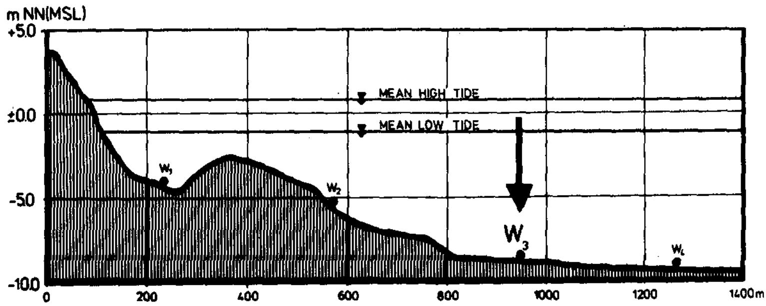

Fig. 2: Wave measuring profile

At least twice a day, about high and low water the waves were recorded simultaneously for a period of 15 minutes. According to a special program, depending upon the actual prevailing wave heights, records were carried out at shorter intervals up to continous records during heavy storm surges.

For the determination of the statistical wave height parameters (H_{max}, H_s, and H_m) and the wave periods a sequence of 100 waves within the 15 minute record was selected and the zero-up crossing method was applied as suggested by DRAPER, 1966.

Within the four years of measurements a maximum wave height H_{max} = 7.2 m was measured at a distance of 1.3 km from the shoreline at position W_4 (Fig. 2).

From a series of several hundred single records the following statistical relationships were obtained (position W_3):

$$H_{max} / H_m = 2.07$$
$$H_{max} / H_s = 1.44$$
$$H_s / H_m = 1.44$$

WIND-WAVE CORRELATIONS

Based on the high number of single records relations between the mean local wind velocities and the wave heights measured seaward of the longshore bar at position W_3 (Fig. 2) could be carried out by means of electronic computations. For this purpose the hourly records of wind direction and velocity were available from a meteorological station near the wave measuring profile for the period from 1965 to April 1976. General relationships between wind and waves are shown on Figure 3 for a storm period in February 1973. Besides a phase shifting of several hours can be seen between the maxima and minima of wind and wave height records.

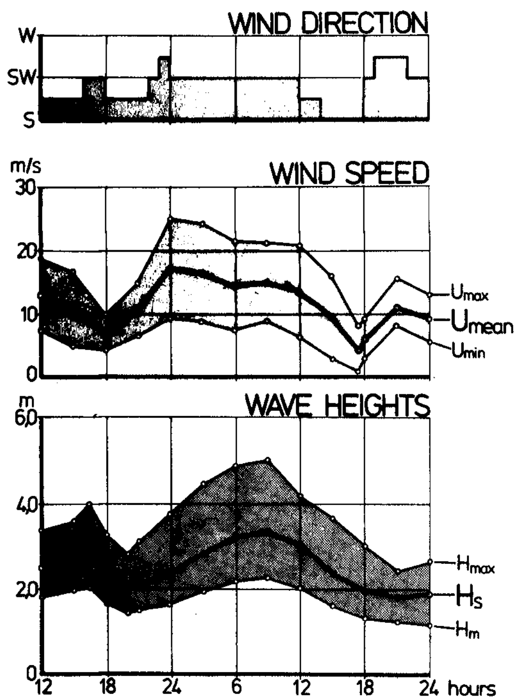

Fig. 3: Wind and Wave height conditions during a storm in February 1973

Figure 4 demonstrates the frequency and directional distribution of the hourly wind records in the years from 1965 to 1976. During nearly 20 per cent of the considered time wind velocities higher than U_{mean} = 10 m/s with significant wave heights $H_s \geqq 2$ m were predominant. The storm causing wind directions are ranging from South of Southwest (SSW) up to West of Northwest (WNW) with a resultant direction lying in between WSW and W.

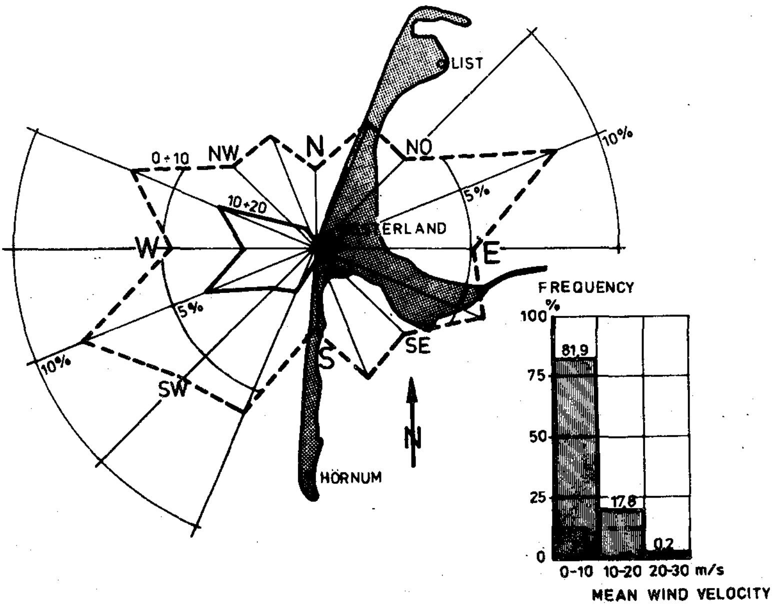

Fig. 4: Frequency and directional distribution of wind records (1965 to 1976)

For wind sectors of 22.5° correlations between the wave generating wind directions ranging from South to Northwest (Fig. 4) and the significant wave heights measured at position W_3 (Fig. 2) were carried out for time differences from one hour up to six hours and besides for the mean wind velocity and direction prevailing during the first to third, the second to fourth and the third to fifth hour before the wave measurement.

The best correlations for all sectors were found for the mean wind direction and velocity prevailing during the second to fourth hour.

The following correlation coefficients were obtained:

Wind Direction	Correlation Coefficient R
S	0.55
SSW	0.80
SW	0.79
WSW	0.91
W	0.96
WNW	0.88
NW	0.49

For the different wave generating wind sectors the measured significant wave heights H_s are plotted as function of the mean wind velocities U_{mean} on Figure 5. Within the wave measuring period from 1971 to 1974 the following highest mean wind velocities lasting for three hours and associated wave heights occurred:

Wind Direction	Mean Wind Velocity for 3 Hours	Significant Wave Height
-	m/s	m
S	12.0	2.7
SSW	14.5	3.2
SW	15.0	3.8
WSW	23.5	5.2
W	22.0	5.2
WNW	20.5	4.9

Additionally the regression lines are drawn for the single wind directions in Figure 5, so that for higher not yet recorded wind velocities the significant wave heights may be extrapolated. The maximum wave heights can be determined by using the already mentioned relationship

$$H_{max} = 1.44 \; H_s$$

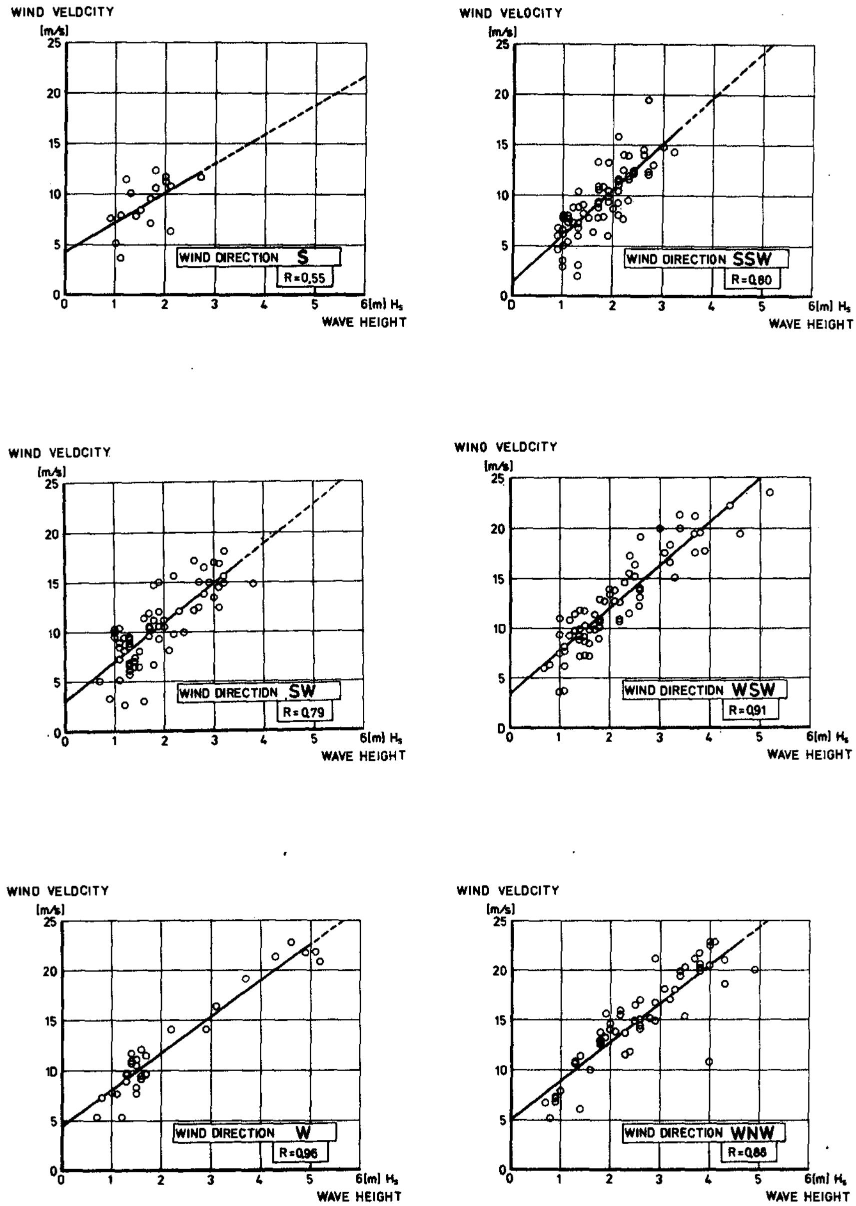

Fig. 5: Correlations between local wind velocities and significant wave heights

Based on the above investigated relationships which yielded satisfying correlations it could be proved that a wave measuring period of a few years can be sufficient in order to find reliable statistical parameters between the wave generating factors and the existing wave heights. The wave measuring period can be ragarded as the calibration phase within the effort to evaluate the longterm wave climate in the years before (= feed-back operation) and after the wave measurements when only wind data are available which can be obtained with a minimum of efforts and expenses.

In the following a further application of the suggested concept will be presented with regard to the aim of finding objective statements for the evaluation of processes caused by wave action.

WAVE ENERGY LOAD

Because the wave action varies from year to year a general time unit is not advisable for the evaluation of the durability of an offshore structure or a coastal protection work. The time scale should be substituted by a distorted time scale by means of computing the integral of the incoming wave energy load per unit width of wave front. The method of expressing the total wave energy load of one season or one year in the electrical unit Kilowatthour (kWh) per meter width of shoreline is regarded as a feasible way of classifying in future the irregular seasonal wave intensities.

By application of the linear wave theory and inserting the significant wave height $H_{s(j,i)}$ computed from the hourly wind records by the above mentioned correlation the single hourly wave loads $\overline{N}$ were determined for the period from 1965 to 1976 and classified according to different criteria.

The incoming wave load $\overline{N}$, expressed in the electrical unit kWh per meter width of shoreline was determined in the following way:

$$\overline{N} = 1.225 \cdot c \cdot \Delta t \sum_{j=1}^{24} \sum_{i=1}^{365} H_s^2$$

with $H_s = H_{s(j,i)}$ = wave height at the hour j in the year i

$c = \sqrt{g \cdot d}$ = wave velocity at position W_3 (Fig. 2)

$d = 10$ m = constant = mean water depth at position W_3

$\Delta t = 1$ = one hour

It is no doubt that the above assumptions incorporate uncertainties and rough assumptions with regard to a quantitative reliability.
Therefore the calculated wave energy loads are not considered from the quantitative point of view, the method is mainly regarded as a reliable basis for the demonstration of the irregular seasonal wave intensities as it is shown on Figure 6 for the period from 1965 (starting with the month of April) up to the end of March 1976

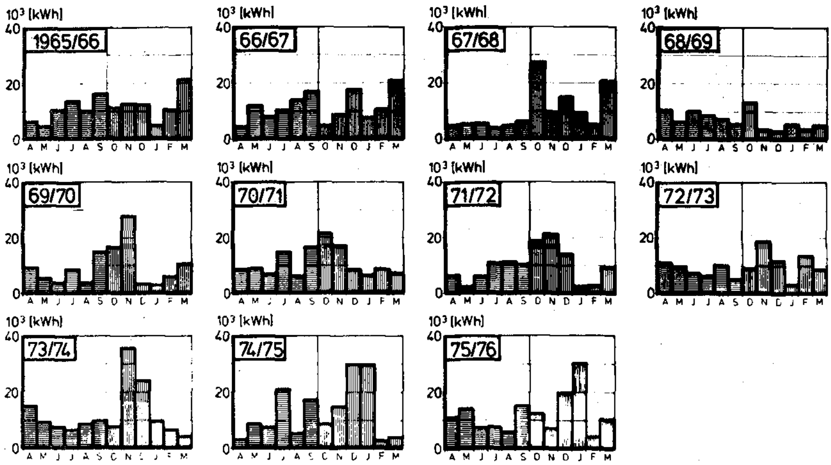

Fig. 6: Monthly wave energy load at position W_3 within the period from 1965 up to 1976

With regard to the classification of the yearly wave energy load as it is demonstrated on Figure 7 the total wave energy load per year (left axis on Figure 7) should be neglected as already mentioned; instead the mean of the considered period (= 100 per cent) should be determined and deviations from the mean should be expressed in percentage (right axis).

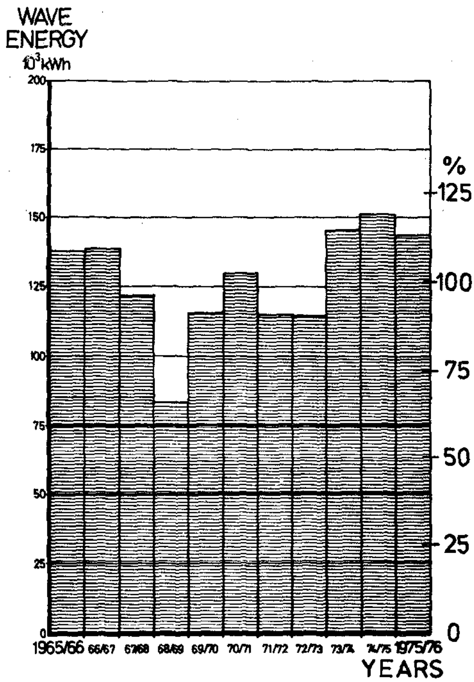

Fig. 7: Yearly wave energy loads in the years from 1965 to 1976

So for example the wave intensity could by classified be means of deviations from the mean wave load as follows:

> 110 %	=	high
90-110 %	=	normal
< 90 %	=	low

The next figures may help to estimate depending upon the long-term wave climate the risks when a work has to be carried out for example during a certain month or season within the year. Figure 8 shows the classification of the single monthly wave energy loads according to the months and seasons of the year for the period from 1965 to 1976. On Figure 9 the sum of the monthly wave energy loads over the same period has been summarized and the deviations from the mean can be seen.

Finally the consideration of incoming wave energy load can be useful with regard to the resultant direction of wave attack which will give an idea into which longshore direction there will have to be expected a net transport of sediments. From Figure 10 it is obvious that there will be surplus of movements in northern direction for the period from 1965 to 1976.

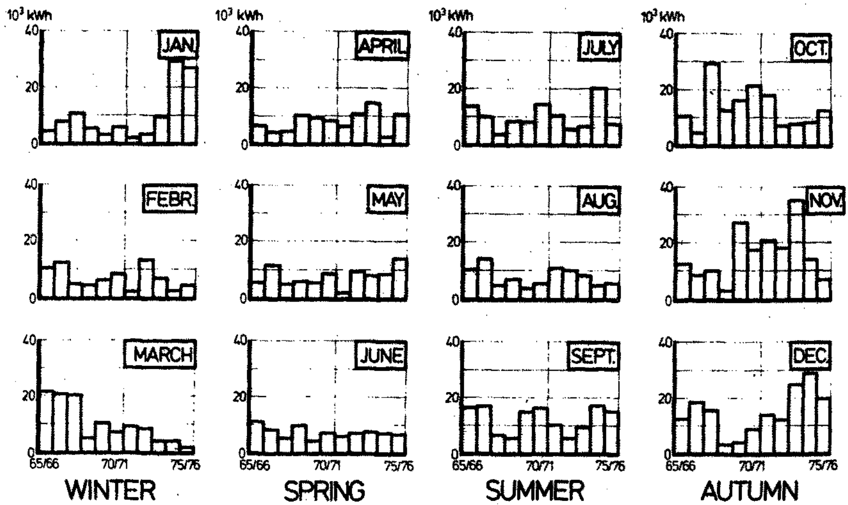

Fig. 8: Classification of the wave energy load according to the months of the year within the period from 1965 to 1976

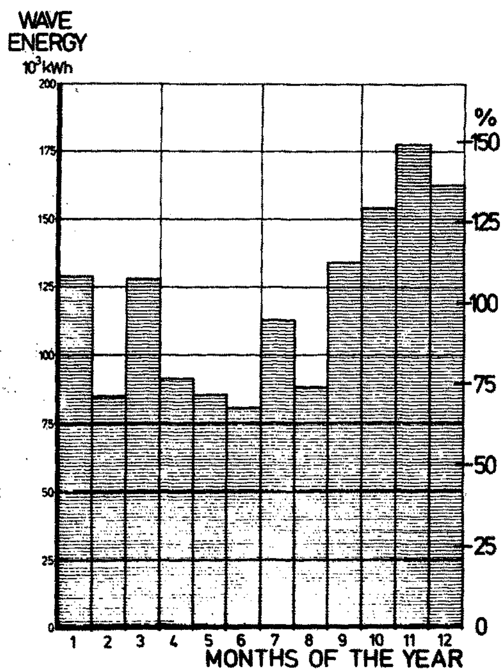

Fig. 9: Total wave energy loads for the months of the year for 1965 to 1976

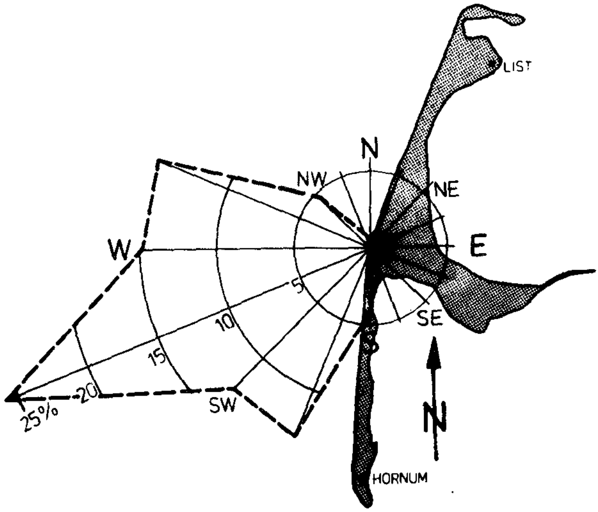

Fig. 10: Frequency and directional distribution of wave energy load for the period from 1965 to 1976

CONCLUSIONS

The attempt to point out relationships between wind velocities occurring from different directions and the wave heights was possible by means of extensive electronic computations. In case it is possible to prove also satisfying correlations for other places of interest the suggested method could be applied in order to receive an objective knowledge of the long-term wave climate and to facilitate the evaluation of processes caused by wave action for an engineer.

ACKNOWLEDGEMENTS

The collection of wave data in the years from 1971 to 1974 was kindly supported by the AMT FÜR LAND- UND WASSERWIRTSCHAFT HUSUM"

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