SECOND INTERNATIONAL CONFERENCE ON
PORT AND OCEAN ENGINEERING UNDER ARCTIC CONDITIONS
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ANALYSES OF WAVE DATA FROM THE NORWEGIAN CONTINENTAL SHELF

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INTRODUCTION

The construction of offshore and coastal engineering structures requires design criteria for which wave conditions are essential.

The first analytically expressed spectrum that has been widely used for engineering design purposes is the so called Neuman spectrum which was used from 1953 to 1964 (1). In 1964 Pierson and Moskowitz published another spectrum that was based on more accurate data (2). This spectrum is now generally accepted by engineers as the most representative for waters all over the world.

A new spectrum that is not yet much applied for engineering purposes is the so called Jonswap-spectrum. The analytical expression for this spectrum is one of the results of the Joint North Sea Wave Observation Project - a comprehensive international experimental effort undertaken in the North Sea offthe Island of Sylt (3). The shape of this spectrum is very different from that of Neuman and Pierson-Moskowitz. Clearly it is important to determine which of the last two spectra are the most representative for waters over the world.

As the Jonswap spectrum is the most representative for the North Sea it is interesting to see if this is the case also for adjacent waters like the Norwegian Continental Shelf. Power spectra calculated from data recorded off the coast of northern Norway is in this paper compared to the Pierson-Moskowitz and the Jonswap spectra.

Bispectra are also computed although this is not yet well known in the engineering literature. The bispectrum is interesting because it gives e.g. information on wether harmonic wave components are coupled or if they can be considered independent of each other. If harmonic coupling, or non-linearities excist, the wave surface can not be considered as a linear superposition of infinetely many sine waves.

THE DATA

The wave measurements have been undertaken in the Lopp Sea off the coast of northern Norway, Fig. 1, from September 1971 to July 1972 by means of the Dutch Datawell waverider. This instrument consists of an accelerometer, two integrators and a radio transmitter placed in a spherical hull of diameter 0.7 meters that is moored to the sea bottom. Vertical accelerations are measured, integrated twice and transmitted to a receiving station as surface displacements. The signal is recorded in analogue form on a strip chart.

At the Norwegian Institute of Technology a new data recording system is recently developed, by which data ends up in digital form on cassette tape. The convertion of data to computer compatible form is then very much simplyfied.

The data recording system is developed under a contract with The Continental Shelf Division of the Royal Norwegian Council for Technical and Scientific Research.

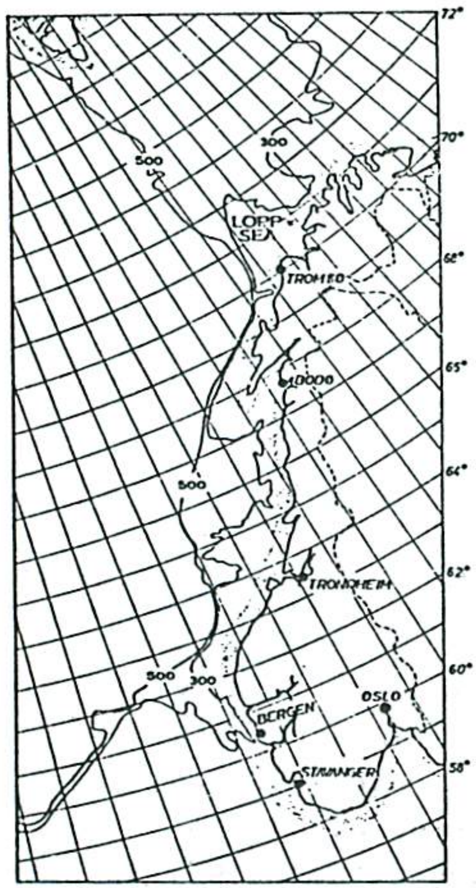

FIG. 1. LOCATION MAP

The measurement period was characterized by frequent storms and waves higher than 15 meters were recorded. The depth at the site was 80 meters.

Every three hours the receiver was automatically switched on and data were recorded for 20 minutes. In most cases this sample length is enough to secure reliable estimates of spectral density.

WAVE SPECTRA

A number of cases with severe wave conditions were selected for wave spectrum calculations. It soon became evident that most of the spectra contain overshoot, Fig. 2, and the energy around the peak frequency was much in excess than would be expected from the corresponding Pierson-Moskowitz spectrum.

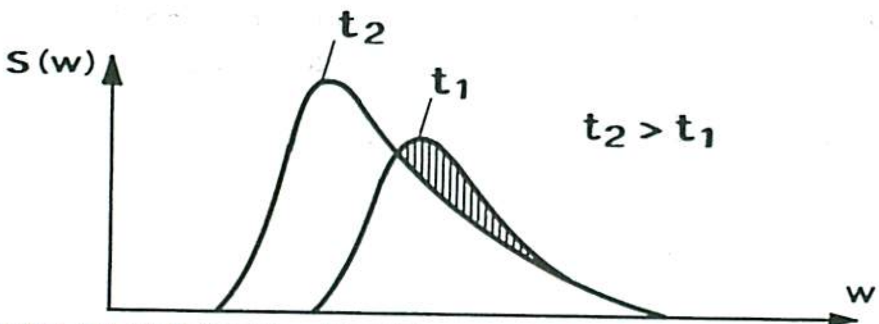

FIG.2 HATCHED AREA INDICATES OVERHOOT ENERGY.

This result becomes particularly interesting when compared to the Jonswap spectrum.

By the Jonswap project the governing mechanisms present when a wind-wave field is built up was investigated. One of the findings was that the energy input from the wind field is accompanied by a non-linear wave-wave interaction mechanism. This mechanism will cause the spectral peak to overshoot that of the corresponding Pierson-Moskowitz spectrum. On the average the peak of the Jonswap spectrum is 3.3 times higher than that due to Pierson-Moskowitz, Fig. 3. It was found, which is also earlier confirmed (1,2,3), that the peak moves towards lower frequencies as the spectrum developes. This is mainly due to the wave-wave interaction mechanism, Fig. 4.

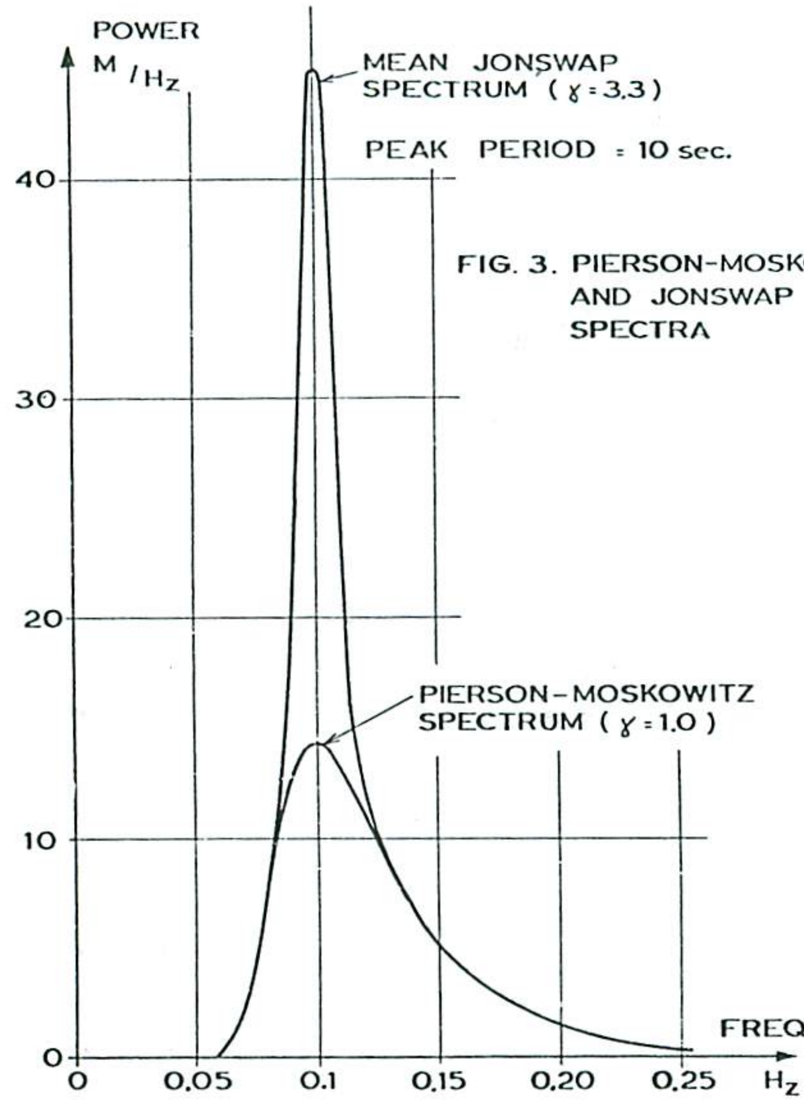

FIG. 3. PIERSON-MOSKOWITZ AND JONSWAP SPECTRA

The Jonswap result were obtained during moderate and steady winds outside Sylt, a nudist island on the NW coast of Western Germany. One question that arises is wether these results are valid under more severe weather conditions.

To study this problem, one needs steady winds with respect to both force and direction, and long duration and fetch. Unfortunately extreme winds in Norwegian waters usually occur in connection with the passage of low pressure systems that cause the winds to change in both force and direction. However, on 18. December 1971 the weather characteristics were suitable for a such study. Steady NW

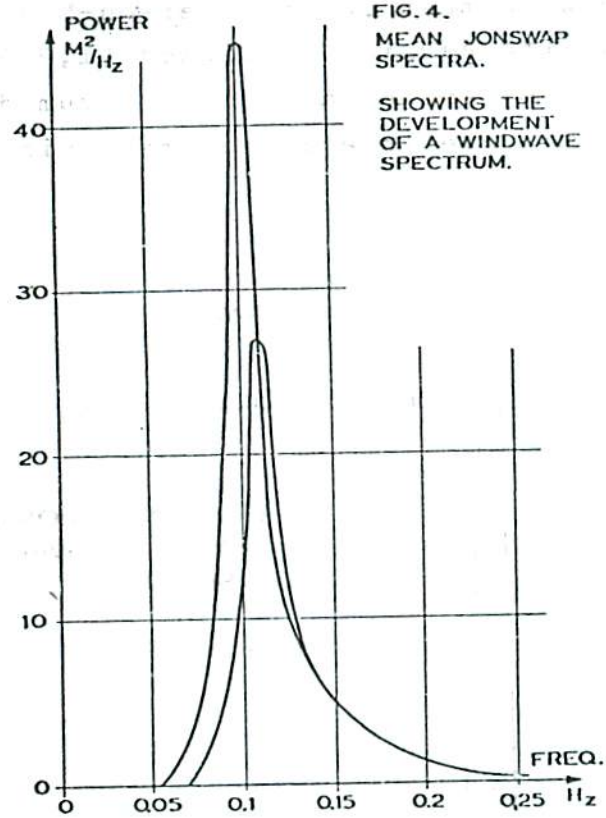

FIG. 4.
MEAN JONSWAP SPECTRA.

SHOWING THE DEVELOPMENT OF A WINDWAVE SPECTRUM.

winds of force 40 knots were generated by a low pressure center that moved with a neglible velocity. One of the calculated spectra are shown along with the corresponding Pierson-Moskowitz spectrum, Fig.5.

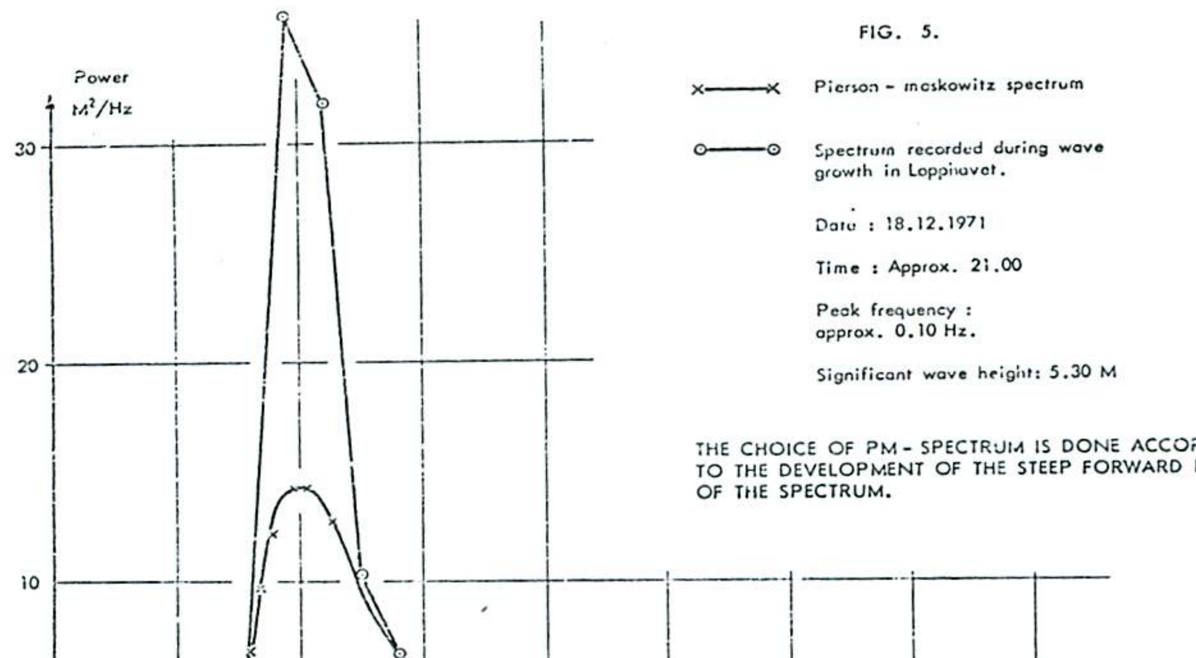

FIG. 5.

Obviously this spectrum contains more energy than the corresponding Pierson-Moskowitz spectrum, and it looks quite similar to that obtained during Jonswap.

The time development of the spectrum as measured in the Lopp Sea is shown on Fig. 6. It is easily seen that the peak moves towards lower frequencies.

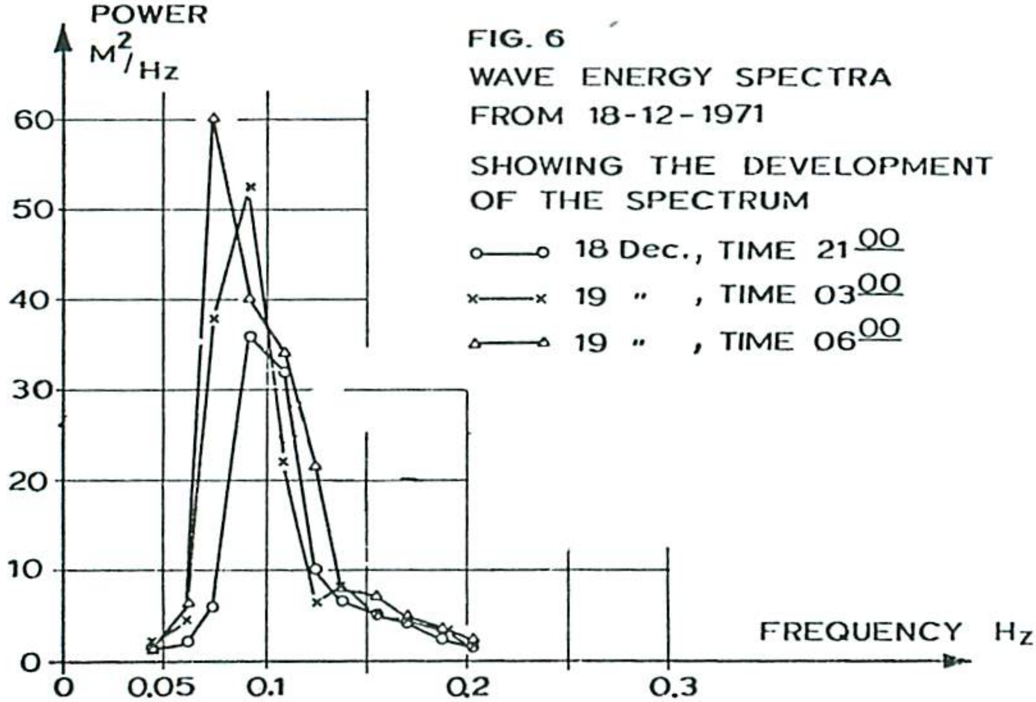

FIG. 6
WAVE ENERGY SPECTRA
FROM 18-12-1971
SHOWING THE DEVELOPMENT
OF THE SPECTRUM

These results have important consequences for engineering applications. The sharply peaked spectra contain more energy than predicted by a Pierson-Moskowitz spectrum and therefore lead to higher waves.

The Pierson-Moskowitz spectrum in the case of peak period of 10 sec leads to a $H_{1/3}$ of 4.0 meters while the calculated spectrum gives $H_{1/3}$ = 5.3 meters - a difference of 33%! For comparison the average Jonswap spectrum gives $H_{1/3}$ = 4.9 meters which is far closer to the calculated value.

For design purposes the Jonswap spectrum should therefore be used, at least for the North Sea and the Norwegian Continental Shelf. The analytical form of this spectrum is given by

$$E(f) = \alpha g^2 (2\pi)^{-4} f^{-5} \exp\left[-\frac{5}{4}\left(\frac{f}{fm}\right)^{-4}\right] \gamma^{\exp\left[-\frac{(f-fm)^2}{2\sigma^2 f^2 m}\right]}$$

where:

α = 0.008

fm = peak frequency

$$\sigma = \begin{cases} \sigma_a = 0.07 & \text{for } f \leq fm \\ \sigma_b = 0.09 & \text{for } f > fm \end{cases}$$

γ = peakedness parameter

$\gamma = 1$ leads to the Pierson-Moskowitz spectrum, and γ equals 3.3 for the average Jonswap spectrum.

Most of the spectra from the Lopp Sea fitted the Jonswap spectrum very well with γ between 1 and 3. The variation in γ naturally reflects the various wind conditions under which waves were measured.

BISPECTRA

General

If a random sea may be regarded as a linear superposition of statistically independent free waves, the sea is completely described by its two-dimensional power spectrum (4). If energy transfer between wave components occur, non-linearity is introduced and the two-dimensional power spectrum fails to give an accurate description of the sea surface.

The bispectrum of a wave record may throw some light upon the non-linearity of the wave motion.

The bispectrum, $B(w_1,w_2)$, of a wave record is the Fourier transform of the mean third order products

$$B(w_1,w_2) = \frac{1}{(2\pi)^2} \iint_{-\infty}^{+\infty} S(\tau_1,\tau_2) e^{-iw_1\tau_1 - iw_2\tau_2} \, d\tau_1 d\tau_2$$

where:

$$S(\tau_1,\tau_2) = \overline{\eta(t)\ \eta(t+\tau_1)\ \eta(t+\tau_2}$$

and the overbar denotes ensemble means.

It is well known that relatively strong non-linearities occur in connection with surf beats and wave breaking, that is for waves on shallow water. Usually the sea surface displacement is considered to be linear to the first order, that is $\eta(t)$ can be represented by

$$\eta(t) = \sum_{n=1}^{\infty} a_n \sin(w_n t + \phi_n)$$

where the phase angles ϕ_n are assumed to be random. Non-linearity can be investigated using the bispectrum, because any major energy content suggests a coupling between the harmonic components.

Stokes and other higher order theories involves a coupling between harmonic components. This leads to a peaking of the waves and a following non gaussian wave topography because the distribution is skewed. This implies that the third order products $(\eta(t))^3$ are non-zero and positive, which explains the relation between nonlinearities and positive values of the bispectrum.

Results

The bispectrum from 6 P.M. of 18. December 1971 have significant positive values of the order 10^2 $meter^3$ sec^2 at frequencies 0.125, 0.56 and 0.188 HZ, the peak of the power spectrum is located at 0.094 HZ. This suggests interactions between the power spectral peak and higher frequencies as well as between each of the frequencies 0.125, 0.188, 0.56 and higher values. We also found strong positive bispectral values around the spectral peak which indicate interactions of the peak with itself and with higher frequencies.

In general we found considerable positive bispectral values in the form of ridges at frequencies close to that of the power spectral peak.

It is interesting to note that our results are different from those obtained by Garrett in 1970 (5) and Barnett in 1972 (6).

The contradiction is probably due to the fact that our bispectra evolvesfrom relatively extreme wave conditions where non-linearities may originate from peaked waves that are close to breaking.

CONCLUSION

Power spectra and bispectrawere calculated for relatively extreme wave conditions. The wave data were recorded by means of the Datawell Waverider off the coast of Northern Norway.

The results show that the Jonswap spectrum fits the calculated spectra better than the Pierson-Moskowitz spectrum. This indicates that the Jonswap spectrum should be applied for Norwegian waters.

Significant positive bispectral values show that a coupling between harmonic wave components occurs. This results in a peaking of the waves and a corresponding non-Gaussian distribution of the wave surface.

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