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The Assessment of a Microwave Directional Wave Measurement System on a Floating Production Platform

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ABSTRACT

In the Spring of 1987 BP initiated a wave measurement trial aboard the Buchan Alpha floating production platform in the North Sea, to assess the performance of a microwave directional wave measurement system by comparison with two conventional buoy systems.

The microwave system performed satisfactorily and can potentially provide suitable wave climate information for operational purposes when linked with the rig motion package. The system has potential to become a useful tool for the assessment and evaluation of rig performance and operability.

INTRODUCTION

Increased attention is being paid to floating production systems as development options for marginal fields. The efficiency of floating exploration and production facilities is a key area of interest, in particular, the measurement and effect of the environment on vessel response, and hence the operability of the system. BP is examining the potential to improve vessel operating performance, through a better understanding of the interrelation of environmental forces and vessel motions. The ability to forecast vessel motions, related to environmental forcing, will lead to improved operating efficiency.

BP has been examining existing methods of measuring directional wave climate together with vessel motion parameters, and, in the Spring of 1987, initiated an assessment trial of a rig based microwave system, aboard its Buchan Alpha floating production platform in the North Sea. The prime objective of the trial was to evaluate the performance of the microwave system against conventional buoy systems, and to provide a comparitive assessment of the systems performance. A secondary objective was to determine the full scale rig response transfer functions, by combining rig motion information and wave spectra measured by the microwave equipment.

References and illustrations at end of paper

THE MEASUREMENT PROGRAMME

The assessment programme was conducted at Buchan Alpha floating production platform, operated by BP, and located in the central North Sea, UK Block 21/1, at 57° 52' N; 00°02'W, in a water depth of 120m. The platform is a converted Pentagone semisubmersible mobile drilling unit. The programme was initiated in mid March with simultaneous wave measurements commencing on the 24th March and concluding on 5th April 1987.

Wave and rig motion measurements were made from the platform using a MIROS MC microwave directional wave measurement system, and simultaneous wave data was obtained from two conventional buoy systems, moored within 1.5km of the platform. The conventional systems were a directional NORWAVE buoy, and non-directional WAVERIDER buoy. Together these systems acted as a reference for the platform based microwave radar, although it should be noted that neither may truly be considered as "ground truth", however, a good deal is known about the accuracy and representativeness of each. The NORWAVE buoy has been used for directional wave data collection totalling 12 buoy-years and has been extensively studied in Norway (e.g., Audunson et al, 1982; Barstow and Krogstad, 1984). Both systems and the MIROS radar have recently been thoroughly tested in the Wave Direction Calibration (WADIC) Project at the Edda Field in the North Sea. The detailed results of that project are confidential at the present time so have not been included in this assessment.

The buoy systems obtained heave time series by double integration of the vertical acceleration, measured by an accelerometer positioned on a gravity stabilized platform with 40 seconds natural period. In addition, the directional buoy measured its own pitch and roll motions, relative to the stabilized platform, using magnetic inclinometers. Simultaneous time series of heave, pitch, roll and compass form the basis for the directional wave analysis which used standard methods (Long, 1980; Barstow and Krogstad, 1984).

The directional buoy recorded 34.14 minute time series, at 1 Hz, each 3 hours. The non-directional buoy recorded 17.07 minute time series, at 2Hz, every hour. Sequencing was designed to correspond with the microwave radar directional scan period of 72 minutes. The directional buoy also measured meteorological parameters (wind speed and direction, air pressure, air and sea temperature), and all data was recorded on magnetic tape aboard the buoy. Primary directional wave and meteorological parameters were transmitted, in near real time, via satellite to land. The buoy position was also satellite monitored. The non-directional data were transmitted direct to the rig, where digitization, data processing, and data storage were performed. A full suite of meteorological information was routinely recorded aboard the rig.

Strict quality control was conducted on buoy data. In the case of the NORWAVE system, a series of internal consistency checks were regularly carried out, providing a check of on-board wind direction against high frequency (wind-wave) direction, and a check of the mean phases of cross-spectra between heave and buoy slopes (Barstow and Krogstad, 1984). The WAVERIDER data underwent several manual inspections and automatic data validation procedures during onshore processing, including checksum and range checking calculations.

The MIROS-MC rig based system used a microwave (5.8 GHz), pulsedoppler mode, to measure the wave surface velocity in a fixed "footprint", 7.5 metres long by 260 metres wide. The width of the "footprint" corresponded to a beamwidth of 30 degrees at a range of 500 metres from the antenna. This wide, thin footprint provided the directional resolution of the system.

The doppler frequency shift of the return radar signal is a measure of the average wave orbital velocity in the footprint, at that instant. A 90 second continuous time series of wave velocity was formed by lowpass filtering of the signal, and this was digitally sampled at 2.86 Hz and Fourier analysed to form the wave power spectrum, in that direction, making use of finite depth linear wave theory.

This scan was repeated every 15 minutes for each of the six look directions. The spectra for each direction were averaged with previous scans to give the final spectral estimate. By summing the spectra over all the directions the total wave energy spectrum was produced, and standard parameters such as significant wave height and mean period were calculated from the spectral moments. Mean wave directions and wave spread were also calculated for routine output. It should be noted that the system as tested had an inherent 180 degree ambiguity with respect to wave direction, due to the pulse doppler technique.

The MIROS wave data were subjected to quality control checks both on-line and in post processing. On-line checks included high frequency and low frequency content and mean offset, in addition to system status checks.

The microwave system can also operate in a dual frequency mode to measure the total current vector, but a detailed description of this capability is outside the scope of this paper (see for example Grönlie et al, 1987).

The received signals were corrected for the additional velocity component and range variation due to antenna motion, resulting from the platform's movement. These correction signals were derived from a motion reference unit, which also provided the complete measurement of vessel motion in six degrees of freedom. This motion data forms the basis of the rig transfer function determination described below.

ENVIRONMENTAL CONDITIONS DURING THE PROGRAMME

A wide range of climatic conditions occurred during the programme with air pressure ranging from 1030 mbar to 960 mbar. Two relatively severe storms occurred, on the 17th and 27th March 1987, with windspeeds peaking at 22m/s during the former event. The latter storm was particularly interesting as the centre of the depression passed directly over the Buchan area on its passage eastwards. Low wind speeds on the 27th corresponded with the lowest recorded air pressure measurement, a shift in wind direction from southerly to northerly occurred in only 3 hours, followed by a very rapid increase in wind speed as the rear of the depression passed. This event naturally produced some rather exceptional crossing, directional seas which are further described below.

The highest significant wave height during the programme exceeded 7m, and the storm of the 27th maintained wave heights greater than 6m for almost 1½ days duration, as the depression moved slowly eastward.

A good cross section of wave directions was encountered during the programme with the notable exceptions of a westerly or a north-easterly component, the former due undoubtedly to fetch limitations, and the latter directions showing no significant periods of wind forcing. An examination of the unidirectionality of the spectral wave components indicates a high percentage of records (35%) are significantly bimodal. This suggests a crossing sea and swell, or two swell trains, which are significantly divergent with respect to direction. The main bimodal events observed during the programme were on the 25th and 28th March 1987, and are discussed in more detail below.

RESULTS

Time Series

Simultaneous wave data were obtained from all three of the measuring systems between 24th March and 5th April 1987. Figure 1 presents superimposed time series of significant wave height, for each system, for this period. Figure 2 provides a plot of the time series of the mean wave direction at the spectral peak for the NORWAVE and the MIROS and the wind direction from the NORWAVE buoy, from 25th to 29th March.

Figure 1 and figure 3 demonstrate that each wave system identified similar events throughout the period, with the MIROS appearing to consistently underestimate wave height in moderate sea states and overestimate at higher wave heights, when compared to the two buoy systems. A statistical evaluation was carried out on simultaneous measurements of significant wave heights from each system, and, as seen in figure 3, showed a high degree of correlation between the systems. A correlation coefficient of 0.98 was evaluated between the NORWAVE and MIROS; with a slightly lower value, 0.97, between the WAVERIDER and MIROS. The underestimation is apparent in the figure at the 2-5m range, with overestimation developing above 6m.

A reasonable correlation was determined for the spectral peak period assessment between the microwave and directional buoy system, with a correlation coefficient of 0.74.

On the 25th March both directional systems indicated a decaying easterly mean wave direction (see figure 2) resulting from prevailing easterly winds in the previous 24 hour period. The wind backed to westerly, then veered southerly towards the end of the day. The corresponding shift in wave direction lagged by some 12 hours, before the mean wave direction stabilised, at 180° as indicated by both systems. A further shift in wind direction occurred on the 27th, when the depression passed directly over the area, and a similar lag period was observed in the changing wind sea. An interesting anomaly can be observed between the NORWAVE and MIROS mean wave direction on this occasion. The NORWAVE indicated a northerly sea, corresponding to the wind direction, however, the MIROS indicated that the wave direction remained at 180°. In this case it must be remembered that the MIROS system had a 180° ambiguity, and the wave directions had been normalised into the 0-180° sector.

Wave Spectra and Directional Spectra

Two excellent examples of bimodal spectra were observed during the assessment trial, on the 25th March and during the deep depression of 27th/28th March, each providing an excellent intercomparison between the two directional systems.

Figures 4 and 5 present representative spectral data from the two events, for the NORWAVE and MIROS system. It should be noted that the contour plots of directional wave spectra (figures 4c and 5c) have been computed by the Maximum Entropy Method after Lygre and Krogstad (1986), which allows resolution of bimodality in the same frequency band. Figures 4d and 5d show the directional spectra for the MIROS in 6 look directions.

It can be seen from figures 4a and 5a that the form of the total spectra for each system correspond closely, however the MIROS spectra appears to underestimate somewhat the total energy. This underestimation is probably a result of the relatively long time span over which observations are made, and the averaging technique used in the MIROS data processing.

The first bimodal event occured on 25th March in a moderate sea state. The NORWAVE directional spectra, show an easterly swell with a developing local wind sea from the west following the passage of a frontal system and its associated rapidly veering winds (see figure 2). Both total spectra correspond well and display the bimodality, however, the MIROS directional spectra (figure 4d) shows significant energy only in the 270° and 300° look directions, whereas the NORWAVE spectra clearly deliniate between east and west. The 180° ambiguity in the MIROS directional spectra is hence apparent.

At midday on 27th March a deep depression was centred directly over the Buchan area, and a bimodal directional spectrum was apparent, consisting of a northerly swell and southerly wind sea. Late on the 27th a local northerly wind developed on the rear of the depression, and had reached 20m/s early on 28th March. The contoured directional spectrum (figure 5c) had become more confused, with the growing northerly wind sea peaking around 0.17 Hz, and the remains of the northerly swell and southerly wind sea from the 27th at 0.10 Hz. The Maximum Entropy Method demonstrated its ability to resolve the northerly swell and southerly wind sea at 0.10Hz.

Once again the ambiguity problem is apparent since the MIROS spectra shows peaks in only the 300°, 330° and 0° look directions and is unable to differentiate between wind sea and swell in opposite directions.

FULL SCALE RIG RESPONSE TRANSFER FUNCTIONS

The floating platform, full-scale, dynamic motion response transfer functions were calculated from the wave power spectrum and the platform motion time series data measured by the MIROS-MC system. Wave power spectra with suitably broad band energy were selected from the data set by visual inspection. The corresponding platform-motion time series were transformed to the platform centre of gravity and Fourier transformed to obtain the corresponding power spectrum for each degree of freedom. The wave spectra were obtained from 90 second time series of wave particle velocity, corresponding to a frequency resolution of 0.01 Hz, hence the motion data were transformed to the frequency domain with the same frequency resolution.

The modulus H(ω) of each transfer function was then calculated as follows:

$$H(\omega)^2 = \frac{Sii\ (\omega)}{Sw\ (\omega)}$$

where Sii (ω) is the auto power spectrum of the motion parameter of interest
Sw (ω) is the non-directional wave power spectrum

This method did not take account of directionality of the wave data, but it was noted where the wave field had a predominant directional component.

Figure 6 presents the MIROS wave power spectrum for 25th March at 2330 GMT, and the corresponding vessel heave spectrum. Figure 7 presents the transfer functions for five degrees of freedom (yaw not shown). It should be noted that this assessment presents a preliminary analysis of rig motions at this time.

By transforming the motion data to different horizontal levels, it was possible to select the frequency components in the surge and sway spectra, due to pitch and roll, which were minimised by the transformation. This then indicated the vertical level of the centre of rotation, in pitch and roll, for various motion frequencies. For example, the centre of rotation for 10 second periods (0.10 Hz) was at a level of 36m above the vertical centre of gravity (VCG); that for 45 second periods (0.022 Hz) was within 1m of the VCG, as might be expected from considerations of static stability.

CONCLUSIONS

The qualitative and quantitative assessment of the motion compensated microwave directional wave measuring system against standard buoy systems (directional, and non-directional) indicates that a good correlation exists in both the time and frequency domains, given the limited amount of data available. Comparisons of wave height and period information between systems show good statistical correlations.

In terms of wave height the microwave system apparently underestimates in moderate seastates and overestimates the higher waves, by comparison with the buoy systems.

In terms of the total power spectrum the microwave system apparently underestimates the total energy.

The resolution of directionality in opposing sea states, due to 180 degree ambiguity in the microwave system, poses a problem in post processing and analysis of data. However, where visual observations can be linked with the systems data products, the ambiguity problem could be partly solved. Thus the system has the potential for operational use.

In the production of integrated total wave power spectra, vessel heave spectra, and vessel response transfer functions, the microwave system should provide a useful tool for the assessment and evaluation of rig performance, and can potentially be applied to produce operational vessel response forecasting in relation to wave forcing.

ACKNOWLEDGEMENTS

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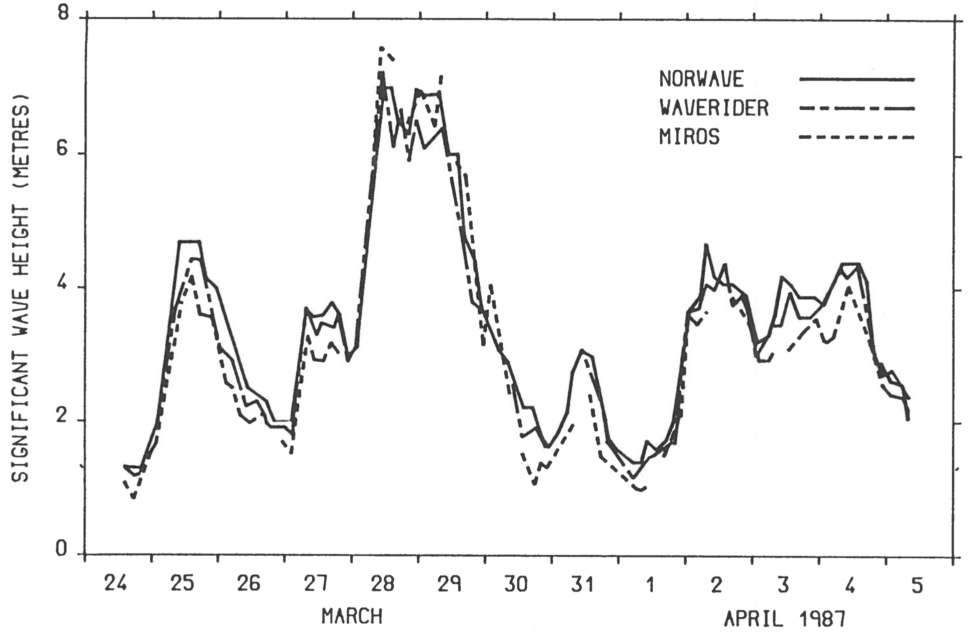

Fig. 1—Significant wave height—Buchan Alpha, 24 March to 5 April, 1987.

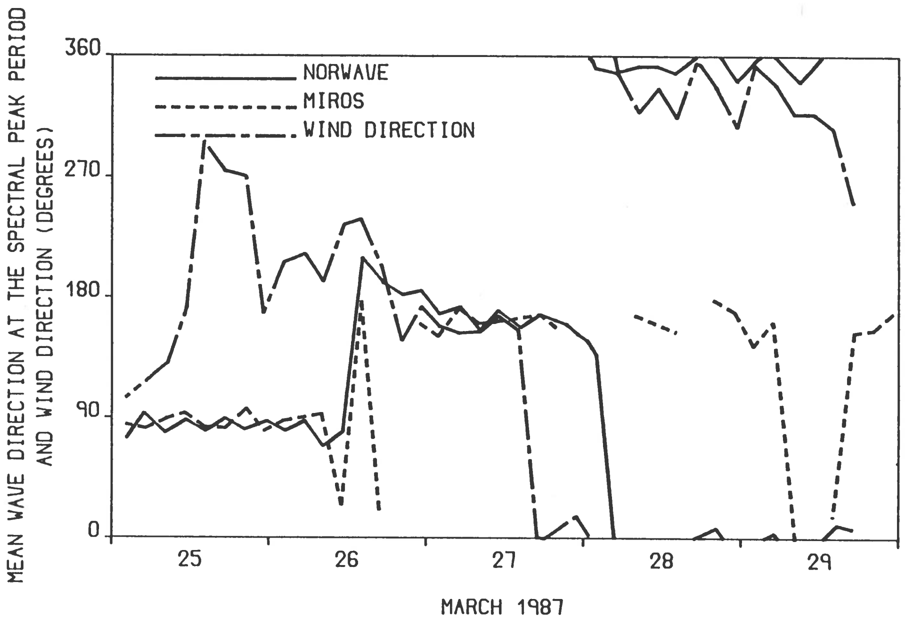

Fig. 2—Wave conditions—Buchan Alpha, March 25-29, 1987.

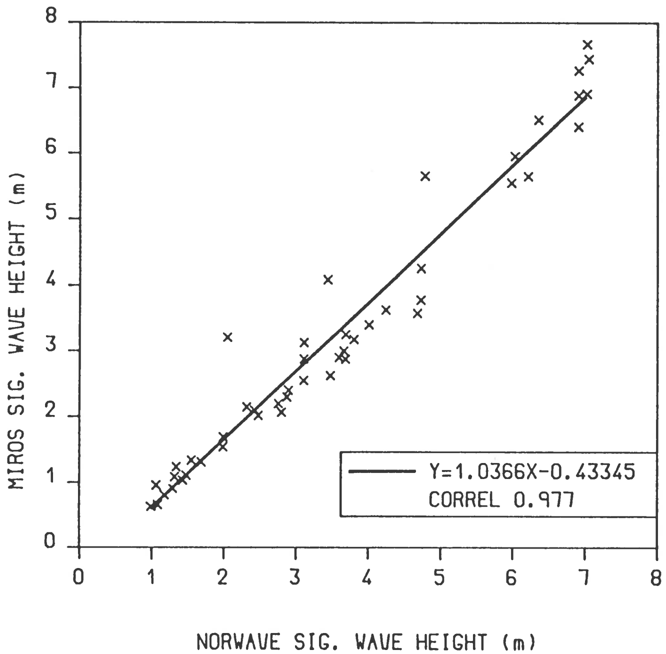

Fig. 3—Regression analysis—significant wave length.

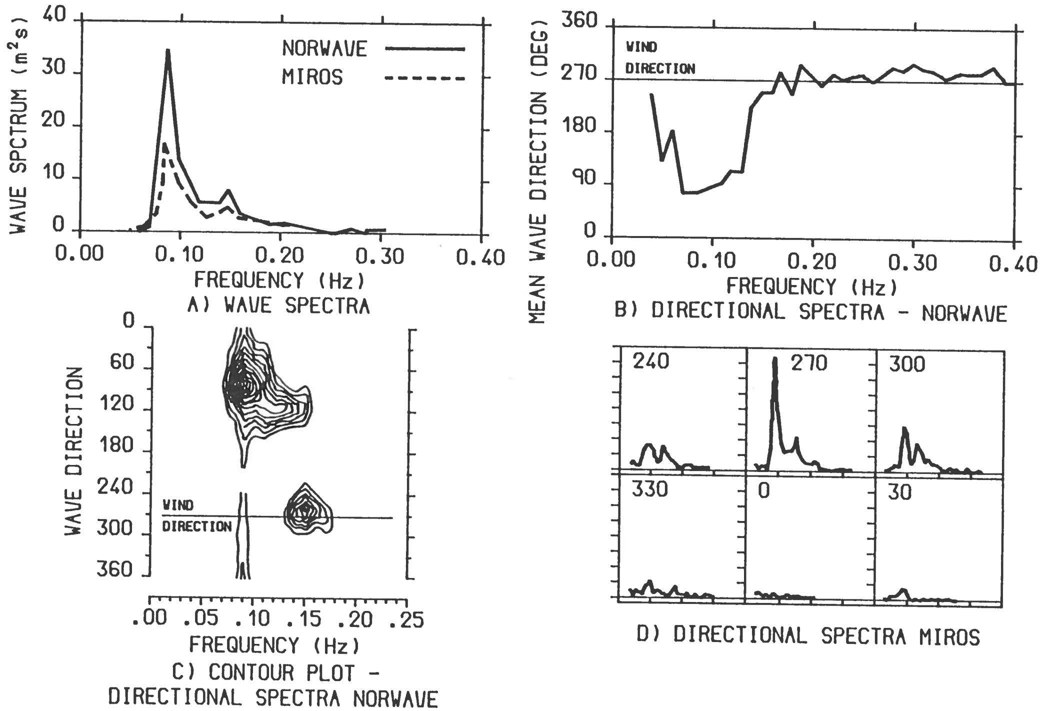

Fig. 4—Spectral plots, 25 March—2000 GMT.

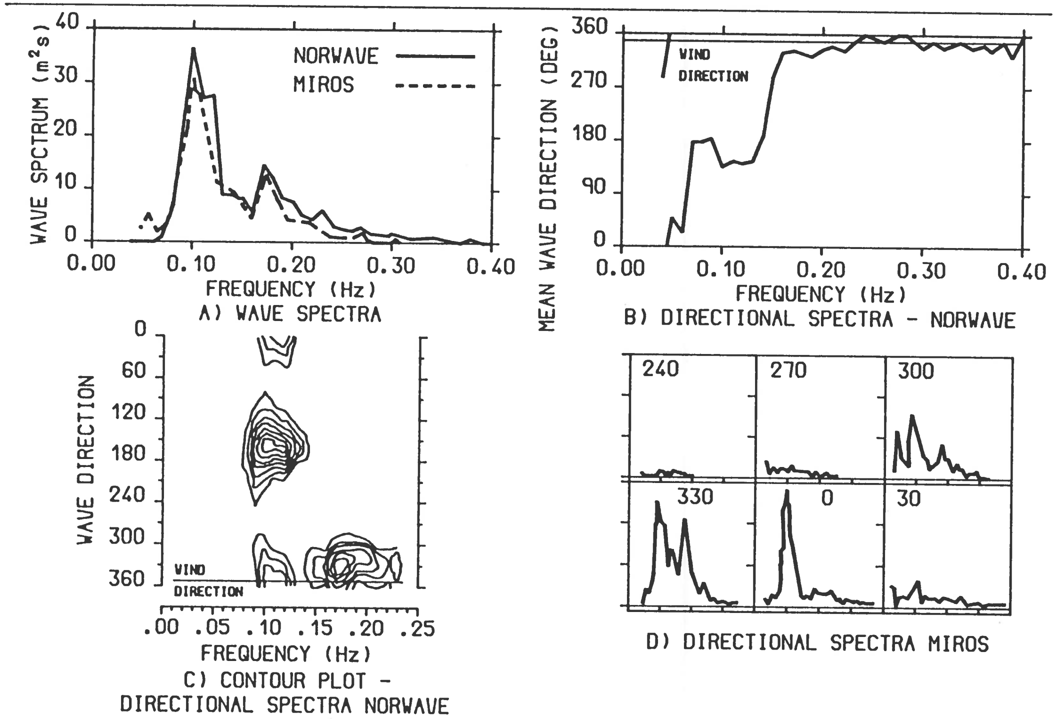

Fig. 5—Spectral plots, 28 March—0200 GMT.

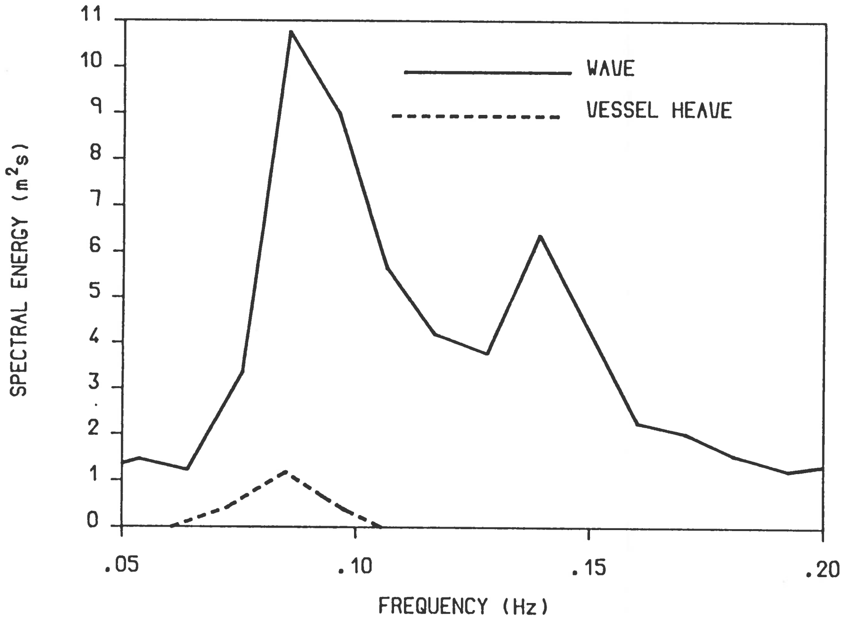

Fig. 6—Wave and vessel heave power spectra, 25 March.

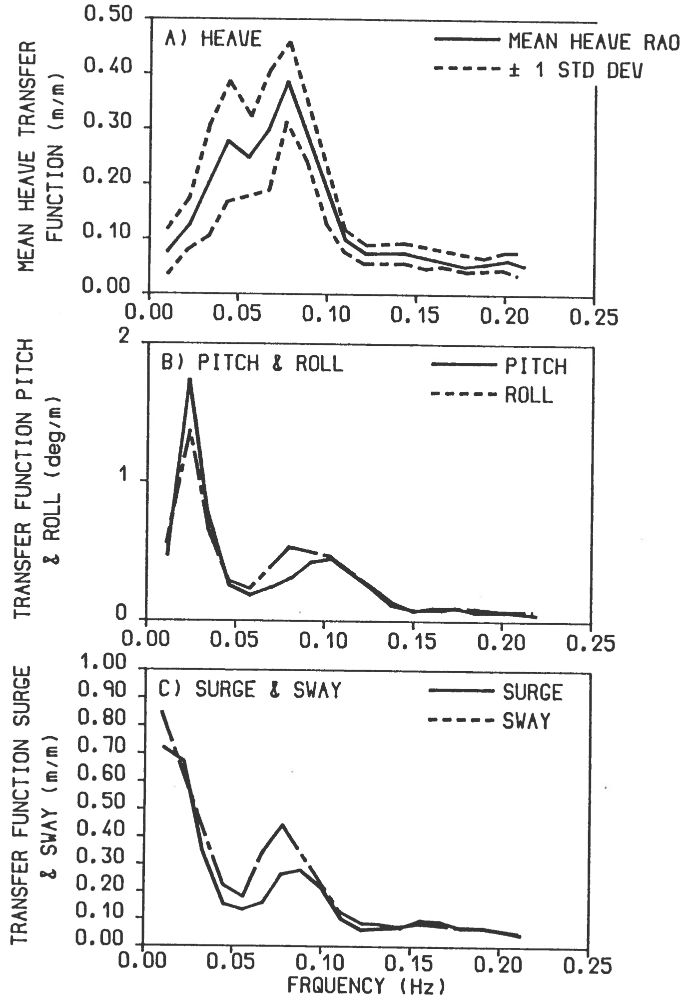

Fig. 7—Transfer functions, March 1987.