CHAPTER 41

DIRECTIONAL WAVE MEASUREMENTS IN RIO DE JANEIRO COAST

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ABSTRACT

This paper presents the experience and results with a slope array of wavestaffs specially designed and built for directional wave measurements from an offshore platform off the Rio de Janeiro coast. We discuss the main features of the system, limitations and noise sources. A promising adaptive technique is introduced.

1. INTRODUCTION

Having one of the biggest coastlines of the world, Brazil still lacks long term wave data, either in offshore areas or in the coast. In the last decade most of the oil production in the country is coming from offshore, and fields as deep as 1500 meters will be exploited in the incoming years. In this way, information on directional wave, wind and current, for the design of new huge structures to face such challenge, is mandatory. Besides that, an emerging consciousness in relation to the occupation, protection and management of coastal areas is also putting a big demand in environmental data.

Three directional wave measurement projects are going one in the Rio de Janeiro State coast (positions are shown in fig.1).

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A) A Directional Waverider buoy in front of Guanabara Bay (Rio de Janeiro city);

This instrument is being used in a joint project conducted by the Federal University of Rio de Janeiro and the Brazilian Navy Hydrographic Office (DHN), owner of the equipment (Melo et al, 1991). The main purpose is to characterise the wave climate along the famous Ipanema-Leblon beach that have been under severe erosion in the last years.

B) A directional buoy built by CONSUB, a brazilian company, for PETROBRAS, moored in 1500 meters of water.

This buoy sends via Imarsat satellite, meteorological and oceanographic data including directional wave data.

C) An array of resistive wavestaffs mounted as a slope array in an offshore platform in waters 100 meters deep;

This paper describes the experience and results with this slope array.

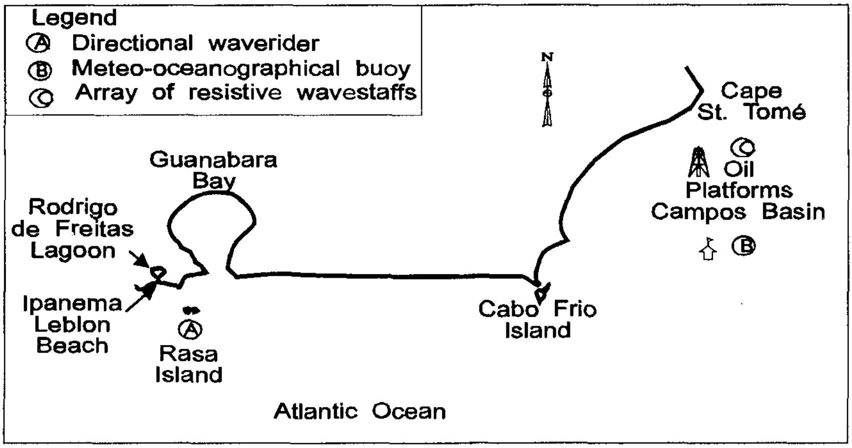

Fig.1 Rio de Janeiro coast with the locations of the directional measurements.

2. DIRECTIONAL MEASUREMENTS FROM AN OFFSHORE PLATFORM WITH A SLOPE ARRAY

The objective of this project is to simultaneously measure wave, current and wind in order to determine long term resultant forces in an offshore platform.

Directional wave measurements are made with arrays of resistive wavestaffs suspended from the platform.

Following the idea of Ford et al (1968), we built a slope array of resistive wavestaffs to be suspended from an offshore platform in the Campos basin. One array consists of four wavestaffs made with 0.25 mm stainless steel wire spirally winded around a 1.25 mm synthetic cable. The staffs are suspended from the platform, fixed in a light frame forming a square of 1.12 m each side. This configuration has shown several advantages in terms of handling, maintenance of vertical position and relative horizontal position among the staffs.

Due to safety reasons (protection against fishing boats) the array is mounted inside the platform; as we discuss later, this can be a source of noise.

The staffs are excited with CW signals in order to extend the life of the wires. All the signals are conditioned and processed in a central station producing surface elevation and two orthogonal surface slopes. We followed the processing techniques of Borgman (1982) and Kuik et al (1987) to get the one point spectrum, main direction and spread about the main direction. We can also calculate the wave number and compare with the value given by the linear theory.

Preliminary results have shown good agreement with visual observation (sea and swell) and measured data (wind and current).

The main characteristics of the slope array are:

Requirements: low drag and small weight in order to be easily placed by hand in the support base and keep good vertical position. In the beginning we have tried just single wires (very low drag), but the sensitivity was not enough for lower frequencies.

Number of staffs: 4 - mounted in a square of 1.12 m side.

Sensor spacing: 1.12 m. The spacing is a compromise between adequate sensitivity for slope measurements and spatial aliasing in high frequencies.

Staff: resistive. A stainless steel wire .25 mm in diameter is spirally winded in a 1.25 mm polypropylene wire.

Resistance: 135 ohms/meter.

Weight: Each staff has a 5 kg weight.

Linearity: 1.7 per cent.

Length: 12 meters.

Excitation: pulsed CW.

Detection: synchronous (sample/hold).

Signal conditioning: all the conditioning circuits are analog, the A/D conversion being done in the computer.

3. DATA ANALYSIS IN SITU

All the data (wave, current and wind) is transferred to a PC type computer and processed in real time; it is also send to Rio via satelite.

The software perform the following operations:

- data acquisition;
- data quality tests;
- time domain analysis;
- frequency domain analysis;
- directional wave analysis.

Raw data and calculated parameters are also send to shore via satelite.

We use the classical Fourier and the Borgman and Kuik techniques mentioned above to calculate the directional spectral parameters (main direction and spread); they are summarized below.

Elevation and slopes for a monochromatic wave $(\mathbf{f},\theta)$ are given by:

$$\eta = \alpha \cos(kx\cos\theta + ky\sin\theta - \omega t + \varepsilon) \quad (1)$$

$$\eta_x = -\alpha k\cos\theta\sin(kx\cos\theta + ky\sin\theta - \omega t + \varepsilon) \quad (2)$$

$$\eta_y = -\alpha k\sin\theta\sin(kx\cos\theta + ky\sin\theta - \omega t + \varepsilon) \quad (3)$$

Taking the origin at (0,0) and $\epsilon=0$;

$$\eta = \alpha \cos\omega t \tag{4}$$

$$\eta_x = -\alpha\, k\cos\theta\sin\omega t$$

$$\eta_y = -\alpha\, k\sin\theta\sin\omega t \tag{6}$$

Now we Fourier transform and take cross spectra:

$$\begin{array}{cccl}
\eta & \eta_x & \eta_y & (7) \\
\\
\alpha\cos\omega t & -\alpha k\cos\theta\sin\omega t & -\alpha k\sin\theta\sin\omega t & (8) \\
\downarrow & \downarrow & \downarrow & \\
\cos\omega t \;\; \sin\omega t & \cos\omega t \;\; \sin\omega t & \cos\omega t \;\; \sin\omega t & (9) \\
\downarrow & \downarrow & \downarrow & \\
\alpha & -\alpha k\cos\theta & -\alpha k\sin\theta & (10) \\
 & \downarrow & \downarrow & \\
 & \alpha^2 k\cos\theta = a_1 & \alpha^2 k\sin\theta = b_1 & (11)
\end{array}$$

$$\textit{main direction} \quad \Rightarrow \quad \theta = atan(b_1/a_1) \tag{12}$$

Kuik et al (1988) suggest that the energy distribution around the main direction, $D(\theta)$, can be associated to a probability distribution, the standard deviation representing the spread of energy.

$$\sigma = \sqrt{2(1 - m_1)} \;\; ; \;\; m_1 = \sqrt{a_1^2 + b_1^2} \tag{13}$$

Some data quality control are made comparing the measured wavenumber (k_m) with the wavenumber given by linear theory (k_l). For the same monochromatic case, taking the spectrum:

$$G_\eta = \alpha^2; \; G_{\eta_x} = \alpha^2 k^2 \cos^2\theta; \; G_{\eta_y} = \alpha^2 k^2 \sin^2\theta \tag{14}$$

and summing:

$$k_m = \sqrt{\frac{G_{\eta_x} + G_{\eta_y}}{G_\eta}} \tag{15}$$

We can see below an example from a fetch limited NE sea, typical of the Campos area. In fig. 2 the spectrum, in fig.3 main direction, in fig 4 spread and in fig. 5 comparison of wavenumbers.

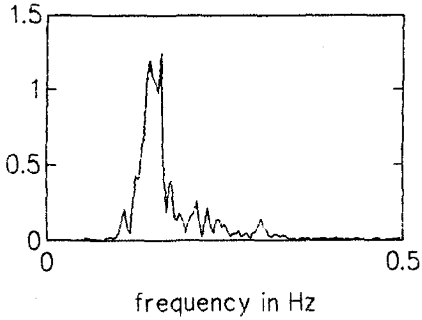

Fig.2 Spectrum of a NE sea

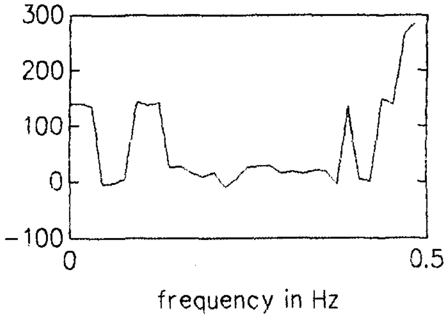

Fig.3 Main direction

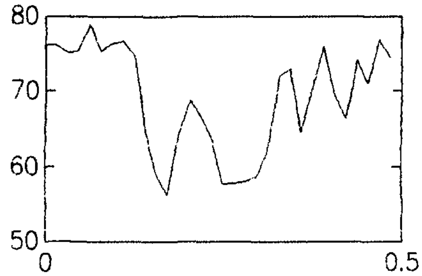

Fig.4 Spread

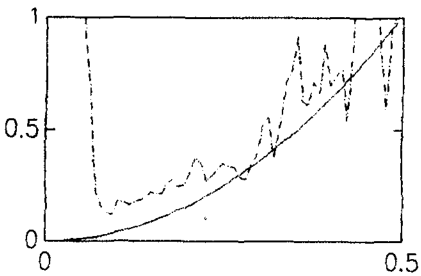

Fig.5 Wavenumbers (k_l, k_m)

4. DATA ANALYSIS ASHORE

Fig.6 shows the evolution of the spectrum for the peak frequency along the record, advancing one value of the series each time. We can notice regions of high and low values suggesting that possibly at a given moment the energy in the main direction is low but could be measurable at other directions.

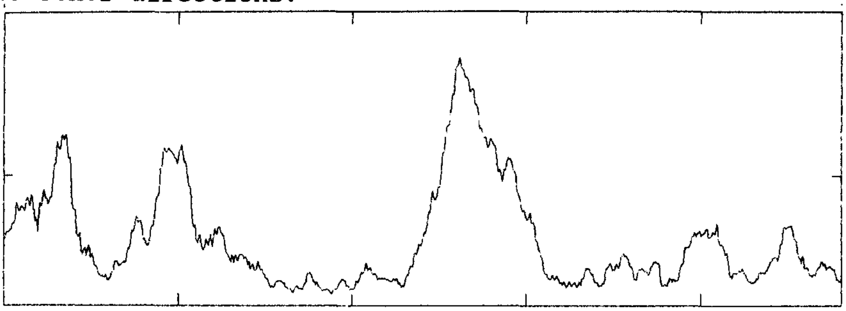

Fig.6 Spectrum (peak frequency) changing with time

We may consider that these ups and downs along the record are due not only to the fact that different frequencies, close together, combine in a constructive or destructive way but also to other factors, identified as noise, non-linearities, non-stationarity, inaccuracies, etc...

- limited number of sensors;
- non-linearities of staffs and circuitry;
- non verticality of staffs;
- influence of platform structure;
- non-stationarity of the wave field;
- finite sensor spacing and aliasing;

All this factors tend to contribute to the non-stationarity of the process along the recording time.

We can recall some basic principles of spectral analysis, quoting Gardner (1988):

The fundamental reason for interest in a statistical (e.g. time averaged) spectrum of some given data is a belief that interesting aspects of the phenomenon being investigated have spectral influences on the data that are masked by uninteresting (for the (purpose at hand) random effects and an additional belief (or, at least, hope) that these spectral influences can be revealed by averaging out the random effects. This second belief (or hope) should be based on the knowledge (or, at least, suspicion) that the spectral influences of the interesting aspects of the phenomenon are time-invariant, so that the corresponding invariant spectral features (such as peaks or valleys) will

be revealed rather than destroyed by time averaging.

The random combination or action of all the mentioned factors could destroy some features of the process rather than enhance if we average along the entire record, as mentioned by Gardner.

We could possibly select some recording periods where a given frequency band or directional sector is showing a better signal quality, wave grouping or other special feature. This is a kind of adaptive technique that we are trying now and we show here some results.

A possible criterium would consider how close are the wavenumber values (measured and from linear theory); another, perhaps, wave grouping. Using the first one, for each selected series (close values of k_l and k_m) we collect spectrum and main direction. The result is a possible representation of the directional spectrum. If we sum, for each frequency, all the contributions in direction we approach the one point spectrum, whose area should agree with the mean square value of the process.

The technique could be resumed as follows:

1) For each sensor take series of **m** point at time, and calculate spectrum, main direction, k_m and spread. (**m** is typically 64,128 or 256).

2) Take the average of all 4 sub-arrays (it is worth while to have some redundancy).

3) Select the series where $\mathbf{ABS}\ (\mathbf{k_m} - \mathbf{k_l}) < \mathbf{s} \times \mathbf{k_l}$;

s between 0.05 and 0.2, for example.

4) Accumulate the spectrum value in the corresponding direction box.

We can see below some results. In Fig.7 we can see a 3D plot of the evolution of the spectrum value and main direction for the peak frequency along a given recording period. During this time we have enhancement of the spectrum value for different direction inside a given sector, changing in a well behaved way.

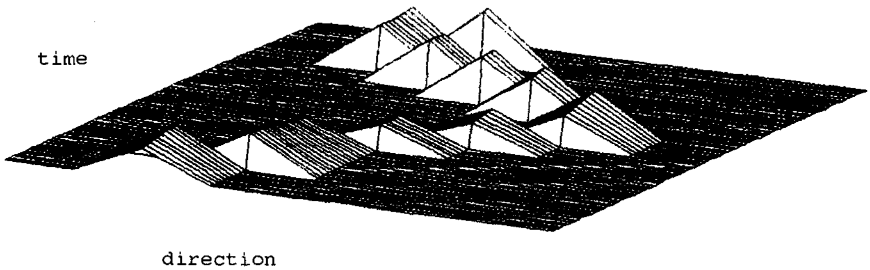

Fig. 7 Spectrum value and mean direction for the peak frequency changing along the time.

In fig. 8 a construction of $D(\theta)$ for the peak frequency taking the contributions of all sub-arrays.

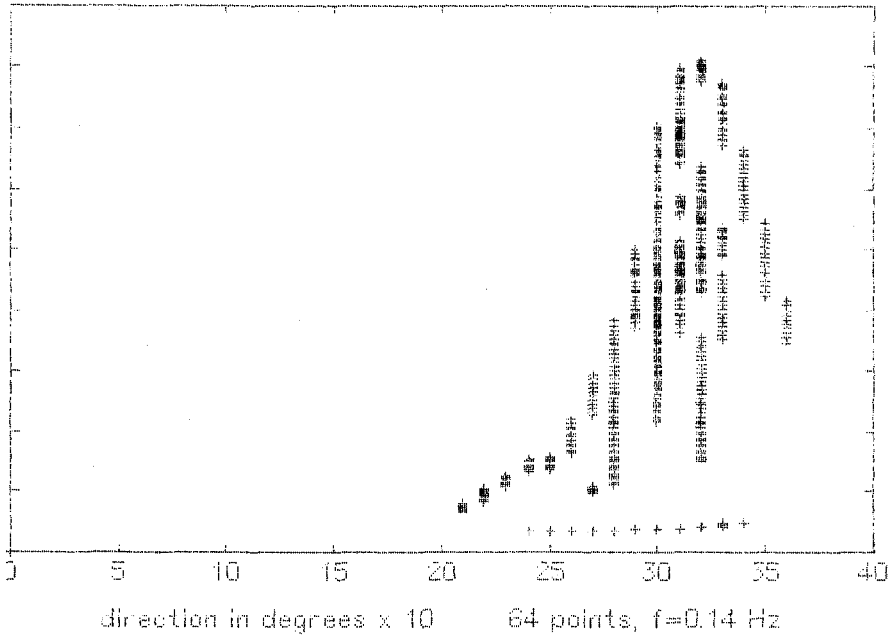

Fig.8 $D(\theta)$ for the peak frequency, using the contributions of all sub-arrays. Vertical axis is spectral density and horizontal axis is direction in degrees.

In fig. 9 we see a 3D plot of "directional spectrum" (frontal view). We have in the same graph two plots of the one-point spectrum. One is calculated using the entire record with 4 d.f. (dashed line); the other one is calculated summing the contributions of direction "boxes" for each frequency (continuous line).

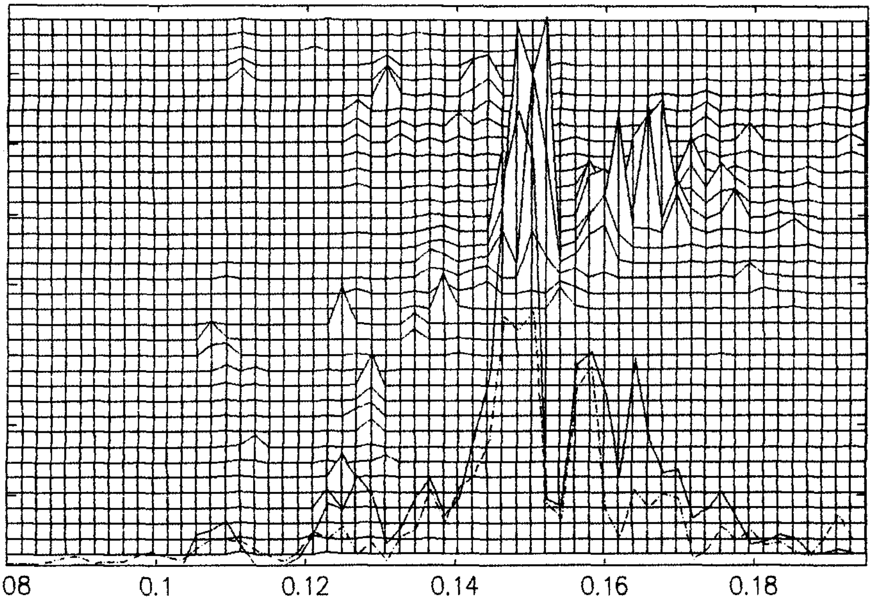

Fig. 9 3D plot of directional spectrum (frontal view). Vertical axis is direction and horizontal axis is frequency (axis z is spectral density). In the same graph one point spectrum.

In fig. 10 a 3D plot of the same data (side view). Vertical axis is frequency and horizontal axis is direction; z axis is spectral density.

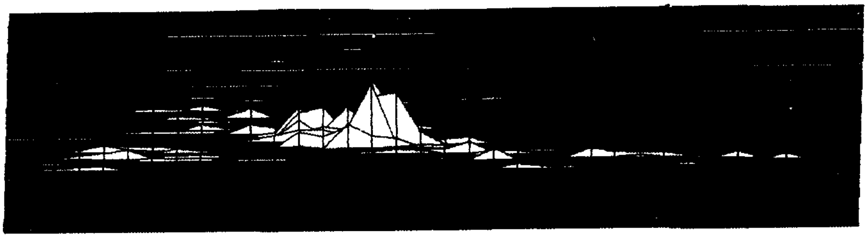

Fig. 10 3D plot of directional spectrum (side view). Horizontal axis is direction; vertical axis is frequency; z axis is spectral density.

5. CONCLUSIONS

The results are showing very good consistency compared with measured wind values and visual observations from the platform. As we would expect the resolution is relatively poor for low frequencies . We are about to use two arrays 30 m apart in an attempt to solve this problem.

The resistive wave staff have been used for many years and is a very cheap and reliable way to get wave data from an ocean fixed structure. Usually it is not very easy as one could expect to make oceanographic measurements from an offshore platform, mainly if it depends on divers, big cranks and special locations, just to mention a few problems. In this way, a small and light array suspended from the spider deck of a platform (the deck closest to the sea level) provided that the resolution is adequate for low frequencies, can be very useful not only as source of log term data but also for the day to day operation of the platform.

Work in progress is toward better resolution in low frequencies, simulations with artificial seas, combination of two or three arrays and the search for adaptive techniques.

ACKNOWLEDGEMENTS

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