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SPECTRAL ANALYSIS OF SHALLOW WATER PROPAGATION OVER ROCK BOTTOMS

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1 Introduction

In two previous papers [1,2], we have presented some experimental results on horizontal wavenumber analysis of shallow water propagation. The method we used was based on the spectral analysis of the output of a synthetic array [3,4]. The spectrum achieved exhibits peaks which correspond to the normal modes present in the water layer. We have investigated different types of bottoms : sand, limestone and granite. Of course we found an increased number of propagating modes when the bottom is of an elastic type. But even if the number of modes is greater it is difficult to extract high order modes.

The purpose of this paper is to extend the method used in the previous paper to realize high order modes detection. The principle is to use a weighted vertical array to focuse the energy only in the direction of the mode we want to detect and to perform the spectral analysis afterwards.

2 Spectral analysis of the acoustic field

We give here a brief summary of the spectral analysis principle. In the far field, the sound pressure generated by a harmonic point source placed at z_o and received by a moving transducer may be written as :

$$p(t,z,z_o) = P_o \sum_{n=1}^{N} \frac{G_n(z,z_o)}{\sqrt{vt}} \; exp[i(\xi_n vt - \pi/4)] \tag{1}$$

with $G_n(z,z_o) = A_n \, sin(K_n z)\, sin(K_n z_o)$, $\xi_n = \frac{2\pi f}{c} sin\theta_n$ and $K_n = \frac{2\pi f}{c} cos\theta_n$
r is the distance between source and receiver, z the depth of the receiver, v the receiver speed, K_n the vertical wavenumbers and ξ_n the horizontal wavenumbers which are the solutions of the well-known *characteristic equation* :

$$1 + V(\xi)e^{2iKh} = 0 \tag{2}$$

where h is the thickness of the water layer and V the reflection coefficient of the ocean bottom.

As one can see in eq 1, the amplitude of each mode depends on the position in the water layer of the source and the receiver. Therefore in many cases some modes are difficult to detect. As there are an increased number of modes in the case of elastic bottoms , it is necessary to extend our method if we want to identify all the propagating modes. So we choose to introduce vertical array processing to realize single mode excitation.

The principle of single mode excitation is based on the property of orthogonality between each mode [5]. We apply to the vertical array a weighting function which reproduce the vertical distribution of one mode so that all the other modes are cancelled.

Then if we analyse by means of an FFT algorithm this type of signal, the resulting spectrum will exhibit peaks corresponding to the $f_n = \frac{fv}{c} sin\theta_n$. The knowledge of these frequencies will lead to horizontal wavenumbers values.

3 Experimental set-up

We have in our laboratory a tank which is a reduced scale model of shallow water propagation. This tank allows changes in the bottom configuration. Therefore it has been possible to realize experiments with 6 cm thick limestone and granite slabs.

A 15 elements vertical array is placed in the water layer and for each mode we want to detect we apply the corresponding weighting function. The water layer thickness is chosen to be equal to vertical array height so that the vertical distribution of the mode is enterely reproduced.

We move at a constant speed a receiver in the sound field pressure and cross- multiply what we receive with the source signal. We start the data acquisition at a distance large enough to ensure far field conditions. Spatial exploration extends from 50 cm to 3.5 m. Absorbers have been put along the tank walls in order to avoid reflexions.

First we remove the zero'th order trend of the signal because of its electronic origin. We then compensate the cylindrical radiation. We also use the zero padding technique to improve visual appearance because of the small size of data acquisition (about 400 samples) due to tank's length. The signal is pad with trailing zeros to perform a 8192-points FFT. No windowing was used.

4 Experimental results

In order to compare the experimental results with theory we need to know the sound speed and density values of the bottom we have put in our tank. Experiments have been carried out in each bottom configuration to determine their acoustic parameters. We have chosen limestone and granite because of the disparity in their sound speed values of longitudinal and shear waves.

- Limestone : $c_p = 3100$ m.s^{-1} , $c_s = 1700$ m.s^{-1}, $\rho = 1930$ kg.m^{-3}
- Granite : $c_p = 5900$ m.s^{-1} , $c_s = 2850$ m.s^{-1}, $\rho = 2700$ kg.m^{-3}

The horizontal wavenumbers of theoritical modes obtained with these values are shown in dashed lines in the following figures.

The number of propagating modes in the case of a granite bottom is 10 and when limestone is present we have 5 propagating modes because of the lower value of the shear waves sound speed in this material.

Experiments were carried out with an acoustic source at a frequency of 80 kHz and with a 103 mm thick water layer.

4.1 Granite bottom

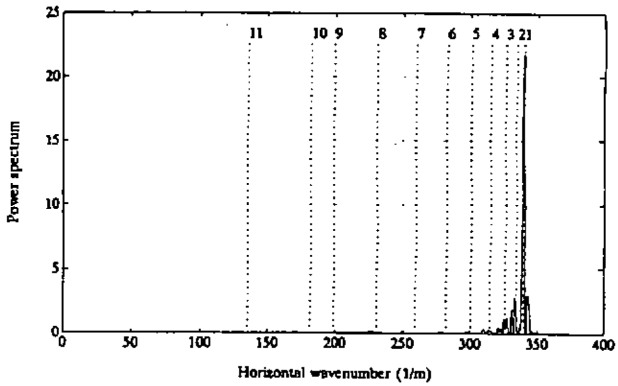

Figure 1 : Horizontal wavenumber spectrum
Antenna weigthed to excite mode 1

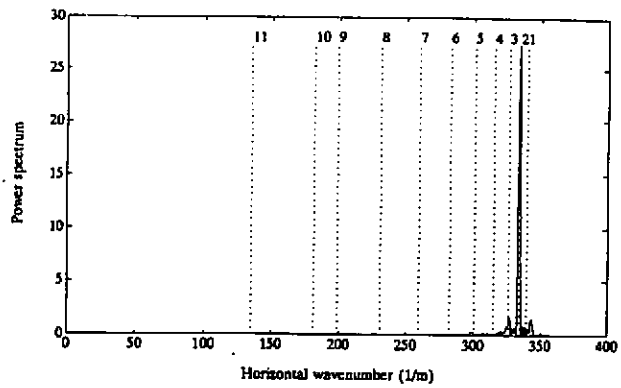

Figure 2 : Horizontal wavenumber spectrum
Antenna weigthed to excite mode 2

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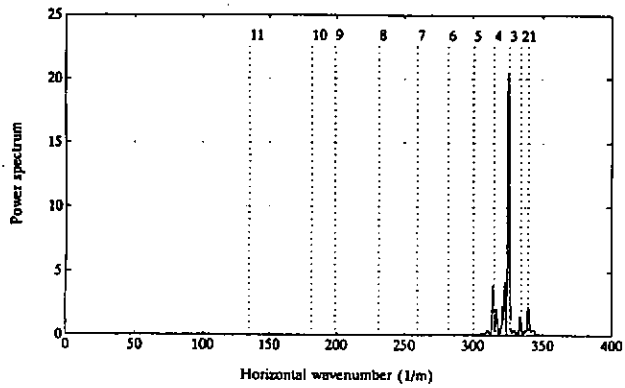

Figure 3 : Horizontal wavenumber spectrum
Antenna weigthed to excite mode 3

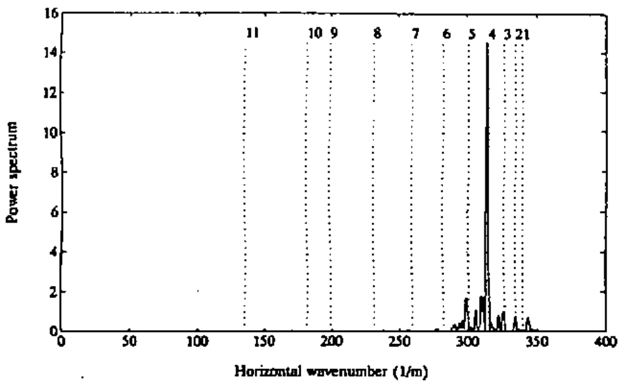

Figure 4 : Horizontal wavenumber spectrum
Antenna weigthed to excite mode 4

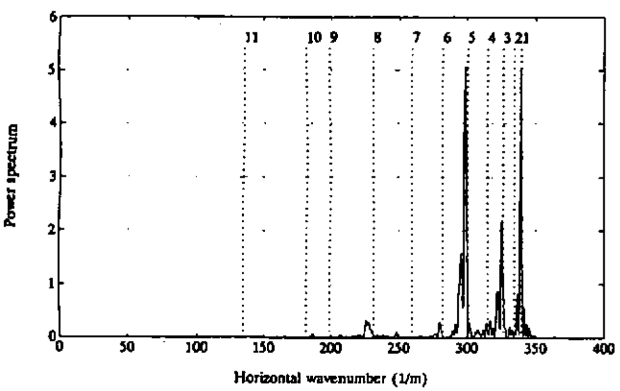

Figure 5 : Horizontal wavenumber spectrum
Antenna weigthed to excite mode 5

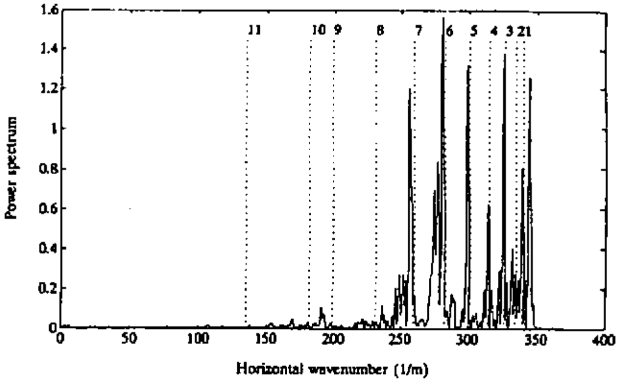

Figure 6 : Horizontal wave-number spectrum
Antenna weigthed to excite mode 6

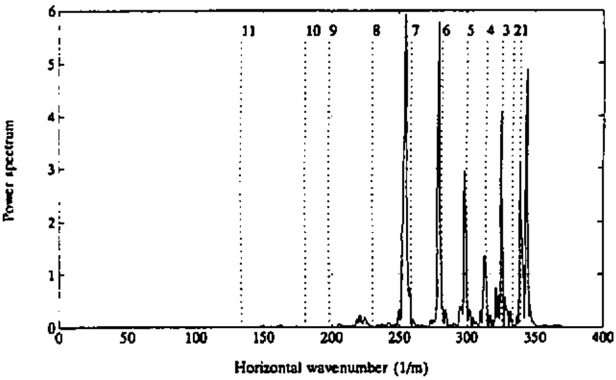

Figure 7 : Horizontal wave-number spectrum
Antenna weigthed to excite mode 7

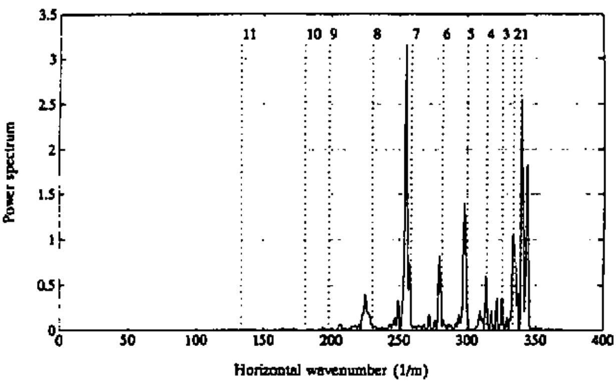

Figure 8 : Horizontal wave-number spectrum
Antenna weigthed to excite mode 8

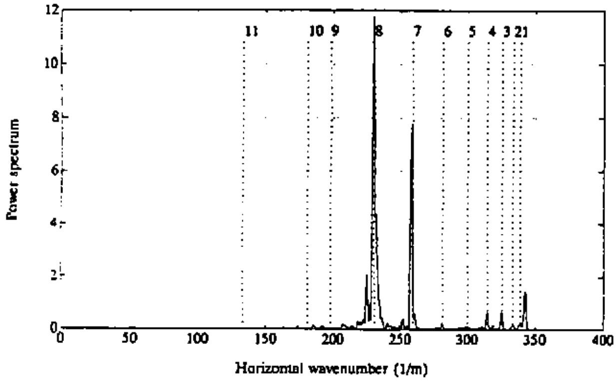

Figure 9 : Horizontal wavenumber spectrum
Antenna weigthed to excite mode 8
Receiver depth chosen

4.2 Limestone bottom

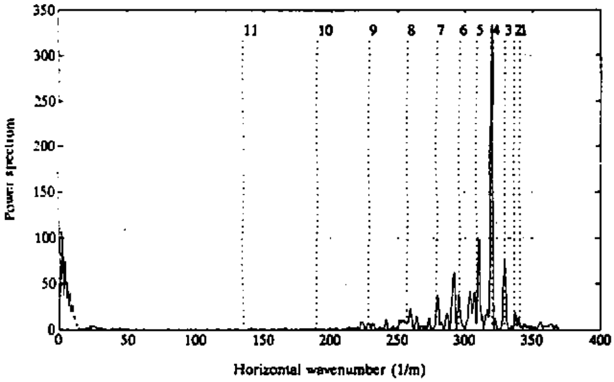

Figure 10 : Horizontal wavenumber spectrum
Antenna weigthed to excite mode 4

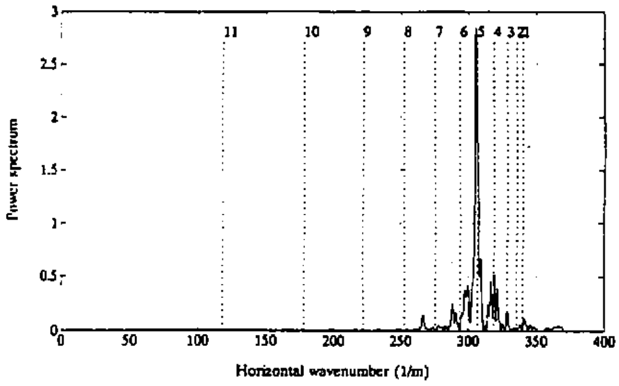

Figure 11 : Horizontal wavenumber spectrum
Antenna weigthed to excite mode 5

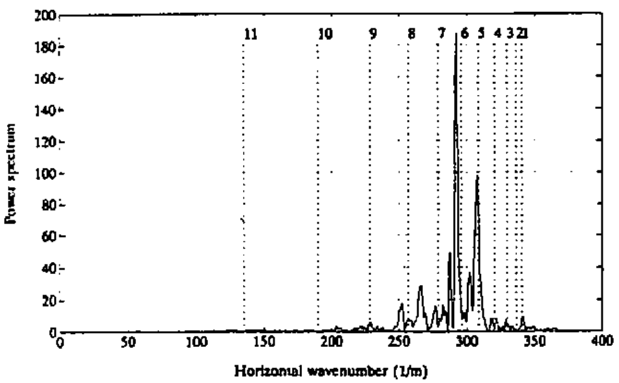

Figure 12 : Horizontal wavenumber spectrum
Antenna weigthed to excite mode 6

5 Comments on the previous results

When granite is used to simulate an ocean bottom mode identification is perform even for high order modes. We were able to detect the eighth mode. But due to the lack of directivity of the vertical array when angles are not grazing it is necessary to choose the receiver depth to improve detection. The modes are well separated and peaks are thin. No extra energy is detected from angles corresponding to non propagating modes.

This is not the case for the limestone bottom. We were able to detect mode 6 which is theoretically evanescent. As calculus shows that the sound speed associated to this mode is very close to c_s we suppose that in fact the real value of c_s is greater than the value we have found experimentally. For mode of order greater than 6 the spectrum achieved are difficult to analyse. We note that peaks are wide and that in general they are not so well separated as in the granite case. We may have some energy corresponding to propagation in the limestone slab. Limestone is known to be a porous media. The width of peaks may be a consequence of this property.

6 Conclusion

The spectral analysis of acoustical data versus range in shallow water propagation associated with the use of a weighting vertical array allows us to detect high order mode. Results were better with a granite bottom than with the limestone bottom. But in general the propagating modes are detected.

It is well known that high order modes are very sensitive to the ocean bottom nature. Results given by the method we used may be used to improve the recovery of the bottom structure. Modes are also sensitive to the angle between the direction followed during acquisition and the source position. The mode detection may lead to the knowledge of this angle.

Acknowledgements
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References

[1] CRISTINI P. and GARNIER J.L. (1992) ,'Some experimental results on horizontal wavenumber analysis of shallow water propagation' in M. Weydert (ed) *European Conference on Underwater Acoustics* pp 321-324 Elsevier Applied Science

[2] CRISTINI P. GARNIER J.L. and GAZANHES C. (1991) 'Normal modes identification in shallow water using spectral analysis : Theory and experiments' J.M. Hovem et al. (eds.) *Shear waves in marine sediments* pp 503-509 Kluwer Academic Publishers

[3] FRISK, G.V. and LYNCH, J.K. (1988) 'Shallow water waveguide characterization using the Hankel transform' J. Acous. Soc. Am. **83** 611- 616

[4] GORSKAYA, N.V. NIKOLAEV, G.N. RYCHOVA, T.A. and SALIN, B.M. (1981) 'Spectral analysis in the investigation of fields of harmonic sources in an acoustic wavaguide' Sov. Phys. Acoust. **27** (2) 110-112

[5] GAZANHES C. and GARNIER J.L. (1981) 'Experiments on single mode excitation in shallow water propagation' J. Acous. Soc. Am. **69** 963- 969