PROC. INST. ACOUSTICS VOL 7 PT 3 1985

APPLICATION OF BACK-SCATTERING ACOUSTIC WAVES IN SUBMARINE CARTOGRAPHY

P.BAILLETTE, A.GOUTIERRE[1] and J.P.LONGUEMARD[2]

[1] Laboratoire de Mécanique, d'Acoustique et d'Instrumentation
Université de Perpignan-66025 PERPIGNAN-CEDEX - FRANCE.

[2] Laboratoire d'Electronique. Ecole Centrale des Arts et Manufactures
92290 CHATENAY-MALABRY. FRANCE.

ABSTRACT

Ultrasonic waves echoed by the sea-bed can be classed in two categories: reflected waves and back scattering waves. The amplitude of each depends on the conditions of measurement and the geoacoustic characteristics of the sediment.

The authors describe a method of measuring the characteristics of the water-sediment interface. They use the coefficient of reflection **R** of the sea-bed to determine the wet density of the clay and silt, and the amplitude of the scattering waves to determine the dimension of the particules (mean grain size Q_2).

The experimental formulate used to measure these characteristics are as follows:

- for the wet density ρ:

$$\rho = a + b\sqrt{R} + cR$$

were a, b, and c depend on the mineralogy.

-for the grain size :

the level of the scattering waves I_D depends on the ultrasonic frequency and the size of the grains. For the prototype used, I_D is at its peak when F is defined as a function of Q_2 by

$$F = a + b \log Q_2$$

The equipment used to obtain these results, functions at frequencies of between 15 and 100 kHz. Results obtained in the Mediterranean are also presented.

RESUME

Les ondes ultrasonores renvoyées par les fonds marins peuvent être classées suivant deux catégories :

- ondes réfléchies,
- ondes rétrodiffusées.

Chacune d'elles a une amplitude fonction des conditions de mesures et des caractéristiques géoacoustiques du sédiment.

Les auteurs décrivent un procédé de mesures des caractéristiques de l'interface eau-sédiment. Ils utilisent le coefficient de réflexion **R** du fond pour déterminer la masse volumique des argiles ou des silts et l'amplitude des ondes diffusées pour déterminer la dimension des particules (médiane granulométrique Q_2 ou modes).

Les relations expérimentales utilisées pour relever ces caractéristiques sont

les suivantes :

- pour la masse volumique ρ:

$$\rho = a + b\sqrt{R} + cR$$

où : a, b et c dépendent de la minéralogie.

- pour la granulométrie :

le fait que le niveau des ondes diffusées I_D découle de la fréquence ultrasonore et de la dimension des grains. Pour le prototype utilisé I_D est maximal lorsque F est définie en fonction de Q_2 par :

$$F = a + b \log Q_2$$

Le matériel utilisé pour obtenir ces résultats fonctionne à des fréquences comprises entre 15 et 100 kHz. Des résultats obtenus en mer Méditerranée sont également présentés.

I - INTRODUCTION

The determination of the sedimental or mechanical values of sea-floor parameters is essential in many cases. Here we will deal with specific aspect of shallow water, where precise mapping (narrow mesh) can not only be done on the basis of sampling (coring or dredging).

Two physical phenomena determine the ultrasonic wave level echoed by the water-sediment interface :

- specular reflection
- wave scattering by the superficial grains of sand.

We have developped a system which enables waves to be emitted near the bottom with frequencies from 15 kHz to 100 kHz, and which statisfies the necessary conditions to obtain these two types of waves. This system provides two types of information (Fig. n°1). The wet density and granulometry of sediments seems to be two interesting parameters (or factors); that is why they are correlated to acoustical characters.

The following procedures was chosen :

- the wave lengths are between 10^{-2}m and $1,5.10^{-1}$m and there is therefore a considerable difference of length in ratio to the grain size;
- the lengths of the acoustical run make it possible to work at Fraunhofer zone and allow the combined action of both physical phenomena (cf.III);
- the duration of wave-emission pulses used is such that a range of about ten sinusoids are necessary for a correct data processing and their periodicity permits a temporal filtering (sorting of the correct echos);
- the equipment is placed on a support which is either stationary on the bottom, or which can be moved about.

II - DETERMINATION OF WET DENSITY

The working process consists of emitting pulse waves with vertical incidence and measuring the level of echo reverberated by the bottom. The possibility of the variation of this echo level due to the existence of scattered waves, leads to the consideration of a mean value calculated with 16 echos corresponding to 16 frequencies. This value of incidence angle also results in a reduced scattering influence.

The case of a flat interface separating two semi-infinite environments will therefore be considered. The value of the reflection coefficient R can be written in this case as :

$$R = \left[\frac{Z_s - Z_e}{Z_s + Z_e}\right]^2 \qquad (1)$$

were Z_s and Z_e are the acoustical impedances of sediment and water.

However it is generally recognised that the velocity of compressional waves in sea water is close to 1500 ms^{-1} near the sea-bed. The impedance Z_e, for a wet density of 1000 $kg.m^{-3}$ in this case is equal to $1,5.10^6 kg.m^{-2}.s^{-1}$. On the other hand, the value of Z_s will vary with the nature of the bottom. In fact, $Z_s = \rho_s C_s$ can range between $2,1.10^6$ and 4.10^6 $kg.m^{-2}.s^{-1}$ and C_s depends on ρ [7-5-2] :

$$C_s = a\ (\psi) + b\ (\psi)\ .\ (\rho - 1,2)^2\ [5] \qquad (2)$$

where ψ is the percentage of carbonates

$a\ (\psi) = 1408 + 0,84\ \psi$

$b\ (\psi) = 600 + 4\ \psi$

It is possible to relate R directly to ρ either by inserting Eq. 2 into Eq. 1 or by looking for a direct relation between R an ρ.

With vertical incidence and when Z_e is known :

$$Z_s = Z_e\ \frac{(1 + \sqrt{R})}{(1 - \sqrt{R})} = 1,5.10^6\ \frac{(1 + \sqrt{R})}{(1 - \sqrt{R})}\ [1]$$

thus $$\rho\ [a\ (\psi) + b\ (\psi)\ (\rho - 1,2)^2] = 1,5.10^6\ .\ \frac{(1 + \sqrt{R})}{(1 - \sqrt{R})}$$

A simpler formula can be used :

$$\rho = d + e\ \sqrt{R} + f.R$$

However the coefficients d, e and f must be weighed according to the percentage of carbonates (fig. 2) which is characteristic of the geographical areas studied (ψ < 10 %, ψ > 80 %). The values of coefficients d, e and f are respectively :

for ψ < 10 %	d = 1,26	e = 0,32	f = 2,7
for ψ > 80 %	d = 1,23	e = 0,32	f = 2,7

The extremes of R levels are for carbonated sand approximately -8 dB, and from -23 to -25 dB for very wet clay (ρ # 1450 kg/m^3) which may be present in estuaries and make up a considerable proportion of deep-sea sediments.

The difference between the two extremes presented here is relatively small. It is thus possible to keep only one value of the different coefficients (d, e, f) in the case of a measure of ρ in relation to R (or to $\sqrt{R}$).

The experimental method chosen to confirm this physical analysis calculated with the correlations ρ_s, C_s obtained on the basis of information given by a Celerimeter consists of placing a structure of measurement on the bottom and relating a mean value of $\sqrt{R}$ to ρ.

The working conditions lead to the measurement of an electrical tension proportional to acoustical pressure, consequently to $\sqrt{R}$, thus $V_r = K\ \sqrt{R}$, and to the calculation of the mean value of 16 measures in each point or station.

Therefore $$\sqrt{R} = \frac{1}{16} \sum_{n=1}^{16} \frac{V_{rn}}{K}$$

The data thus obtained and represented in fig. 2 confirms the interest of this method of measuring wet density.

III - ANALYSIS OF GRANULOMETRICAL MODES

Having a multifrequency emitter-receiver system at a distance r_o above the interface and the grains of sand which might produce a scattering wave, leads to a juxtaposition of several phenomena :

- variation of energy scattered by a grain in relation to its size and to the frequency F.
- reduction of the number of grains involved in the evolution of the beam of the sounders also dependent on F. [3, 4].

If the acoustic energy scattered by one grain is defined by :

$$I_D = \frac{P_o^2}{2Z_e r^2} \phi\ (Q_2, F) .\ g\ (\theta, F),$$

and the number of grains, of granulometric mean Q_2, which scatter by surface element

by
$$N = \frac{K_1}{\pi Q_2^2}\, ds,$$

then the total scattered energy for a surface S will be [3, 6].

$$I_T = \iint_S \frac{P_o^2}{2Z_e r^2} \phi\ (Q_2, F)\ .\ g\ (\theta, F).\ \frac{K_1}{\pi Q_2^2}\ .\ ds$$

where :

$\frac{P_o^2}{2Z_e r^2}$ represents the incident intensity for a spheric wave.

$\phi\ (Q_2, F)$ is the response function of a grain $\phi\ (Q_2, F) \simeq [1 + (\frac{4\pi\ Q_2}{\lambda} \cos \Delta)^2]$
k_1 is a swelling coefficient
$g\ (\theta, F)$ takes into account the variation of the beam of sound

$$g\ (\theta, F) = \left[\frac{2\ J_1\ (\frac{\pi\ D}{\lambda} \sin \theta)}{\frac{\pi D}{\lambda} \sin \theta} \right]^4$$

The intensity value I influencing a receiver-sounder placed for back-scattering at a distance r will be :

$$I_T = \left[\frac{P_o^2}{2Z_e r^2}\ \frac{K_1}{Q_2^2} \phi\ (Q_2, F) \right] \times \left[\sum_{n=1}^{\infty} \frac{1}{2^n} \sin\left[2\theta + (n-2)\frac{\pi}{2}\right] g^{n-1}\ (\theta, F) \right]$$

where g^{n-1} (θ, F) is the $(n-1)^{th}$ derivative of $g\ (\theta, F)$.

The level of scattered waves I_T will be at its highest when the frequency has specific value as regards Q_2 (fig. n°3). The experimental analysis of the phenomenon shows (fig.n°4) that I_T present limits, for :

$$F = a + b \log Q_2$$

Series of experiments conducted in-situ and in laboratory for different sounder-floor distances (r_o) confirm this direction of variation. Nevertheless the coefficients a and b depend on r_o. The same phenomonon takes place for an emission in contact with the sediment, but then a = -20 and b = 55.

IV - CONCLUSIONS

Simultaneous use of two types of acoustic waves (reflected and scattered) enables definition of two geotechnical factors (wet density and mean grain size).

Such equipment, with automatic data collector mounted on a vehicle suitable for use near the bottom, would provide a precise geotechnical mapping of specific sea-bed areas at low cost.

ACKNOWLEDGEMENTS

We would like to thank the "Direction des Etudes et Recherches Techniques - Ministère de la Défense" who supported and encouraged this research.

REFERENCES

[1] J. BRESSON, J.P. LONGUEMARD. Mesure du coefficient de réflexion d'ondes ultrasonores à proximité du fond marin à des fréquences comprises entre 20 et 100 kHz. Revue de Physique Appliquée, T. 14, Septembre 1979.

[2] E.L. HAMILTON. Sound velocity density relations in sea floor sediments and rocks. J. Acoust. Soc. An. 63 (2) Février 1974.

[3] J.P. LONGUEMARD. Mesures in situ de l'amplitude des ondes réfléchies ou rétrodiffusées par les sédiments marins : application à la détermination in situ des modes granulométriques. Revue de physique appliquée, tome 13, Septembre 1978.

[4] J.P. LONGUEMARD, A. GOUTIERRE. Diffusion des ondes ultrasonores par le fond marin en fonction de la granulométrie. 2ème Collogue international sur la diffusion des ondes ultrasonores. Univ. Paris VI (4-7 Décembre 1984).

[5] J. MOUSSIESSIE. Contribution à l'étude des relations entre l'acoustique et les qualités géotechniques des sédiments marins. Thèse 3° cycle Université de Perpignan, Février 1984.

[6] A. PAKA. Etude du frottement d'une surface métallique au contact du sable. Diminution du frottement par ultrasons. Thèse 3° cycle Université de Perpignan, Février 1984.

[7] D. TAYLOR-SMITH. Acoustic and mechanical loading marine sediments. Marine Sciences Plenum Press. New-York, 1974.

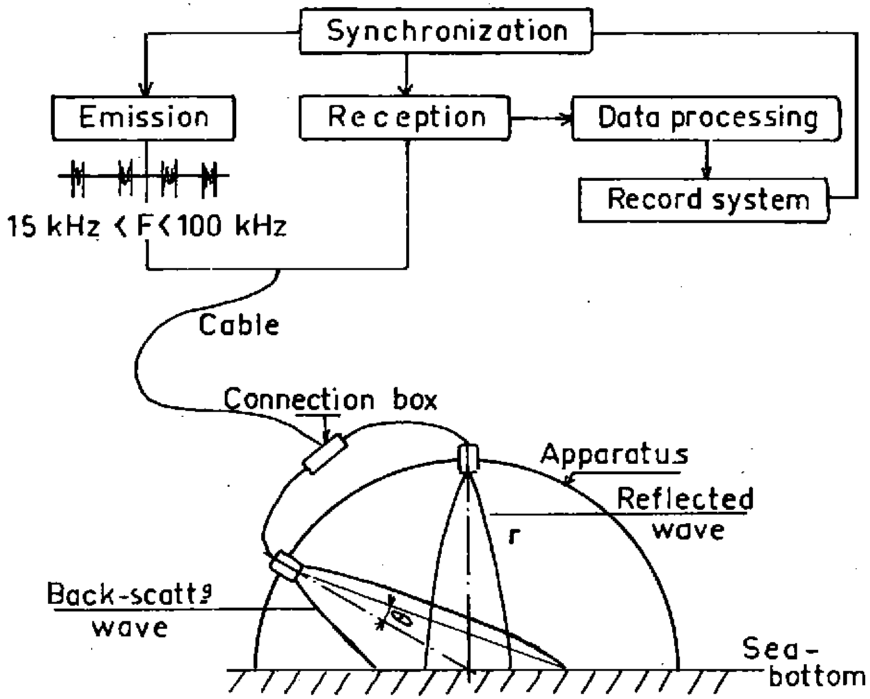

Fig. n°1 : Block diagram of equipment

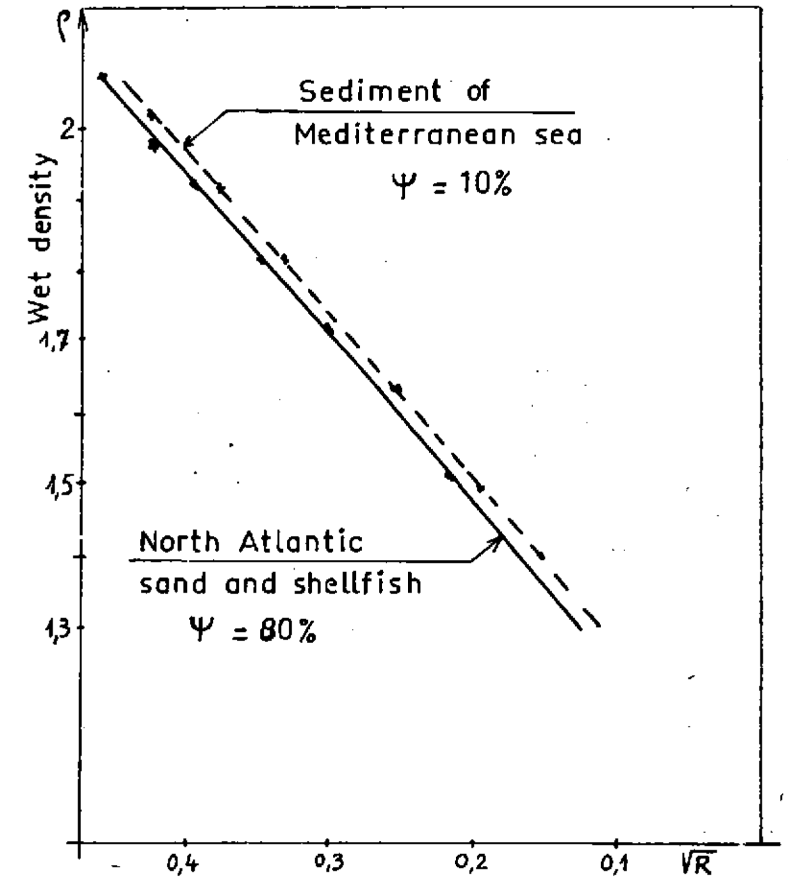

Fig. n°2 : Correlation between $\sqrt{R}$ and ρ

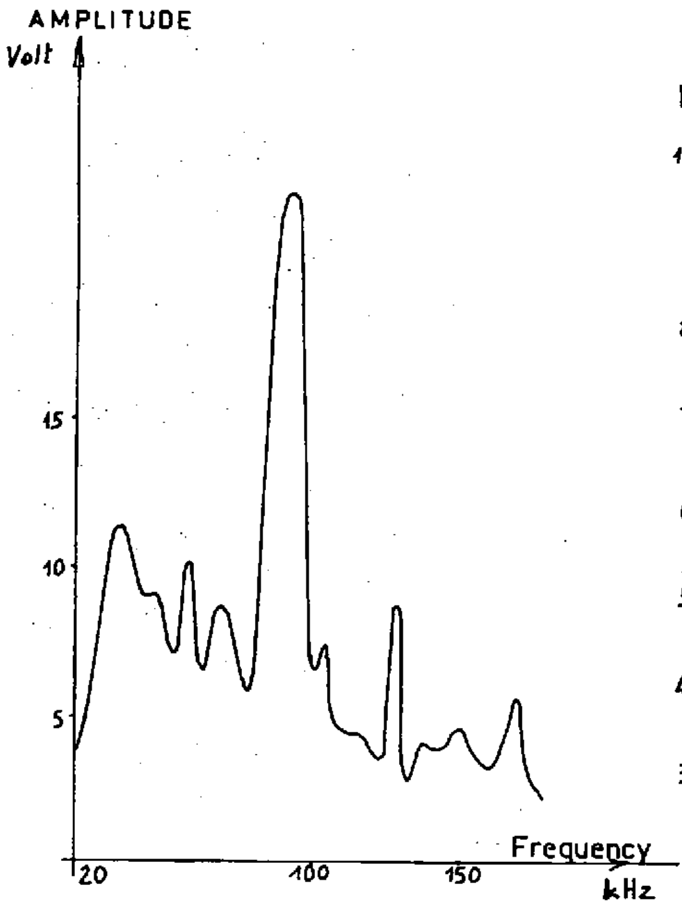

Fig. n°3 : Sound pressure variation in relation to frequency

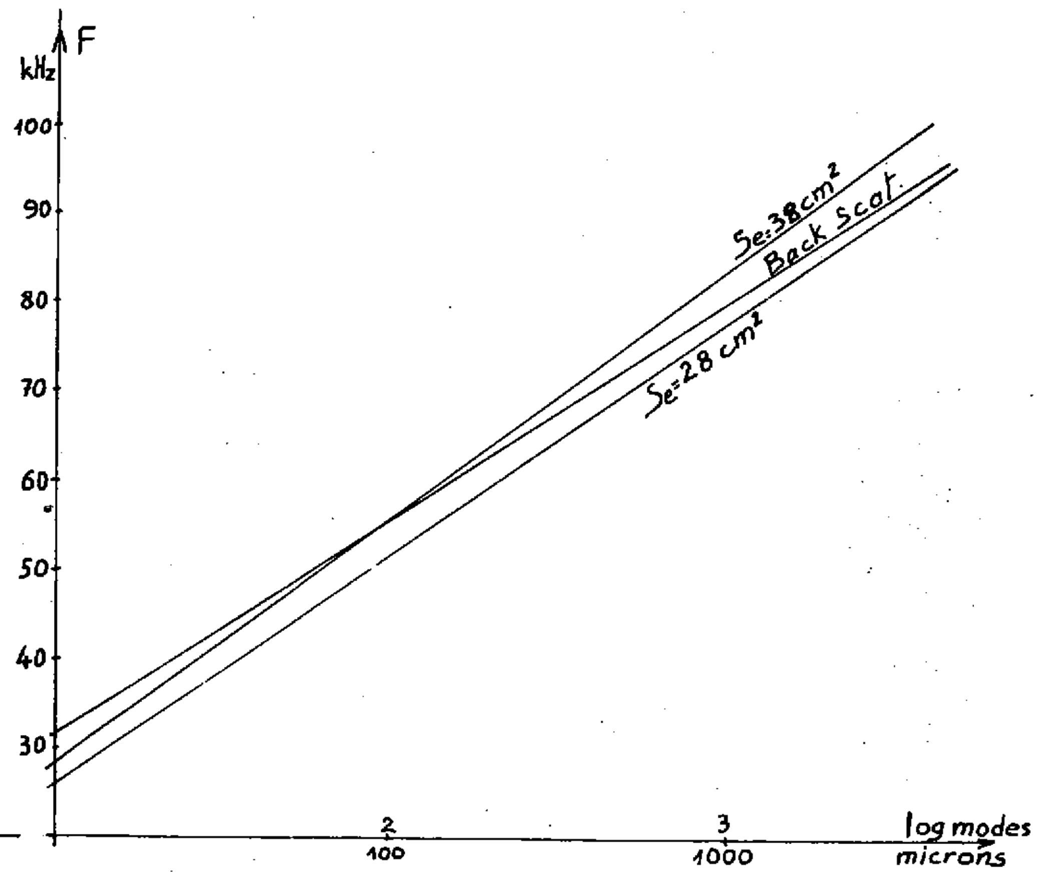

Fig n°4 : Frequency of echo pressure peak in relation to granulometrical mode [3]