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# MEAN GRAIN SIZE AS FUNCTION OF SPECTRAL AMPLITUDE: A NEW REGRESSION LAW FOR MARINE SEDIMENT CORES

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## Abstract

*Geophysics has been developed in order to supply indicative estimations in soil mechanics like the grain size distribution of finely grained soils as clay, silt and fine sands. The paper describes the attempt to characterize porous and saturated marine sediments with a non destructive technique which is the acoustic wave, in order to determine the correlation with geotechnical measurements. The characterization of physical parameters of marine sediments was based on research methods which permit to describe the parameters defining different types of sediment and zones of sedimentation; to determine fundamental parameters that influence the propagation of the acoustic waves in saturated and porous means; to define quick and indicative methods for characterization of physical parameters of analysed means. The acoustic measurements were carried out at SACLANT-NATO of La Spezia (I), where the Vertical Multi Sensor Core Logger (V-MSCL) was used. The results of acoustic tests were compared to the grain size curves of the sediments and the propagation characteristics such as velocity, density, porosity and absorption of experimentally determined data. The analyses are based on various mathematical models presented in literature, in order to predict and to describe physical mechanisms of the wave propagation using a simplification of the sediment structure. The target of the study was to determine a new mathematical law that linked the mean grain size to a directly*

*measurable parameter such as the spectral amplitude, and to offer the possibility to obtain the first indicative value of the sediment mean grain size.*

*The determined exponential law represents an innovative and quick approach to determine a physical characteristic of saturated and porous sediments such as the grain size in a non destructive way based on the spectral analysis of the wave propagation form.*

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## Keywords

acoustic waves, finely grained soil, grain-size curve

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## 1 INTRODUCTION

With the innovative laboratory test presented in this paper, using frequencies, it is possible to estimate the physical characteristics (density, porosity, permeability, mean grain size) of the sediment and the microstructure of its matrix up to the order of a millimetre. The wavelength and the frequency of the used acoustic waves are function of the grain size of the sediment. Using different intervals of frequency, with different signal penetration, fine structures of the sediment can be distinguished from the coarse ones.

The mathematical and physical principles of the acoustic waves propagation in saturated porous media are known from Biot's theory. Compressional and shear velocities can be calculated by the elastic theory from the density, shear, and bulk modulus of the sediment. The problem is how to determine them from the properties of the constituent parts. Biot showed that composite properties could be determined from the porosity and the physical properties (density and moduli) of the fluid, the solid material, and the frame of the sediment. To account for different frequencies of propagation, it is necessary also to know the frequency, the sediment permeability and the fluid viscosity. Biot theory takes into account frequency variations, and allows for relative motion between fluid and the sediment frame. As a result, it predicts some of the observed changes of velocity as

function of frequency. It also predicts the existence of a so-called slow compressional wave in addition to the shear wave, and a compressional, or fast wave. The slow wave arises when the fluid and the sediment frame move in opposite phases with each other. Its velocity is related to fluid mobility, but unfortunately it has been only observed in the laboratory, not in in-situ measurements, where it degenerates into a diffusion phenomenon apparently too highly attenuated to be observed. With Biot's theory, it is also possible to evaluate the attenuation coefficient, the loss of energy or the amplitude of waves as they pass through media. The attenuation and the velocity of propagation of the acoustic waves depend on frequency. The grain size and the porosity can influence the attenuation of the P-waves; in particular, the attenuation is proportional to the grain size and inversely proportional to the porosity. High attenuation is related to coarse grains and low porosity

[1-2]. The variety of the examined cores of sediment shows a different influence of the lithology on the shapes of the acoustically transmitted signals. The comparison between the attenuation, estimated from acoustic measurements, and the curves of Biot's model shows that the main attenuation mechanism is a global viscous flow of the interstitial water [3].

## 2 DATA BASE

The geophysical and geotechnical analysis performed on marine sediment cores, collected during the survey "Boundary 2003" in the Channel of Malta (Figure 1) will be presented [10]. The analysis was carried on by the Undersea Research Centre SACLANT-NATO of La Spezia.

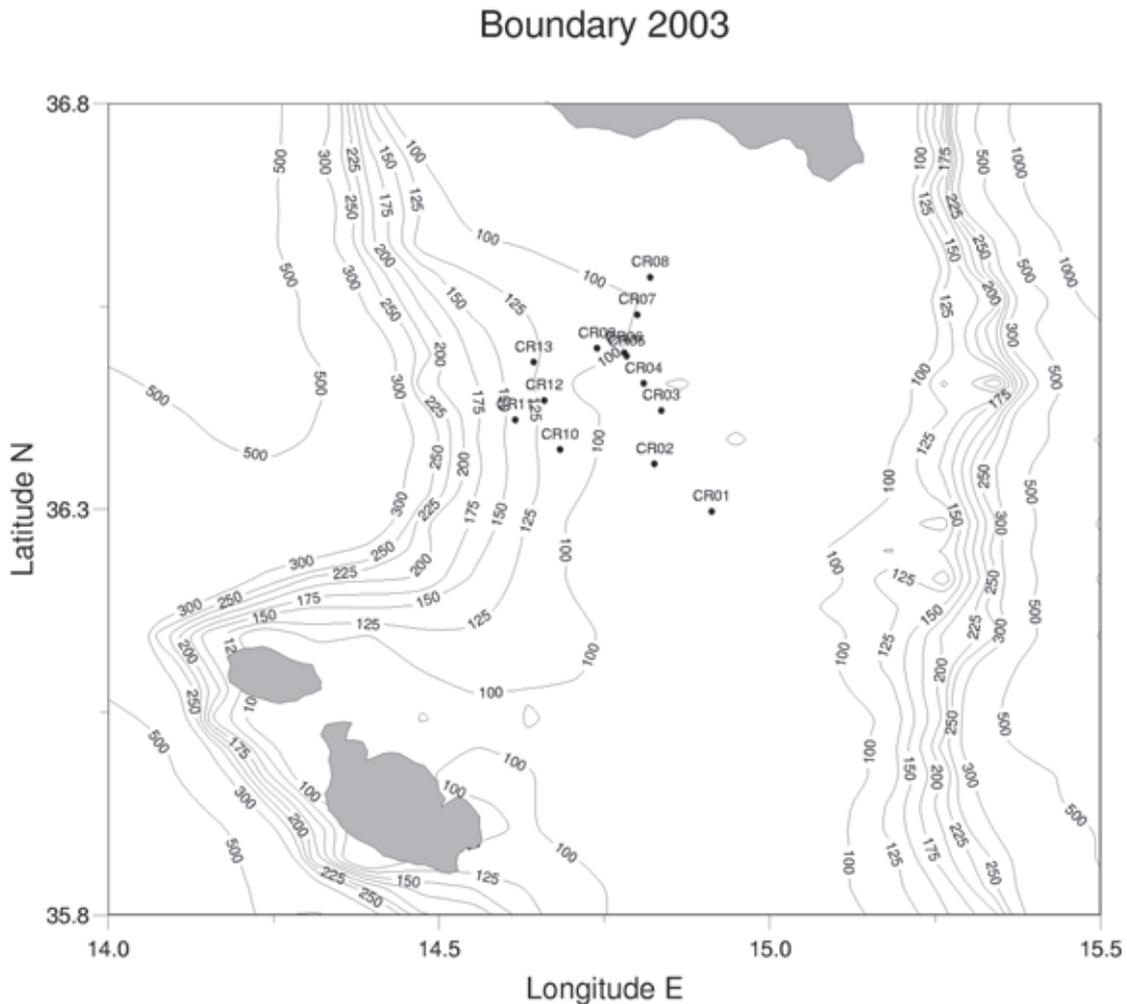


Figure 1. Boundary 2003.



Figure 2. Saclant Nato V-MSCL.

The sediment cores, of the diameter of 11 cm and length of 120 cm, were collected preserving the water-sediment interface. The analyses were performed with the Vertical Multi Sensor Core Logger (V-MSCL) [4]. The measurements of acoustic (P-wave velocity, impedance, wave form) and physical properties (density, porosity) were recorded completely automatically. The instrument is a prototype, which was produced especially for the Undersea Research Centre SACLANT-NATO of La Spezia, for logging the core in a vertical position. It is suitable for studying cores with preserved water-sediment interface (Figure 2).



Figure 3. Core 5.

The analyses were performed without extruding the sediment from the casing, with an interval sampling of 1 cm. The P-wave analyses were carried on using a couple of acoustic rolling transducers with the frequency interval between 50 to 500 kHz and the fundamental frequency of 250 kHz. Radial P-waves were transmitted through sediment cores and digitally recorded.

In Figure 4 the signals passing through the most representative gravity core (CORE 5) are shown. The water signal of greater amplitude wraps all the other wave forms.

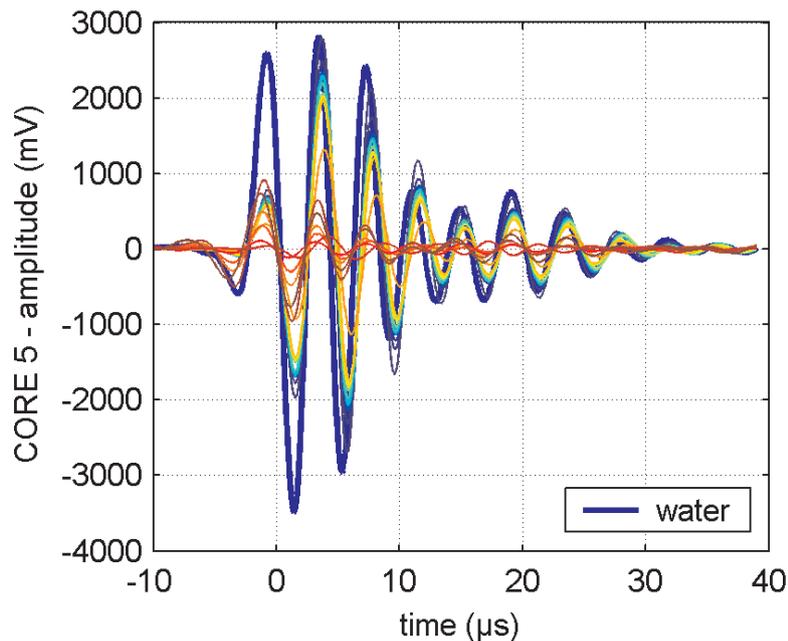


Figure 4. P-wave forms collected along the Core 5.

### 3 RESULTS

The attenuation of the acoustic signal depends on porosity, grain size and permeability of the sediment.

Both acoustic parameters (the P-wave velocity and the coefficient of attenuation) can be used for estimating the mean grain size. Biot's theory was used to model the velocity and attenuation data of gravity cores from the Channel of Malta. Data were compared to physical parameters of marine sand, silt and clay sediments of continental terrace from Hamilton [5-8], who discussed, in several reports, elastic properties of marine sediments from major locations in the North Pacific Ocean, in relation to a wide variety of laboratory and in-situ measurements.

Figure 5 and Figure 6 present a comparison of analyzed P-wave velocity and attenuation at four different traces along the gravity core 5, and the theoretical P-wave velocity and attenuation based on Biot's model.

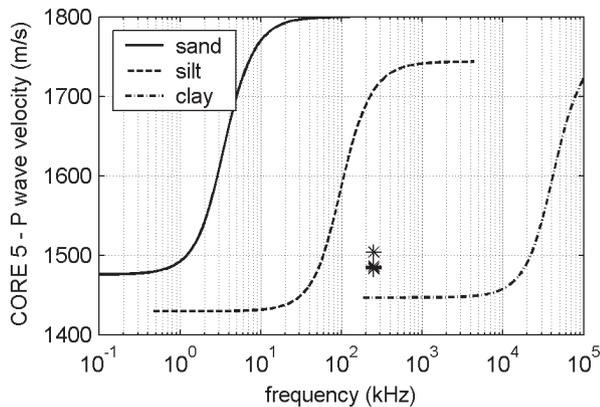


Figure 5. Comparison of theoretical data with velocity data of CORE 5 according to Biot's theory.

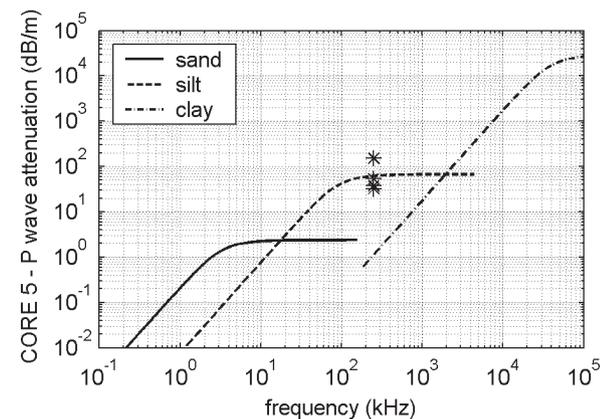


Figure 6. Comparison of theoretical data with attenuation data of CORE 5 according to Biot's theory.

The same four traces along the gravity core 5 were used to obtain the grain-size distribution curve (Figure 7) with laser grain size analysis in comparison with the acoustic measurements obtained with V-MSCL [9-11-12-13-14].

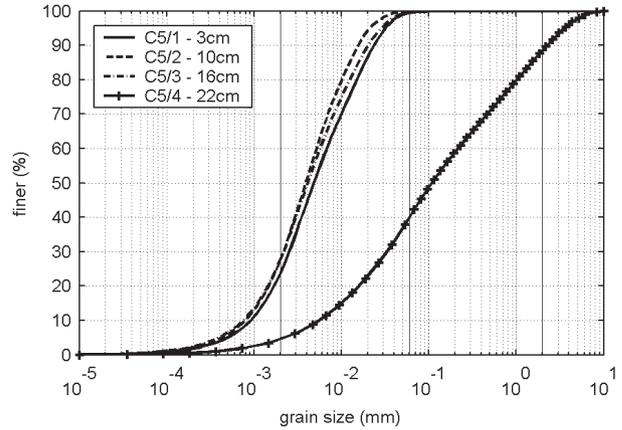


Figure 7. Grain-size distribution curve for CORE 5.

Gravity core 5, from the comparison with Biot's model, can be classified as a silty-clay sediment. An interpretative description of possible attenuation mechanism is based on the technique of spectral difference method, which is used to obtain the attenuation of the gravity cores. If  $A_1(f,x)$  and  $A_2(f,x)$  are the amplitude spectra of an unattenuated reference, the water signal wave form, and an attenuated signal, the generic trace of the sediment, the attenuation can be computed as:

$$attenuation(f) = \frac{\ln(A_1(f,x)) - \ln(A_2(f,x))}{x} \quad (1)$$

where  $f$  is the fundamental frequency of the V-MSCL and  $x$  is the travel path that corresponds to the diameter of the gravity core liner.

Spectral amplitude is calculated on the basis of Welch's method, which divides time series data into segments, overlapping and computing a modified periodogram of each segment, averaging the power spectral density estimates [15].

Figure 8 presents a quantitative image of the attenuation characteristics of the complete gravity core 5 through an attenuation surface. The frequency dependent attenuation of each trace (1 cm) is displayed versus the core depth. In the resulting three-dimensional shading surface the finely grained sediments, weakly attenuated, are represented by a valley, whereas coarsely grained sediments, highly attenuated, occur as a steep hill.

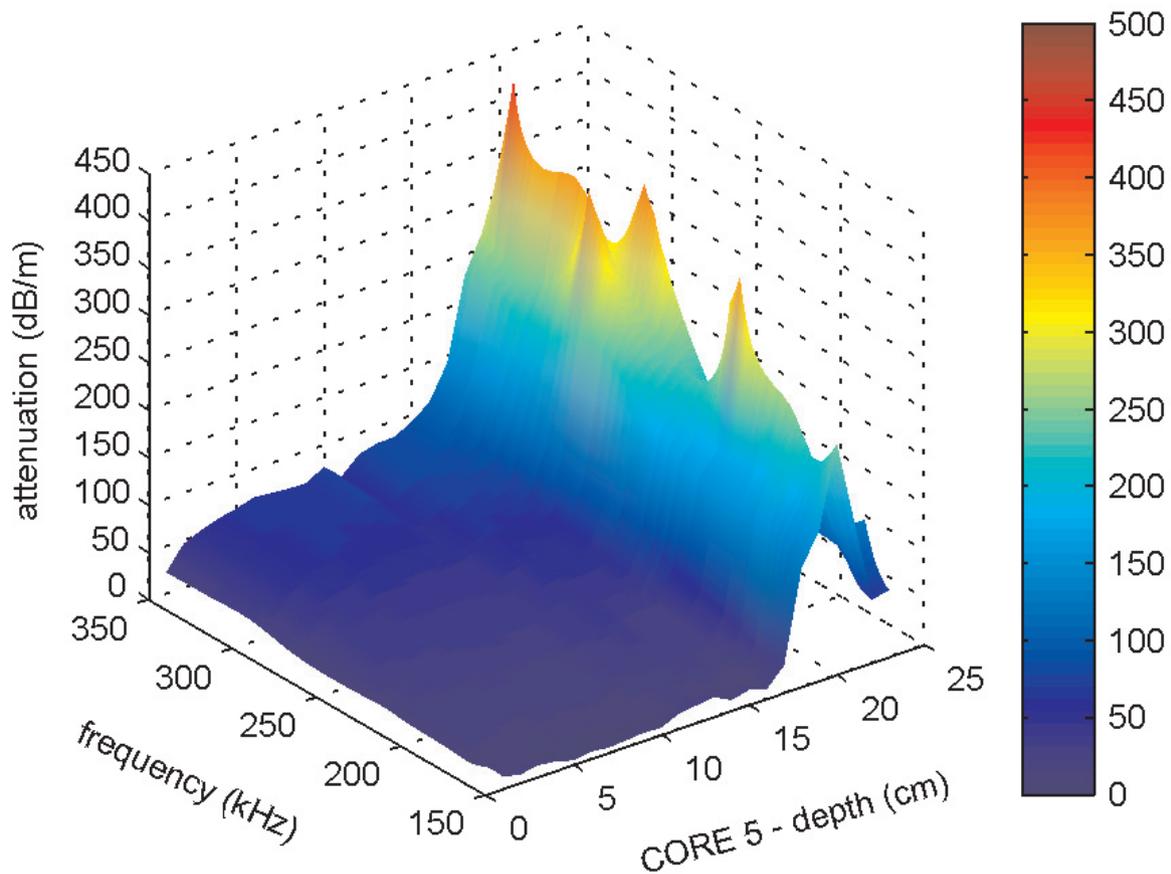


Figure 8. Attenuation surface of gravity core 5.

#### 4 CONCLUSIONS

A correlation between the grain size distribution and the spectral amplitude of P-wave was used to establish a regression law which allows to predict the mean grain size of the sediment if the P wave spectral amplitude is given.

Therefore, the spectral amplitude values are correlated with the mean grain size and arranged with respect to the sorting of the sediment.

An exponential law:

$$m. g. s. (mm) = 2.2 \cdot 10^3 s. a. (dB)^{0.8} \quad (2)$$

which describes the mutual relationship between the spectral amplitude and mean grain size, was fitted to the data points of the Channel of Malta and used for the mean grain size prediction.

Figure 9 presents the regression curve, derived from the exponential law, which lies quite close to the measured data points.

The exponential law and the derived regression curve prove that the P wave spectral amplitude can be used as a reference parameter for a fast prediction of the mean grain size.

On the basis of the presented results it is possible to claim that V-MSCL permits to determine the widest possible range of information from core samples in a consistent, accurate, cost- and time-effective manner. At the same time, elaborated measurements and presented results confirm the appropriateness of the chosen frequency and the correlation of the results with Biot's model.

This spectral amplitude analysis provides a tool to reduce a time-consuming grain size analysis, and a non-destructive and fast approach to evaluate physical

properties of sediment of an intact core which represents a local and punctual parameter to predict regional parameters.

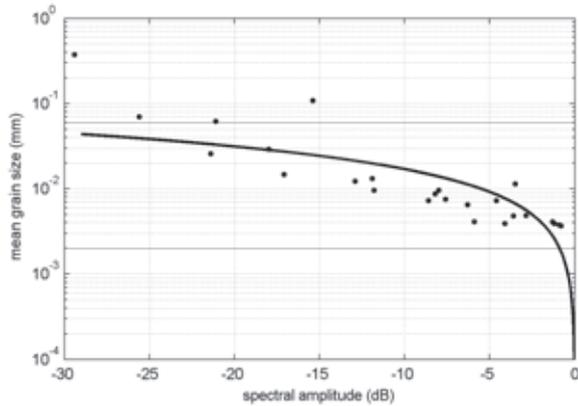


Figure 9. Regression law.

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