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A portative celerimeter for measurement and analysis of compressional speed and attenuation in marine sediments: description and first results

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Geoacoustic parameters of the seafloor are required for accurate sonar prediction and analysis of seismic reflection profiles, especially in shallow water. They are generally established by means of empirical relations. The presented work is part of CARASEDIM, an experimental project devoted to refine these geoacoustical relations in marine sediments, including coarse sands. We focus on the results of the celerimeter prototype that has been developed for that purpose. This portative device is equipped with two emitting probes and two receiving probes allowing to transmit signals between 40kHz and 400kHz. It is designed to both laboratory and in-situ measurements. We discuss about the processing techniques, the protocole of measurement and about the first results. Some laboratory results are presented in both real coarse sands and artificial glass beads. They are compared with theoretical models of sound propagation in sediments based on various assumptions (fluid, visco-elastic, porous ...).

1 Introduction

This paper concerns geoacoustical relations in marine sediments involving acoustic parameters (as sound speed) and other physical parameters (as mean grain size). These relations are required for both civil and military applications. Sonar performances depends on bottom reflection properties which are deduced from geoacoustical parameters. On the other side, seismic analysis is based on acoustic profiles and a major task for the geologist is to deduce what is the real sediment from that data. Many efforts have been done in that field for years [1], [7], in particular concerning the soft sediments of deep waters or rock reservoirs properties for petroleum applications. Interest for coarser sediments as sands is more recent. Significative contribution have been done through in-situ experimentation [3], through laboratory measurements [2] and through theoretical modeling [4]. Nevertheless, these measurements and modeling have generally been conducted with fine or well-sorted sands or glass beads.

CARASEDIM (CARactérisation Acoustique des SEDIments Marins) is an experimental project which focus on marine sands, including coarse sands. It consists in developing a celerimeter prototype for both in-situ and laboratory environments, measuring speed and attenuation of the sound in sands and analyzing the collected data by comparing results with various theoretical models. In this paper, we focus on the first tank experiment that have been conducted with the celerimeter prototype. The first section presents the experimental context. The second section concerns the celerimeter description and the third part shows the first laboratory results.

2 The experimental layout

2.1 Tank design

These first tests consisted in measuring compressional sound speed in a tank filled with marine sand and submerged by sea water. We began with measurements in a tank because it provides a more or less controlled environment suitable to physical interpretation. Later, we also plan to do in-situ measurements by means of divers and to compare these results with laboratory results. Transducers are not directive and a consequence of this is to give constraints on tank dimensions. A typical emitted signal is a windowed-Cw signal and we consider 4λ as a minimum length (duration) for such a signal. It is therefore necessary to move apart the tank side walls to be able to separate multipath arrivals. Considering the range difference (RD) between direct and wall-reflected path, (RD) has to be superior to the signal spreading (in dashed lines). As shown in Fig.1, 17cm is a minimum range to the wall for the particular case of a 30 cm distance between emitter and receptor.

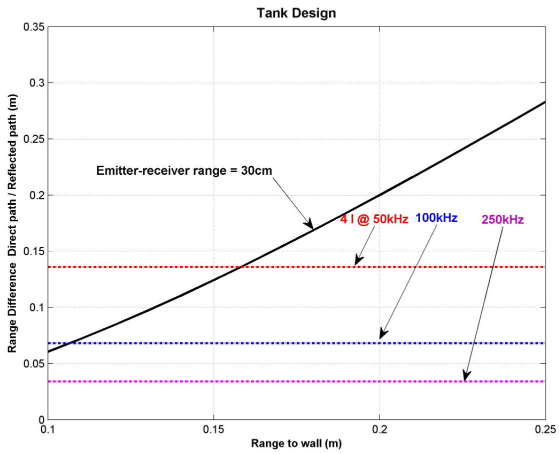

Figure 1: Size constraints for the tank. We report the range difference RD between direct and wall-reflected path versus the range to the side wall (in black).

On that basis, a simulation of the multi-path has been done (Fig.2) for a windowed 100 to 250kHz chirp signal propagated in a tank (dimensions 60 cm long, 40 cm large). The celerimeter is configured for a 40cm emitter-receiver range, located on the center of the tank, with stakes buried at 10 cm below the surface of a 30 cm thickness sand. The direct path is well separated and it will be used for sound speed computation.

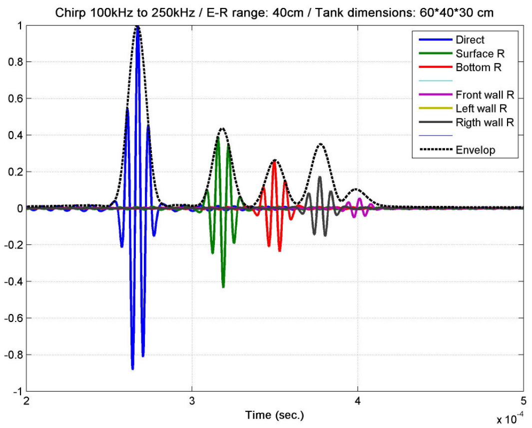

Figure 2: simulation of the multipath inside the tank.

On the other side, it is necessary to reduce the tank size to minimize the material required volume. At least, the tank size is balance between these constraints and measures 60cm long, 40cm large and 50cm high. It is built in stainless steel. A Plexiglas window has been fixed on a side wall to visualize a section of the material and to observe bubbles when degassing. A setting stick has been placed inside to quantify the compaction effect. A rubber tubing with a filter and a tap has been added at the bottom to evacuate the sea water.

Figure 3: Top left, picture of the tank. Top right, balance for the tank filled with sediment and water. Bottom, tank on the vibrating table.

As can be seen on Fig.3, the tank is filled with sediment and sea water. Compaction is done by a vibrating table (using an electric vibrator). Weight and volume are measured to obtain a first porosity estimate.

2.2 Samples

Sediment samples have been extracted from sand beaches considering various mean-grain size and various shell percentage for future use. Each sand sample have been stored in a tank filled with sea water for several weeks and often shacked and mixed to eliminate trapped air bubbles. Samples have been placed on a vibrating table for compaction and degassing processes.

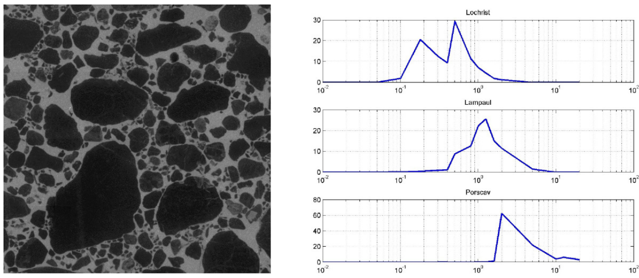

Figure 4: Left, image of the sand Sa02. Right, three stored marine sands with very different granulometry (from top to bottom, Sa01, Sa02 and Sa03).

Their size fractions have been determined with seaves from 100µm to 20mm. Porosity have been measured by image processing (Fig. 4).

For that first trial, three samples have been used: glass beads (sorted between 0.4 and 0.8mm), a medium sand containing many shells (Sa01) and a coarse sand (Sa02). As a first step, some basic characteristics are given in Table 1. Mean grain size are calculated with the Folk relation [7].

Table 1: Sediments characteristics.

Material	Mean grain size (mm)	Porosity (%)
Glass beads	~0.6	~35
Sa01	1.35	?
Sa02	0.61	30

3 The celerimeter prototype

3.1 Background

That first prototype is designed for compressionnal sound speed and attenuation measurements. There are various way of measuring sand sound speed: by direct time of flight between buried probes, by time of flight between probes in contact with a box filled with sand, by resonance chamber or by accelerometers [5].

Because we plan to handle with very different environmental conditions, we chose a simple way of measuring sound speed, based on buried emitters and receptors stakes.

3.2 Description

The celerimeter is composed of a waterproof housing containing the electronic. Four transducers are located inside stakes separated by an adjustable distance from 5cm to 50cm (Fig. 5). Some adjustable wedges allows variable depths measurements until 15cm. It weighs less than 10kg and it is equipped by handfuls to facilitate portability and to help the penetration in coarse sands. It can be used down to 50 meters water depths.

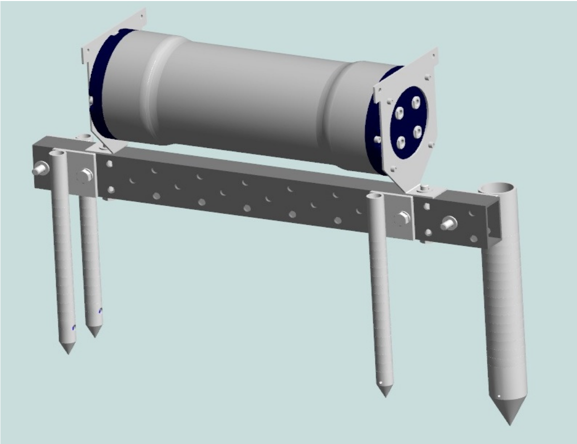

Figure 5: Drawing of the celerimeter prototype.

It has a programmed autonomous mode for diving operations. In laboratory, it is directly connected by an Ethernet link to the remote PC. Signals are recorded in wav files at 10MHz sampling. There are two emitters, one operating between 40kHz and 120kHz and one operating between 100kHz and 400kHz. There are two non-aligned receivers at two different ranges from each emitter. Frequencies choice is a balance between far-field conditions, signal attenuation and tank size. That large range of frequencies should be suited to cover nearly all kind of grain size and to find out frequency dependencies as well as scattering processes.

It is possible to choose every kind of signal by means of a friendly interface (Fig. 6). CW short duration signals (15µsec to 100µsec) and Chirped long duration signals (10msec.) have been successfully tested. The raw received signal is stored on disk and may be directly downloaded for processing operations. Algorithms computing sound attenuation and sound speed are at prototype step and are Matlab designed.

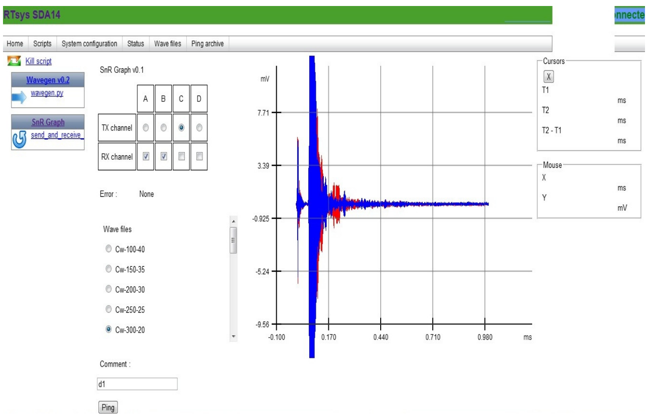

Figure 6: Screenshot of the IO interface. Left, operator friendly build the desired E-R configuration and choose a signal for emission. Right, plot of the received signals on both channels.

On Fig.7, we show a plot of the Celerimeter raw received signals (voltage versus time) for various frequencies. For each caption, the signal on the left is the emitted signal and the signal on the right is the signal propagated in the granular medium (here, in glass beads). We see the amplitude variability mainly due to transducer frequency response. The difference of time arrivals depends on the two receiver ranges.

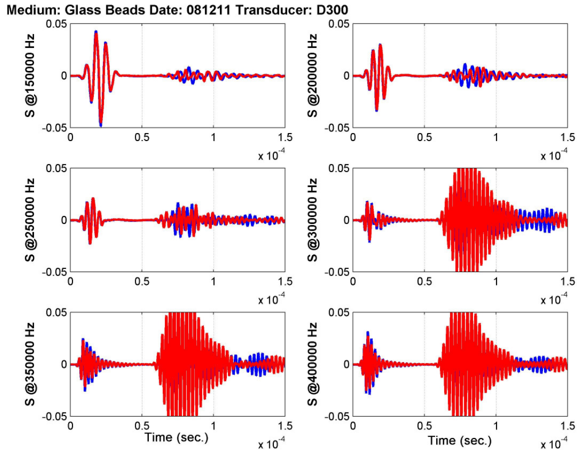

Figure 7: From top left to bottom right, received signals at 150, 200, 250, 300, 350, 400 kHz (channel 1 in red, channel 2 in blue). Note that amplitude scale is the same for all captions (there is no saturation on the three last signals).

4 First results

4.1 Measurements

A first sequence of tank measurements (Fig. 8) have been conducted on the 3 samples Gb01, Sa01, Sa02 (described above) to measure sound speed. Salinity was measured with a Vernier probe based on conductivity. A first measurement was done in pure water to refine actual ranges between sensors (see Table 2) considering Del Grosso sound speed formulae.

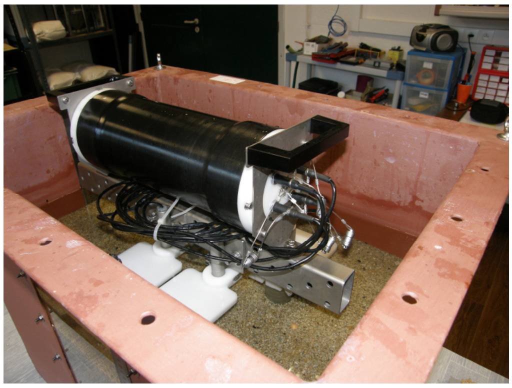

Figure 8: Celerimeter measuring Sa02 sound speed in tank.

Table 2: Geometry of the celerimeter. Probe depths were 10cm. Temperature was 11.4°C

Transducer	Range to the receiver	Estimated	Measured
LF 40-120	E-V1	15cm	14.38
	E-V2	11cm	10.65
HF 100-400	E-V1	20cm	20.25
	E-V2	13.5cm	14.01

Only short windowed CW pings were used. We have defined two sequences of pings (SP), one for each transducer:

- SP1: Cw of 40, 35, 30, 25, 20, 15, 15 μsec for the respective frequencies of 100, 150, 200, 250 , 300, 350 et 400kHz

- SP2: Cw of 90, 80, 70, 60 ,50 μsec for the respective frequencies of 40, 60, 80, 100, 120kHz.

For every sample, we did 6 successive measurements by driving in the celerimeter at a new location each time. A measure is a SP1 ping sequence followed by a SP2 sequence.

Various algorithms have been tested for sound speed calculation. Presently, the used algorithm is based on the envelop of the intercorrelation between the theoretical emitted signal and the received signal.

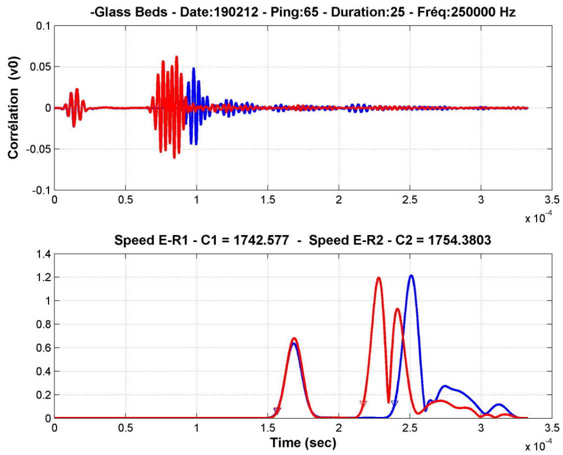

Figure 9: Sound speed processing for a ping at 250kHz in glass beads. Top, voltage versus time of received signals (in blue for channel 1, in red for channel 2). Bottom, envelop of the correlated signal showing emitted and received signal spikes used for time of flight calculation.

Time of flight is deduced from front-spike detection on emitted signal and on the first received arrival (Fig.9). Front-time is defined as a percentage of the spike amplitude. Sound speed is then deduced from the exact range. A calculation is done for every ping and for each channel. Variability of results is small (less than 15m/s in the given example).

4.2 Results

Data were processed to establish the sound speed dispersion curve versus frequency for the three analysed samples (Fig.10). A sound speed at a given frequency is the average of the six successive measures. As can be seen, we didn't get a recovering between SP1 and SP2 transducer ranges because signal quality was degraded at the limit of the band. Our discussion mostly concerns results of SP2 transducer. Glass beds results are close to those obtained by theoretical calculation (see Fig. 11). Coarser sand (Sa02) show a decreasing speed when frequency increases. Note that Sa02 sound speed is low (less than 1500m/s for higher frequencies). This could be consistent with the expected scattering effect [2].

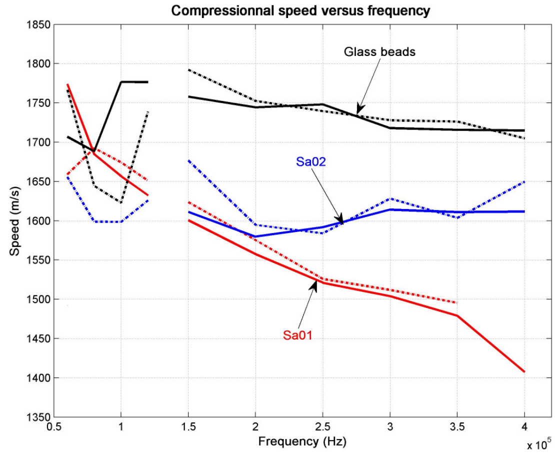

Figure 10: Sound speed versus frequency for the three samples, between 60kHz and 400kHz (dashed lines for channel 1). Results enclose SP1 and SP2 transducer contributions.

Nevertheless, these tests have to be refined. First, sand compaction have been largely modified by the manual degassing phase which could have significantly decreased the speed. Secondly, these results have been based on an automatic process. Generally, we have observed that one or two (eventually more, depending on material) pings were corrupted, which impact strongly on the result.

4.3 Modeling

The link between the geotechnical properties of sediments (mean grain size, porosity, density,...) and their acoustical properties can be established with theoretical model of sound propagation in marine sediments. Among the various approaches, two models are currently widely used: the Biot model and the Buckingham model (see [6] and references therein). The Biot model is based on the description of marine sediments as porous media, described by 13 parameters, and predicts the propagation of three volume waves: two compressional waves and a shear wave. In the Buckingham model (also known as Grain Shearing (GS) theory), the macroscopic properties of acoustic waves in the sediment volume is obtained through a description of the microscopic processes occurring at grain contacts. This leads to the prediction of the existence of two waves, one compression and one shear, whose sound speed and attenuation are obtained by the knowledge of 8 parameters. Among these parameters, three can neither be measured nor calculated. Thus, they are obtained by fitting experimental measurements, e.g. compressional speed and attenuation and shear speed at a single frequency [8]. In Carasedim project, we decided to use the GS theory because it seems more appropriate to model the acoustic properties of sandy seafloor and because it involves directly the mean grain size of the sediment which is a very important parameter for seafloor characterization processes.

A full comparison between experimental results and GS theory predictions can not yet be achieved for two main reasons. First, we still lack of measurements of geotechnical properties of the sandy sediments used in the experiments. And second, we also still lack of mesurements of attenuation. Nevertheless, we can compute the sound speed and attenuation predicted by GS theory, using parameters chosen by M.J. Buckingham in a similar experiments of sound propagation in glass beads [8]. Our glass beads results (Fig. 10) appear close to these theoretical results (Fig. 11) but further measurements (geotechnical and acoustical) needs to be performed to conclude on this approach.

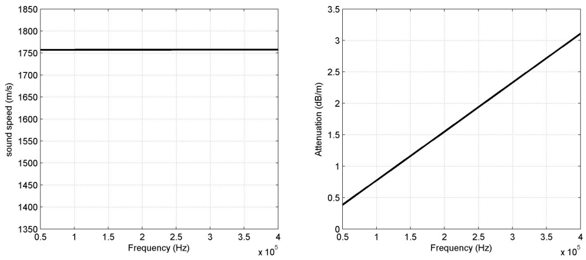

Figure 11: Sound speed dispersion curve for glass beads, based on the Buckingham theory [4].

5 Conclusion

A celerimeter prototype has been designed to study marine sands acoustic properties. A first tank experiment have been conducted with three different samples, two marine sands and glass beads. It allowed to refine sound speed calculation algorithms and it already provided interesting results. Good signals were obtained even in coarse sands and calculated acoustic speed are close to those predicted by theory. This is a good basis for the future tasks of the project.

Acknowledgments

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