USING SEDIMENT POROSITY AS AN EFFECTIVE GEOACOUSTIC PARAMETER FOR SONAR PERFORMANCE PREDICTION

John C. Osler[1]
[1]Defence R&D Canada–Atlantic, P.O. Box 1012, Dartmouth, Nova Scotia, Canada, B2Y 3Z7,
e-mail:john.osler@drdc-rddc.gc.ca

1. BACKGROUND

Performance prediction modelling for active sonar requires the geoacoustic properties of the surficial seabed sediments in order to account for the transmission loss and reverberation due to seabed interaction. Calculating the transmission loss and scattering of acoustic energy typically require the geoacoustic properties to be parameterized in terms of their density, compressional and shear sound speeds, and their associated attenuations. These parameters are often measured on physical samples, such as cores, or obtained from inversions of purpose designed acoustic experiments. The former are costly to collect and prone to artifacts due to disturbance during collection, handling and storage. In addition, the measurements must be corrected to the *in situ* conditions, notably temperature and pressure, and possibly for dispersion effects as the sound speed on cores is typically measured at much higher frequencies (hundreds of kHz) than that of interest. Numerous acoustic techniques have been developed to obtain geoacoustic parameters and can yield excellent results. However, these techniques typically require specialized equipment and detailed analysis that preclude their widespread use. This challenge provides the motivation to develop instruments or techniques that reduce the number of independent parameters that must be measured to effectively parameterize the seabed. This is particularly true in a rapid environmental assessment scenario in which the number and type of measurements must be limited and the analysis streamlined.

2. INTRODUCTION

The porosity of a marine sediment is the volume of the interstices, that is the pore space, between the sediment grains, per unit volume of sediment. In marine sediments, the pore space is typically filled with seawater though it is also possible to have gas. Empirical studies suggest that the porosity of the surficial sediments is a physical property of the seabed to which the more traditional properties (density, attenuation, and sound speeds) may be related [1, 2]. For example, using data from over two hundred cores collected in littoral waters, using divers or box cores to minimize artifacts, Briggs and Richardson [2] have established a regression relationship between porosity, n, in percent, and compressional sound speed, V_p, given by $V_p = 1.574 - 0.015n + 0.001n^2$ with a coefficeint of determination of $r^2 = 0.954$. In their research, this and other relationships are used to determine seabed properties from normal incidence measurements of acoustic impendance. Noting that porosity strongly controls geoacoustic properties of sediments, Prior and Marks [3] have developed a series of nine seabed geoacoustic models representing regular increases in porosity that start from rock, move through coarse grained sediment and end with fine grained mud. They argue that these models provide a satisfactory parameterization for the majority of ocean sediments and use them as the basis for a 'pragmatic approach' to modelling transmission loss and inversion for seabed properties.

The energy scattered at low grazing angles on 'smooth' seabeds is dominated by scattering mechanisms within the near surface sediment volume. Scattering measurements in this regime have been successfully modelled using a theoretical framework that attributes the scattering to inhomogenities that are represented physcially by variations in sediment porosity [4]. There is also emperical evidence using backscatter data from swath bathymetry systems on the Eel River and New Jersey ONR Strataform sites that the backscattered intensity in sand sediments decreases with increasing porosity [5]. On 'rough' seabeds, the scattering from the water-sediment interface is appreciable and degrades the correlation between porosity and backscattered energy.

This review of the literature suggests that *in situ* measurements of porosity may serve as an effective single parameter for characterizing seabed properties for both transmission loss and reverberation in sonar performance prediction. To this end, DRDC Atlantic is developing an *in situ* probe that can measure geotechnical (large strain) and geoacoustic (small strain) properties of the seabed, including porosity.

3. SEDIMENT PROBE

The DRDC Atlantic free fall cone penetrometer (FFCPT) test probe consists of a nose cone instrumented with geotechnical sensors, power supply, electronics, and tail pressure sensor (Fig. 1). As the probe penetrates into the seafloor, it measures acceleration and dynamic sediment porewater pressure as a function of depth. It also records hydrostatic pressure in the water and has an optical backscatter sensor for mudline detection capability. This combination of sensors permit the direct application of geotechnical analysis methods and parametric-based correlations already long established in engineering practice [6]. The DRDC Atlantic FFCPT has been developed in collaboration with Brooke Ocean Technology (BOT) Ltd. and Christian Situ Geoscience (CSG) Inc. (both in Dartmouth, Nova Scotia). It incorporates the basic sensor suite from an earlier 11.43 cm (4.5 inch) O.D. prototype into a modular 8.89 cm (3.5 inch) O.D. design (Fig. 1). Additional ballast or geoacoustic sensors can be integrated into the probe because of its modular design. The first module being developed measures resistivity as a means to determine porosity.

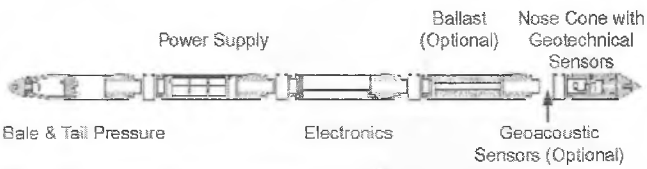

Figure 1: Schematic diagram of the DRDC Atlantic FFCPT.

The resistivity module has been developed by BOT and ConeTec (Vancouver, British Columbia) using the design principles of a static resistivity CPT system as described by Campanella and Weemees [7]. Conformal with the O.D. of the probe, there are two cylindrical brass electrodes, 1.5 cm wide, separated by 6.7 cm and isolated by sections of an insulating material—Delrin (Fig. 2). Once the probe has penetrated the seabed, a static resistivity measurement is made by generating a current-switched AC sinusoidal wave, at a frequency of about 1 kHz. Dynamic resistivity measurements during penetration [8] are ultimately desired, however, the high rate of initial penetration poses several technical challenges, such as an excitation rate of several hundred kHz, that have yet to be overcome.

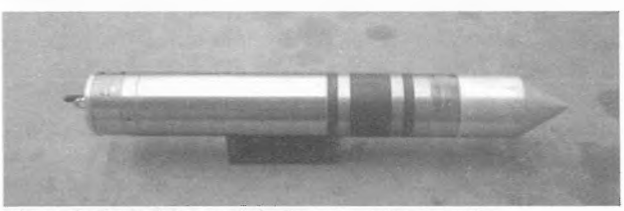
Figure 2: Resistivity module for measuring porosity

The measured bulk resistivity is a function of the resistivity of both the pore fluid and the sediment grains as well as the shape of the pore spaces. Assuming that the resistivity of the pore fluid is low, as with seawater, and there is not an abundance of clay minerals, then Archie's [9] law may be applied. It is $\rho_b/\rho_f = an^{-m}$, where ρ_b is the bulk resistivty, ρ_f is the fluid resistivity, a is a constant (usually 1 for unconsolidated sediments), n is the porosity, and m is a function of grain shape (~1.5 for sands).

4. RESULTS

The DRDC Atlantic FFCPT and resistvity module were deployed at a number of locations in St. Margaret's Bay, Nova Scotia, in June 2002. Some of the measurement locations are co-located with high quality sediment cores as well as drops from two other types of penetrometers that only measure acceleration. At the time of preparation of this manuscript, the data are still being analyzed. However, it is already clear, and encouraging, that a systematic increase in bulk resistvity has been observed as the test locations progressed from high to low porosity sediments.

REFERENCES

1. Hamilton, E.L., and Bachman, R. T., Sound velocity and related properties of marine sediments, *J. Acoust. Soc. Amer.* **72**, 1891–1904 (1982).
2. Richardson M. D. and Briggs, K., On the use of acoustic impedance to determine sediment properties, *Proc. Inst. Acoustics* **15**, 15–23 (1993).
3. Prior M. K. and Marks S. G., Deduction of seabed type using in-water acoustic measurements, *Proc. Inst. Acoustics* **23**, 74–82 (2001).
4. Hines, P. C., Theoretical model of acoustic backscatter from a smooth seabed, *J. Acoust. Soc. Amer.* **88**, 324–334 (1990).
5. Evans, R. L., Measuring the shallow porosity structure of sediments on the continental shelf : a comparison of an electromagnetic approach with cores and acoustic backscatter, *J. Geophys. Res.* **106**, 27047-27060 (2001).
6. Robertson P. K., Soil classification by the cone penetration test, *Can. Geotech. J.* **27**, 151–158 (1990).
7. Campanella, R. G. and Weemees I., Development and use of an electrical resistivity cone for groundwater contamination studies. *Can Geotech. J.* **27**, 557–567 (1990).
8. Rosenberger A., Weidelt P., Spindeldreher C., Heesemann B., and Villinger H., Design and application of a new free fall *in situ* resistivity probe for marine deep water sediments, *Marine Geology* **160**, 327–337 (1999).
9. Archie, G. E., The electrical resistivity log as an aid in determining some reservoir characteristics. *Trans. Amer. Inst. of Mineral Metallurgy Eng.* **146**, 54-62 (1942).