1992

An Acoustic Impedance Method for Subbottom Material Characterization

Richard G. McGee
US Army Engineer Waterways Experiment Station

Robert F. Ballard, Jr.
US Army Engineer Waterways Experiment Station

McGee, Richard G. and Ballard, Jr., Robert F., "An Acoustic Impedance Method for Subbottom Material Characterization" (1992). *US Army Research*. 93.
http://digitalcommons.unl.edu/usarmyresearch/93

Published in Hydraulic Engineering: Saving a Threatened Resource—In Search of Solutions: Proceedings of the Hydraulic Engineering sessions at Water Forum '92.
Baltimore, Maryland, August 2–6, 1992. Published by American Society of Civil Engineers.

AN ACOUSTIC IMPEDANCE METHOD FOR SUBBOTTOM MATERIAL CHARACTERIZATION

Richard G. McGee[1], M. ASCE
and
Robert F. Ballard, Jr.,[2] M. ASCE

Abstract

This paper discusses modified seismic reflection technique tailored to the characterization of bottom and subbottom materials. The application of acoustic impedance principles has resulted in the development of a method for rapidly determining the type and density of subbottom materials scheduled for dredging. Acoustic theory is discussed only in sufficient detail to enable the reader to understand basic concepts.

Introduction

Each year, the U.S. Army Corps of Engineers spends millions of dollars worldwide on river and harbor maintenance and ship channel realignment projects. Currently, the Corps relies on drilling and laboratory testing programs to assess marine sediments in terms of material type, density, and thickness for the purpose of characterizing proposed dredging sites. These sampling and coring programs are costly, however, and provide only discontinuous information about the material characteristics. This approach does not effectively address situations where actual subbottom conditions are highly variable.

In 1988, the Corps of Engineers launched a major research and development initiative called the Dredging Research Program DRP directed toward developing new or better dredging technologies. The U.S. Army Engineer Waterways Experiment Station WES heads this initiative. Under DRP, a waterborne geophysical technique has been developed to remotely and efficiently determine the characteristics of subbottom marine sediments in a continuous fashion using

---

[1] Research Hydraulic Engineer, Hydraulic Structures Division, Hydraulics Laboratory, US Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199
[2] Geophysicist, Earthquake Engineering and Geosciences Division, Geotechnical Laboratory, US Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199

impedance calculations of acoustic reflection data together with limited in situ sampling.

The Acoustic Impedance Method

The acoustic impedance method is a modification of the seismic reflection technique commonly used in offshore oil exploration but tailored to shallow water environments. As energy generated from an acoustic source, in the form of a plane wave, arrives at a boundary between two layers of differing material properties, part of the energy will be reflected back towards the surface and part is transmitted (Figure 1). A portion of the transmitted energy will undergo absorption or attenuation in the layer while the remainder propagates through to the next stratigraphic boundary. According to Snell's law governing refraction, it is possible to represent the relationship between the incident, reflected, and transmitted waves. This was first accomplished by Zoeppritz in 1919 (Caulfieldand Yim 1983). One term arising in the Zoeppritz equation (Equation 1) is Z , the acoustic impedance; the product of the transmission velocity and the density of the material. Thus, the impedance represents the influence of the material's characteristics on the reflected and transmitted waves. The actual percentage of the wave's energy that is reflected is the reflection coefficient, R , and is defined by a ratio of acoustic impedances. The equation relating the impedance and the reflection coefficient for a normal incident plane wave is

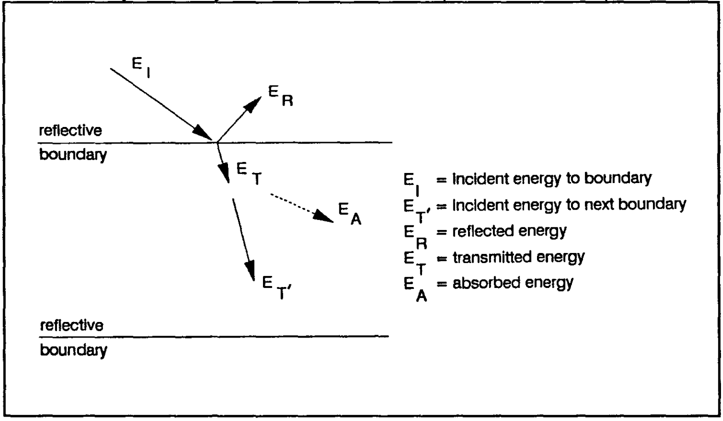

Figure 1. Energy Path Schematic.

$$Z_2=Z_1(1+R)/(1-R) \tag{1}$$

where Z_2 is the impedance of the second layer, and Z_1 is the impedance of the first layer.

The relationship between acoustic impedance and specific soil properties has been empirically derived from world averages of measured impedance versus sediment characteristics (Hamilton and Bachman 1970, 1972, 1982). Further development of statistical models and algorithms (Caulfield and Yim, 1983) establishes relationships between the acoustic impedance and soil properties (porosity, bulk density, grain size, etc.) for sediments within various natural marine environments and allows the identification and characterization of the subbottom layers from acoustically derived seismic reflection data.

Data Acquisition and Analysis

A source of acoustic energy deployed just below the water surface generates acoustic waves that propagate downward through the water column and sediments. High-resolution subbottom profiling systems, specifically designed for use in shallow water, with typical operating frequencies below 12 kilohertz (kHz), are used. The systems used herein have been band limited at the given frequencies in which they operate. Therefore, the appropriate energy source must be selected, depending on the characteristics of the subbottom material, to sufficiently meet the objectives of a given project. As a rule, the lower frequency energy sources have greater penetration into the bottom; however, they lack the vertical resolution of higher frequency systems. Unfortunately, the higher the frequency, the higher the signal attenuation within the bottom, limiting penetration.

As the transmitted energy propagates through sediment of varying densities and acoustic velocities, energy is reflected at geologic boundaries where there is a distinct contrast in the acoustic impedance between the layers. Reflected signals are amplified, filtered, and recorded with a specially designed shallow seismic, digital data acquisition system developed in conjunction with Caulfield Engineering (Caulfield 1991b). This system provides a real-time presentation of the seismic signal for acquisition quality control and records the data on disk for postprocessing.

Processing of the seismic data involves determining the precise reflection coefficient at each detectable reflection horizon. The analysis software, also developed with Caulfield Engineering (Caulfield 1991a), corrects for transmission losses due to spherical spreading, compensates for absorption losses in each layer as a function of the center frequency of a band-limited seismic trace, and utilizes classical multilayer reflective mathematics to compute equivalent reflection coefficients and impedances of the sediments as if they were surface layers, thereby classifying the lithostratigraphy (Hamilton 1972; Caulfield and Yim 1983).

Seismic reflection signatures are not universally unique, i.e., several combinations of geologic conditions could conceivably yield similar signal characteristics resulting in similar impedance values. But in a given geologic region such as the Mississippi

Sound or San Francisco Bay, a particular sediment usually has a characteristic, relatively narrow range of impedance values. Therefore, project-specific calibrations can be utilized to relate specific acoustic signatures to respective reflectors. Using calibration procedures incorporating local core data, the acoustic reflection data are processed to yield accurate acoustic impedance values at reflection horizons for the geologic region of interest. Estimates of in situ density are derived from the computed impedance and correlated with ground truth information Figure 2. Testing to date has shown that density estimates to within 5 percent accuracy can be obtained (Ballard and McGee 1991). A plot of the impedance function versus laboratory measurements of density from core samples is presented in Figure 3. Also, for undisturbed, natural marine sediments, acoustically derived interpretations of the lithology are provided. Figure 2 compares the acoustic prediction of the lithology with actual core logs.

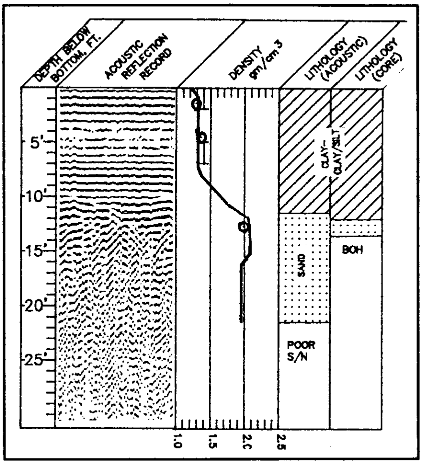

Figure 2 Typical Subbottom Calibration.

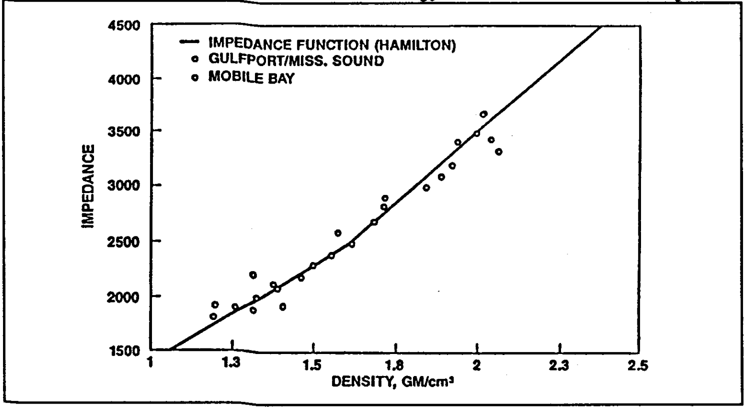

Figure 3 Computed Impedance versus in Situ Density

After calibration of the data, processing of the virtually continuous seismic data profiles commences. The digitally recorded data are processed using the coefficients for transmission and absorption losses determined during the calibration phase. The results provide continuous precision impedance predictions with estimated material velocities and densities of the shallow subbottom layers. Figure 4 presents a portion of the results of a recent impedance survey conducted in the Gulfport Ship Channel in support of a channel realignment project. Shown are profile lines delineating the extent of pertinent density zones. The virtually continuous coverage greatly decreases the possibility of undetected bottom material condition changes. In addition, better estimates of specific material volumes to be removed by dredging were provided.

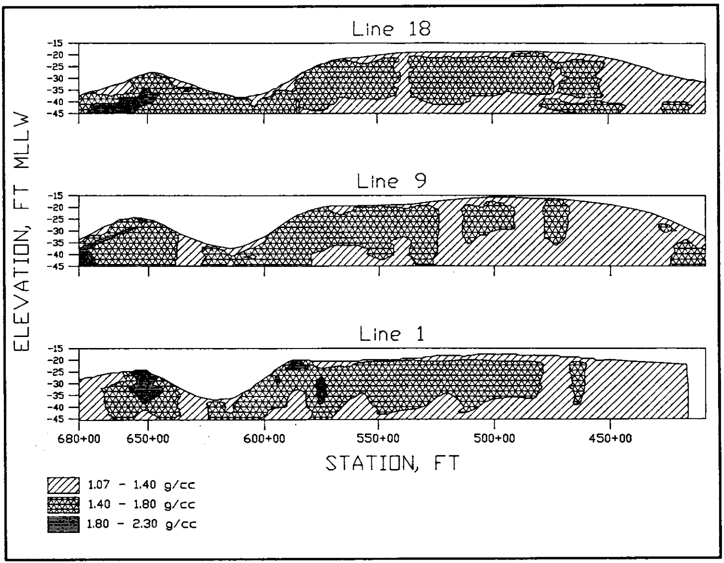

Figure 4 Gulfport Ship Channel Density Profiles

Summary

In its present state of development, acoustic impedance processing of seismic reflection data can provide an accurate, continuous description of the bottom and subbottom marine sediments in terms of density and material type in a rapid, cost-effective manner. Results from properly calibrated acoustic impedance surveys have been used to provide Corps' Districts and dredging contractors with the following:

1. Density estimates of marine sediments
2. Representative subbottom material types
3. Continuous subbottom information for planning and designing dredging and sampling programs
4. Estimates of the volume and type of material to be removed through dredging

5. A detailed and continuous geologic database for aiding long-term planning of future work

This technique, however, is not limited to sediment characterization for dredging interests, but can also provide essential information on the following.

1. Location of marine sand deposits for beach replenishment
2. Long-term monitoring of dredged material disposal areas
3. Delineation of submarine geologic formations
4. Detection of submarine features such as pipelines or other dredging hazards
5. Identification of fluid mud in navigable waterways

Acknowledgement

The tests described and resulting data presented herein, unless otherwise noted, were obtained from research conducted under the Dredging Research Program of the United States Army Corps of Engineers by the United States Army Engineer Waterways Experiment Station. Permission was granted by the Chief of Engineers to publish this information.

Appendix 1 - References

Ballard, R. F., Jr. and McGee, R. G. (1991) "Subbottom site characterization by acoustic impedance" *Proceedings of the U. S. Army Corps of Engineers Surveying Conference*, July 15-17, Louisville, KY, 1C-1-10

Caulfield, D. D. (1991a) " Acoustic core system manual, version 4.5x" Caulfield Engineering Group, Oyama, British Columbia, Canada.

Caulfield, D. D. (1991b) "Digital field shallow seismic aquisition system manual, version 1.2x" Caulfield Engineering Group, Oyama, British Columbia, Canada.

Caulfield, D. D. and Yim Y. C. (1983) "Prediction of shallow subbottom sediment acoustic impedance while estimating absorption and other losses" *J. Can. Soc. Explor. Geophys.*, 19(1):44-50.

Hamilton, E. L. (1970) "Sound velocity and related properties of marine sediments, North Pacific" *J. Geophys. Res.*, 75(23):4423-4446.

Hamilton, E. L. (1972) "Compressional-Wave attenuation in marine sediments" *Geophysics*, 37:620-646.

Hamilton, E. L., and Bachman, R. T. (1982) "Sound velocity and related properties of marine sediments" *J. Acoust. Soc. Am.*, 72(16):1891-1904.