Near-Grazing Angle Acoustic Scattering Across A Rough Interface Into A Viscoelastic Solid - Laboratory Measurement And Perturbation Theory Model

Garfield R. Mellema*, Terry E. Ewart*, and Kevin. L. Williams
Applied Physics Laboratory
College of Ocean and Fishery Sciences
University of Washington
1013 NE 40th Street
Seattle, WA 98105-6698

*Department of Electrical Engineering
University of Washington
Box 352500
Seattle WA 98195-2500

voice: (206) 543-1300, FAX: (206) 543-6785, email: mellema@apl.washington.edu

Abstract -- Refractive spreading and attenuation limit the coverage of sub-bottom sonar by reducing both its angular resolution and amplitude, especially at angles near critical. As a means of overcoming these limitations, there has been great interest in post-critical penetration into sediments. One explanation for the reported post-critical penetration is rough interface scattering. In order to evaluate the importance of this effect, a simplified laboratory environment has been constructed to isolate rough interface scattering in an environment which excludes conditions necessary for alternate hypotheses. Accurate characterization of the medium is ensured by replacing the sediment with a homogeneous viscoelastic solid. The transducers are located in the water column, where their response can be well characterized. An automated positioning system and an interface area that is much larger than the correlation length of the roughness are employed to allow many independent measurements and thus, well determined statistics. A perturbation theory model has been implemented for comparison with experimental results and to assist in the selection of interface roughness spectra.[1]

INTRODUCTION

In order for a sonar in the water to detect targets in sub-bottom sediment it is necessary for the signal to be transmitted from the water column into the sediment. Although this can be done by refraction, effective refractive penetration is reduced to a limited region by both attenuation and refractive spreading. The ability of a sonar signal to penetrate the sediment at grazing angles below the critical angle would increase its range and coverage.

Acoustic signals have been measured in sub-bottom sediments having arrival times and amplitudes inconsistent with the refractive compressional ray path. Several hypotheses have been proposed to explain these arrivals including Biot waves [1], scattering due to water-sediment interface roughness [2] and scattering due to inhomogeneities in the sediment. In the Biot wave hypothesis, the fluid-filled porous structure of the sediment permits the existence of two compressional waves: a fast wave where the wave in the sediment lattice is in phase with the wave in the fluid-filled pore space and a slow wave where they are out of phase. In the rough surface scattering hypothesis, the interface roughness scatters the compressional wave into the sediment with significant amplitude. In the third hypothesis, the evanescent wave is scattered by impedance fluctuations in the sediment. Using differing paths and sound speeds, both of the first two hypotheses have been applied to fully explain observed penetration. Unfortunately, the conditions of the in-situ measurements were such that none of the mechanisms could be definitively proven or disqualified. The goal of this effort is to examine the roughness mechanism in isolation to evaluate its contribution.

EXPERIMENTAL SETUP

A simplified laboratory environment was constructed in which conditions were idealized for the measurement of rough interface penetration while excluding conditions necessary for the Biot wave and volume inhomogeneity hypotheses. Acrylic, used in place of sediment, can be accurately machined to a specified roughness while its homogeneity precludes the other proposed penetration mechanisms. The water above the acrylic is continuously purified and degassed. A partial vacuum under the acrylic effectively doubles the height of the apparatus at the expense of potential interference among the direct, reflected, refracted and scattered signals. The transducers are located in the water, where their radiation patterns can be accurately measured, and they can be easily relocated using an automated positioning system without disturbing the

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Applied Physics Laboratory
College of Ocean and Fishery Sciences, University of Washington

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ONR Code 321OA
Ballston Tower #1
800 N. Quincy Street
Arlington, VA 22217-5660

From: Kevin L. Williams, Senior Physicist

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(2) "Near-grazing angle acoustic scattering across a rough interface into a viscoelastic solid - laboratory measurement and perturbation theory model," Garfield R. Mellema, et al., Proceedings of the 16th International Conference on Acoustics, Seattle, Washington, June 1998, 3 copies, including 298 Form and copy of DTIC 50 Card

Enclosed please three copies each of two scientific publications that complete the subject grant requirement for a final report. The grant also funded a significant part of the Ph.D. work of Garfield Mellema, who is carrying out a laboratory test of penetration due to surface roughness. Once his thesis is complete, I will forward a copy to you for your information.

Kevin L. Williams

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1013 NE 40th Street Seattle, Washington 98105-6698 (206) 543-1300 FAX (206) 543-6785

characteristics of the acrylic. The positioning system accuracy is better than 0.1 mm and measurements are made using a computer controlled arbitrary waveform generator and data acquisition system. The transmitter response was measured and a pre-emphasized maximal bandwidth minimum duration source signal was designed. The entire apparatus was held at a fixed temperature. The setup is as shown in Fig. 1 with only the compressional and scattered wave paths shown.

MODELING

A perturbation theory model was constructed using independently measured characteristics of the experimental setup. For the first-order, rough interface model, a filtered power law roughness spectrum was used. A transducer arrangement was selected which allowed sufficient time for the water-to-water scattered signal (path 1 in Fig. 1) to decay before the arrival of the acrylic-to-water (path 2) and water-to-acrylic (path 3) scattered signals. Although the two scattered signals arrive at coincident times with nearly equal amplitudes, it is the subcritical water-to-acrylic scattering (path 3) which is of main interest. By adjusting the parameters of the roughness spectrum within the $kh < \sim 1$ limit of perturbation theory a clearly observable scattered arrival corresponding to the paths 2 and 3 can be isolated in time for certain geometries (Fig. 2).

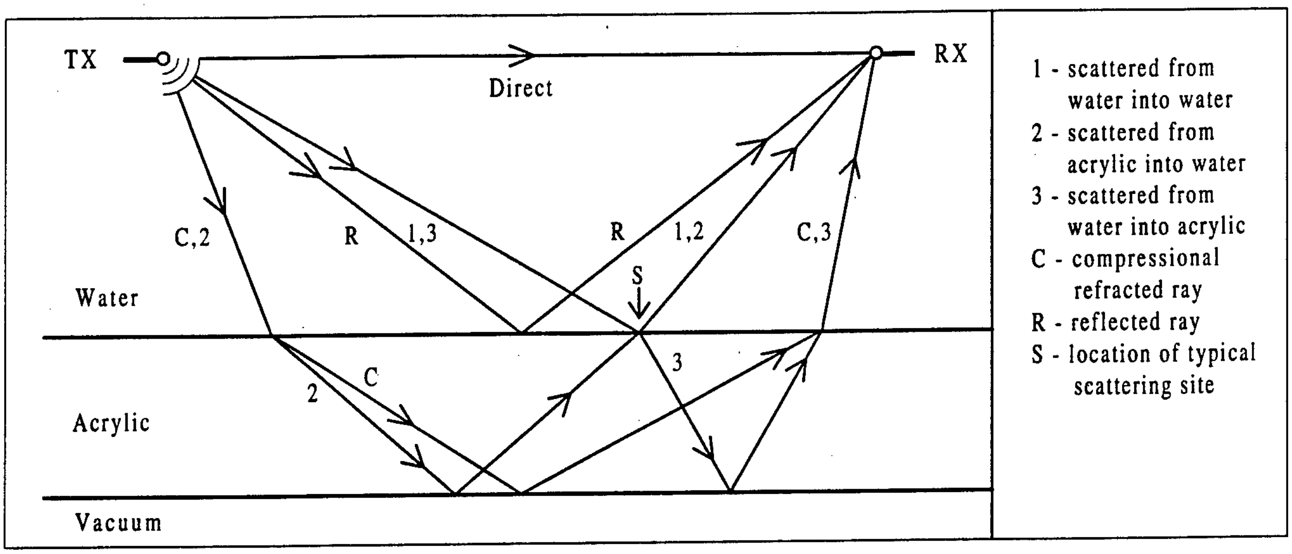

Figure 1. Experimental setup showing compressional and scattered wave paths in the acrylic.

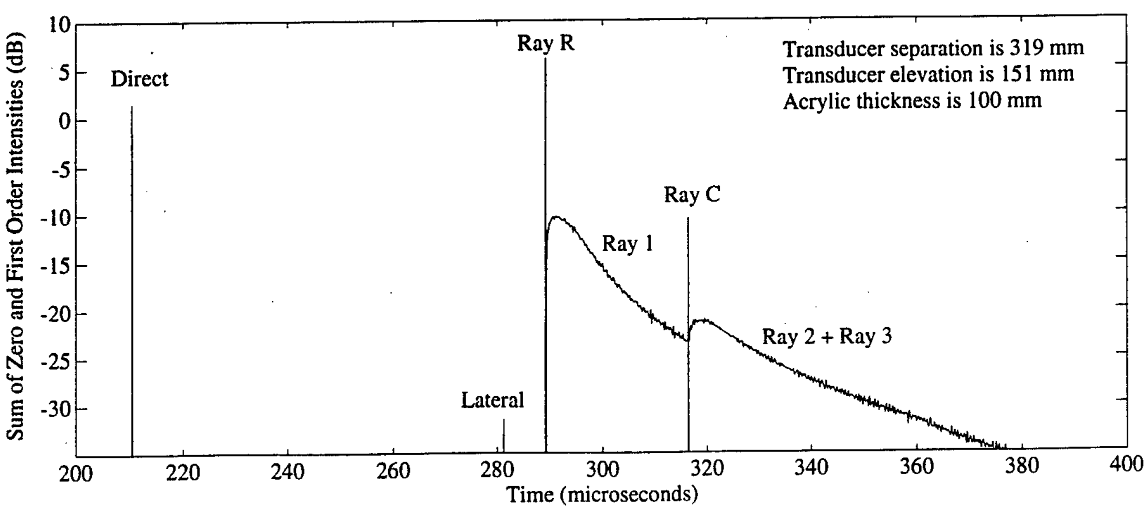

Figure 2. Perturbation theory result for the geometry shown in Fig. 1.

ONGOING WORK

Comparison of modeled and measured reflection and refraction from the smooth acrylic surface showed excellent agreement, demonstrating the accuracy of the experimental apparatus and the model parameters. The perturbation theory model was used to select a roughness spectrum to be machined into the acrylic surface. Realizations of the roughness spectrum were generated and a single realization chosen. Instructions for controlling a CNC milling machine were generated and roughness spectra calculated from the results of milling simulations to check the method accuracy. Having confirmed the suitability of the calculated spectra, rough surface machining was begun.

For the rough surface case, an ensemble of measurements is needed for comparison with the ensemble average scattering values of the perturbation theory model. For the chosen roughness spectrum and transducer geometry it is possible to obtain about 200 uncorrelated realizations on the specified surface by translating the transducers between measurements.

REFERENCES

[1] F.A. Boyle and N.P. Chotiros, "Experimental detection of a slow acoustic wave in a fluid-saturated porous solid", J. Acoust. Soc. Am. vol. 91, pp. 2615-2619, May 1992.

[2] J.E. Moe, "Near and Far-Field Acoustic Scattering through and from Two-Dimensional Fluid-Fluid Rough Surfaces", Technical Report APL-UW TR9606, Applied Physics Laboratory, University of Washington, October 1996.

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6. AUTHOR(S)
Garfield R. Mellema, Terry E. Ewart, and Kevin L. Williams

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Applied Physics Laboratory
University of Washington
1013 NE 40th
Seattle, WA 98105-6698

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
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