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BOTTOM ACOUSTIC BACKSCATTERING AT LOW GRAZING ANGLES IN SHALLOW WATER, PART I: BOTTOM BACKSCATTERING STRENGTH

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I. INTRODUCTION

Acoustic bottom backscattering measurements were made in May 1982 about 1 mile offshore from Mission Beach near San Diego, California, and in June 1983 about 30 miles offshore from Charleston, South Carolina. The measurements were made using transducers mounted on a tripod assembly about 4 m tall that rested on the bottom. The horizontal and vertical orientation of the transducers were controlled and monitored by test personnel on a nearby oceanographic tower at San Diego and on an instrumented boat at Charleston. The acoustic measurements were made over a range of grazing angles from 2-10^{o} and a range of frequencies from 30 to 95 kHz.

The transmitted pulse waveforms were either cw (pulse lengths of 0.25-25 msec) or linear FM (1-25 msec pulses with 1-4 kHz bandwidths) and were generally transmitted on alternate pings until approximately 75 pings of each pulse type had been transmitted.

Description of test areas

The ocean bottom in both test areas was medium to fine grain sand with similar sediment geoacoustic properties. In the San Diego area, two distinct sediment types were encountered; the coarser sand region was characterized by sand waves with 50-60 cm wavelengths and 10-20 cm heights while the finer sand region was characterized by more randomly oriented sand ripples with 10-20 cm wavelengths and heights of approximately 1-2 cm. In the Charleston area, the ocean bottom more nearly resembled the coarser sand sediment encountered near San Diego; both test areas were relatively free of marine fauna.

Reference targets were placed in the measurement areas at both test sites to serve as easily identifiable acoustic references in range and azimuth angle. These targets were fluid filled focusing spheres and the acoustic target strength of each sphere was measured under freefield conditions at the Lake Travis Test Station (LTTS) calibration facility. These targets were extremely useful for reference purposes during measurements and also during data analysis.

II. DATA ANALYSIS DESCRIPTION AND RESULTS

A. Introduction

The acoustic measurement data were recorded on analog (San Diego) and digital (Charleston) magnetic tape records, converted to standard 9-track digital data records in the laboratory and processed by use of analysis software written for a general purpose computer (CDC CYBER 171). The digital data record format was such that each transmitted pulse and subsequent reverberation period was identified by pulse type, frequency, time, and number of sequential samples composing the digital data record. An envelope was generated for each ping and was then smoothed by time averaging with a moving time window equal in length to the pulse duration.

A number of sequential ping cycles (usually 30 to 50) using the same pulse waveform were assembled to form an ensemble. Statistical tests were then performed in order to assure that the assembled envelope records constituted a valid ensemble. An existing ray tracing computer program was used to relate time after initiation of the pulse transmission to pathlength, horizontal range, and grazing angle. A horizontally stratified water column based upon a measured sound speed profile was assumed within the ray tracing computations.

The acoustic data from both measurement sites were analyzed to determine the behavior of bottom backscattering strength as a function of grazing angle, effective horizontal beamwidth, transmit signal type, frequency, and bottom type. Since backscattering strength was calculated by averaging over an ensemble of envelope records, an attempt was made to select data representative of the characteristic being investigated over a time interval during which propagation conditions remained relatively stable.

B. Bottom backscattering strength versus grazing angle

The bottom backscattering measurements were intended to provide information at grazing angles below about 15°. The low grazing angle limit, corresponding to longer ranges, was observed to depend upon the propagation and sea surface conditions existing at the time the particular backscattering measurements were made. In particular, energy backscattered from the sea surface prevented meaningful measurements below about 2°, since energy backscattered from the bottom became contaminated by energy backscattered from the sea surface at the longer ranges.

An example of observed bottom backscattering strength versus grazing angle at 30 kHz is shown in Fig. 1 for which contamination by surface reverberation becomes significant at about 3° grazing angle. Thus, the useful range of bottom backscattering strength information lies between about 3° and 9.5° in this figure. Within this region of grazing angles the trend (solid line) of the bottom backscattering strength follows that of 10 log $(\sin^2\theta)$, where θ is the grazing angle. This Lambert's rule behavior, discussed by Urick[1], is not uncommon for observed backscattering at low grazing angles for bottom conditions where the roughness scale is the same order as the acoustic wavelength.

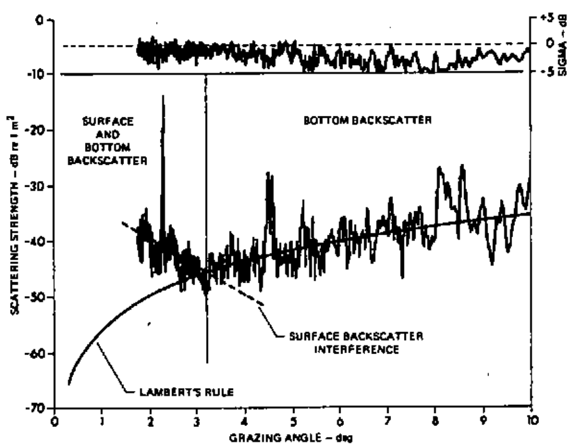

FIGURE 1
BACKSCATTERING STRENGTH MEASURED OVER 5 PINGS OF A TILT SCAN BETWEEN ELEVATIONS -1.39° AND -6.81°, AT 30 kHz WITH A 0.25 msec cw PULSE

A measure of the variation of bottom backscattering strength versus grazing angle was calculated for each ensemble of envelope records. The measure used was the coefficient of variation (the standard deviation from the mean divided by the mean value) at each grazing angle. An example of this measure is shown in Fig. 1 where the quantity sigma = 10 log V versus grazing angle has been plotted where V is the coefficient of variation.

C. Beamwidth dependence

The measurement equipment was configured such that individual receiving array stave outputs as well as beams formed by combining the stave outputs were recorded during acoustic measurements. Figures 2 and 3 show comparisons of estimated backscattering strength from measurements near San Diego and Charleston, respectively, for the horizontal beamwidths of a sum beam (using all 12 receiving array staves) and a single stave for a frequency of 30 kHz. For the examples shown, and for other pulse types analyzed, there was no observed dependence of mean bottom backscattering strength on beamwidth. (Some minor differences were noted in the reverberation statistics and are discussed in an accompanying paper). In all cases the variation of the curves from the general trend with grazing angle was noticeably less for the larger beamwidths associated with the staves than for the beamwidths associated with the sum beams.

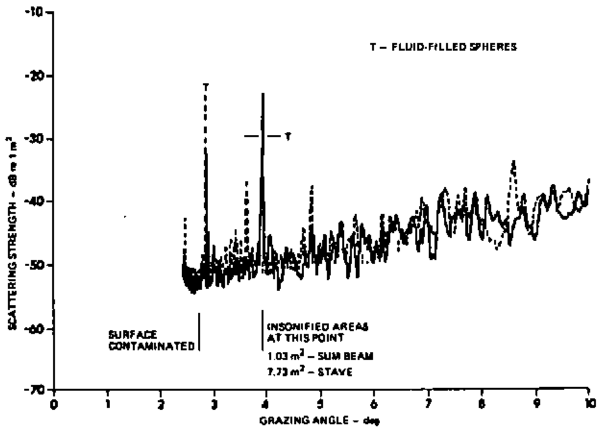

FIGURE 2
COMPARISON OF BACKSCATTERING STRENGTH ESTIMATES AT 30 kHz USING A COMBINED AZIMUTHAL BEAMWIDTH OF 21.1° (SOLID LINE) AND 2.8° (DASHED LINE)
IN BOTH CASES A cw PULSE OF 0.4 msec WAS USED

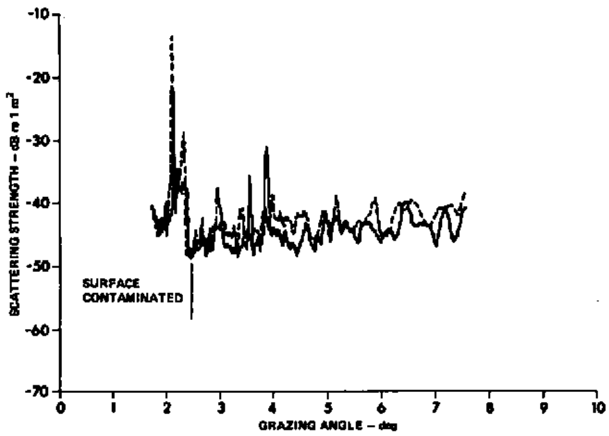

FIGURE 3
COMPARISON OF BACKSCATTERING STRENGTH ESTIMATES AT 30 kHz FROM THE CHARLESTON AREA USING A COMBINED AZIMUTHAL BEAMWIDTH OF (a) 21.1° (SOLID LINE), AND (b) 2.8° (DASHED LINE)
IN BOTH CASES A 1 msec, 4 kHz FM PULSE WAS USED

D. Pulse type dependence

The average bottom backscattering strength versus grazing angle exhibited no dependence upon pulse type or pulse length for either of the measurement areas or for any of the frequencies used. Examples of results from measurements made using sum beam outputs and a frequency of 60 kHz are in Fig. 4 for San Diego and Fig. 5 for Charleston. In all cases, it can be seen that the bottom backscattering strength associated with each pulse type tended to vary randomly about the same mean value for each frequency and measurement area.

The results for the FM slide pulse types, with time-bandwidth products greater than unity, were smoother; all the data have been smoothed by averaging over the pulse length.

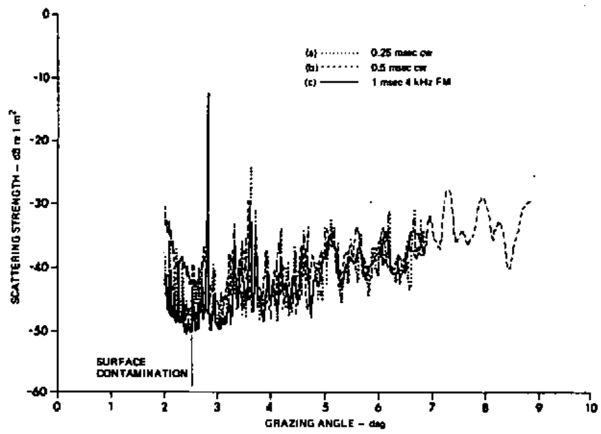

FIGURE 4
COMPARISON OF BACKSCATTERING STRENGTH AT 60 kHz USING (a) 0.25 msec cw, (b) 0.5 msec cw, AND (c) 1 msec 4 kHz FM PULSE TYPES
(NOTE: CURVES (a) AND (c) OBTAINED WITH VERTICAL TILT ANGLE OF -3° WHILE CURVE (b) OBTAINED WITH VERTICAL TILT ANGLE OF -6°)

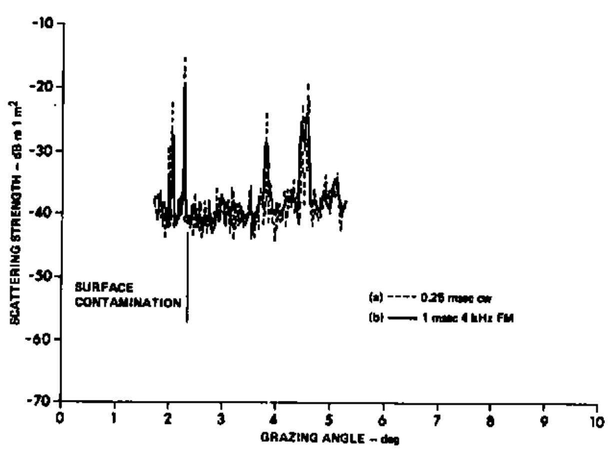

FIGURE 5
COMPARISON OF BACKSCATTERING STRENGTH AT 60 kHz NEAR CHARLESTON USING (a) 0.25 msec cw, AND (b) 1 msec, 4 kHz FM PULSE TYPES

E. Frequency dependence

The bottom backscattering strength as a function of grazing angle was found to fit Lambert's rule fairly well for all frequencies and pulse types used in both measurement areas. Therefore the backscattering strength B_S may be expressed as

$$B_S = 10 \log \mu + 10 \log (\sin^2\theta) \quad , \tag{1}$$

where θ = grazing angle and 10 log μ = backscattering strength in dB at normal incidence if Lambert's rule were valid at normal incidence.

A $\sin^2\theta$ function was fitted to each backscattering strength versus grazing angle curve resulting from measurements made in both test areas and the value of 10 log μ was estimated. The quantity 10 log μ was then plotted as a function of frequency and the results are shown in Fig. 6.

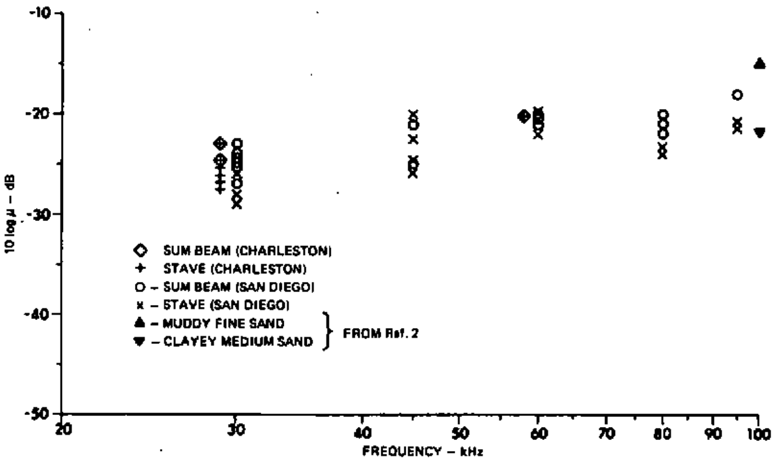

FIGURE 6
ESTIMATED VALUES OF THE BOTTOM BACKSCATTERING CHARACTERISTIC
10 log μ versus FREQUENCY FOR THE SAND BOTTOM REGIONS NEAR
SAN DIEGO, CA AND CHARLESTON, SC
THE CHARLESTON DATA WERE MEASURED AT A BEARING OF 110°N, AND THE SAN DIEGO DATA AT 25°N
THE DATA INCLUDE GRAZING ANGLES FROM ABOUT 2.5° TO ABOUT 10°

Within the particular bottom regions for which Fig. 6 applies (fine and medium sand) and over the frequency range observed, an increase in bottom backscattering strength with frequency was observed. Due to the scatter in the data points, a frequency dependence of 10 log f^n, where $1 \le n \le 1.5$, can be inferred. This frequency dependence is consistent with that reported by McKinney and Anderson [2] of approximately 10 log $f^{1.6}$ for field measurements in sand bottom regions. Two points are also shown in Fig. 6 at 100 kHz that were estimated from data below 10° grazing angle [2] for sand of about the same particle size as that of the San Diego area. These points compare very well with data plotted at 95 kHz from the current measurements.

F. Azimuth dependence

For the purpose of measuring azimuth dependence, a set of data was taken in the San Diego area at 30 kHz in which the sonar beam was slowly scanned over a large sector of the bottom. The bottom in the San Diego measurement area may be separated into two regions--fine sand and coarse sand regions--with a discernible boundary between them; the scan data included measurements in both regions.

The backscatter data appeared to follow Lambert's rule except where there was a transition from one type of sand to another. The data were blocked into nine groups of ten pings each which, at a scan rate of 1.7° between adjacent pings, would correspond to 17° sectors. The total sector covered was 153°.

Within each block, the average Lambert normal incidence backscattering strength 10 log ˋ was estimated. Where there was a clear transition from one type of bottom to another, the block was subdivided at the transition range. The results are shown in Fig. 7. The measured values of 10 log μ ranged from -26 dB to -34 dB; both extreme values were measured over the coarse sand region. At the boundary between the two types of sand, surprisingly, the fine sand showed a higher value of 10 log μ.

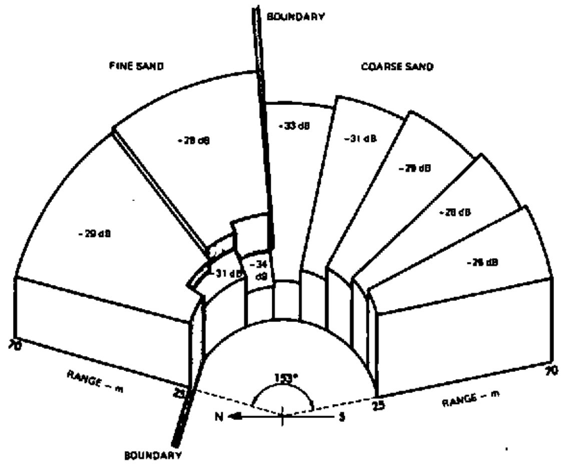

FIGURE 7
MEASURED VALUES OF S_0 FROM A SLOW SCAN OF THE BOTTOM
GROUPS OF 10 PINGS, WHICH SPAN SECTORS OF 17°, WERE BLOCKED AND AVERAGED.
THE MEASUREMENTS WERE MADE AT 30 kHz WITH A SYSTEM BEAMWIDTH OF 2.8°.
THE SCANNED AREA COVERED BOTH FINE AND COARSE SAND REGIONS, WITH MEAN GRAIN SIZES 9×10^{-5} m AND 5×10^{-4} m, RESPECTIVELY

Fixed azimuth data were analyzed from the Charleston area at azimuthal angles of 110°N and 155°N. The mean values for 10 log μ for these two data sets differed by 3 to 4 dB, indicating that some azimuthal dependence in backscattering strength was present at this test site also.

IV. CONCLUSIONS

The lack of an independent measure of propagation loss is believed to have contributed to the scatter of the data at each frequency. Although fluid-filled spherical acoustic targets were calibrated under freefield conditions and deployed in the bottom measurement regions at both test sites, the deployment geometry, environment, and system parameters combined to prevent the use of this information to help reduce uncertainties in propagation loss. The acoustic targets were very useful as reference points in range and bearing during data acquisition and again during data analysis efforts.

The estimated bottom backscattering strength versus grazing angle plots were often observed to increase with decreasing grazing angle below about 3° as has been reported.[2] The observed background levels at the lower grazing angles were found to depend upon pulse length, to be above ambient noise levels, and to correlate with wind speed. The ranges involved when background levels were observed to increase with decreasing grazing angle were consistent with backscattering from the air-water surface.

The bottom backscattering strength was observed to be independent of beamwidth and pulse lengths at all frequencies used in the acoustic measurements.

The frequency dependence of the bottom backscattering strength over the range of frequencies used at both measurement sites was observed to follow a 10 log f^n, where n was between 1 and 1.5. This observed behavior is consistent with results reported in Ref. [2].

An azimuthal dependence was observed in the bottom backscattering strength measurements from both test areas. Analyses results on bottom roughness are limited at this time; however, the bottom backscattering results observed are expected to be attributable to sand waves and, particularly, to their orientation.

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[2.] C. M. McKinney and C. D. Anderson, "Measurements of Backscattering of Sound from the Ocean Bottom", J. Acoust. Soc. Am. 36, No. 1, 158-163 (1964).