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Studies on Sound Signal Scattering from Varying Seabed Sediments of the Western Continental Shelf of India: Cochin to Mangalore

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ABSTRACT

A study on the interaction effect of the acoustic signal with three different sediment type seabottoms off the shelf area between Cochin and Mangalore of the West coast of India is performed. Analyses by means of Probability Density Function (PDF) of echo amplitude, root mean square (rms) roughness of the seabed and coherent reflection coefficient at the water bottom interface show that the areas are generally smooth. A comparative study of the reflection coefficients computed from the ground truth information [1] and coherent reflection coefficients estimated from the echo data reveals that the interface scattering is dominant in the coarse grained sandy and silty sand bottom areas. However, in the fine grained sediment area, the interface scattering is found to be absent.

INTRODUCTION

Sonar reflection profiling of the seafloor is a well established method for various objectives like characterization of the seabed, determination of geotechnical properties etc. In the past few years, a considerable amount of work has been done to determine the qualitative as well as quantitative seabottom characteristics by acoustic methods in conjunction with sediment sampling [2-6]. The present work is devoted to understand the interaction effects of the acoustic signal with the three varying sediment type seabottoms off the shelf areas around Cochin and Mangalore of the West Coast Of India. In order to collect the echo data from the different areas, an interface for echo data acquisition is developed to obtain the echostrength of the single beam echosounder (ELAC) operating at 12 KHz. This design is a modified form of the data acquisition system for the sparker signal [7] in order to obtain the echo signal from the sedimentary layers.

As far as geology of the area is concerned the nature of the overall sediment distribution is known for the three areas whereby the echo signal data is collected [8]. The reflection coefficient of these areas is determined based on the information obtained through ground truth and subsequent computations carried out [1]. From the above study the experimentally determined reflection coefficients of the different areas does not concur with the reflection coefficients obtained from the ground truth. One of the possible causes of the variation in reflection coefficients is scattering i.e., study of second order statistics is necessary [9]. Jackson has detailed the nature of scattering i.e., interface as well as volume scattering and has also shown that for normal incidence direction the interface scattering is prominent [10]. Fox and Hayes have developed an accurate spectral estimation technique from the digitized depth data to determine the roughness parameter of the area [11]. Though the

digitized depth values are unavailable the echosounder records of the areas are generally flat. In the absence of digitized depth data, the rms roughness parameter is being determined by Stanton's method [12]. Stanton developed a technique to compute the PDF (Probability Density Function) of the seabottom peak echo amplitudes which is being applied in this work. Talukdar and Lawing [13] have developed a method to determine a factor - which is a measure of the relative roughness or smoothness of the seabottom and is used here. The relationship between this factor and other parameters are studied to compute the bottom interface root mean square (rms) roughness [12,14] of the three areas. Tolstoy and Clay [15] had enunciated a theory to estimate the reflection coefficient of the area where bottom roughness is known. Based on that we compute the coherent reflection coefficient for the three areas using the interface rms roughness parameter.

ANALYSIS

The Rice PDF describes the echo peak amplitude E from the seabed [12]

$$P(E) = [2E(1+\gamma)] / \langle E \rangle^2 \exp\{-[(1+\gamma)E + \langle E \rangle] / \langle E \rangle\} I_0(Q) \quad (1)$$

where $I_0(Q)$ is the modified Bessel function and

$$Q = 2E \sqrt{(1+\gamma)} / \langle E \rangle$$

Here, $\langle E \rangle$ is the expected value of the echo peak obtained and is the measure of the relative roughness or smoothness of the bottom and can be presented as

$$\gamma = (300/\pi) B K \eta^2 \quad (2)$$

where B is the beamwidth between e points in radians of the transducer beampattern, K is the operating wavenumber and η is the rms roughness of the seabottom. In order to determine the roughness value of the different areas, a method of moments was applied based upon Talukdar and Lawing [13]. In this method, moments of theoretical PDF are matched with the sample moments i.e. a matching method of the observed mean to the theoretical mean is performed to compute γ .

The moments of the Rice distribution (eqn.1) is expressed with respect to μ and $E/\langle E \rangle$ as

$$\mu = \sqrt{3/2} (1+\gamma) \exp(-\gamma/2) [I_0(\gamma/2) + I_2(\gamma/2)] \quad (3)$$

From above eqn.(3) it may be seen that (the ratio of the mean of the observed peaks to the second moment of the data obtained at different areas) are varying between Rayleigh (for $\gamma=0, \mu = \sqrt{2}$) and Gaussian ($\gamma=1$). Hence matching of the sample mean to the theoretical allows to determine γ . The experimental values are obtained for different areas and well matched PDF curves are plotted. The values of B (beamwidth) is 25.06° and K is computed for a frequency of 12 KHz and an assumption is made for $\eta = 5$ in our area

and subsequent use of these values in eqn. (2) helps to calculate rms roughness of the area.

In the reference [1], layerwise reflection coefficient is determined based on experimental echo values. The reflection coefficient which is represented by the ground truth is determined using sound velocity, density and attenuation at the water sediment interface. The attenuation coefficient is estimated from the measurement technique used to acquire echo data. The experimentally determined reflection coefficients of the different areas does not concur with the reflection coefficients obtained from the ground truth.

Hence a further extension of the study is made to understand whether the interface scattering influences the reflection coefficient. According to Tolstoy and Clay [15] the coherent reflection factor is expressed as

$$\langle R \rangle = R_0 e^{-2k^2 \sigma^2} \quad \text{-----(4)}$$

where R_0 is the reflection coefficient computed using the theory based on ground truth information [1].

DISCUSSIONS

The echo peak amplitudes for each transmission was evaluated and their occurrence determined in different intervals. This was done with the help of software in TURBO BASIC. The experimental echo peak PDF graph was then plotted from the above exercise and presented in terms of percentage.

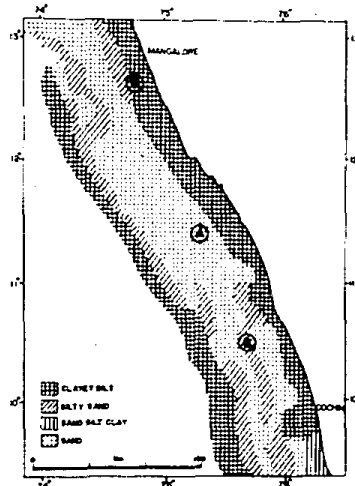


Fig.1 Map of the Survey Area

Fig. 1 represents the survey region off Cochin and Mangalore of the West Coast of India. Amongst the three areas chosen for the study, area A consists of coarse grained sandy bottom, the position being around $11^{\circ} 30' N$ and $75^{\circ} 16' E$. The area B is relatively less coarse having a silty sand bottom around the area $10^{\circ} 40' N$ and $75^{\circ} 25' E$, while the area C is an acoustically low velocity region consisting of fine grained clayey silt. The area C is around $12^{\circ} 40' N$ and $74^{\circ} 40' E$. The total number of pings collected in areas A, B, and C are 400, 253 and 227 respectively.

The experimental PDF (histogram) and theoretical PDFs (curve) of the different areas are presented in fig. 2. Fig. 2 shows that the narrowest PDF is obtained for sandy bottom while the PDFs are becoming broader for clayey silt and silty sand. The PDFs though, are Gaussian for all the three areas. The scattering phenomenon is minimum for the coarse grained sandy bottom. γ , the measure of relative roughness or smoothness is found to be highest for sandy bottom ($\gamma=11$). γ for clayey silt and silty sand bottoms are 7 and 6 respectively. The rms roughness for different areas are calculated from eqn.2, which reveal that the rms roughness for sandy bottom is less than those for clayey silt and silty sand (Table I). Using eqn. (4), the coherent reflection coefficients $\langle R \rangle$ are computed. R_0 is the reflection coefficient computed based on the ground truth of the different areas. The calculations of R_0 are

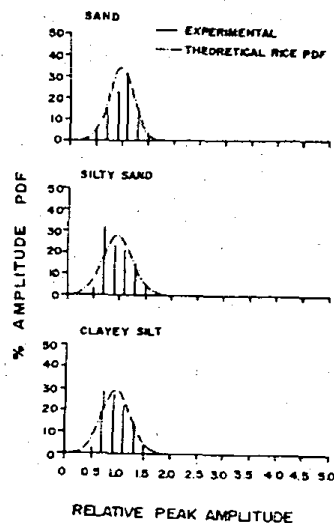


Fig.2 PDF for different sediment areas

covered in reference [1], hence will not be elaborated here. The computed values of the coherent reflection coefficient are presented in Table I. The experimental reflection coefficients seem to be in

TABLE I The reflection coefficients based upon ground truth, coherent reflection coefficient, experiment and rms roughness of different areas.

Area	rms roughness (m.)	Reflection Coeff. based on ground truth (R_0)	Coherent Reflection Coeff. ($\langle R \rangle$)	Experimental Reflection Coeff.
Sand (A)	0.0066	0.39	0.32	0.34
Silty Sand (B)	0.0075	0.32	0.24	0.26
Clayey Silt (C)	0.0073	0.15	0.11	0.17

close concurrence with the coherent reflection coefficient for the coarse grained sand and silty sand areas which supports the fact that interface scattering is dominant in these areas. For clayey silt area (C), the differences in reflection coefficients are found to be higher. The probable cause of such effect may be attributed to the inhomogeneity of the seabottom, i.e. volume scattering. According to Jackson [10], for normal incidence direction the contribution towards scattering is basically from the interface. Hence the effect of volume scattering is negligible. This fact does not explain the discrepancy in the coherent reflection coefficient for the fine grained sediment area. This requires a more detailed study which is not being probed into in this paper. More light could be shed on this subject from the paper of Chivers et. al. [16], which says that the volume scattering has a more implicit contribution in the case of a broad beam even for a normal incidence direction. As the present study has been carried out with a 25.06 beamwidth, it may be said that the effect of volume scattering plays a significant role in the fine grained sediment area.

CONCLUSIONS

A study has been performed to understand the manner in which varying sediment type seabottoms of the shelf area in the West Coast of India interact with a 12 KHz. echosounder signal and certain results have been inferred. Diverse methods like PDF determination, rms roughness evaluation and estimation of coherent reflection coefficient indicate that the seabottom in the three areas is relatively smooth. The rms roughness for a sandy bottom is lower than that for clayey silt and sandy silt. An investigation into the reflection coefficient reveals that the scattering for the coarse grained sandy and silty areas is from the interface while for the fine grained clayey silt area, the effect of interface scattering is not observed.

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