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Underwater Sound Scattering Model of the Topographic Features of the Sea Floor

D. SRINIVASAN, K. R. G. K. MURTY, & G. R. K. MURTY
Naval Physical & Oceanographic Laboratory, Cochin-682004

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Abstract. A description of the sea floor with respect to underwater acoustic transmission giving rise to reflection and scattering is studied. The plane wave reflection coefficients and scattering coefficients are estimated from the topographic features of the floor and the physical properties of the sediments. A bottom loss model for an area off west coast of India is presented.

1. Introduction

The applications of marine geological and geophysical measurements to the problems in underwater acoustics are important for a sonar operator. The results of such studies would be necessarily in the form of Geoacoustic Models relating the geological and the corresponding acoustic parameters. Several problems relating the system of operation, nature of the medium and the associated processes are to be resolved carefully for bringing a realistic model.

There are two approaches for the problem, a direct approach and an indirect approach. In the direct approach, the experiments relating the input and output are directly involved. An experimental set up for such studies include a sonar system consisting of a transmitter, receiver on one side, a continuous seismic profiler, or a side-scan sonar and a sediment sampler on the other side. The ratio of the receiving signal pressure to the incident signal pressure at the bottom interface gives the Bottom Loss values. The experimental data collected can be ensembled to form a statistical model. In the indirect approach the known geological parameters are linked with the acoustic parameters through various physical processes. The physical processes include the phenomena of scattering caused by the roughness of the sea bottom, absorption caused by porous sediments and reflectivity caused by the differences in acoustic impedances of the bottom and water at the interface. A mathematical theory developed by assuming a near bottom model in the absence of direct measurements, for each phenomena will be an ideal one.

Several attempts have been made to estimate scattering at the sea surface and bottom, by Eckart[1], Tolstoy and Clay[2] and Clay and Leong[3]. But the medium and measuring system impose certain limitations. The experimental measurements of Bottom Loss values were conducted by Mackenzie[4], Urick[5] and Eckart[6] in Atlantic and Pacific oceans, while Hamilton[7], Shumway[8], Akal[9], Clay and Leong[3] utilised geological data in computing bottom loss models.

In this paper an attempt is made in computing a Bottom Loss Model by indirect approach using the geological data for an area off West Coast of India.

2. Spectral Estimates of Topographic Features

A quantitative assessment of the topographic features can be better estimated either from the echograms or from the records obtained using a seismic profiler or a side-scan sonar. The analysis mentioned in the preceding paragraphs is based on echograms collected for the area under study using the echo sounder 'ELAC' operated at 21 KHz.

Spectral estimates were made from the echograms along the cruise tracks by reading the interval between two successive peaks and the height of each peak. These are shown in Fig. 1 alongwith the qualitative nature of the bottom as seen from echograms. The bottom features can be described by Type A—a smooth bottom, Type B—a smooth bottom with very closely spaced irregularities, Type C—a wavy but smooth bottom, type D—a wavy bottom with gentle undulations of a rolling surface, Type E—wave like features with sharp peaks of all wavelengths, Type F—hummocky type features, Type G—irregular hyperbolas generally seen on the shelf edges of very high amplitudes. The bar graphs given in Fig. 1 indicate the height of the peaks and wavelengths present in that region. Based on the results of spectral estimates, the area is classified as having six categories of wavelengths.

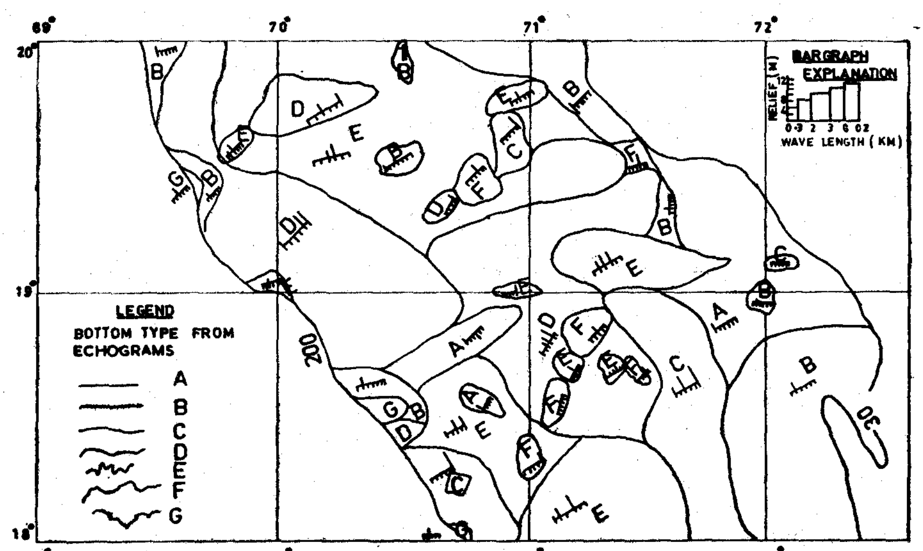

Figure 1. Spectral estimates of bottom topography.

I Smooth
II 0.3 Km
III 2 Km
IV 0.5 to 2 Km
V 2 to 6 Km
VI >6 Km

3. Geology of the Area

Distribution of grain size parameters for the area was studied by Nair[10], Stewart *et al.*[11] during International Indian Ocean Expedition (IIOE) and by Murthy[12] *et al.* during 1978. A brief summary of the results obtained by Murthy[12] are reproduced here.

The sediment distribution map is given in Fig. 2. The sediments are mainly classified into three types. Type I—silts and clays comprising the finer fraction of sediments. Type 2—Sands admixed with clays or silts and Type 3—sands. The coarser sediments with their phimedians in the range 0 — 2ϕ occupying the outershelf while phimedians in the range 2 — 4ϕ occupying the middle shelf. Finer portion of sediments are limited to 30 fm line. With low calcarious content, these are believed to be terrigenous muds[10,12]. Occasional rock out crops, cobbles, pebbles intercalated with mud etc. are reported in this area by Naval hydrographic charts[13]. In this area, Nair[10] reported the presence of silicified wood and basaltic outcrops. It is probable that the sands are relict ones; partly covered by terrigenous muds. The $CaCo_3$ content, support the view that they are relict sands belonging to postglacial period. Subaerial erosion weathering and abrasion of this part of the shelf are some of the agents attributable for the rough terrain.

4. Application of Theory of Reflection and Scattering to the Ocean Floor

(a) Computation of Bottom Reflection Loss Values

For any plane surface the reflected pressure signal (P^1) is related to incident pressure signal (P_0) as

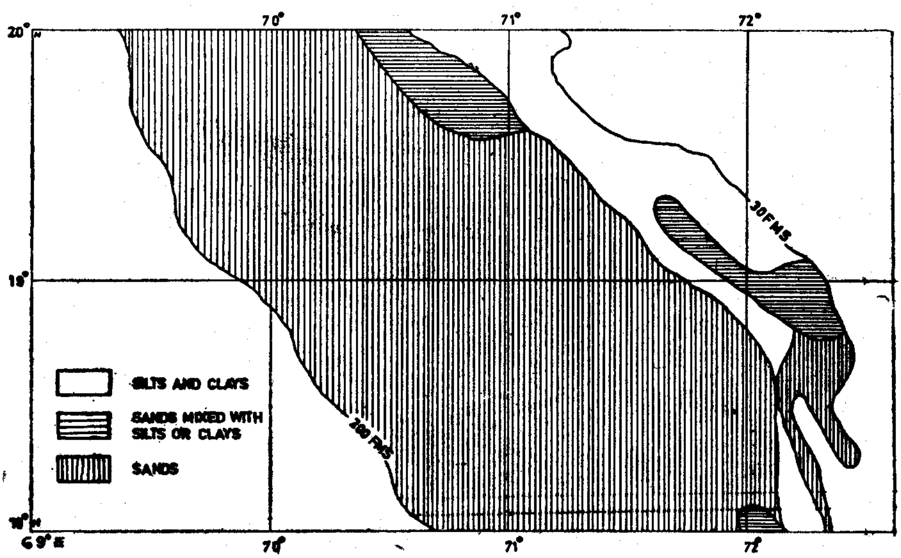

Figure 2. Distribution of bottom sediments.

$$P^1 = \hat{R} P_0 \tag{1}$$

and

$$\frac{\partial P^1}{\partial n} = -\hat{R}\frac{\partial P_0}{\partial n} \tag{2}$$

where $\hat{R}$ is the reflection co-efficient and $(\partial/\partial n)$ is the normal to the derivative.

Assuming a plane wave incident on a plane surface between two fluids, Rayliegh[14] developed a formula for the Reflection Co-efficient ($\bar{R}$) by defininig $\bar{R}$ as the ratio of reflected amplitude to the incident amplitude, given by

$$\bar{R} = \frac{\dfrac{\rho_s}{\rho_w} - \dfrac{\sqrt{C_w^2/C_s^2 - \cos^2\theta_i}}{\sqrt{1-\cos^2\theta_i}}}{\dfrac{\rho_s}{\rho_w} + \dfrac{\sqrt{C_w^2/C_s^2 - \cos^2\theta_i}}{\sqrt{1-\cos^2\theta_i}}} \tag{3}$$

at vertical incidence $\theta_i = 90°$ (θ_i measured from horizontal)

$$\bar{R} = \frac{\rho_s C_s - \rho_w C_w}{\rho_s C_s + \rho_w C_w} \tag{4}$$

and Bottom Reflection Loss $(dB) = -20 \log (\bar{R}) = 10 \log \hat{R}$ (4a)

where ρ_s and ρ_w are the densities of sediment and water respectively, C_s and C_w are the velocities of sound in sediment and water respectively.

In the normal case, part of the sound energy will be attenuated into the sea bottom and part of the energy will be reflected. Rayleigh has not considered the effect of volume attenuation of the sound beam in sediments. Morse[15] has modified Rayleigh's Formula by incorporating the attenuation of sound in the sediment. Modified Rayleigh's Formula as given by Morse[15] is

$$\hat{R} = \bar{R}^2 = \left(\frac{P_r}{P_i}\right)^2 = \frac{(h - \delta \sin \theta_i)^2 + g^2}{(h + \delta \sin \theta_i)^2 + g^2} \tag{5}$$

at vertical incidence θ_i-90° (measured from horizontal)

$$\hat{R} = \bar{R}^2 = \frac{(h - \delta)^2 + g^2}{(h + \delta)^2 + g^2} \tag{6}$$

$$BRL = 10 \log (\hat{R}) \tag{7}$$

where P_r and P_i are the reflected and incident pressures of sound beam respectively. θ_i = the angle of incidence measured from horizontal

$$h^2 = B + (A^2 + B^2)^{1/2}$$

$$g^2 = -B + (A^2 + B^2)^{1/2}$$

$$A = \alpha/\beta$$

$$\beta = 2\pi f/c_s$$

$$\alpha = \text{Attenuation coefficient (nepers/meter)}$$

$$B = \tfrac{1}{2}\,[1 - (\cos\theta_i/n)^2 - (\alpha/\beta)^2]$$

$$n = c_w/c_s$$

$$\delta = \rho_s c_s/\rho_w c_w$$

A knowledge of speed of sound in sediment and density of the sediment is necessary for computing BRL values, either by using Eqn. (7) or with approximation by using the Eqn. (4).

(b) Scattered Sound from the Sea Floor

This scattered pressure field from the sea floor for normal incidence is estimated using the relation of Clay and Leong[3].

$$\langle P^2\rangle/P_0^2 = 16\sin^2\Delta\phi\cdot S \tag{8}$$

where $\Delta\phi$ is the beam width of the transducer and

$$\text{scattering function } S = \frac{\hat{R}^2}{16}\cdot\frac{R^2}{X^2}\cdot u^2 \tag{9}$$

where

$$\left.\begin{aligned} u &= (2\pi)^{-1/2}/s(s^2 + 4/\pi)^{1/2} \\ s &= [8^{1/2}\,K\sigma^2]\cdot R/(XL_c) \\ K &= 2\pi/\lambda \\ X/R &= S/N\,\Delta\phi \\ L_c &= 30\,\sigma^{1\cdot25} \end{aligned}\right\} \tag{10}$$

The values of scattering function S and (10 log $(\langle P^2\rangle/P_0^2)$ are computed using the above relation for different values of roughness parameter σ and beam width $\Delta\phi$ for different frequencies.

Assuming a roughness of 0.2 meters for Type A, C, D, F and G and 0.5 meters for Types B and E, scattering loss values are estimated and added to the bottom reflection loss [Section 4 (*a*)] arrive at the total Bottom loss Model as given in Fig. 3. For the area in reference the total bottom loss values varied from 13 to 32 dB for normal incidence.

5. Reflectivity of the Sea Floor

Often the nature and type of sea bottom can be judged qualitatively by assessing the depth of penetration of echo into the bottom and strength of the echo through

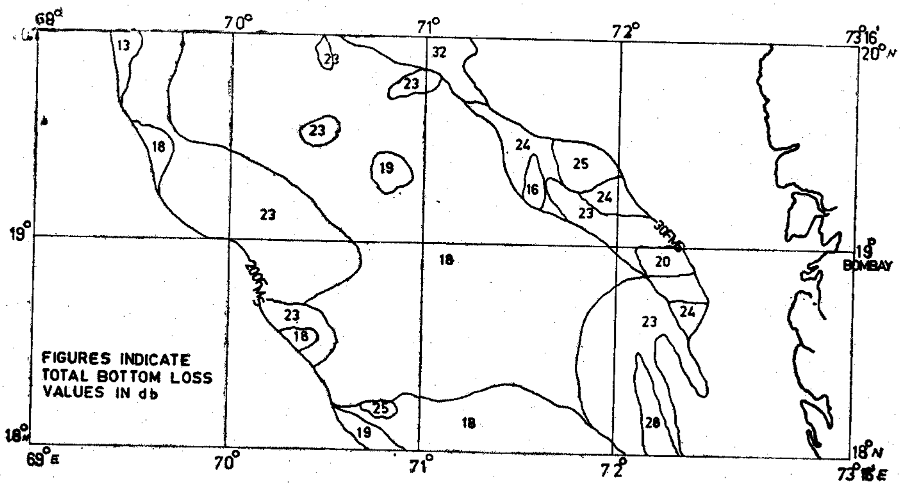

Figure 3. Bottom loss model (estimates based on 3° beam width, 7.5 KHz signal frequency at vertical incidence).

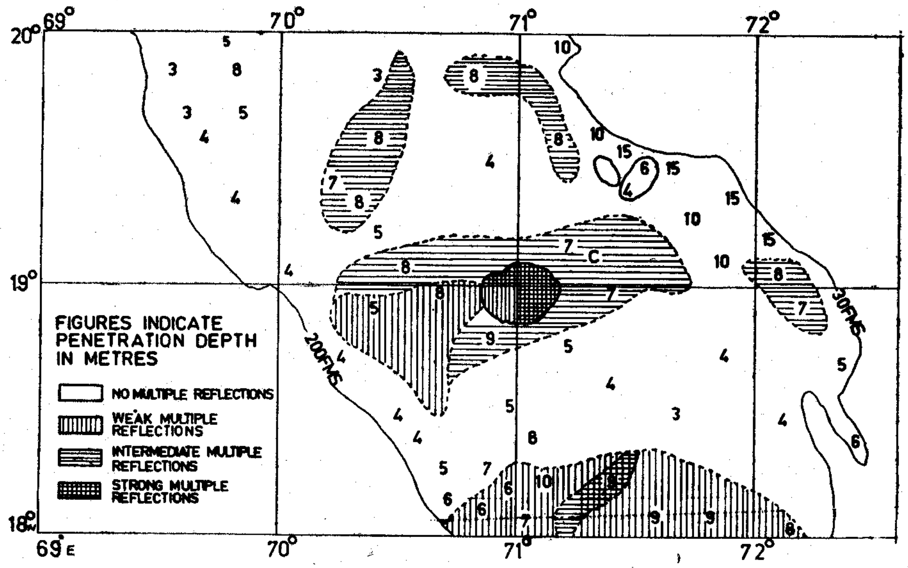

Figure 4. Reflectivity of the sea bottom.

multiple reflections. A qualitative assessment is made and the results are given in Fig. 4. Numerals in the figure indicate the depth of penteration of echo in meters $\left(\text{assuming } \frac{c_w}{c_s} = 1\right)$. The penetration depth varied from 3m for a coarse sandy bottom to 15m for a clayey bottom. In other words, a thin scattered echo is noticed for a sandy bottom comparaed to a smooth but broad echo over clayey bottom.

It is quite possible that a strong echo returning from the sea bottom often gives rise to multiple reflections. No multiple reflections are seen on the outer shelf regions dominated by coarser sediments and in the 30 — 50 fms line dominated by silty clays or clayey silts. Swanson[16] pointed out that coarse sands, gravel, pebbles scatter sound energy, and much of the sound energy will be absorbed by silty or clayey bottoms. Strong to moderate reflections are noticed in 50 — 70 fm line on the central shelf region dominated by fine sands.

The penetration depth values are plotted against acoustic impedance (ρc), Phimedian (ϕ) and porosity (P) in Figs. 5(a, b, c). The regression analysis yielded following equations :—

$$PD = 24.4 - 4.86 \times 10^{-3} (\rho C), \; \nu = -0.83 \tag{11}$$

$$PD = -4.24 + 0.236 P, \qquad \nu = -0.81 \tag{12}$$

$$PD = 1.92 + 13.6 \log_{10}\phi, \qquad \nu = -0.84 \tag{13}$$

Penetration depth values correlated with Phimedian, Acoustic Impedance and Porosity in the descending order. Comparison of Figs. 3 and 4 indicated a better correlation between the qualitative assessment made by the echo types and quantitative assessment of the topographic features.

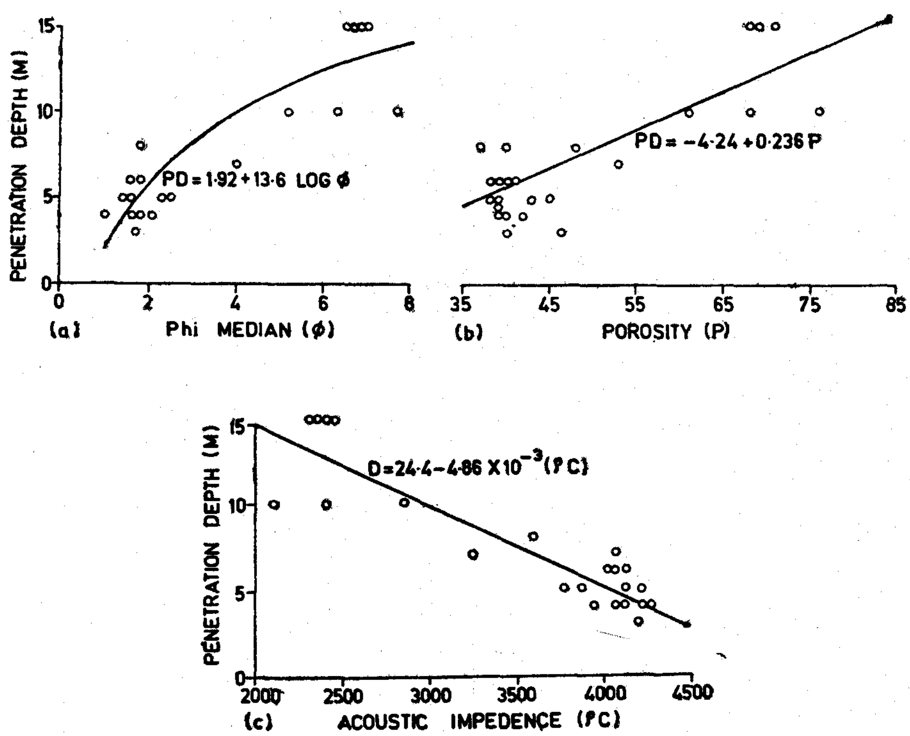

Figure 5. Regression analysis; (a) Phimedian *vs* penetration depth; (b) Porosity *vs* penetration depth; and (c) Acoustic impedance *vs* penetration depth.

6. Conclusion

The results obtained by applying the theory of sound scattering and reflection to an area off West Coast of India where the geology is known; are presented in Sections 2 through Section 5.

Figs. 1 and 2 indicate a smooth bottom between 30 – 50 fm line dominated by silty clays or clayey silts. The middle shelf region between 50 – 70 fm line is dominated by sands. The topographic relief is occasionally reaching 8m. The outershelf is dominated by the presence of coarser sands with relief in the range 1 – 2 m. This is clear that the area is moderately rough.

A comparison of Figs. 1, 2 and 3 indicate the contribution of scattering to the total bottom loss model is dominant on the outer shelf region while contributions of reflectivity is dominant in the 30 – 50 fm line. Moderate scattering is noticed on the middle shelf. The presence of pinnacles of the order of 4–8 m in the middleself region do not contribute much to the scattering. Probably they are locally smooth. The multiple reflections from this region are strong indicating a strong return of the echo.

With the good correlation noticed between Figs. 3 and 4, the Bottom Loss Model presented here will be a representative one. However. a better assessment of the realistic nature of this Bottom Loss Model can be made only from experimental measurement. It is proposed to carry experimental studies in the same area using an acoustic source and a receiver.

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