Geoacoustic model for a shallow water site in the Arabian Sea based on bottom loss measurements

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Results and analysis of bottom reflection loss measurements made at a shallow water site in the Arabian Sea off Kochi are presented as a function of frequency (2-12 kHz) and seabed grazing angle (11\degree-34\degree). Measurements are interpreted as estimates of the modulus of the plane wave reflection coefficient. First, the bottom reflection loss derived from a homogeneous fluid half-space model is compared with measured results. It is observed that the half-space model fails to provide accurate results for higher grazing angles especially at higher frequencies. Fine-scale sediment layering is considered to be the cause of frequency and grazing angle dependence and for improved modeling, a sediment layer overlying a half-space is used. The best-fit geoacoustic model is obtained by fitting the model to bottom loss data in the least-square sense. Bottom loss based on the best-fit geoacoustic model agrees well with the measured data over the entire frequency range.

\textbf{Keywords:} Bottom reflection loss, geoacoustic model, shallow water, acoustic propagation

**Introduction**

The geo-acoustic parameters of sediments play an important role in determining shallow water sound propagation and reverberation characteristics. Sediment geoacoustic properties can be extracted from bottom reflection loss measurements where it is difficult to carry out direct \textit{in situ} measurements. Several studies have been conducted to understand the interaction between sound and the sea bottom. Most of the reported experiments were at low frequencies (<1 kHz) where considerable amount of acoustic energy penetrates into the bottom\textsuperscript{13}. In the mid-frequency (1-10 kHz) range, the depth of penetration decreases gradually with increase in frequency. Moreover, in the presence of a transition layer, the bottom properties vary with increase in depth and as such the interpretation of bottom reflection measurements becomes complicated. Bottom loss measurements made over the entire mid-frequency range serve as a useful data set to investigate geoacoustic properties as a function of depth.

Several analytic studies have been carried out to derive bottom reflection loss and understand the mechanism of acoustic plane wave reflection from horizontally stratified fluid layer for linearly varying density and sound speed\textsuperscript{1-8}. Some of the previous studies focussed on estimating sediment properties within a transition layer, i.e., to invert sound speed gradient or attenuation within this layer. Spofford\textsuperscript{9} introduced a technique to estimate the sound speed gradient using acoustic bottom loss data between 50-1600 Hz. Holland \textit{et al.}\textsuperscript{10} obtained density and sound speed gradients in the transition layer by a Bayesian inversion approach between 300-1600 Hz. Choi and Dahl\textsuperscript{11} presented bottom-loss measurements made in the East China Sea as a function of frequency (2-20 kHz) and grazing angle (range 15-24\degree). They found reasonable agreement with a reflection coefficient model based on a sediment layer overlying a half-space model for which the sound speed in the surficial transition layer is allowed to vary as a linear $k^2$ profile (square of the wave number varies linearly with depth). With the help of mid-to-high frequency acoustic measurements, they could clearly demonstrate a strong variation in bottom loss as a function of grazing angle at 4 and 8 kHz and minimal variation at 2, 16 and 20 kHz and related that to $\rho (1 m) -$ thick layered structure in the near-surface.
sedi-ment. Recently, Yang et al.\textsuperscript{12} studied geo-acoustic inversion using bottom loss data and demonstrated that forward scattering from topographic changes is important at mid-frequencies (2-5 kHz) as compared to sediment density and sound speed parameters.

The objective of this paper is to determine the best-fit geoacoustic model for a shallow water location in the Arabian Sea based on bottom loss measurements made at 2.5, 3.0, 6.0, 9.0 and 12.0 kHz frequencies. The seabed grazing angles realized during the measurement ranges from 11 to 34\textdegree. Measurements are interpreted as estimates of the modulus of the plane wave reflection coefficient. The observed bottom loss is compared to -20log|\( R \)|, where |\( R \)| is the modulus of the plane wave reflection coefficient.

Initial modelling of bottom reflection loss with a homogeneous half-space model failed to provide accurate results for higher grazing angles especially at higher frequencies. The density, compressional velocity and attenuation used as input for this model were obtained from sediment grab sample analysis. Often, the top layer usually gets washed away during sediment grab sample analysis making it difficult to ascertain its properties. In general, the thickness of these sediments is highly variable due to local accretion and erosion processes. To account for frequency and grazing angle dependence, sediment overlying a half-space model is considered consisting of a soft transition layer with a positive sound speed gradient overlying a hard homogeneous half-space.

This paper is organized as follows. First, the acoustic field measurement procedure and methodology of bottom loss estimation are presented. Then, the experimental results of bottom loss are compared to those obtained using a homogeneous fluid half-space model. Later, for improved modelling, sediment overlying a half-space model is considered consisting of soft surficial sediment overlying a homogeneous half-space consisting of sand. An optimum set of geoacoustic model parameters is identified by fitting the model to bottom loss data in the least-square sense. Finally, the results of inversion are summarized and its implications are discussed.

**Materials and Methods**

**Measurements of Bottom Loss**

Experimental measurements were made at a shallow water site in the Arabian Sea 119 km west-south-west of Kochi to study shallow water acoustic propagation characteristics. Measurements were made on March 6, 2013 onboard INS Sutlej. Fig. 1 shows the schematic of the experiment. The water depth was measured to be 68 m and found to be nearly constant along the experimental track. Analysis of sediment grab samples collected at the site reveal that the area with water depth ranging from 60 to 80 m is covered with sand. The estimated compressional wave speed varied from 1626 to 1828 m/s. The logarithmic grain size \( M_z = -\log_2[d/d_0] \) varied from 1.53 to 4.05 (where \( d \) is mean grain diameter in mm and \( d_0 \) is the reference length of 1 mm), indicating the presence of coarse to fine sand with porosity varying from 37.8-63.2\% and bulk density from 1.65-2.1 g/cm\(^3\).

An M18-C6.0 broadband projector from Geospectrum Transducers Inc. (GTI) was used for transmissions for frequencies ranging from 6 to 12 kHz. It has a peak transmitting voltage response (TVR) of 147.4 dB re 1 \( \mu \)Pa/ V at 1 m at a frequency of 11.5 kHz. An ITC 2010 transducer from International Transducer Corporation, Santa Barbara, CA was used for 2.5 and 3 kHz transmissions. It has a peak TVR of 137 dB re 1 \( \mu \)Pa/ V at 1 m at a frequency of 2.4 kHz. The transmitters were omnidirectional over the angular range used in the measurements. The ITC and GTI projectors were lowered to depths of 16 m and 24 m respectively (Fig. 1). The transmitted signals were received by omnidirectional B & K 8105 hydrophones of sensitivity -195.4 dB re 1 V/\( \mu \)Pa. The hydrophones were deployed at 18, 24, 28 and 32 m depths during the experiment. The hydrophone and projector depths were monitored...
by depth sensors. CW pulses (2.5, 3.0, 6.0, 9.0 and 12.0 kHz) of length 2 ms were transmitted for different source receiver configurations. The observed sea-state during the experiment was 0-1. For each of the configuration, 20 pulses were transmitted with a repetition interval of 200 ms. The source-receiver ranges as determined from GPS data varied from 150 to 500 m. The accuracy of GPS data is within 10 m. The sound speed profile obtained at 1440 hours IST on 6 March 2013 and the corresponding eigenrays for a source-receiver separation of 150 m are shown in Fig. 2. In this configuration, the source is located at a depth of 16 m and the four receivers are at 18 m, 24 m, 28 m and 32 m depths. Tables 1 and 2 give a summary of the various grazing angles realized for all the configurations. The spreading correction based on geometry is also presented. The sound speed profile measured with a CTD cast is also plotted alongside. The top-to-bottom sound speed variability was observed to be less than 3 m/s, such that the refraction effects were minimal. The sound speed measured near the bottom is close to 1543 m/s.

Fig. 2–Eigenray plot showing the first 3 arrivals for a source receiver separation of 150 m. Source depth is 16 m and the receiver depths (R1, R2, R3 and R4) are 18, 24, 28 and 32 m respectively. The sound speed profile is plotted alongside.

<table>
<thead>
<tr>
<th>S No.</th>
<th>Range (m)</th>
<th>Source &amp; Receiver Depths (m)</th>
<th>Grazing angle (deg.)</th>
<th>Direct-bottom TDOA, ms</th>
<th>Spreading Loss Correction, dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>150</td>
<td>16 18</td>
<td>34.19</td>
<td>20.36</td>
<td>1.65</td>
</tr>
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<td>2</td>
<td>150</td>
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<td>32.61</td>
<td>18.09</td>
<td>1.48</td>
</tr>
<tr>
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<td>150</td>
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<td>16.54</td>
<td>1.37</td>
</tr>
<tr>
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</tr>
<tr>
<td>5</td>
<td>190</td>
<td>16 18</td>
<td>28.21</td>
<td>16.64</td>
<td>1.10</td>
</tr>
<tr>
<td>6</td>
<td>190</td>
<td>16 24</td>
<td>26.81</td>
<td>14.75</td>
<td>0.98</td>
</tr>
<tr>
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<td>13.47</td>
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<tr>
<td>8</td>
<td>190</td>
<td>16 32</td>
<td>24.82</td>
<td>12.17</td>
<td>0.82</td>
</tr>
<tr>
<td>9</td>
<td>290</td>
<td>16 18</td>
<td>19.34</td>
<td>11.33</td>
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<tr>
<td>10</td>
<td>290</td>
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<tr>
<td>11</td>
<td>290</td>
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<td>9.13</td>
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<tr>
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<td>290</td>
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<td>8.24</td>
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<td>465</td>
<td>16 24</td>
<td>11.60</td>
<td>6.40</td>
<td>0.18</td>
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</table>
Table 2–Source Receiver geometry, realized bottom grazing angles, time difference of arrival (TDOA) between direct and bottom paths and spreading loss correction based on ray tracing results for 6.0, 9.0 and 12.0 kHz.

<table>
<thead>
<tr>
<th>S No.</th>
<th>Range (m)</th>
<th>Source &amp; Receiver Depths (m)</th>
<th>Grazingangle (deg.)</th>
<th>Direct-bottom TDOA, ms</th>
<th>Spreading Loss Correction, dB</th>
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<tbody>
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<td>16.68</td>
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</tr>
<tr>
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<td>1.00</td>
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<td>10.51</td>
<td>0.65</td>
</tr>
<tr>
<td>8</td>
<td>210</td>
<td>24 32</td>
<td>20.80</td>
<td>9.49</td>
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<tr>
<td>9</td>
<td>230</td>
<td>24 28</td>
<td>20.02</td>
<td>9.66</td>
<td>0.55</td>
</tr>
<tr>
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<td>24 32</td>
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</tr>
<tr>
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<td>17.92</td>
<td>9.64</td>
<td>0.43</td>
</tr>
<tr>
<td>12</td>
<td>290</td>
<td>24 24</td>
<td>16.84</td>
<td>8.52</td>
<td>0.39</td>
</tr>
</tbody>
</table>

The reflection loss in the specular direction is the difference, in decibels, between the intensities of the incident and reflected waves. Spreading and absorption loss corrections need to be incorporated to compensate for the direct and bottom reflected paths between the projector and hydrophone obtained from measured data. Absorption loss was calculated using temperature and salinity measured by CTD casts during the experiment. In the frequency band of 2-12 kHz, absorption loss is of the order of 1 dB/km. For the source-receiver configurations realised during the experiment, the difference in absorption loss between the direct path and the bottom path is negligible. The spreading loss correction was incorporated into bottom loss estimates for each of the grazing angles. It varied from 1.65 dB at 34.2° to 0.18 dB at 11.6° (Tables 1 and 2).

Sediment overlying a half-space model

A forward model for the reflection coefficient consisting of a water layer and sediment overlying a half-space is considered to incorporate frequency and angle dependence in the estimates of bottom loss. The expression for reflection coefficient can be written as

$$ R = \frac{R_{ij}(1 + R_{23}) + R_{23}(1 + R_{12})}{1 - R_{21} R_{23}} $$

where $R_{ij}$ is the reflection coefficient at boundary $ij$ and subscripts 1-3 indicate water, finite-depth layer and half-space respectively. The finite-depth layer of thickness $L$ is allowed to have some positive sound speed gradient. In this layer, the sound speed is allowed to vary as a linear $k^2$ profile, where $k$ is acoustic wave number. The linear $k^2$ sound speed profile governing the reflection coefficient model is given by

$$ \frac{1}{c_2^2(z)} = 1 - \frac{2\beta z}{c_2^2(0)} $$

where $\beta$ is the gradient of sound speed.

Eq. (2) can be approximated as follows:

$$ c_2(z) = c_2(0)\left(1 - \frac{2\beta z}{c_2(0)}\right)^{-1/2} $$

For $\frac{\beta z}{c_2(0)} << 1$

The sound speed profile becomes

$$ c_2(z) = c_2(0) + \beta z $$
The region below this layer is modelled as a half-space with constant density and sound speed. Here, a model formulated by Ainsle \(^7\),\(^8\) is implemented which incorporates the plane wave reflection coefficient given by Eq. 1. The formulation provides analytic solutions of the depth-dependent Helmholtz equation for specific canonical gradients. The continuity of pressure and normal component of particle velocity across a given boundary is applied to obtain the reflection coefficient for each layer. At the water-sediment layer interface, applying the continuity of pressure and normal component of water particle velocity we get,

\[
1 + R_{12} = T_{12} \frac{P_1^+ (z = 0)}{P_2^+ (z = 0)}
\]

where \(T_{ij}\) is the transmission coefficient at boundary \(ij\) and \(\rho_i\) and \(\gamma_i\) are sediment density and vertical wave number in layer \(i\), respectively.

\[\frac{i\gamma_{1}}{\rho_{1}} (1 - R_{12}) = \frac{T_{12}}{\rho_{2}} \frac{\partial P_{2}^{+} (z = 0)}{\partial z}
\]

Substituting (6) into (7) and solving for \(R_{12}\) yields

\[
R_{12} = \frac{\rho_2\gamma_1 - \frac{\partial P_2^+ (z = 0)}{\partial z}}{\rho_1\gamma_2 \frac{i\gamma_2 P_2^+ (z = 0)}{\partial z} + i\gamma_2 P_2^+ (z = 0)}
\]

Also,

\[
R_{21} = \frac{i\gamma_2 P_2^+ (z = 0)}{\rho_2\gamma_1 - \frac{\partial P_2^+ (z = 0)}{\partial z}} + \frac{\rho_2\gamma_1}{i\gamma_2 P_2^+ (z = 0)}
\]

Similarly, \(R_{23}\) is given by the following equation,

\[
R_{23} = \frac{\partial P_2^+ (z = h)}{\partial z} \frac{P_3\gamma_3}{\rho_2\gamma_3} + \frac{P_2^+ (z = h)}{\rho_2\gamma_2}
\]

where \(h\) is the thickness of the finite depth layer. As a result, equations (8), (9) and (10) become reflection coefficients for layers of homogeneous fluid media.

**Results**

**Analysis of Measured Bottom Loss**

The results of bottom loss after correcting for spreading loss are plotted in Fig. 3 and Fig. 4 for 2.5, 3 kHz and 6, 9, 12 kHz respectively. The bottom loss curve for a homogeneous fluid half-space model is also plotted for reference. The density, compressional sound speed and attenuation coefficient for this model are 2.1 g/cm\(^3\), 1645.0 m/s, and 0.7 dB/m/kHz, respectively.

![Fig. 3–Bottom Reflection Loss (given by -20log|R|) measured at 2.5 and 3.0 kHz. For reference homogeneous half-space bottom loss model curve is also plotted.](image)

![Fig. 4–Bottom Reflection Loss (given by -20log|R|) measured at 6, 9 and 12 kHz. For reference homogeneous half-space bottom loss model curve is also plotted.](image)
The half-space model results are found to be reasonable at 2.5 and 3 kHz. However, it is evident that the half-space model fails to predict the frequency and grazing angle variation observed at 6, 9 and 12 kHz, especially at higher grazing angles. The average reflection loss values at 2.5 kHz are clearly lower than that at 3 kHz for most of the grazing angles measured during the experiment. The bottom reflection loss plots at 2.5 and 3.0 kHz show the possible presence of an apparent critical angle between the soft low velocity layer and the half-space close to 26°. The corresponding compressional wave speed in the soft layer is close to 1445 m/s. Hence, the initial search space for starting sound speed in the transition layer is set from 1400 – 1700 m/s.

For grazing angles ranging from 26-30°, bottom reflection loss at 6 kHz is significantly higher than that at 9 and 12 kHz. This indicates that the thickness of the soft layer is of the same order as the wavelength at 6 kHz. Acoustic interaction with the bottom at 6, 9 and 12 kHz is expected not to extend beyond the soft low velocity layer. The sound intensity attenuates significantly before reaching the interface between the soft layer and the half-space.

The bottom loss data at 2.5 and 3 kHz clearly exhibit oscillations as a function of grazing angle. This is not evident at 6, 9 and 12 kHz bottom loss data due to limited penetration into the bottom at higher frequencies. Robins obtained analytical expressions of reflection coefficient for a two-layered sediment consisting of a transition layer and a substrate. He observed that for frequencies where acoustic wavelength is of the same order as the layer thickness, the reflection loss is very sensitive to changes in frequency. He also showed that the density profile shape has very little influence on bottom loss as kL value increases from 2.5 to 8.

Bottom loss data at 2.5 and 3.0 kHz show more variability with grazing angle as compared to that at 6, 9 and 12 kHz indicating deeper penetration at 2.5 and 3.0 kHz frequencies. Bottom reflection loss at 6 kHz is significantly higher than that at 9 and 12 kHz indicating that the thickness of the soft layer is of the same order as the wavelength at 6 kHz which is close to 25cm. Hence, the initial search space for the finite layer thickness (L) is assumed to be 10-60 cm for which the kL value in the soft surficial layer varies from 1-6. In this paper, geoacoustic parameters are obtained by fitting the two-layered model to bottom loss data in the least-square sense as presented in Choi and Dahl. The reflection coefficient model is driven by eight geo-acoustic parameters as listed in Table 3; these are estimated from the data by minimizing the weighted squared error between the data and the model predictions for a candidate set of parameters.

The objective function is written as

$$ Q = (X_i - M_i)^T W_i (X_i - M_i) $$

where

- $X_i =$ Measured bottom loss as a function of grazing angle and frequency,
- $M_i =$ Modeled bottom loss as a function of grazing angle and frequency,
- $W_i =$ Diagonal weight matrix composed of $1/\sigma_n^2$ where $\sigma_n^2$ is the measurement variance for the nth bottom loss estimate.

3. Sediment attenuation is included by making the sound speed complex in the manner used in Mourad and Jackson.

**Discussion**

**Inversion based on Bottom Loss Data**

A geoacoustic model provides description of the acoustic bottom properties and is part of the input to an acoustic propagation model in addition to bathymetry and source information. One of the objectives of this study is to investigate the presence of a soft sediment layer with positive sound speed gradient sandwiched between sea water and a homogeneous half-space. The thin surficial layer is assumed to be soft with fluid-like properties whereas the underlying half-space is assumed to be hard and forms the main reflecting layer. This is a typical model for sandy sediments. Our inversion first aims at estimating the thickness of the transition layer and the starting sound speed in the half-space layer. As indicated earlier, the initial search space for the finite layer thickness (L) is assumed to be 10-60 cm for which the kL value in the soft surficial layer varies from 1-6. In this paper, geoacoustic parameters are obtained by fitting the two-layered model to bottom loss data in the least-square sense as presented in Choi and Dahl. The reflection coefficient model is driven by eight geo-acoustic parameters as listed in Table 3; these are estimated from the data by minimizing the weighted squared error between the data and the model predictions for a candidate set of parameters.

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The values used for the sea-water sound speed just above the sediment interface and density are 1543 m/s and 1.0 g/cm³. In the two-layered fluid sediment model, the top layer is allowed to have a positive sound speed gradient which is consistent with the presence of sandy sediments. As a result, the sound speed varies as a linear $k^2$ profile, where $k$ is acoustic wave number. The second layer is modelled as an infinite half-space of constant sound speed that terminates the bottom impedance. Mean loss values and variance for different grazing angles and frequencies are listed in Table 4.

**Constrained ranges of geoacoustic parameters based on objective function surfaces**

In this analysis, objective function surfaces are used to arrive at the optimized set of geoacoustic parameters. To obtain the best-fit geoacoustic model, first we define an initial search space to discretize.
ranges for each of the 8 sediment parameters. The initial search space is based on information regarding the composition of the sediments obtained from previous experiments in the trial area. This search space is further examined to identify a more narrowed range for each of the 8 parameters which represent the final search space. Initial analysis indicates that the bottom reflection loss is more sensitive to density ($\rho$), compressional velocity ($c$) and compressional attenuation ($\alpha$) in the soft layer. In order to identify the most probable region and identify the correlation between different parameters, the objective function surfaces are generated in terms of $\rho$-$c$ and $c$-$\alpha$. The objective function surface representing correlation between density and compressional velocity in the soft sediment layer ($\rho_2$ - $c_2$) and the homogeneous half-space ($\rho_3$ - $c_3$) at 6 kHz are depicted in Fig.5.

In the objective function surface plot, the area approaching red represents the most probable region (minimum value of objection function) for the inversion results. It is observed that density and compressional velocity have an inverse relation as the product of the two represents acoustic impedance. Density and compressional velocity have an inverse relation as the product of the two determines acoustic impedance. The final search space for sediment density and compressional velocity in the top layer and the homogeneous half-space ($\rho_2$, $c_2$, $\rho_3$, $c_3$) are determined based on the correlation between the density and compressional velocity of the sediments. The white boxes (Fig. 5.) represent the most probable region for inversion results and represent the final search space for inversion. The final search space for compressional attenuation in the two layers ($\alpha_2$ and $\alpha_3$) are selected based on results presented in Fig. 6.

<table>
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<tr>
<th>Parameter</th>
<th>Initial Search Space</th>
<th>Final Search Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c_2$ (0)</td>
<td>1400 – 1700 (m/s)</td>
<td>1400 – 1500 (m/s)</td>
</tr>
<tr>
<td>$c_2$ ($L$)</td>
<td>$c_2$ (0) – 1900 (m/s)</td>
<td>$c_2$ (0) – 1700 (m/s)</td>
</tr>
<tr>
<td>$c_3$</td>
<td>1600 – 1900 (m/s)</td>
<td>1600 – 1700 (m/s)</td>
</tr>
<tr>
<td>$\rho_2$</td>
<td>1.0 – 2.0 (g/cm$^3$)</td>
<td>1.5 – 1.7 (g/cm$^3$)</td>
</tr>
<tr>
<td>$\rho_3$</td>
<td>1.0 – 2.6 (g/cm$^3$)</td>
<td>1.8 – 2.2 (g/cm$^3$)</td>
</tr>
<tr>
<td>$L$</td>
<td>0.1 – 0.6 (m)</td>
<td>0.1 – 0.2 (m)</td>
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<tr>
<td>$\alpha_2 / f$</td>
<td>0.0 – 0.8 (dB/m/kHz)</td>
<td>0.1 – 0.3 (dB/m/kHz)</td>
</tr>
<tr>
<td>$\alpha_3 / f$</td>
<td>0.2 – 0.8 (dB/m/kHz)</td>
<td>0.6 – 0.8 (dB/m/kHz)</td>
</tr>
</tbody>
</table>

The constrained parameter ranges of initial and final search space are given in Table 5. An exhaustive search is carried out in the final search space to minimize the objective function. The results of inversion for the best-fit geo-acoustic parameter set

![Fig. 5–Normalized objective function surfaces estimated at 6 kHz in terms of sediment density and compressional velocity in the top layer ($\rho_2$ and $c_2$) and the homogeneous half-space ($\rho_3$ and $c_3$). The area approaching red represents the minimum value of objection function.](image-url)
Fig. 6–Normalized objective function surfaces at 6 kHz in terms of sediment sediment compressional velocity and attenuation in the top layer ($\alpha_2$ and $c_2$).

Fig. 7–Diagram of the best fit geoacoustic parameters for a sediment overlying a half-space model showing the geoacoustic parameters of the transition layer and the homogeneous half-space.

are summarized in Fig. 7. The thickness of the transition layer is about 0.13 m. In this layer, the compressional varies from 1443±5 m/s to 1645±5 m/s. The density of the intermediate layer is 1.6 g/cm$^3$ corresponding to that of sandy silt. The compressional attenuation obtained in this layer is 0.2±0.01 dB/m/kHz. Density of the half-space is 2.1 g/cm$^3$ which is consistent with that of coarse sand. The compressional velocity and attenuation in the half-space are 1645±5 m/s and 0.7±0.05 dB/m/kHz respectively. The uncertainty estimate for each of the parameters reported in Fig. 7 represent 5% increase in the best-fit objective function value estimated from Eq. 12.

Fig. 8–Measured bottom loss data (mean and standard deviation) and modelled bottom loss based on a sediment overlying a half-space model of seabed at 2.5 and 3kHz (dashed line).

Fig. 9–Measured bottom loss data (mean and standard deviation) and modelled bottom loss based on a sediment overlying a half-space model of seabed at 6, 9 and 12 kHz (dashed line).
The best match plots between data and the sediment overlying a half-space model at 2.5, 3 kHz and 6, 9 and 12 kHz are shown in Fig. 8 and Fig. 9 respectively. Half-space model curve is also plotted for reference. The half-space model curve is in good agreement with the bottom loss data at 2.5 and 3 kHz only. However, the measured data is in good agreement with the model predictions based on the 2-layered sediment reflection coefficient model over the entire frequency range. It is evident that the observed variation in bottom reflection loss with grazing angle, especially at higher frequencies is associated with the sound speed variation in the thin surficial sediment layer.

Conclusion

Bottom loss measurements were made at a shallow water site (~68 m water depth) in the Arabian Sea 119 km west-south-west of Kochi. Results are presented for frequencies ranging from 2-12 kHz. The seabed grazing angles realized during the measurement ranges from 11 to 34°. Bottom loss expressed in terms of the modulus of plane wave reflection coefficient (|R|) is estimated from measured data. The observed bottom loss is compared to modelled bottom loss based on sediment overlying a half-space reflection model.

The best-fit geoacoustic model is obtained by fitting sediment overlying a half-space model to bottom loss data in the least-square sense. Optimization is carried out by generating objective function surfaces for density, compressional velocity and attenuation of the sediment layers and identifying the most probable region for inversion. An exhaustive search is carried out in the most probable region to arrive at the best-fit geoacoustic model. It was observed that the best-fit parameter set agree reasonably well with the observations of bottom loss over the entire frequency range (2-12 kHz).

Bottom loss data at 2.5 and 3.0 kHz show more variability with grazing angle as compared to that at 6, 9 and 12 kHz indicating deeper penetration at 2.5 and 3.0 kHz frequencies. The bottom reflection loss plots at 2.5 and 3.0 kHz suggested the possible presence of an apparent critical angle between the soft low velocity layer and the half-space close to 26°. Bottom reflection loss at 6 kHz is significantly higher than that at 9 and 12 kHz indicating that the thickness of the soft layer is of the same order as the wavelength at 6 kHz which is close to 25 cm. Acoustic interaction with the bottom at 6, 9 and 12 kHz frequencies were found to be restricted to the soft low velocity layer.

Scope for future work

Direct measurements of geoacoustic parameters have to be made at the test site to verify the inversion results obtained from bottom loss measurements. The best-fit geo-acoustic model must be tested and verified with a new dataset of bottom loss as a function of frequency and grazing angle at the same location.

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