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USING OF FREQUENCY DEPENDENCE OF SOUND REFLECTIVITY FOR ELASTIC LAYERED BOTTOM RECONSTRUCTION

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The relation between the sound reflection losses measured at fixed grazing angles and the characteristics of the sediment layer and the underlying half-space is considered. Based on this relation, a method of the reconstruction of the sea bottom characteristics is developed for a ocean bottom consisting of a single sediment layer overlaying a semi-infinite elastic half-space. Using this bottom model, the reconstruction of the characteristics of a layered elastic bottom is performed from the numerically simulated data with induced synthetic error. The work was supported by the RFBR (97-05-64712).

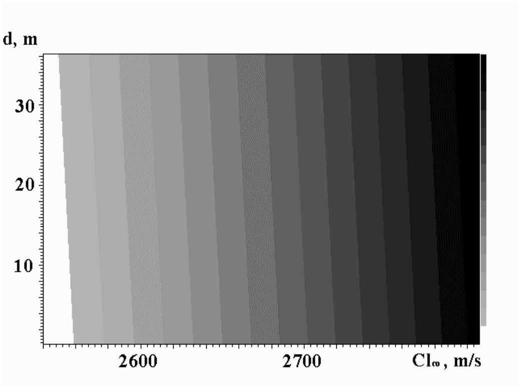
This paper presents an attempt to estimate the characteristics of a layered medium by frequency dependence of reflection losses. Our approach is based on the fact that the shape of the projection of the selected level of the reflection losses onto the plane of medium characteristics (e.g., for example, the plane representing the sediment layer thickness versus the compressional sound velocity in the half-space) depends from frequency at a fixed grazing angle. We will reconstruct layered medium characteristics in few steps.

The values of the reflection loss RL, are presented by shading: the dark areas in the graphs correspond to the maximal values of the reflection losses. The subscript ∞ indicates the parameters characterizing the elastic half-space. For example, C_l and η_l are the compressional velocity of sound and the attenuation of compressional waves in the layer, ρ and d are the density and the thickness of the layer, while $C_{l\infty}$, $C_{t\infty}$, $\eta_{l\infty}$, $\eta_{t\infty}$ and $\rho_{l\infty}$ are the compressional and shear sound velocities and attenuation factors in the half-space, and the half-space density. At fixed grazing angles, variations in the characteristics of both the layer and the half-space causes variations of the reflection losses RL within certain limits. If the value of the reflection losses is fixed we can select the region of the bottom parameters, at which the given value of the reflection losses is possible. The more narrow is the range selected for the variations of the reflection losses RL, the smaller is the region of the corresponding values of d and $C_{l\infty}$ in the (d,$C_{l\infty}$) plane, i.e., the region of parameters corresponding to the given value of the reflection losses. We will call such regions the "parameter regions".

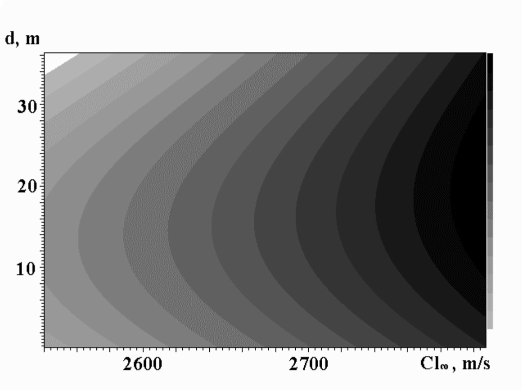
The shape of the parameter regions can considerably vary with changes in the selected value of RL, as well as with variations in the frequency and the grazing angle of the plane waves incident on the layered bottom (Fig.l a-c). The fact that the shapes of the parameter regions corresponding to a given range of the variations of the reflection losses depend from the frequency and the grazing angle may be used for the determination of the parameters of a layered bottom.

Let us assume that only two parameters of a layered bottom, for example, d and $C_{l\infty}$, should be determined (other parameters, in the layer and in the half-space, are assumed to be known). Because all experimental measurements are performed to a finite accuracy and, in addition, depend from the natural fluctuations, we will include in our consideration the error ε characterizing the measurements of the reflection loss RL(θ) at different grazing angles. The error ε will determine the range of the possible variations of the quantity RL(θ) relative to the experimentally measured values RL(θ), and, hence, in the plane (d,$C_{l\infty}$) it will determine the width of the region where the calculated losses coincide with the experimental data within the required accuracy.

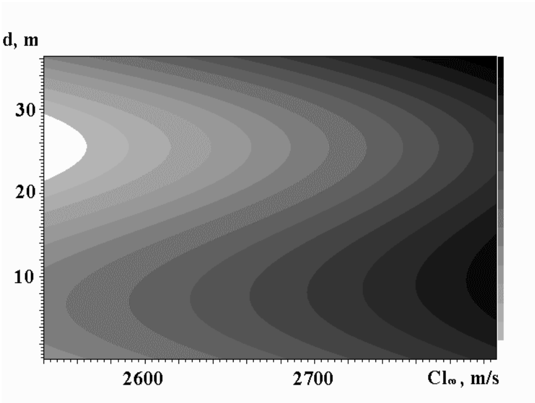
Let us consider a numerical realization of our method for synthetic model data. We assume that we know the values of the reflection losses RL_{m1}, RL_{m2} and RL_{m3} for three frequencies f_1=16 Hz, f_2=500 Hz, f_3=1000 Hz at fixed grazing angle θ =60°. The concrete values of RL_{m1}, RL_{m2}, RL_{m3} can be taken from the model calculations where all bottom characteristics including d and $C_{l\infty}$ are assumed to be known. To make the numerical example more illustrative, we take ε=0.01 dB. Evidently, in the full-scale oceanic experiments, such measurement accuracy is impossible. But this assumption will allow us to demonstrate the possibility of reconstruction of the characteristics of medium by frequency dependence of bottom reflection losses. For reconstruction we calculate the dependence RL($d,C_{l\infty}$) for some frequencies (f_1=16 Hz, f_2=500 Hz, f_3=1000 Hz at grazing angle $\theta=60^o$) corresponding to the measured values of the reflection loss (Figs. 1 a-c).



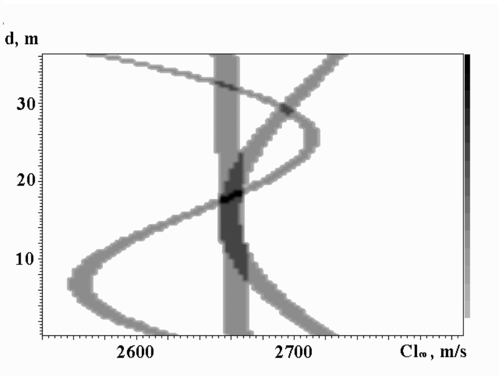
a)



b)



c)



d)

Fig.1 a,b,c. Dependencies of the reflection loss on the thickness of the sediment layer d and the longitudinal sound velocity $C_{l\infty}$ plane for three frequencies f_1=16, f_2=500 and f_3=1000 Hz at the grazing angle $\theta=60^o$.
Fig.1 d. The resulting parameter regions determined in the ($d,C_{l\infty}$,) plane for the these three frequencies.

In the graph representing the results of calculations for fixed values of the frequency and the grazing angle, we select the regions corresponding to the variation of the reflection loss from ($RL_m-\varepsilon$) to ($RL_m+\varepsilon$). We perform a similar operation for all frequencies, for which the experimental values of the reflection loss were obtained. The resulting parameter regions determined in the ($d,C_{l\infty}$) plane for three frequencies (Fig.1 d) will coincide only partially, due to the difference in their shapes.

This fact will restrict the set of medium parameters corresponding to the measured values of the reflection loss. Thus, we determine the interval of the values of the sea bottom parameters that provide the experimental values of the reflection loss at all frequencies used in the measurements.

The procedure of d and $C_{l\infty}$ determination is illustrated in Fig.2 a. In the ($d,C_{l\infty}$) plane parameter regions for three frequencies under study (f_1=16 Hz, f_2=500 Hz, f_3=1000 Hz) are superimposed. The region of overlap is marked by dark gray and corresponds to the

reconstructed values of d and $C_{l\infty}$. The d and $C_{l\infty}$ values obtained as a result of the reconstruction agree well with the exact values of d and $C_{l\infty}$. The reconstruction error is determined by the width of the region of overlap. Analogy operation may be done at other grazing angles.

For reconstruction procedure formalization we introduce the function ϕ determined in the domain of the parameters to be reconstructed as

$$f = \sum_k \sum_i J(p_1, p_2, p_3, ..., p_n),$$

where $J(p_1, p_2, p_3, \ldots, p_n) = \begin{Bmatrix} 1, \left|V_c - V_m\right| \le e \\ 0, \left|V_c - V_m\right| \ge e \end{Bmatrix}$, p_1, p_2, p_3, …, p_n are layered bottom parameters, k is number of frequencies, at which experimental measurements were done, i is number of angles used for the experimental measurements, ε is measurement error, V_m and V_c are the measured and calculated values of the reflection coefficient (or the reflection loss RL_m and RL_c), respectively. We determine the parameters of medium by the maximum of the function ϕ.

The method of reconstruction of bottom parameters by frequency dependence of reflection losses proposed in this paper was tested in application to the numerically modeled data with induced synthetic error.

At first, we determine the characteristics of medium that are most critical for the reflection loss. An inaccurate setting of the parameters weakly affecting the reflection loss may cause only slight deviations of our estimates, because of the considerable difference in the reflection loss derivatives with respect to different characteristics of medium.

We use the method described above for the reconstruction of both the compressional sound velocity $C_{l\infty}$ in the half-space and the half-space density ρ_∞ from the synthetic data of the reflection losses RL. Data at three different grazing angles and 30 frequencies (in the range from 16 Hz to 1000 Hz) for every angle were used. Mean value of induced in data synthetic error was equal to 0.2 dB for all frequencies and grazing angles. Because the reflection loss also strongly depend from the transverse sound velocity $C_{t\infty}$ in the half-space, we calculate the function ϕ for $C_{t\infty}$ varying within the limits determined by the statistical data on its variations in the real conditions. The result obtained from the calculation of the function $\phi(\rho_\infty, C_{l\infty})$ is shown on the $(\rho_\infty, C_{l\infty})$ plane (Fig.2 a). Here, the darker areas correspond to the greater values of the function. Other parameters of bottom model during the calculations of $\phi(\rho_\infty, C_{l\infty})$ were equal to mean values of it's statistical variation.

a) b)

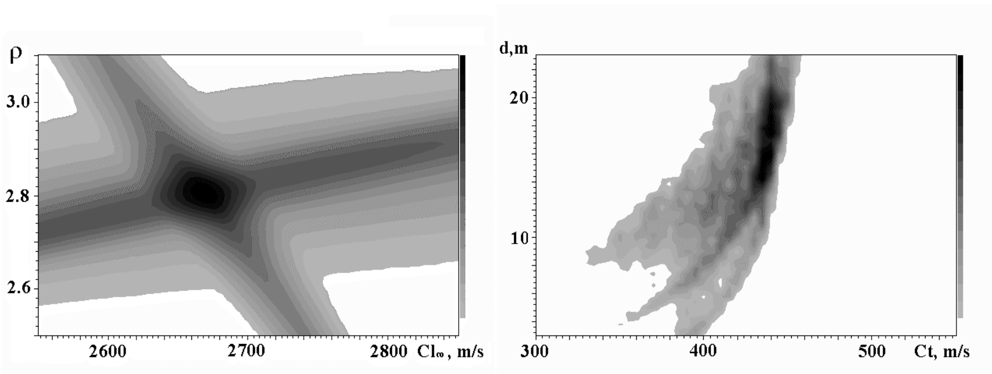


Fig.2. a) Rezult of $\phi(\rho_\infty, C_{l\infty})$ calculation; b) - result of $\phi(d, C_{t\infty})$ calculation for synthetic data with induced errors.

From Fig.2 a, one can see that the function $\phi(\rho_\infty, C_{l\infty})$ reaches its maximum at the plane $(\rho_\infty, C_{l\infty})$ in the point with the coordinates ($C_{l\infty}$=2650 m/s, ρ_∞=2.8 g/cm^3). Because, in the calculation of the function $\phi(\rho_\infty, C_{l\infty})$, the value of $C_{t\infty}$ was varied, and the variations of $C_{t\infty}$ have the most profound effect on the reflection loss, one should expect that the variations of all other parameters of the model will cause no additional changes in the reconstructed values of $C_{l\infty}$ and ρ_∞. To determine the values of d and C_t, we calculate the function $\phi(d, C_{t\infty})$ with a simultaneous variation of the half-space density ρ_∞. The results obtained by calculating the function $\phi(d, C_{t\infty})$ are shown in Fig.2 b. From Fig.2 b one can see that the reconstructed values are $C_{t\infty}$=440 m/s and d=18 m.

It should be noted that the proposed method has some limitations. Specifically, we assumed that the structure and the type of rock forming the layered bottom were known, and such an assumption determined the limits of the possible variations of the sea bottom characteristics. It is possible that to obtain reliable results at higher frequencies, a more complicated model of the sea bottom will be required. Thus, we proposed a method of a reconstruction of the medium parameters from the experimentally measured frequency dependencies of bottom reflection losses. The method can be used either independently or for a preliminary determination of the characteristics of a layered bottom with their subsequent reconstruction by other methods. The possibility of a preliminary determination of all or several parameters of a layered bottom makes it possible to restrict the range of the search. The work was supported by the Russian Foundation for Basic Research ([1] 97-05-64712, [1]00-05-64956).