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ESTIMATION OF BOTTOM PARAMETERS IN SHALLOW WATER BY SPECTRUM OF WIDE BAND SIGNAL

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On the base of the bicomponent bottom model sound propagation in shallow water is discussed. As bottom parameters we consider porosity, coefficient of sound attenuation and coefficient of volume scattering. The method of estimation of the bottom characteristics is advanced which is based on the comparison of the experimental and calculated spectra of received wide band signal.

It is common knowledge that sound field depends heavily on the bottom parameters in shallow water. This enables us to relate the bottom characteristics to the measuring parameters of acoustic signal, propagating in near bottom sound channel and in this way to determine this characteristics by the comparison of the experimental and calculated acoustic data. (The bottom characteristics corresponding to the best agreement between experiment and calculation are considered as true.) On the whole this method fall in the matched field tomography. It provides a possibility to estimate the averaged acoustic characteristics of the upper layer of the bottom sediment in shallow water. In this paper we propose to use the similar method to determine frequency dependence of coefficient α , which related to imagine part of wave vector in bottom k_1 : $(k_1 = 2\pi f c_1^{-1}(1 + i\alpha/2))$, where c_1 is sound speed in bottom. (Coefficient of sound attenuation β is equal to $\beta = 2\pi f \alpha / c_1$, that is, it varies directly as α). Notice that this work is an extension of paper [2], where the pure empirical dependence was derived for frequency band (28 ÷ 70 Hz) for Barents sea $\alpha = 0.005(f/28)^{2.2}$. In this work we tried to find the more adequate dependence $\alpha(f)$ from the physical point of view which based on the assumption about the bottom structure and on the different mechanism of sound attenuation.

The foundation of our approach is the following model of shallow water. Water layer with density ρ and with the vertical profile of sound speed $c(z)$ lies at half space packed by sediment. The sediment represents the bicomponent medium (water and mineral parties). The main parameter which characterizes sediment is the porosity κ that equal to the ratio of volume filled by water to total volume of considered sample of bottom. On the base of the simplified model the bottom parameters are represented by κ . In particular sound speed of compressional wave c_1 and density ρ_1 are equal to

$$c_1 = c_H (1.631 - 1.78\kappa + 1.2\kappa^2), \quad \rho_1 = \rho_H (2.604 - 1.606\kappa) \quad (1)$$

where c_H and ρ_H are sound speed and density in water near by bottom surface respectively.

The main idea of this work is as follows: to separate two basic mechanism of sound attenuation. The first one relates to absorption (sound transformation to heat). We will denote by α_a (β_a respectively) the coefficient α related to this mechanism. The second one is scattering by bottom inhomogeneities (As the result sound energy leaves a beam). In this case we will use notation α_v and β_v . According to experimental data for bottom sediment in shallow water coefficient β_a varies directly as frequency f in wide band 10 Hz - 1 MHz. ($\beta_a = \beta_{af} f$). (In work [3] the empirical dependence $\beta_{af}(\kappa)$ was obtained, however its accuracy is not great and it can be hardly used in practice) Notice that the mechanism, related to absorption, can be represented as the result of the rubbing together of parties. It is necessary to stress that according to theory of water-saturated porous medium [4,5] sound absorption can be caused also by the other reasons. In this case the coefficient β_a

depends on frequency in nonlinear way. However it has been observed in sediment of continental shelf that the contribution of the nonlinear mechanism is small.

The other reason of sound attenuation is scattering [6]. The majority of the regions of shallow water have smooth bottom relief and for low frequency ($<100\text{Hz}$), for great length of sound wave scattering is caused by volume inhomogeneities. For volume inhomogeneities of different scales the attenuation coefficient β_v has frequency dependence with index of power equaled 2 - 4 ($\beta_v \sim f^{2-4}$) which depends on relation between wave length and the scale of inhomogeneity.

By this means, if we assume that sound attenuation is caused by the two mechanism mentioned above, the coefficient α will have the following frequency dependence:

$$\alpha = \alpha_a + \alpha_v = \alpha_a + \alpha_v^0 (f / f_0)^{b-1} \quad (2)$$

where $b = 2 \div 4$. Let us next estimate the values of the coefficients in equation (2) by comparison calculated and experimental interference pattern of sound field in frequency domain. At calculations we will use the following known expression for sound field in waveguide $P(r, z, f)$ in a point with coordinates (r, z) , which is produced by monochromatic source with frequency f located in a point

$$(0, z_0): \quad P(r, z, f) \approx -A \sqrt{\frac{i}{8\pi}} \sum_n \psi_n(z_0) \psi_n(z) \frac{\exp(i\xi_n r)}{\sqrt{\xi_n r}} \quad (3)$$

where complex coefficient A characterizes spectral power $W(f)$ and initial phase of source. $|A| = \sqrt{8\pi\rho c(z_0)W(f)}$, $\psi_n(z)$ and ξ_n are the eigen functions and the eigen values of the Sturm-Liouville problem. Notice that frequency dependence of receiving signal (3) is defined by the all terms in the right side of the equation, because the eigen functions and the eigen values depend from f .

Using (3) for unmoving source and receiver we can calculate the set of dependencies $|P(f)|^{theor}$ (the set of interference patterns in frequency domain) for different values of the coefficients in (2). In doing so we assumed that the eigen functions and the eigen values depend on frequency as parameter. It is significant that we used vertical profile of sound speed $c(z)$, measured in the experiment.

We use experimental dependence $|P(f)|^{exp}$ measured at stationary acoustic track in Barents Sea as well as in work [2]. Let recall the main conditions of the experiment. The linear frequency modulated signals were transmitted in a band of 25-95 Hz. The distance between the unmoving source and receiver was 13.82 km. The sea depth along the acoustic track varied slightly around to $H \approx 170$ m. According to seismography, the upper layer of bottom sediment was homogeneous. The main experimental result which was used in this work is the spectrum of received signal averaged in frequency band 5 Hz. It has been the spectrum that represents interference pattern in frequency domain in the receiving point $|P(f)|^{exp}$. Notice that the averaging signal spectrum did not depend on time, that is it did not change from one signal to another. In other word obtained interference pattern depended slightly on the fluctuations of the waveguide parameters caused by the mesoscale variability of the medium. It can be used for determination of the acoustic characteristic that are interested for us. Because of this the calculated dependencies were averaged in frequency band 5 Hz as well.

For a comparison criterion we used root mean square between the calculated and experimental dependencies. Let us have experimental $|P|_i^{exp}$ and calculated $|P|_i^{theor}$ spectra represented M frequency samples. $|P|_i = |P(r, z; f_i)|$; $i = 1, \dots, M$. Thus

$$\sigma = \sqrt{\sum_{i=1}^M (|P|_i^{exp} - |P|_i^{theor})^2} \quad (4)$$

A minimum of σ (zero in ideal case) signals the best selection of bottom model. We will consider that in this case the model parameters correspond to fact.

The full list of parameters which classify the calculated spectrum looks like this: $z_0, z, r, c_0(z), c_H, H, \kappa, \alpha_a, \alpha_v^0, b$. The values of the first six parameters were measured in the experiment, the latest parameters are estimated by the comparison; in so doing we assumed that speed and density in the bottom depend on porosity as (1). It is significant for the estimation that the distinct parameters effect on the spectrum in different ways. Porosity variation causes the shift of spectrum in frequency domain as whole. (Decreasing of a porosity is equivalent to that bottom to become rigid, effective channel width to diminish that causes frequency shift in the high frequency direction.) Remaining parameters $(\alpha_a, \alpha_v^0, b)$ affect primarily on the energy characteristic of the spectrum (on the values of minima and maxima) and do not affect on its frequency shift. Thus in the first stage we matched a porosity value in such way that the frequency values of the interference maxima of the calculated spectrum coincided with the experimental ones. In this case the values of attenuation were chosen in an arbitrary way in the field of realistic ones. The desired value of porosity was obtained equal to 0.3. According (1) it corresponds to the density of sediment $\rho_1 = 2.1 \text{ g/cm}^3$ and the bottom sound speed $c_1 = 1765 \text{ m/s}$.

In the second stage we looked for the optimal attenuation parameters. Taking into account the results of previous calculations [2] and the relatively low frequency band of the transmitting signals we assumed that coefficient b was equal to 4. Coefficients α_a and α_v^0 were determined by exhaustive search of values. According to the calculations the best agreement between experiment and theory took place in frequency band 28-70 Hz. The specific coefficient of absorption α_a and volume scattering α_v^0 were obtained equal $\alpha_a = 0.005$; $\alpha_v = 9.3 \cdot 10^{-8} f^3$ or $\alpha = 0.005 + 9.3 \cdot 10^{-8} f^3$ (Hz). Notice that for such dependence $\alpha(f)$ sound attenuation caused by volume scattering dominates on a frequency higher than 40 Hz.

In conclusions it should be stressed that the obtained values of the bottom parameters close to typical ones for Barents Sea.

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R E R E R E N C E S

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