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# NUMERICAL ANALYSIS OF THE SHOLTE WAVE IN THE SEDIMENT LAYER OF THE SEA BOTTOM

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The numerical analysis of the normal modes in the liquid layer/solid sublayer/liquid bottom modelling sediments with low shear elasticity was carried out. The phase and group velocities of normal modes and structure of waveguide pulse response were analyzed. Identified normal modes have properties similar to Sholte waves experimentally observed.

There are a lot of experimental works [1] – [6] indicating and analyzing the low-speed waves in the sea subbottom sediments with low shear elasticity. These waves are identified as Sholte waves existing on the interface of liquid and solid half-spaces. In all the experiments they are selected in a tail part of the pulse response as substantially low-speed with effective velocity $20 \div 30\ m/c$ and substantially narrow-band wave processes.

Experimental results of these articles are shown in the table, including a depth of test side $H$, detection distance $R$, characteristic frequency range $\Delta f$ and effective propagation speed $C_{Sh}$. These data convincingly testify to the presence of direct connection of the frequency of observing Sholte waves with depth of test side. As the excitation source in all experiments was sufficiently wide-band with the upper frequency $f \approx 100\ Hz$, it is possible to explain selective generation of specific spectral components of Sholte waves by the influence of waveguide formed by liquid layer and sediment sublayer with low shear elasticity and with more or the less clear boundaries.

**Table**

| | [1] | [2] | [3] | [4] | [5] | [6] |
|---|---|---|---|---|---|---|
| $H$, $m$ | 4 | 76 | 65 | 144 | 2600 | 3800 |
| $R$, $m$ | 300 | 300 | 300 | 419 | 2000 | 1910 |
| $\Delta f$, $Hz$ | 15÷20 | 10÷16 | 12÷16 | 3÷8 | 1÷2 | 0,5÷1,5 |
| $C_{Sh}$, $m/c$ | 100÷180 | 200÷300 | 90÷150 | 45÷100 | 40÷120 | 35÷60 |

The present paper seeks to explain the selective generation of observing low-frequency waves based on analysis of dispersion characteristics of the two-layer waveguide.

The dispersion equation for normal modes in loaded solid layer of thickness $2l$ with parameters $r_0$, $C_L$, $C_t$ (density, compression wave velocity, shear wave velocity) can be written in the canonical form:

$$Z_s Z_a + \frac{1}{2}(Z_s + Z_a)(Z_1 + Z_2) + Z_1 Z_2 = 0, \qquad (1)$$

where $Z_1$, $Z_2$ - specific input impedances of loads on planes $z = \pm l$ of the solid layer, $Z_s = \frac{s_{zz}^{(s)}}{iwu_z^{(s)}}$, $Z_a = \frac{s_{zz}^{(a)}}{iwu_z^{(a)}}$, $w$ - circular frequency, $u_z^{(s)}, u_z^{(a)}, s_{zz}^{(s)}, s_{zz}^{(a)}$ - symmetric and antisymmetric components of normal bias and stress

The input impedance of the liquid layer of thickness $h$ and one of the liquid half-space are given by formulas:

$$Z_1 = \frac{iwr_1}{k_{31}} tg(k_{31}h),\ k_{31}^2 = k_1^2 - x^2,\ k_1 = \frac{w}{C_1}, \qquad (2)$$

$$Z_2 = \frac{iwr_2}{k_{32}},\ k_{32}^2 = k_2^2 - x^2,\ k_2 = \frac{w}{C_2},$$

where $r_1$, $C_1$, $r_2$, $C_2$ - densities and sound speeds in the liquid layer and liquid half-space, $x$ - propagation constant.

Substituting (2) in (1) we obtain the unknown dispersion equation.

A key role in formation of the waveguide sound field at rather long distances from a source belongs to normal modes with the real propagation constant among which one can select properly normal waves of set $n(1)$ for which $\operatorname{Im} x_n^{(1)} = 0$, $\operatorname{Re} k_{32}^{(1)} = 0$, $\operatorname{Im} k_{32}^{(1)} < 0$, and quasinormal (generalized) waves of set $n(2)$ for which $\operatorname{Im} x_n^{(2)} = 0$, $\operatorname{Re} k_{32}^{(2)} = 0$, $\operatorname{Im} k_{32}^{(2)} > 0$.

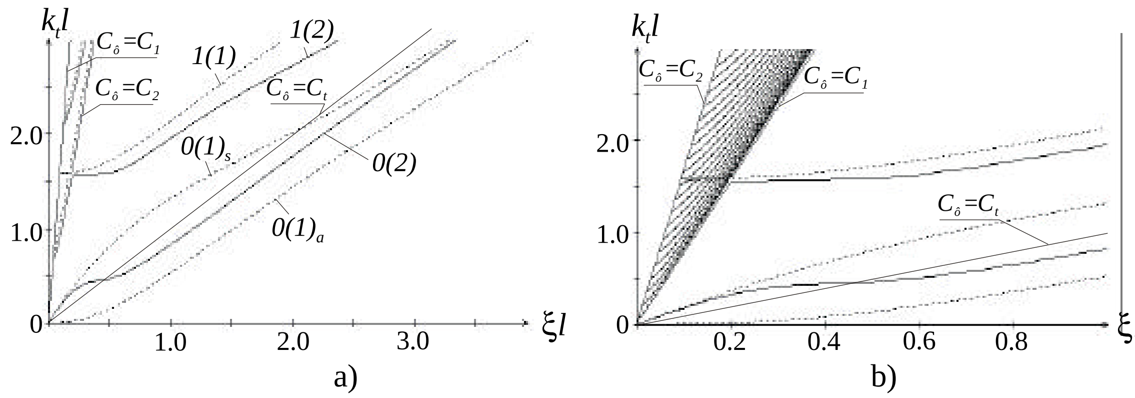


**Fig. 1.** Dispersion dependence for the normal waves in liquid layer/solid sublayer/liquid half-space

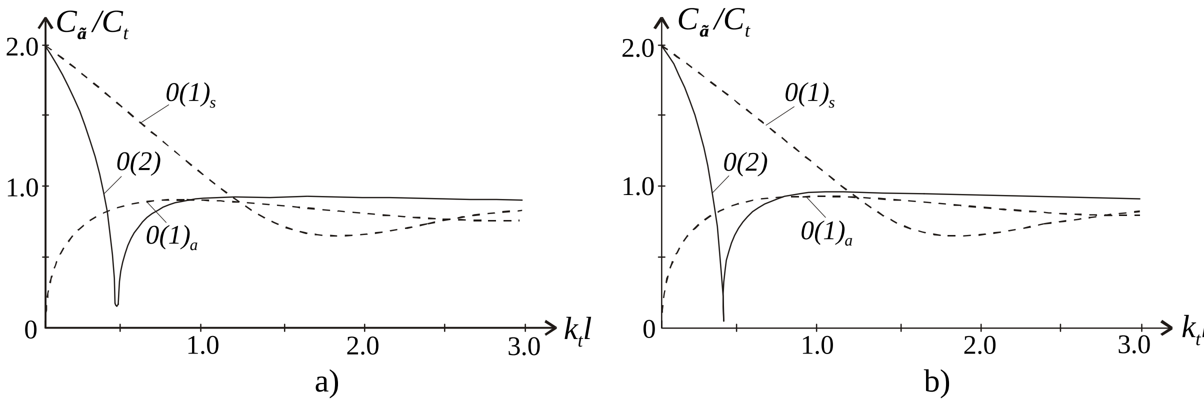


**Fig. 2.** Group velocities of the normal waves; $h_1 = 100$

In a complete collection of normal waves of the sets $n(1)$, $n(2)$ it is possible to select normal waves of zero order not having critical frequency and normal waves of the higher order for which propagation constants are real on frequencies larger than certain critical ones. The normal waves of zero order form triple of waves among which the properly normal waves are symmetric and antisymmetric Lamb waves, the third wave is a generalized one. Its type of symmetry substantially depends on load character of layer and can vary from the symmetric type to antisymmetric.

Fig. 1, a shows a common pattern of dispersion dependences for 9 normal modes of the sets $n(1)$, $n(2)$, among which one can select the group of normal waves of the liquid layer with phase velocities varying in the range $C_1 < C_{ô,n} < C_2$, and group of the low-speed normal waves of a rigid sublayer with the phase velocities being similar to the shear wave velocity $\tilde{N}_t$. Waveguide parameters have the following values close enough to real: $h_1 = h/l = 20$, $r_{10} = r_1/r_0 = 0.5$, $r_{20} = r_{21}/r_0 = 1.7$, $C_{L2} = C_L/C_2 = 0.6$, $C_{1L} = C_1/C_L = 0.8$, $a = C_t/C_L = 0.1$. Fig.1, b illustrates dispersion dependences for 45 normal modes of the sets $n(1)$, $n(2)$ for the value of parameter $h_1 = 200$.

Fig. 2 shows group velocities of the first triple of normal waves of zero order for the variation of $r_{20}$ from $1.7$ (a) to $1.5$ (b). At variation in waveguide parameters the transformation degree of symmetric type into antisymmetric for generalized normal wave is changed conserving of the main characteristic property, namely the group velocity in a zone of transformation can assume arbitrarily small values. In passing of the dispersion dependence from one group to another, i.e. in zones of the strong transformation, the group velocity can also assume extremely small values. Thus, the transformation effects with participation of generalized normal waves are very characteristic of the waveguide considered, since they lead to formation of the low-speed waves and just on the discrete frequency set.

The waveguide pulse response for the medium with losses for total set of the normal waves generating in the range $wl / C_t \in (0.2 \div 3.0)$, $N = 25$, $r / l = 100$, $h_1 = 100$ is illustrated in Fig. 3, a and for $N = 45$, $r / l = 500$, $h_1 = 200$ - in Fig. 3, b; $\bar{t} = t \cdot C_t / l$ .

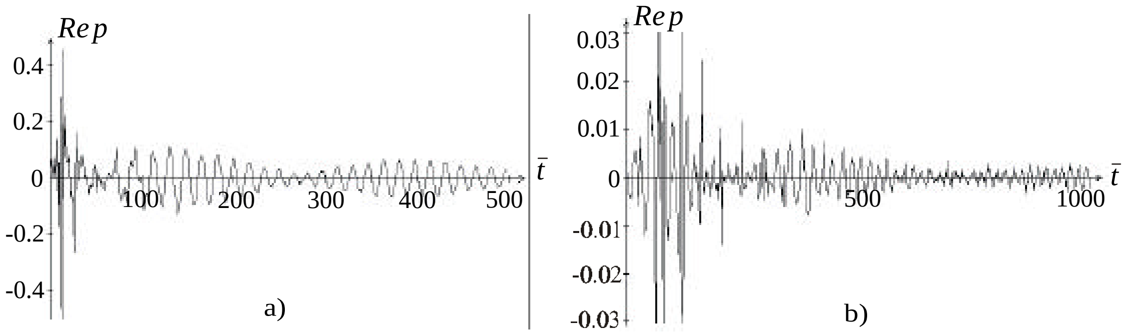


**Fig. 3.** Pulse characteristics of waveguide; $d_t / f = 6.5\, dB / m \cdot kHz$

The coefficients of an attenuation in liquid layer, liquid half-space and solid sublayer assuming in calculations correspond to those given in the paper [7]. On pulse characteristics it is possible easily to see water modes in the head part of impulse, low-speed modes of the solid sublayer in tail part of impulse and their decay in the narrow-band components in the absorption medium, which transmit only discrete low-frequency components.

The discrete components are consistent either with transformation frequency of the zero generalized wave from symmetric type to antisymmetric or transformation frequencies of the water higher order modes to modes of the solid sublayer. Anomalously low values of the group velocity and anomalously high excitation coefficients correspond always to such frequencies that is why they are observed in a tail part of the impulse even at large attenuation.

The structure of the pulse characteristic of the two-layerer waveguide with losses correspond rather well to that one observing in experiments [1] – [6], however the performed calculations do not verify the presence of Sholte wave in pulse response.

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