SUMMARY
The observation of slow wave phenomena within an oil-saturated layer at seismic frequencies is the main subject of our discussion. The theory of wave propagation cannot explain this phenomenon well enough. We develop a theory for a model of an oil-saturated layer which includes a two-phase medium consisting of a solid body with fluid-filled cracks. Solution within the framework of this model shows the possibility of slow wave formation with high amplitudes at low seismic frequencies. Results of the theoretical research correspond to the data of the cross-hole seismic experiment.

THEORETICAL RESEARCH
As starting point we use a simple model of an oil-saturated layer. This consists of a liquid layer sandwiched between solid half-spaces. Corresponding analytical (Krauklis, 1962; Krauklis at al., 1992) and numerical solutions show the possibility of slow wave formation with high amplitudes. This wave dominates inside the layer and it attenuates very quickly outside it. The result of analytical and numerical solutions corresponds to the result of Chouet (1986) and Ferrazzini and Aki (1987) which they used for the interpretation of volcanic tremors. However the model of a liquid layer is too simple for the description of oil-saturated rock and only shows the principle of slow wave propagation with high amplitude at seismic frequencies. It cannot explain very low velocity of the slow wave in a finite thickness layer. We develop a theory for a model of an oil-saturated layer which includes a two-phase medium consisting of a solid body with fluid-filled cracks. We use the matrix method (Molotkov, 1984) and the principle of an equivalent model. The resulting solution describes wave propagation in an elastic-liquid cracked medium. The solution shows three P waves propagating along the cracks. The velocities of these waves are \( V_1, V_2, V_3 \):

\[
V_1^2 = \frac{\hat{p}_1 + (ac + b^2)\tilde{p}_1}{2c\hat{p}_1} - 4ac\hat{p}_1\tilde{p}_1, \\
V_2^2 = \frac{a}{\rho_s}; \\
V_3 = \rho_s(1 - \phi); \quad \hat{p}_i = \rho_i/\phi
\]

where \( \rho_s \) is the density of the solid part of the medium; \( \rho_i \) is the density of the liquid part of the medium. Also

\[
a = \frac{4\mu(\lambda + \mu)(1 - \phi)}{\lambda + 2\mu}; \quad b = \frac{\phi(1 - \phi)}{\lambda + 2\mu}; \quad c = \frac{1 - \phi}{\lambda + 2\mu}
\]

where \( \lambda \) is the Lame's constant of a solid part; \( \lambda_s \) is the Lame's constant of a liquid part; \( \mu \) is the shear modulus; \( \phi \) is the porosity. Velocities \( V_1 \) and \( V_2 \) correspond to the quasi-compressional and plate-compressional waves accordingly. Velocity \( V_3 \) corresponds to the slow wave. If the porosity is very small (\( \phi < 0.1 \)) the velocity of the slow wave may be expressed as
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\[ V_s = 2V_r \sqrt{\frac{\phi(1-V_r^2)}{V_r^2}} \frac{\rho_r}{\rho_s}, \]

where \( V_r = \sqrt{\mu/\rho_s}, \quad V_p = \sqrt{\lambda+2\mu/\rho_s}. \)

We examine the solution for the case of a fluid-filled cracked layer sandwiched between two solid half-spaces. The dispersion equation for oscillations in this case is the same as in the case of the liquid layer (Krauklis et al., 1992) but the term \( a \) which defines the distribution of the slow wave energy inside fluid-filled cracked layers is quite different. In our case it is

\[ a = \frac{\sqrt{(V_{ph}^2 - V_r^2)(V_{ph}^2 - V_p^2)}}{V_{ph}^2 - V_r^2} \sqrt{\frac{\rho_r + \rho_s}{\rho_r}} (1 - \phi), \]

where \( V_{ph} \) is the phase velocity of the slow wave. We can calculate \( V_{ph} \) from equation:

\[ V_{ph} = \sqrt{\frac{k^2 - \frac{4\pi^2}{h^2}}{\mu + \rho}}. \]

CONCLUSIONS

Slow waves were observed inside an oil-saturated layer at seismic frequencies. This wave had very low frequency (10 Hz), very low velocity (300 m/s) and high amplitude. Known theories of the wave propagation in a two-phase medium cannot explain this phenomenon. We have developed a theory for the wave propagation in an elastic cracked solid which contains a fluid. The solution for the case of a fluid-filled cracked layer sandwiched between two solid half-spaces shows the possibility of slow wave formation with high amplitude and low velocity at low frequencies.

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REFERENCES


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Fig. 2 The phase velocity of slow wave vs. porosity ($\phi$), wavenumber ($k$) and thickness of layer ($h$).

Fig. 3 Distribution of the vertical (a) and horizontal (b) components of slow wave amplitude in the liquid-filled cracked layer: $\phi$ is porosity.

Fig. 4 The vertical (a) and the horizontal (b) components of slow wave amplitude vs. porosity ($\phi$), wavenumber ($k$) and thickness of layer ($h$).

Fig. 5 Model (a) and data of the laboratory experiments (b): $X_{min}$ is the distance between source (S) and the first receiver ($X_{min}$=0.08 m); $X_{max}$ is the distance between S and the last receiver ($X_{max}$=0.44 m); $dX$ is the distance between receivers (R) ($dX$=0.02 m); $h$ is thickness of the layer ($h$=0.005 m).