ATTENUATION ELASTIC WAVES IN ROCKS IN THE REGION OF LOW-INTENSITY OSCILLATIONS

V. S. Yamshchikov

Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 3, pp. 134-136, 1965

It has been established in theoretical studies [1, 2] that in cases where the deformations of a solid due to elastic waves are small, the relation between the components of the stress and strain tensors may be considered linear, that is, in the region of small-amplitude oscillations it is possible to limit oneself to second-order terms in the expansion of the elastic energy in powers of the strain tensor. A feature of this approximation is the absence of interaction between longitudinal and transverse waves. If, however, the strains are high, the relation between the components of the stress and strain tensors becomes nonlinear and in the elastic energy expansion cubic terms must be taken into account. In this case the elastic waves are waves of finite amplitude. A consequence of the nonlinear relation between the components of the stress and strain tensors is that it is necessary to take into account the interaction between longitudinal and transverse waves. In a study of these waves in solids nonlinear effects have been detected experimentally [3].

Since in using ultrasonics as a tool for the investigation of materials it is possible to use waves of small amplitude and, to some extent, waves of finite amplitude, that is, low-intensity elastic oscillations, it is of interest to determine the boundary between the region of existence of waves of small and finite amplitude. To distinguish these waves when propagated in rocks, we used the change in the type of damping of elastic waves as a function of intensity.

The experimental investigations were made of the apparatus shown schematically in Fig. 1 (where 1 is the stabilizer, 2 is the ultrasonic generator, 3 is the emitter, 4 is the detector, 5 is the oscillograph, 6 is the sample, and 7 is the bath).

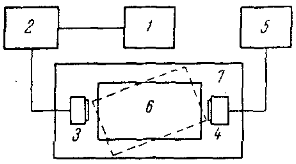

Fig. 1

The acoustic unit (emitter—sample—detector) was placed in a special bath in which water served as the contact layer. This made it possible to maintain a uniform energy relationship between the piezoelectric transducers and the sample. The thickness of the contact layer for the excitation of longitudinal waves was fractions of a millimeter and for the excitation of transverse waves—about 1.5-2 cm.

The emitter was a quartz plate with a natural frequency of 880 kc/sec. The maximum power P was about 8.5-9 W and the active area of the emitter was 4 cm^2. The power was regulated uniformly in steps. The experiments were carried out under continuous emission conditions.

The radiated power was checked by means of a mechanical ultrasonic power gage. The measuring error was ±0.25 W.

In this experiment, when the power intensity I W/cm^2 delivered by the quartz transducer was changed by a certain amount, the amplitude of the ultrasonic wave passing through the sample of investigated rock was recorded on the screen of the oscillograph. Since the amplitude characteristic of the receiving channel was linear in the measurement range in question, the effect of intensity on the damping of the ultrasonic wave was evaluated on the basis of the change in the amplitude of the wave passing through the sample, which was recorded on the oscillograph. Experiments were run several times on each rock sample.

To permit a comparison of the results, irrespective of the absorbing properties of the investigated type of rock, we introduced the relative quantity K_α, the relative amplitude of the wave passing through the sample, which is equal to the ratio of the measured amplitude A at the corresponding intensity to the initial amplitude A_0 at the intensity 0.23 W/cm^2, that is,

$$K_\alpha = A_i/A_0. \tag{1}$$

An experimental investigation was made of the change in the character of damping of longitudinal and transverse waves in dense rocks (diabase, peridotite) as a function of intensity in the interval from 0 to 2 W/cm^2.

Longitudinal ultrasonic waves were generated in the rock samples by the ringing method. In exciting "pure" transverse waves in samples we used the phenomenon of total internal reflection of a longitudinal wave, which is linked with the deflection of the latter through some critical angle relative to the propagating elastic wave. In our case the value of the angle of total internal reflection for a longitudinal wave was 15° for periodotite, and 18° for diabase.

The experimental results (K_α values) are given in the table for longitudinal and transverse waves.

Figure 2 shows the dependence of the relative amplitude for longitudinal (1) and transverse (2) ultrasonic waves on the intensity for peridotite. The graph shows that for longitudinal elastic waves at some intensity (1-1.5 W/cm^2) there is a nonlinear dependence between the intensity and the relative amplitude of the wave passing through the sample. In the region of oscillations at intensities from 0 to 1.2-1.5 W/cm^2 there is a clearly expressed linear dependence of the change in relative amplitude of the longitudinal wave on intensity. It may therefore be concluded that elastic waves propagating with an intensity corcoresponding to the appearance of nonlinear effects should be considered waves of finite amplitude.

The point of appearance of a nonlinear dependence of attenuation on the intensity of the oscillations in different rocks is not constant. This can apparently be attributed to their different densities. The dividing point falls in the intensity interval from 1 to 1.6 W/cm^2. Nonlinear effects appear earlier in denser rocks.

P, W	I, W/cm^2	Longitudinal	Transverse	Longitudinal	Transverse
		Diabase		Peridotite	
0.9	0.23	1.00	1.00	1.00	1.00
1.9	0.47	1.18	1.37	1.25	1.47
2.6	0.65	1.32	1.62	1.45	1.88
3.1	0.78	1.48	1.87	1.65	2.12
3.6	0.90	1.58	2.00	1.85	2.35
4.5	1.12	1.65	2.25	1.95	2.60
5.5	1.37	1.72	2.50	2.00	2.90
6.4	1.60	1.75	2.75	2.05	3.12
7.2	1.8	1.79	3.00	2.07	3.22
8.6	2.15	1.81	3.15	2.09	3.56

The relationship between the relative wave amplitude and intensity is almost linear for a "pure" transverse elastic wave in the given range of variation of intensity. Insignificant deviations from linearity are probably related to anisotropy of the physical properties of the investigated rocks.

These experimental relationships are confirmed and explained by theoretical investigations made earlier in connection with the problem of the propagation of elastic waves in homogeneous elastic media [2].

It was assumed in [1] that, correct to cubic terms, the elastic energy per unit volume of a deformed body under the influence of a propagating elastic wave of finite amplitude is given by

$$\varepsilon = \frac{\lambda + 2\mu}{2} J_1^2 - 2\mu J_2 + \frac{l + 2m}{3} J^3 - 2m J_1 J_2 + n J_3. \qquad (2)$$

Here λ and μ are the Lamé constants, l, m, n are certain constant coefficients of anharmonicity, J_1, J_2, J_3 are the invariants of the strain tensor, equal for the case of propagation of a plane elastic wave along the x-axis to

$$J_1 = u_{11},\ J_2 = u_{12}^2 - u_{13}^2,\ J_3 = 0$$

(u_{ik} is the displacement vector).

If the wave is longitudinal ($u_x \neq 0$, $u_y = u_z = 0$), the elastic energy is equal to

$$\varepsilon = \frac{\lambda + 2\mu}{2} u_{11}^2 + \frac{l + 2m}{3} u_{11}^3. \qquad (3)$$

However, if the wave is a pure shear wave ($u_x = 0$, $u_y \neq 0$, $u_z \neq 0$), the energy is equal to

$$\varepsilon = 2\mu (u_{12}^2 + u_{13}^2) \qquad (4)$$

It can therefore be seen that for a longitudinal wave of finite amplitude there should be nonlinear effects, whereas for a purely transverse wave such effects are absent.

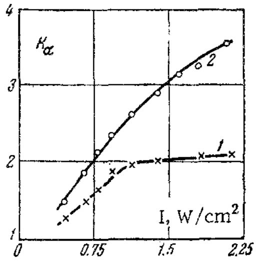

Fig. 2

These points are fully confirmed by experimental data obtained from the propagation of low-intensity longitudinal and transverse elastic waves in rocks.

The results of this investigation should be taken into account in the study of the damping of sonic and ultrasonic waves in rock media.

REFERENCES

1. L. D. Landau and E. M. Lifshitz, Mechanics of Continua [in Russian], Gostekhizdat, 1954.

2. A. L. Polyakova, "Nonlinear effects in solids," Fizika tverdogo tela, vol. 6, no. 1, 1964.

3. V. A. Krasil'nikov and A. A. Gedroits, "Distortion of a finite-amplitude ultrasonic wave in solids," Vestn. Mosk. un-ta, no. 2, 1962.

3 June 1964 Moscow

Correction to E. G. Sakhnovskii's article "Viscous friction and heat flux for a partially ionized medium flowing in a plane channel with allowance for anisotropy of the transport coefficients," Journal of Applied Mechanics and Technical Physics no. 2 March–April 1965.

The table of values of the parameters at the top of page 81 should read as follows:

1	$\omega_e \tau_0 \ll 1,$	$\omega_i \tau_i\ \theta$	$s \in [0,1]$
2	$\omega_e \tau_0 = 40,$	$\omega_i \tau_i \ll 1,$	$s \ll 1$
3	$\omega_e \tau_0 = 40,$	$\omega_i \tau_i \ll 1,$	$s = 1$
4	$\omega_e \tau_0 = 1,$	$\omega_i \tau_{in} = 1,$	$s \ll 1$
5	$\omega_e \tau_0 = 1,$	$\omega_i \tau' \theta = 1,$	$s = 1$