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CHANGES IN THE PARAMETERS OF LONGITUDINAL AND TRANSVERSE ELASTIC WAVES DURING TORSION OF ROCK SAMPLES

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Abstract

Full Text

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GEOPHYSICS

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CHANGES IN THE PARAMETERS OF LONGITUDINAL AND TRANSVERSE ELASTIC WAVES DURING TORSION OF ROCK SAMPLES

The state of rocks in the earth' s crust, especially in the zone affected by tectonic processes and mining workings, is characterized by the presence of a complex stress field, including compressive, tensile, and shear stresses.

Known studies on the influence of the stress field on the acoustic parameters of elastic waves, with the exception of our previously published work (^{1}), cover the region of compressive stresses. Experimental data on the influence of shear stresses in rocks on the parameters of elastic waves are absent from the scientific literature.

At present there is practically no standard method for testing rocks in pure shear. But even if existing methods (^{2}) are taken into account, the use of most of them for the purposes of the present work is not possible because of either technical difficulties in carrying out sounding of the sample or the local nature of the shear stresses. Therefore, in the present case we used the method of torsion of a cylindrical rod, the theory and practice of which are well known ($^{3-6}$).

Table 1

Rocks	ρ, g/cm^3	Porosity, %	V_p, m/s	V_s, m/s	E, N/m^2 $\times 10^{-10}$	G, N/m^2 $\times 10^{-10}$	Poisson' s coefficient, ν	α_p, cm^{-1}	α_s, cm^{-1}	σ_c^{pr}, kg/cm^2	σ_t^{pr}, kg/cm^2	τ_{usl}^{pr}, kg/cm^2	$\frac{\sigma_p}{\sigma_c}$, %	$\frac{\tau}{\sigma_c}$, %
Novodanilovsk granite	2.6	3.5	5050	2970	5.65	2.28	0.24	0.1	0.2	1430	67	190	4.7	13.3

Rocks	ρ, g/cm^3	Porosity, %	V_p, m/s	V_s, m/s	E, N/m^2 $\times 10^{-10}$	G, N/m^2 $\times 10^{-10}$	Poisson's coefficient, ν	α_p, cm^{-1}	α_s, cm^{-1}	$\sigma_{\mathrm{c}}^{\mathrm{pr}}$, kg/cm^2	$\sigma_{\mathrm{t}}^{\mathrm{pr}}$, kg/cm^2	$\tau_{\mathrm{usl}}^{\mathrm{pr}}$, kg/cm^2	$\frac{\sigma_p}{\sigma_{\mathrm{c}}}$, %	$\frac{\tau}{\sigma_{\mathrm{c}}}$, %
Dzhezkazgan sandstone	2.67	1.5	5150	3050	6.1	2.5	0.23	0.07	0.12	1700	170	220	10.0	13.0
Kuzbass sandstone	2.6	2.5	4100	2600	4.15	1.8	0.15	0.15	0.4	1250	89	120	7.1	9.6
Ural white marble	2.67	0.5	4400	2700	4.67	1.95	0.195	0.12	0.3	715	42	70	5.9	9.8

The stressed state of such a rod under torsion is characterized by pure shear along a plane perpendicular to its axis and pure tension along a plane inclined at an angle of 45° to the axis. In addition, the tangential stresses are distributed nonuniformly over the cross section of the sample, increasing toward its surface. Despite the complexity of the stressed state of the sample in this case, purely shear stresses arise in the elements of the twisted rod, which are difficult to obtain by another method.

In a sample of a material that is weaker in tension than in shear (all rocky rocks), failure of the rod has the character of separation along a helical surface inclined at an angle of about 45° to the axis of the sample. From the maximum observed torque it is customary to calculate the maximum tangential stress, called the conditional strength:

$$\tau_{\mathrm{usl}}^{\mathrm{pr}} = M_{\mathrm{max}}/W_{\mathrm{kr}},$$

where W_{kr} is the torsional section modulus.

The experiments were carried out on samples of the same rocks as in work ([1]). Here an expanded physicomechanical characterization of them is given (Table 1). The experimental technique is also described, in the main, in the work mentioned above. The difference here is that, in the holes of the grips arranged along the diameter, forks of a special design were installed instead of rods. The shanks of the forks were fastened in a standard pendulum-type torsion machine, with coaxiality of the sample, shanks, and torque maintained. In addition, the method for processing the experimental data was expanded by introducing calculation (7), which makes it possible, from the change in signal amplitude with pressure, to judge the change in the attenuation coefficient:

$$\Delta_\tau \alpha = [\ln A(0) - \ln A(\tau)]/l,$$

where $A(0)$ is the amplitude at $\tau = 0$; $A(\tau)$ is the amplitude at the given load; l is the length of the sample. The influence of the unloaded part of the sample in the grips was also taken into account.

As a result of experiments involving torsion of the samples and sounding them along the axis (Table 2), it was established that the changes in the characteristics of both transverse and longitudinal waves in this case are minimal, and, in terms of the signs of the increments, analogous to those observed under tension.

Table 2

Rock / No.	kgm	kg/cm^2	% of breaking load	$-\Delta V_p$, %	$-\Delta V_s$, %	$\Delta\alpha_p$, %	$\Delta\alpha_s$, %
Dzhezkazgan sandstone	1	21.5	9.5	0.0	0.0	0.0	0.8
Dzhezkazgan sandstone	2	43	19.5	0.0	0.1	5.0	1.7
Dzhezkazgan sandstone	3	64.5	28.5	0.0	0.2	14	2.5
Dzhezkazgan sandstone	4	86	38	0.02	0.3	26	3.4
Dzhezkazgan sandstone	5	107.5	47.5	0.05	0.4	38	4.2
Dzhezkazgan sandstone	6	129	57	0.08	0.5	48	4.9
Dzhezkazgan sandstone	7	150.5	66.5	0.1	0.6	58	7.2
Dzhezkazgan sandstone	8	172	76	0.15	0.7	67	12

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Rock / No.	kgm	kg/cm^2	% of breaking load	$-\Delta V_p$, %	$-\Delta V_s$, %	$\Delta\alpha_p$, %	$\Delta\alpha_s$, %
Dzhezkazgan sandstone	9	193.5	85.5	0.25	0.8	76	19
Dzhezkazgan sandstone	10	215	95	0.5	1.0	85	28
Kuzbass sandstone	1	19.5	16	0.1	0.02	6.0	2.5
Kuzbass sandstone	2	39	32	0.3	0.06	9.0	5.0
Kuzbass sandstone	3	58.5	48	0.6	0.13	12	8.0
Kuzbass sandstone	4	78	64	0.8	0.25	18	12
Kuzbass sandstone	5	97.5	80	1.1	0.5	27	15
Granite	1	16	8.5	0.0	0.0	0.0	0.0
Granite	2	32	17	0.0	0.01	1.0	0.0
Granite	3	48	25.5	0.0	0.03	2.0	0.0
Granite	4	64	34	0.0	0.08	3.0	0.0
Granite	5	80	42.5	0.0	0.12	4.0	0.0
Granite	6	96	51	0.03	0.2	5.0	0.5
Granite	7	112	59.5	0.1	0.25	6.0	1.0
Granite	8	128	68	0.2	0.3	10	2.0
Granite	9	144	76.5	0.3	0.4	18	5.0
Granite	10	160	85	0.5	0.7	33	9.0
Marble	1	18	26	+0.2	0.1	0.0	3.0
Marble	2	36	52	+1.0	1.5	5.0	6.0
Marble	3	54	78	+3.0	5.0	7.5	10.0

The greatest changes were obtained for the attenuation coefficient of the longitudinal wave in Dzhezkazgan sandstone: $\Delta\alpha_p = 85\%$. This is 23.0% less in absolute value than under compression, and almost three times less than under tension. The changes in attenuation of the transverse wave are many times smaller than under tension. The changes in ultrasonic velocities are practically insignificant. It is noteworthy that the principal changes in the parameters of elastic waves are observed in the range of loads close to destructive ones; in some cases the first half of the load produces no changes at all in the measured characteristics.

This fact can be explained by the nature of shear stresses. It is known that pure shear is equivalent to a stressed state caused by tension in one direction and by equal compression in the perpendicular direction. Since, in the ideal case, both of these stresses are directed at the same angle (about 45°) to the axis of the sample (and consequently to the direction of sounding), their effects on the acoustic characteristics in the initial stage of loading are added and in sum give zero. With a further increase in load, in a rock-type material the tensile stresses begin to exert the predominant influence,

which was also recorded by the experiments performed. The presence of an increase in the velocity of the longitudinal wave in marble in this case is an exception, which may be explained by distortion of the stress rhombus in the specimen with a predominance of compressive stresses.

Finally, the experiment as a whole did not confirm the expected greater change in the attenuation of the transverse wave as compared with the longitudinal one. It is possible that, when conditions are created for a purer shear, different results may be obtained. However, it also seems quite probable that, in practice, in large volumes of rock, the shear mechanism described above will have precisely such an effect on the recorded parameters of elastic waves as was obtained in the experiments performed.

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