Determination of Elastic Wave Velocities in Rocks by Means of Ultrasonic Impulse Transmission.

By

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Abstract

Velocities of longitudinal and transversal elastic waves in rock specimens have been determined from the transmission times of ultrasonic impulse (50 KC—300 KC) through them at ordinary temperatures and pressures. POISSON's ratios have also been calculated from the velocities of the two kinds of elastic waves.

18 specimens of granite and 34 of marble, all collected from various localities of Japan, were examined. In addition, 12 specimens of marble from Italy and various other kinds of rock, such as andesite, sandstone, tuff, etc. were also examined. The experimental results are summarised as follows:

	longitudinal wave (km/sec.)	transversal wave (km/sec.)	POISSON's ratio
Granite	4.09-5.89	2.51-3.55	0.19-0.28
Marble	3.75-6.94	2.02-3.86	0.18-0.35

Within the frequency range of our experiments, dispersion phenomena have been found in none of the rock specimens examined.

§ 1. Introduction

The elastic constants of rocks for low and audio-frequencies have been measured by a number of workers. In experimental laboratories, the constants can be determined from the resonance frequency of a rod of rock specimen which is subjected to standing elastic vibrations (K. IIDA: 1939). In fields, on the other hand, the constants can most directly be determined from the time of transmission of artificial or natural seismic waves. If one wishes to use this direct method in laboratories, an inconveniently long specimen of rock will be needed, because the specimen must be at least several times as long as the wave-length of the elastic wave used. This difficulty will disappear if ultrasonic frequency is used instead of audio-frequency. In the present paper, the writer is going to describe the results of his laboratory determinations of elastic constants of rocks from the time of transmission of ultra-

sonic waves (50 KC—300 KC) in rock specimens. The dimensions of the specimens are 20 cm × 17 cm × 6 cm in case of granite and 12 cm × 9 cm × (2~1) cm in case of marble.

§ 2. Apparatus and Experimental Method

Fig. 1 shows the general view of the apparatus used and Fig. 2 is its schematic diagram. The apparatus consists of a pulse generator, pulse amplifier, sweep circuit, time mark circuit and cathod-ray oscillograph.

BaTiO₃ crystals were used to generate and receive ultrasonic waves of 50 KC, while quartz crystals were used for 150 KC and 300 KC. For the latter case, X-cut crystals were used for longitudinal waves, while Y-cut crystals were used for transversal waves. D. S. HUGHES and J. H. CROSS (1951) used X-cut crystals for both kinds of waves, but according to the writer's experiences, Y-cut crystals are more adapted for transversal waves.

The pulse generator (including power am-

plifier) which excites the crystals has been so designed that the pulse is sent into the specimen a short time after the sweep circuit begins to operate. Sweep signals are fed to the horizontal plate circuit of the cathod-ray oscillograph while the input impulse to the rock specimen and the output impulse from it are both fed to the vertical plate circuit of

University, and was constructed by his assistant, Mr. T. YAMADA.

§ 3. Rock Specimens

The rock specimens examined are as follows:

Granite	18	Japan
Marble	33	Japan
Marble	12	Italy
Marble	1	Korea,

all collected by Mr. S. NAGAOKA. These were placed at the writer's disposal by the kindness of Professor S. MATSUSHITA. The localities from which they were collected are listed in Tables I and II. Each of the rock specimens has its own characteristic appearance and has the proper name according to its place of occurrence as also listed in the tables. The properties of these specimens of granite and marble are believed to be such that they well represent those of the corresponding rocks which occur in their respective places. Unfortunately, however, chemical and mineralogical compositions of the specimens have not yet been determined.

§ 4. Results

The cathod-ray oscillograms due to longitudinal and transversal waves in rock specimens were taken photographically. Fig. 3 is one of the records obtained for a granite specimen. On the first record are shown the incident and received wave pulses due to the X-cut quartz crystal oscillations, while the third those due to the Y-cut crystal oscillations. The second and fourth records are time marks corresponding to the records above them. As is clear from the records, when the X-cut crystal is used, only one phase can be seen in the wave trains received. This phase corresponds to the longitudinal wave. In contrast to this, when the Y-cut crystal is used, the wave trains received show two sharply distinguishable phases, the first smaller one corresponding to the longitudinal wave and the latter larger one to the transversal wave. It is likely that in case of the Y-cut, while the main oscillations of the

Fig. 1. General view of the experimental apparatus.

Fig. 2. Schematic diagram of the experimental apparatus.

the oscillograph together with time marks. The time marks are given at every 3 ± 0.06 microseconds. The apparatus was designed by Assistant Professor F. KONDO of the Department of Electrical Engineering, Kyoto

- (1) Longitudinal wave of X-cut crystal.
- (2) Time Mark.
- (3) Longitudinal and transversal waves of Y-cut crystal.
- (4) Time Mark.

Fig. 3. An example of records obtained for a granite specimen.

Fig. 4. Longitudinal and transversal wave velocities in granite specimens.

Fig. 5. Longitudinal and transversal wave velocities in marble specimens.

crystal are in X-direction and produce the transversal wave, those in Y-direction due to the thickness oscillation produce the longitudinal wave.

The velocities of longitudinal and transversal waves obtained for various specimens are listed in Tables I and II for granite and marble specimens respectively. Figs. 4 and 5 have been obtained by taking the transversal wave velocity v_s in ordinate and the longitudinal wave velocity v_p in abscissa. The points in these figures are seen to lie approximately on a straight line within a certain range of velocity values. The velocities of elastic waves in granite and marble range as follows:

	v_p (km/sec.)	v_s (km/sec.)
Granite	4.09-5.89	2.51-3.55
Marble	3.75-6.94	2.02-3.86

Poisson's ratios as well as densities of the rock specimens are also given in Tables I and II. The range and the average values of Poisson's ratio are as follows:

	range	average
Granite	0.19-0.28	0.23
Marble	0.18-0.35	0.27

Table I. Locality, Proper Name, Longitudinal and Transversal Wave Velocities, Poisson's Ratio and Density of Granite.

No.	Locality	Proper Name (Japanese)	V_p , km/sec.	V_s , km/sec.	POISSON'S ratio	Density gr/cm ³
1	Hyogo-Pref.	Akao-ishi	5.75	3.27	.26	2.86
2	"	Hon-mikage (I)	5.77	3.50	.21	2.77
3	"	" (II)	5.38	3.16	.28	2.79
4	Ôsaka-Pref.	Kitazima-ishi	5.89	3.37	.26	2.76
5	"	"	5.63	3.16	.27	2.77
6	Aichi-Pref.	Kuro-sansyu-mikage	4.91	2.89	.24	2.65
7	Ehime-Pref.	Oshima-ishi	4.45	2.70	.21	2.78
8	Kagawa-Pref.	Yoshima-ishi	4.86	3.00	.19	2.77
9	"	Agi-ishi	4.56	2.78	.21	2.71
10	"	Shokai	5.40	3.05	.27	2.70
11	Okayama-Pref.	Kitaki	4.83	2.96	.20	2.68
12	"	Sabi-ishi	5.02	3.10	.19	2.62
13	"	"	5.30	3.03	.26	2.94
14	"	Inushima-ishi	5.18	2.88	.28	2.87
15	"	Aoki-ishi	4.09	2.51	.20	2.77
16	"	Kitaki-ishi	5.71	3.55	.19	2.70
17	"	Mansei-ishi	4.77	2.81	.24	2.70
18	"	Muneage-ishi	4.62	2.85	.19	2.77

Fig. 6. Longitudinal waves in a sandstone specimen excited by different frequencies.

- (1) Time mark. (3 microseconds.)
 (2) 300 kc/sec. X-cut crystal.
 (3) 150 kc/sec. X-cut crystal.
 (4) 50 kc/sec. BaTiO₃.

The average values of Poisson's ratio as determined by our experiments agree with BIRCH's value (1938). The averages of the ratios of the longitudinal and transversal wave velocities are as follows:

	ratio
Granite	1.69
Marble	1.78

Finally, no tendency has been found that the velocity of elastic waves depends on the ultrasonic frequency within our frequency range (50 KC-300 KC) and also within the accuracy of our experiments. One of the experimental results which indicates this conclusion is shown in Fig. 6. This record was taken with a sandstone specimen. Although

Table II. Locality, Proper Name, Longitudinal and Transversal Wave Velocities, Poisson's Ratio and Density of Marble.

No.	Locality	Proper Name (Japanese)	V_p km/sec.	V_s km/sec.	Poisson's ratio	Density gr/cm ³
1	Yamaguchi-Pref. Akiyoshi	Shiro	5.62	3.26	.25	2.66
2	" "	Hakuchuzitu	5.97	3.32	.28	2.73
3	" "	Midoriiriishi	5.34	2.96	.28	2.80
4	" "	Shirakumo	6.08	3.73	.20	2.93
5	" "	Usugumo	5.48	2.92	.30	2.76
6	" "	Hakuyo	6.14	3.22	.31	2.76
7	" "	"	5.09	2.80	.28	2.73
8	" "	Oka sarasa	5.89	2.96	.33	2.73
9	" "	Kinmon	5.85	3.46	.23	2.79
10	" "	Kinteki	5.89	2.83	.35	2.74
11	" "	"	6.02	3.54	.24	2.72
12	" "	Oka	3.75	2.02	.29	2.68
13	" "	"	5.11	3.12	.21	2.66
14	" Omine	Hakuyo	5.25	3.13	.24	2.83
15	" "	Shisuishiki	6.15	3.84	.18	2.66
16	" "	Uzura	6.05	3.48	.26	2.72
17	" Ota	Sarasa	6.37	3.31	.31	2.70
18	" "	Okibuse	5.92	3.64	.19	2.80
19	Tokushima-Pref. Tokushima	Kamo	6.48	3.92	.21	2.76
20	" "	Kinkamo	6.34	3.43	.29	2.76
21	" "	Aka-kamo	5.98	3.04	.33	2.76
22	" Akaishi	Sato-shima	5.80	3.07	.31	2.72
23	" "	Kinkaseki	6.10	3.70	.27	2.79
24	Kochi-Pref. Kochi	Ao-keiryu	5.41	3.15	.24	2.72
25	" "	Keiryu	5.67	3.10	.29	2.82
26	Gifu-Pref. Akasaka	Ki-sarasa	6.94	3.86	.28	2.74
27	" "	Aka-sarasa	6.16	3.76	.21	2.70
28	" "	"	6.10	3.70	.21	2.69
29	" "	Kuro-sarasa	6.01	3.50	.24	2.62
30	" "	Kuro	6.19	3.75	.21	2.70
31	Ibaragi-Pref. Mayumiyama	Shimanezumi	6.23	3.38	.29	2.72
32	Okayama-Pref. Naruha	Aiko	5.72	3.18	.28	2.72
33	Wakayama-Pref. Yuasa	Kamo	6.02	3.10	.32	2.73
34	Yamanashi-Pref.	Shihanseki	5.14	2.72	.30	2.80
35	Ryukyu Islands	"	5.38	3.00	.28	2.39
36	Korea, Heizyo	Akagasumi	6.00	3.30	.28	2.70
37	Italy		6.33	3.51	.26	2.66
38	"		5.90	3.28	.28	2.58
39	"		5.70	3.20	.27	2.75
40	"		5.53	2.99	.29	2.59
41	"		5.25	2.92	.28	2.62
42	"		4.68	2.43	.28	2.88
43	"		5.31	2.75	.32	2.82
44	"		6.62	3.31	.33	2.64
45	"		5.20	2.53	.35	2.75
46	"		5.74	2.84	.34	2.72

three different frequencies were used as indicated in the figure, no difference is seen in the time between the input and arrival of waves.

So far, the results for granite and marble have been described. We have made similar experiments for about 150 specimens of other kinds of rock. The results of these experiments will be reported in the near future.

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