THE OCCURRENCE OF ELASTIC SHOCKS DURING DESTRUCTION OF ROCKS AND ITS RELATION TO THE SEQUENCE OF EARTHQUAKES

BY

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1. Introduction

Several reports [1-3] have shown that the elastic shocks take place accompaning the fractures of rock specimens under some stress conditions and also that the magnitude of elastic energy is dependent on the dimension of the fractures.

It seems that the minor fractures may occur at the irregular points in the brittle heterogeneous materials under an uniform external stress. Therefore, the characteristics of the occurrence of the fractures in the heterogeneous materials may have a close connexion with the successive occurrence of micro-shocks prior to the main earthquakes.

The following is a discussion on the time characteristics of the elastic shocks being compared with those of the earthquakes of shallow foci.

2. Apparatus and Method of Observations

In order to apply a mono-axial compression to the test specimens, a loading apparatus of a single lever type was used for this experiment. The elastic shocks caused by the fractures of the rock specimens were observed by an acoustic method. Murata's $BaTiO_3$ ceramic vibrator was set on the specimen as a transducer of the elastic shocks. The signals were amplified by an amplifier with a transmission band of 30-10,000 cps and were recorded by an electromagnetic oscillograph having a natural frequency of 100 cps. The strain of the rock specimens, in the process of the stress application, was also measured by a Shinko type electric resistance strain meter.

The following samples were used as test specimens.

1. Granite (Fukushima Pref.)
2. Marble (Yamaguchi Pref.)
3. Dunite (Ehime Pref.)
4. Sandstone (Osaka Pref.)

The dimension of the cylindrical specimen was 30 mm in diameter and 60 mm in length. When the propagation velocity of the elastic wave in the rock specimen is equal to 3.0 km/sec., the wave length of 60 mm (length of the specimens) corresponds to a frequency of 50,000 cps, which is far beyond the limit of the transmission band of the recording system. However, if it is assumed that the elastic shock is a single pulse in the form of an attenuating sinusoid, the amplitude of the shock being recorded is proportional to the amplitude of the initial shock, as was shown in a paper of S.D. Vinogradov [4]. Thus, the relative energy of the elastic shocks is calculated as a square of the maximum amplitude, whereas the absolute value of their energy and their wave form cannot be determined directly from the recordings.

When examined under the microscope, the granite has many original fractures and defects, but the sandstone has nearly uniform structure. Among these specimens the marble and the dunite are also heterogeneous, more or less, in examination on a similar scale. In the next section, the characteristics of heterogeneity of rocks will be examined in relation to the generation of the elastic shocks.

3. Results of Observations

When the compressional stress of 800-950 kg/cm^2 was applied to the rock specimens in room temperature, many of the elastic shocks were observed until the main rupture took place.

Fig. 1 is a record of the elastic shocks whose amplitudes are larger than 3 mm and the durations of vibrations are about 0.1 sec..

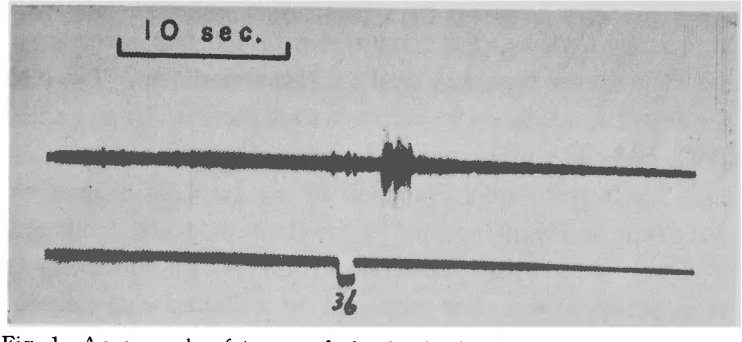


Fig. 1 An example of traces of elastic shocks prior to a main rupture.

The relative energy of the elastic shocks is calculated as a square of the maximum amplitude, that is, $E=ka^2$, where a is the maximum trace amplitude and k is a constant. If an average elastic strain ε is assumed to distribute uniformly in the volume V of the strained rock specimen, the strain energy is given

by $E'=\mu\varepsilon^2 V/2$, where μ is an elastic constant.

When an elastic shock occurs inside the rock specimen, a fraction p of the elastic strain energy is converted into wave energy. Accordingly, E is given by $E=pE'$ and the elastic strain ε is expressed by

$$\varepsilon=\kappa E^{\frac{1}{2}}=\kappa_1 a \qquad (1)$$

where $\kappa^2=2/(p\mu V)$ and $\kappa_1{}^2=2k/(p\mu V)$.

Using the formula (1), the summation of ε of successive shocks $\Sigma\varepsilon$ or $\Sigma E^{\frac{1}{2}}$ was calculated and plotted against time, as shown in Fig. 2, being compared with the strain curve of the rock.

As may be seen from these graphs, in so far as the strain has a linear relation with the applied stress of comparatively short duration, no elastic shock occurs inside the specimens except that a few shocks are observed in the case of the dunite. But at the beginning of the non-linear strain, a number of elastic shocks begin to take place abruptly and thereafter they occur at a constant rate until they again begin to increase and the main repture takes place. Furthermore, it is interesting to note that the pattern of $\Sigma E^{\frac{1}{2}}$ changes in parallel with the strain curve throughout the all stages of the rock creep.

The characteristics of the rocks summarized in Table 1 show that the non-elastic ultimate strain of the respective rocks varies remarkably and systematically with the number of shocks or $\Sigma E^{\frac{1}{2}}$ and also that they indicate approximately the degree of heterogeneity of the rocks as was examined under the microscope.

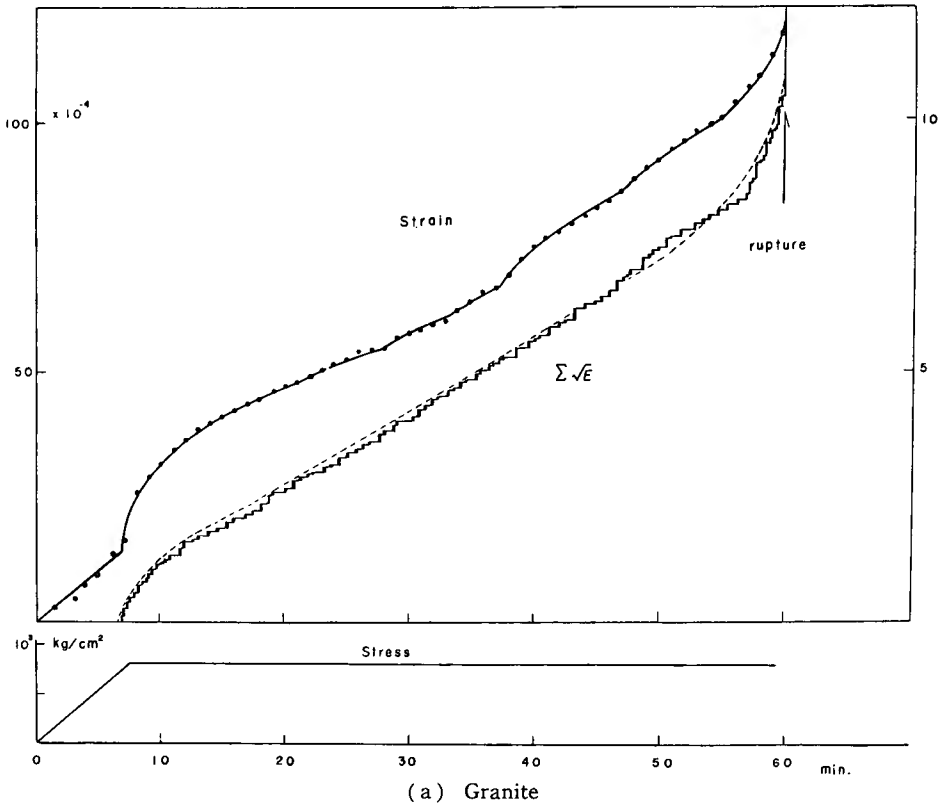
On the basis of these facts, it is clarified that the elastic shocks are caused by the local brittle fractures and the mechanism of the non-linear strain or the

Table 1 Characteristics of the rocks.

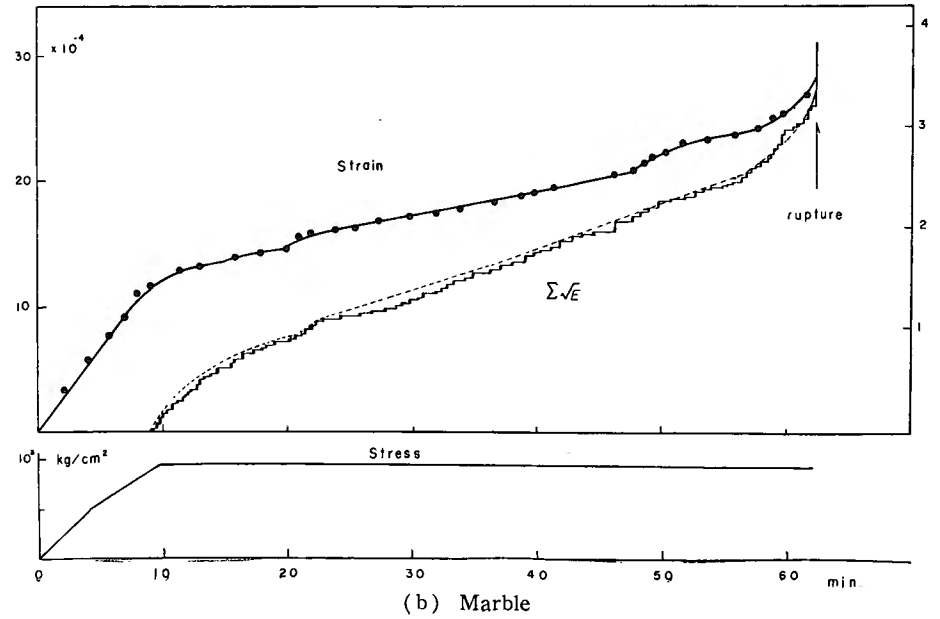
	Granite	Marble	Dunite	Sandstone
Elastic Ultimate strain	15×10^{-4}	7.0×10^{-4}	11×10^{-4}	0.9×10^{-4}
Non-elastic Ultimate strain	105×10^{-4}	19×10^{-4}	17×10^{-4}	1.0×10^{-4}
Number of Elastic shocks	105	85	69	15
$\Sigma E^{1/2}$*	10.5	3.3	2.6	0.4
Heterogeneity of Materials**	highly heterogeneous	heterogeneous	heterogeneous	nearly homogeneous

* Measured on a conventional scale.

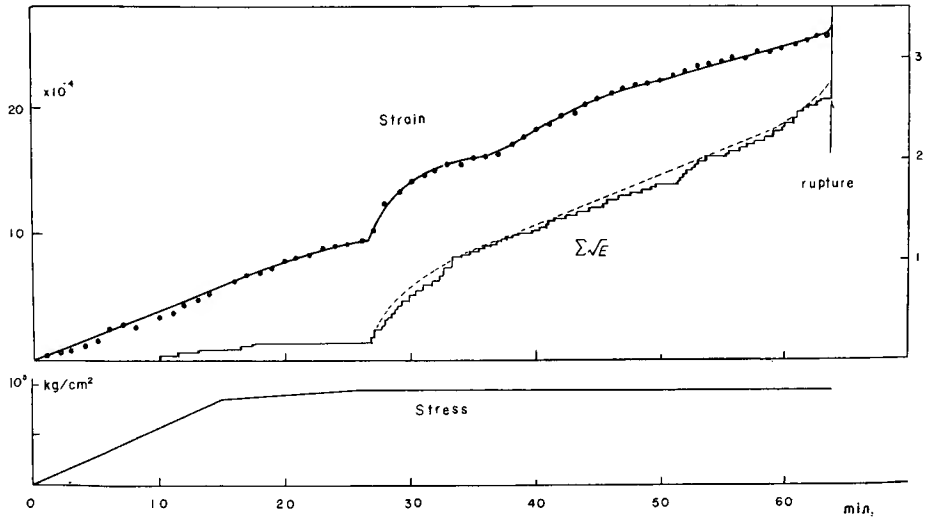
** Examined under the microscope.



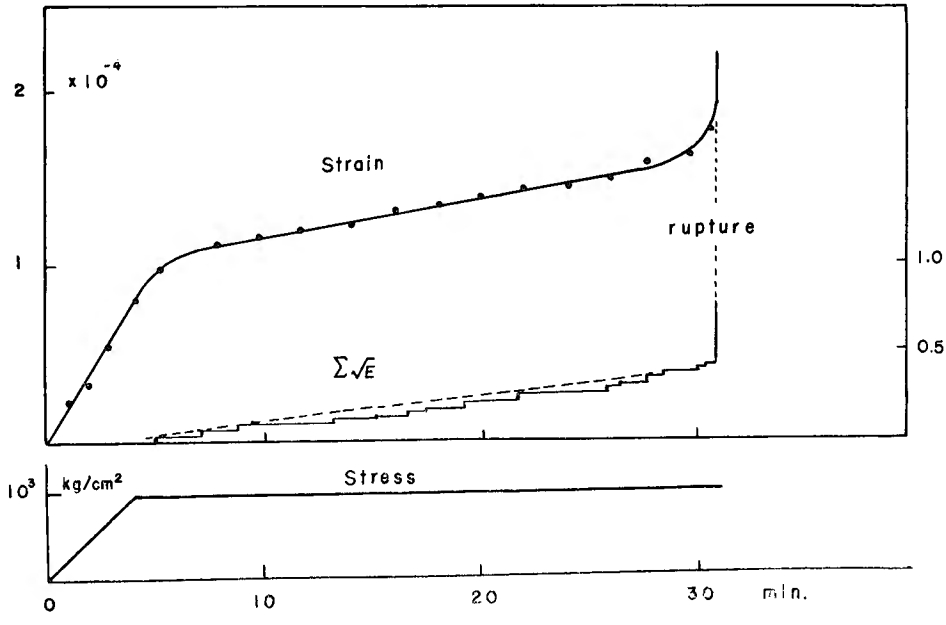
(a) Granite



(b) Marble



(c) Dunite



(d) Sandstone

Fig. 2 Strain curves measured in lateral direction and summations of the square root of elastic energy of successive shocks in arbitrary units.

creep of rocks is closely related to the occurrence of the local fractures inside the rock specimen.

Under the continuous application of constant stress, the strain of rocks has been measured by many authors [5, 6] and expressed by

$$S=a+b\log t+ct \qquad (2)$$

where t is the duration of stress application and a, b and c are appropriate constants.

The strain curves shown in Fig. 2 are also well expressed by this formula except in the part immediately before the main rupture.

As shown in the previous papers [7], the before-shock sequence of earthquakes has a quite similar pattern of occurrences, that is, the accumulated sum of the square root of the wave energy of the successive earthquakes ($\Sigma E^{\frac{1}{2}}$) agrees well with the formula (2).

If the main earthquakes of shallow foci are caused by the fractures in the earth's crust, minor shocks will occur in the brittle heterogeneous region under the gradually increasing stress. From this view point, the process of occurrences of the elastic shocks in the rock specimens can be applied to that of before-shocks, and hence the occurrence of the main earthquakes may be predicted by the observations of micro-earthquakes.

In conclusion of this report, the writer would like to express his cordial thanks to Professor Kenzo Sassa for his kind instruction and encouragement.

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