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Measurements of Velocity Variation of Rock Samples under Uniaxial Stress by a Modified Transmission Method

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Abstract

An improved method of measuring in-situ stress, which is based on the anisotropic behavior of sound wave velocity, was presented. In the method, velocities must be measured as a function of stress on one side plane of a rock body. This kind of measurements causes some problem that the transmission efficiency of P-wave which is the best indicator of stress is low, meaning that the velocity variation for the other type of waves has to be measured and it might not be noticeable.

To examine this problem, four devices are developed. Then, using them we measured the velocity variations of rock samples under uniaxial stresses in the way stipulated by this method. The measurements show that the velocity variation can be clearly detected though the type of the wave was not identified.

1. Introduction

Many interesting phenomena observed are considered to be caused by stresses acting in the crust. Earthquakes, crustal deformation and volcanic eruptions are the typical examples. There are many researches involving the measurement of crustal stress. It may be interesting to measure stress variation in relating volcanic activities. Although there are many measurements of strain variation, the direct measurement of stress being active seems to be rare.

It is considered that the elastic theory is not a good one to apply for shallow activities in a volcano. Physically stress and strain are different quantities and do not correspond one to one except the case of perfectly elastic body. As a consequence, the direct measurement of stress is worth to perform. Although for this purpose, several methods of measuring stress are already exist, there seems to be no method which is easy to perform repeatedly with low cost.

To do the measurement, Maeda and Shimizu (1983) proposed a method by using a relation between velocity or its anisotropic variation and applied stress. It is well known that the velocity of rock depends on stresses applied. The velocity variation is attributed to the change in volume and shape of cracks in the rock (O'Connell and Budiansky, 1974). When the stress is anisotropic, the velocity of the rock becomes anisotropic. It is also considered that this velocity anisotropy is attributed to the directional dependence of change in volume and shape of cracks. The fact that velocity variation or anisotropy is a function of stress can be put inversely as that the stress applied is a function of its variation or anisotropy. This means that if we know its variation or anisotropy as a function of stress, by measuring velocities, we can estimate the stress being applied.

The procedure which Maeda and Shimizu (1983) proposed is, as follow,

1) drill a hole to some depth,
2) drill several small holes from the bottom of the hole,
3) measure velocities between the smaller holes.

The measured values are compared with the values of the core sample, measured as a function of stress, retrieved from the bottom of the hole.

A serious defect of this procedure in practice is the step 2). If we can measure the velocity at the bottom of a hole as a function of direction, it will be sufficient when we assume that one of the principal stress is in the axis of the hole. This means that an emitter and a receiver must be attached on one surface plane of a rock body. Although this type of measurements is usually made in a sonic log in the vertical direction, it is not easy to perform when the hole diameter is small and required accuracy of the measurements is rather high. In possible situations, we have to employ a rather high frequency signal. It is needed to develop a device adequate for this purpose.

In this report we examine what type of devices is efficient and by the device how accurately we can measure the velocity variation as a function of stress.

2. Devices

The device which can be employed in a field measurements must satisfies following several requirements,

1) Size of the device, especially width, must be limited say 60 mm in width.

2) It can emit and receive a signal on one side of a rock body. (usual transmission method can't be used)

3) In order to measure the directional dependence of the velocities, we can easily repeat a procedure to attach and remove the emitter-receiver pair to/from the bottom of a hole, which may be not sufficiently smooth.

Taking account of these requirements, we designed four types of devices, which were shown in Fig. 1. The devices are mainly made of three parts, one supporting unit and two transducer rods which contain a piezoelectric transducer

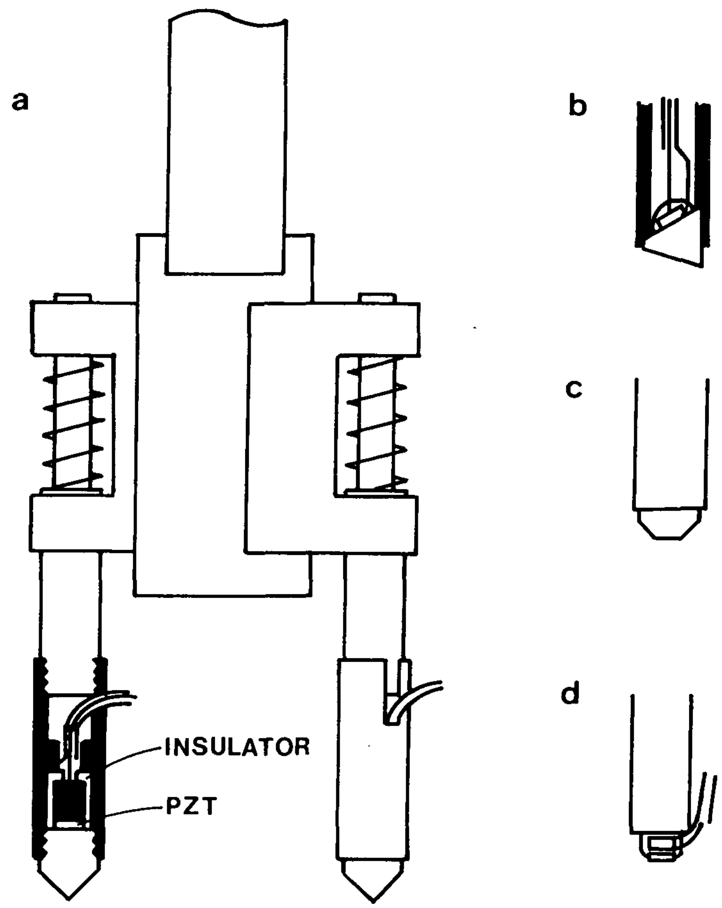

Fig. 1. The whole structure of the device *a*. The transducer rod of the devices *b*, *c* and *d*.

(PZT). The supporting unit is common and only the transducer rods are different.

The width of the device is taken to be less than 60 mm and the distance between the emitter and receiver is about 40 mm. With this distance, a rather high frequency signal will be desirable to make the measurement accurate. The signal frequency in the range of 0.1 to 5 MHz may be adequate. We used PZT of characteristic frequency of 2 MHz, but the pulses which activate the transducer have a rise time of 0.5 μsec and a half width of 2 μsec.

Characteristic features of four type of the transducer rods are as follow;

a) This has a sharp tip which makes it point contact with a rock surface. The piezoelectric transducer of compressional mode is placed between the base of a brass cone and a metal rod with diameter equal to that of the transducer. Point contact makes it easy to know the length of the signal path.

b) The type *b* device has a different tip structure made of tungsten carbide which is cut out from a column with angles 60° and 15° at each end. The same type transducer as the type *a* is attached at one end, of which angle is 60°, of the tip.

c) This device is produced from the type *a* device by cut out the pointed tip in order to increase the contact area. To improve mechanical matching with samples, a lead plate is attached to the end surface of the cone.

d) A piezoelectric transducer is attached on one end of a brass column. On the transducer, a lead plate is attached with the same reason as the device *c*.

3. Measurements

Measurements of velocities as a function of uniaxial stresses were made on one of side surfaces of granite samples having a size of $30 \times 30 \times 73$ mm. The direction of the emitter to the receiver is parallel to loading axis. We expect that the variation of velocity will be maximum in this direction. We measured arrival times of signals reached to the receiver after stacking a sufficient number of the signals under a given stress. Measurements were repeated at several different stresses. Then we calculated velocities assuming that the path of the signals is straight line from the emitter to receiver.

The efficiency of the devices can be judged by the amplitudes of the first phase of output signals with constant input pulses. Figure 2 shows the examples of observed signals obtained through four devices. It can be seen from the figure that the amplitude of the first phase obtained by the device *c* is the

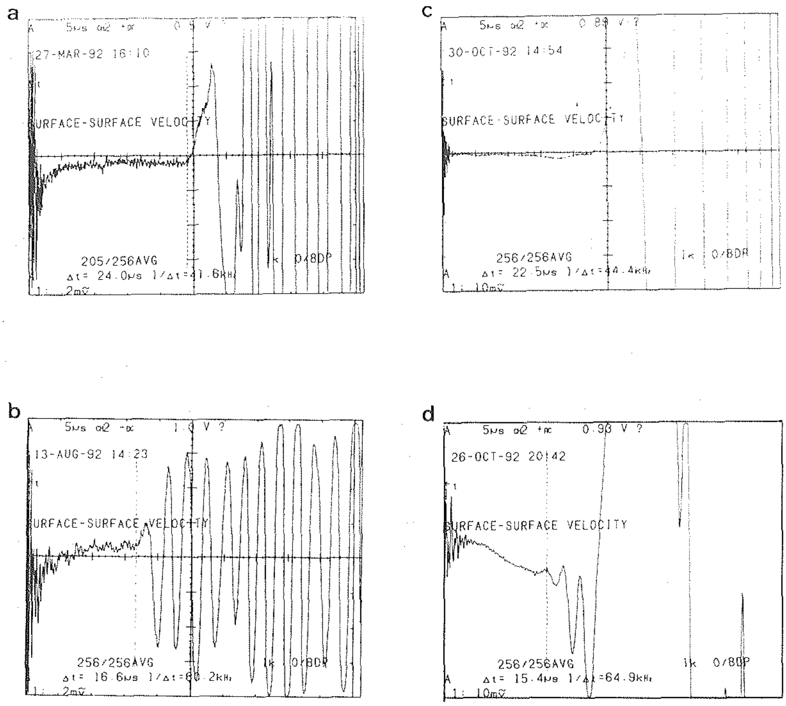

Fig. 2. The example of observed signals obtained through four devices. The stress applied is 50 to 100 bar. A broken line indicates the arrival of the first phase.

largest ; it is ten, twenty and four times larger than that of the device *a*, *b* and *d* respectively.

Wave forms of the first phase observed by the devices *a* and *c* are nearly the same, which reflects the fact that the internal structures of the emitter-receiver rods are the same except the form of the tip of them.

The above comparison shows that the device *c* is the most adequate for practical use.

The next problem to be examined is whether we can detect the velocity variation as a function of stress. The reason for this is as follow ; The radiation pattern of P-waves by a PZT with compressional mode attached on a plane has the maximum intensity in the direction perpendicular to the plane and usually the minimums in the directions parallel to the plane. On the other hand, the velocity variation of the P-wave is the largest comparing to that of other kinds of waves with the same amount of stress change.

From these we can not expect as a matter of fact that our arrangement of the transducers is adequate for the present purpose. For our purpose it is not required to observe direct P-waves but sufficient to be able to measure the velocity variation of a certain phase as a function of stress.

To examine this problem, we measured the velocities using the four type devices described in the preceding section. Although the velocity itself would not depend on the type of the devices. At any rate, we can check the feasibility of the devices. Figure 3 shows the velocity variations as a function of the uniaxial stress. Each figure *a, b, c* and *d* was obtained by using a device of type *a, b, c* and *d*, respectively. It is evident that we can detect the velocity variation though we don't know what kind of wave we are measuring. A rather smooth variation of the velocity obtained by using the device *a* may be attributed to its sharp tip. Other devices contact to rock samples over a line or a plane, though the length or the area is less than several millimeters or square millimeters. Under stress, strain of the sample causes to change the contacting condition of the devices with a sample. This change may affect the transmission efficiency or the effective distance between the emitter and receiver,

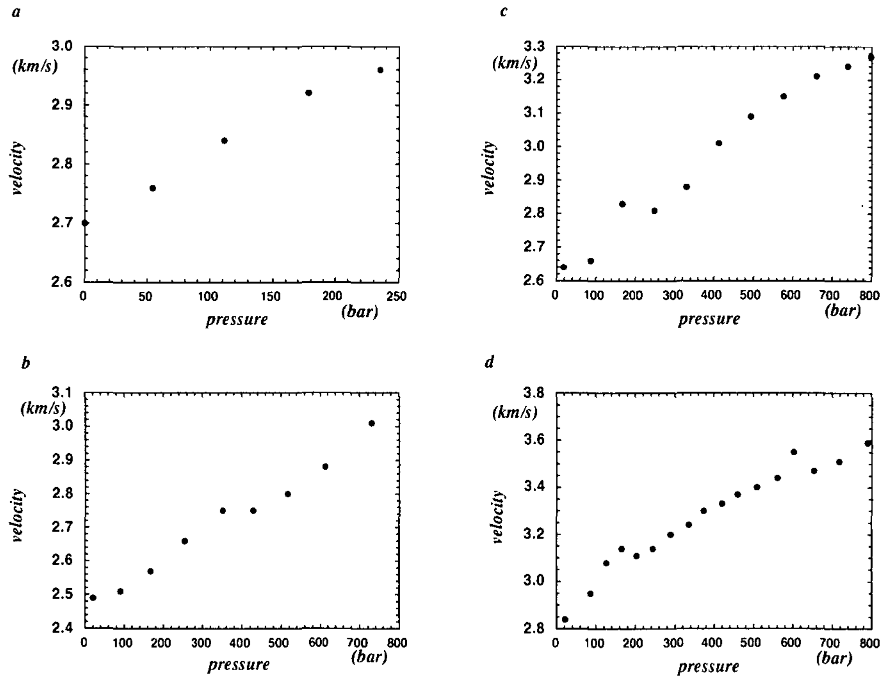

Fig. 3. The velocity variations as a function of the uniaxial stress.

resulting an ostensible anomaly in the variation. Determination of the effective distance between the emitter and receiver introduces some ambiguity in the calculation of velocities from the observed transmission times. The total amounts of the velocity variation under stress up to 800 bar (80 MPa) are 21%, 24% and 26%, when device *b*, *c* and *d* are used respectively. These devices contact with the samples not on a point but over a length or an area. Especially the devices *c* and *d* contact with a sample over a circular area of 6 mm in diameter. This makes the effective distance a bit ambiguous and may result in the different amount of the velocity variation given above.

The total amounts of the velocity variation in the present cases (less than 10% for the stress of 200 bar) are rather low comparing to that reported by Maeda and Shimizu (1983) (nearly 30% for the same stress). This difference may be attributed to the fact that the amounts of the velocity variation depend on the type of waves among which P-wave shows the largest variation. We can say that what we measured is at least not P-wave. The amount affects the accuracy of stress deduced from the data ; The larger the variation is, the more accurate the stress deduced is. Judging from their results, we deduce that the accuracy of the present method will be 30% or less.

4. Conclusions

It has been proved that by the present method the velocity variation can be detected though the variation has been a bit smaller than that of the P-wave. The type of the waves to which the wave we measured belongs was not identified. At any rate, the possibility to deduce the stress acting by measuring velocities has become evident.

For the purpose, the type *c* device is preferable but is needed to improve the stability of its contact with a rock surface.

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