DISASTER PREVENTION RESEARCH INSTITUTE

BULLETIN No. 32 MARCH, 1960

VARIATION OF THE ELASTIC WAVE VELOCITIES OF ROCKS IN THE PROCESS OF DEFORMATION AND FRACTURE UNDER HIGH PRESSURE

BY

SHOGO MATSUSHIMA

KYOTO UNIVERSITY, KYOTO, JAPAN

DISASTER PREVENTION RESEARCH INSTITUTE
KYOTO UNIVERSITY
BULLETIN

Bulletin No. 32 March, 1960

Variation of the Elastic wave Velocities of Rocks in the Process of Deformation and Fracture under High Pressure

By

Shogo MATSUSHIMA

Variation of the Elastic wave Velocities of Rocks in the Process of Deformation and Fracture under High Pressure

By

Shogo MATSUSHIMA

Geophysical Institute, Faculty of Science, Kyoto University

(Communicated by Prof. K. Sassa)

Abstract

Variation of the ultrasonic velocities of granite in the process of deformation and fracture caused by the axial compressional stresses was observed under high confining pressure up to 5,000 atmospheres. At the initial stage of deformation, the velocities increased with the overlapped stresses, then reached the constant value in cases of both the axial direction and the transverse of it. In the facture range, however, the velocities of waves passing through in the direction transverse to the axis remarkably decreased with the progression of facture, while such change of velocities was scarcely observed in the axial direction.

The tendency of the velocity change as stated above decayed rapidly with elevating pressure. Then, these phenomena can be explained with the assumptions of pores, closed initially and extended by pressures or stresses at the fracture stage, the same as the increase of strength with that of pressure and the extraordinary stress-strain relation reported in the previous papers.

Introduction

In our previous experiments[1] on the mechanism of deformation and fracture of igneous rocks, we researched that the rocks had the extraordinary values of Poisson's ratio in the fracture range caused by the axial compressional stresses. That is, the lateral strain increases abruptly with the increase of the stress in this range, and the ratio of the lateral strain to the longitudinal is far beyond 0.5, suggesting that the volume of the specimen increases with development of fracture, because the longitudinal strain varies almost linearly. Under elevating confining pressure these phenomena gradually disappear with the increase of pressure, and over two or three thousands atmospheres they are scarcely observed.

On the other hand, the strength of rocks increses rapidly with the increase of pressure, but the rate of the rise of the strength has the same decreasing tendency as of the variation of Poisson's ratio in the fracture range.

These properties will be the characteristic of igneous rocks, and can be elucidated by a large number of pores contained in the rock specimen which may act like "the Griffith's cracks" in case of fracturing. The volume-increase at fracturing can be interpreted with the assumption that the progression of such pores or cracks produces the accumulation of a bulk of cavity. The increase of strength with that of pressure can be explained by closing of the pores.

It has been clearly explained from the experimental results by F. Birch[2] and D. S. Hughes[3] that such cavities originally contained in the rocks have a remarkable effect upon the elastic wave velocities of them under pressure. The influence is stronger under a lower pressure. On the other hand, it has been reported[4] that the variation of elastic wave velocities of metals caused by the plastic deformation is within the limit of only one per cent.

Then it is expected that at the fracturing under a relatively low pressure, the velocities of rocks decrease appreciably, for they have also the considerable bulk of cavities produced in themselves. Yet, from the experiments of the strain measurements, it is supposed that this decrease must be remarkable in the direction transverse to the applied axial stress, though the velocities of the axial one may scarcely change.

F. Birch has also suggested that the factors having influence on the seismic wave velocity in the crust are pressure, temperature and the mineral composition of it. The rise of pressure increases velocity, that of temperature decreases it, and the increase of the composition of the basic minerals strongly increases the velocity in general.

However, under the pressure which can not perfectly close the pores of rocks, the applied differential stresses overlapped to the hydrostatic pressure will be able to affect upon the wave velocities, for they can close the pores too.

From the above viewpoint, we studied the variation of the elastic wave velocities of granite in the process of deformation and fracture caused by the axial compressional stresses under moderate confining pressures up to 5,000 atmospheres.

Experimental Methods

Fig. 1 shows schematically the methods of ultrasonic measurements of rocks under the axial compressional stress combined with high confining pressure both a) in the direction of the axis and b) transverse to the axis. The high pressure equipment and the full sketch of the triaxial cylinder for this experiment were shown in the previous paper.

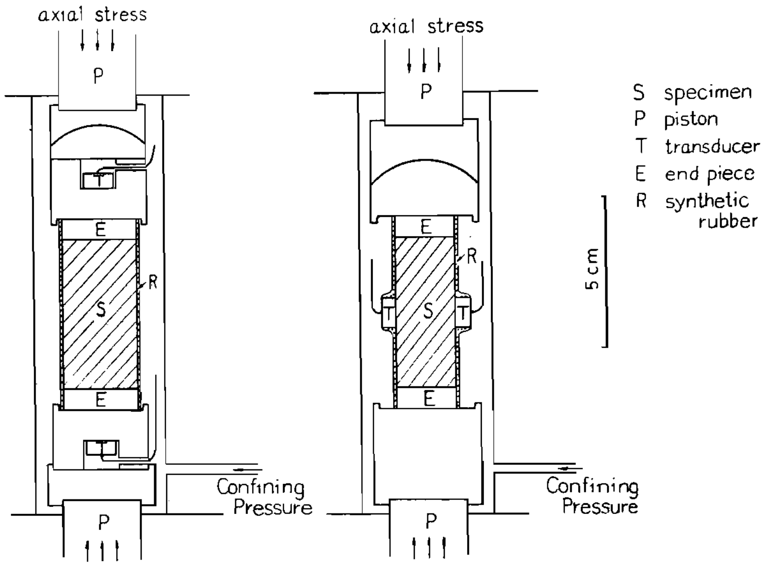

Fig. 1. The schematic representation of the methods for the measurements of the ultrasonic wave velocities under axial compressional stress combined with high confining pressure, a) in the axial direction, and b) in the direction transverse to the axis.

Specimens used for the measurements of the axial direction shown in Fig. 1, a) are the long columns of Kitashirakawa biotite granite 50 m/m long and 25 m/m in diameter, and that of the transverse direction in b) are the square pillars of the same location, 50 m/m height and 20 m/m in the base.

All specimens are covered with synthetic adhesive rubber. The barium titanate crystals are used as the ultrasonic transducer which generates dilatational waves of frequency of 500 k.c..

Experimental Results

In Fig. 2 and Fig. 3, the variation of the dilatational wave velocities with stress respectively in the axial and the transverse direction under various confining pressures is shown. In each case, the velocities show the increase with the increasing of the axial stress, and reach the nearly constant value. This will mean that the pores of the specimen have not yet been perfectly closed under these pressures, and that the overlapped forces close gradually such residual cavities. Under higher pressure, the additional stresses scarcely affect on the variation of velocity, for the pores are fully closed. The ultimate values of velocities are nearly constant for each specimen without regard to the measured directions and the confining pressures.

In the fracture stages, however, the tendency of the velocity change is quite different in each observed direction. The velocities of the transverse direction abruptly decrease with the progress of the internal failure which is caused by the increase of stress and with the lapse of time, though that of

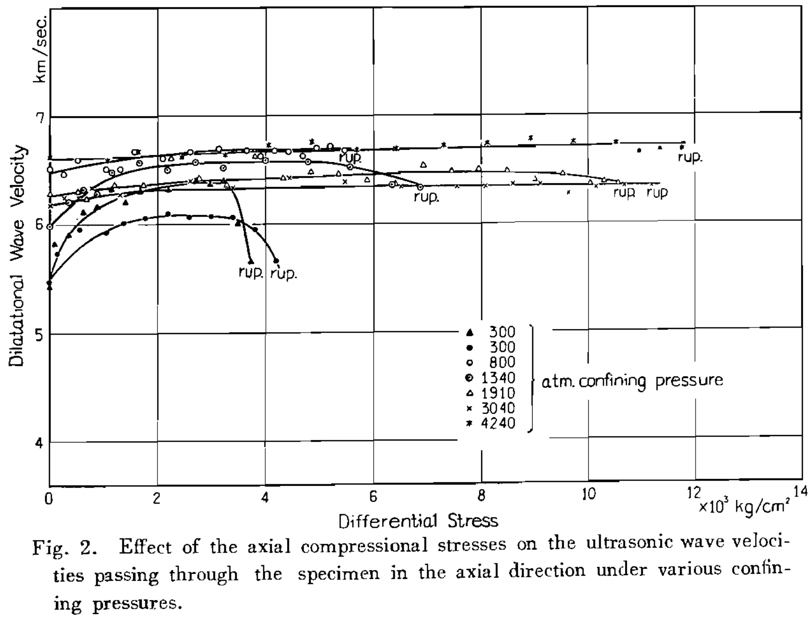

Fig. 2. Effect of the axial compressional stresses on the ultrasonic wave velocities passing through the specimen in the axial direction under various confining pressures.

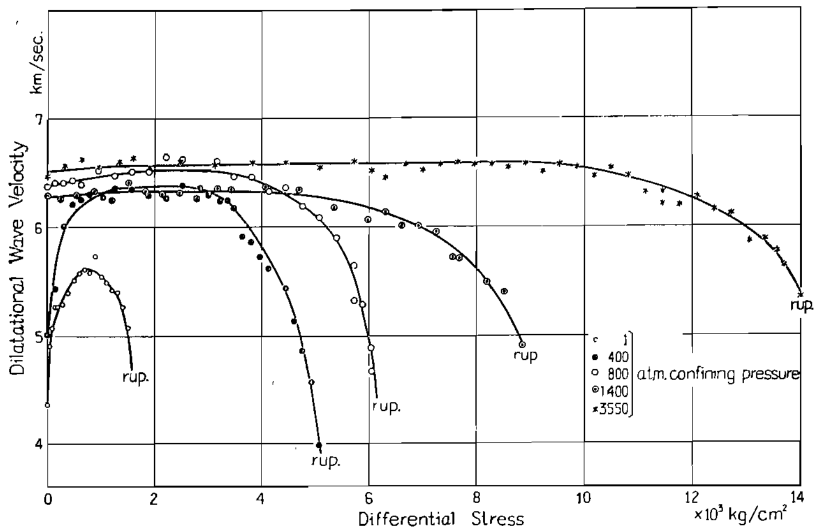

Fig. 3. Effect of the axial compressional stresses on the ultrasonic wave velocities passing through the specimen in the direction transverse to the axis under various confining pressures.

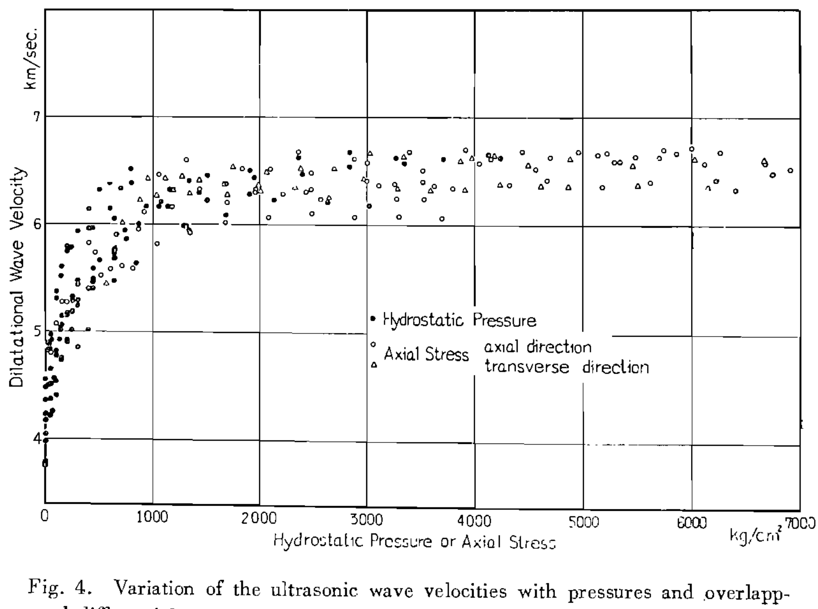

Fig. 4. Variation of the ultrasonic wave velocities with pressures and overlapped differential stresses.

the axial one are approximately constant up to the rupture moment. The change of length of specimens is negligible to this tendency, for this effect is in the limit of the observed error. The above phenomena will show that the considerable apertures are produced in the lateral direction with the progress of fracture. This tendency gradually decays under higher pressure, it is the same tendency as observed at the strain measurements.

As expected before, it is shown in Fig. 4 that the elastic wave velocities of rocks increase with the increasing of the applied axial compressional stresses overlapped to the confining pressure as well as with that of the hydrostatic pressure. The rates of the increase by the hydrostatic pressure and the axial stress are the same order of the magnitude, though the numbers of the observed values are insufficient to assert it. Then it may be said that the overlapped forces have nearly the same effect upon the wave velocity as hydrostatic pressure.

Conclusion

It will be supposed, though it may be very impudent, that the seismic wave passing through the relatively shallow region in the crust, where the composed rocks are highly stressed by a overlapped force and being fractured, decreases its velocity in the direction transverse to the applied force. In the deeper part of the crust, these effects may not be observed, because the confining pressure is strong enough here to be brought no change of velocity by the overlapped force.

If the above argument is possible on the earth's crust, the variation of the seismic wave velocity can be observed in the progress of the shallow forcus earthquakes, or even of the somewhat deeper earthquakes, fo which the region extends to the part near the surface, such as accompanied by the surface faulting.

It will be possible to explain the velocity distribution, considering the stress distribution in the crust.

Acknowledgements

The writer wishes to express his sincere thanks to Professor K. Sassa for his continual encouragements.

The present study has been performed by the aid of the resarch funds of the Ministry of Education for this Institute.

References

1) S. Matsushima, "On the flow and fracture of igneous rocks.", J. Phys. of the Earth., (In Press)

——, "On the deformation and fracture of granite under high confining pressure.", J. Phys. of the Earth., (In Press)

2) F. Birch, "Seismic structure of the crust.", Contributions in Geophysics, vol. 1, 158–70 (1958)

3) D. S. Hughes, C. Maurette, "Elastic wave velocities in granites.", Geophysics, vol. 21, 277–84 (1956)

——, ——, "Variation of elastic wave velocities in basic igneous rocks with pressure and temperature.", Geophysics, vol. 22, 23–31 (1957)

4) R. S. Bergman, R. A. Shahbender, " Effect of statistically applied stresses on the velocity of propagation of ultrasonic waves.", J. Appl. Phys., 1736–38 (1958)

Publications of the Disaster Prevention Research Institute

The Disaster Prevention Research Institute publishes reports of the research results in the form of bulletins. Publications not out of print may be obtained free of charge upon request to the Director, Disaster Prevention Research Institute, Kyoto University, Kyoto, Japan.

Bulletins :

No. 1 On the Propagation of Flood Waves by Shoitiro Hayami, 1951.

No. 2 On the Effect of Sand Storm in Controlling the Mouth of the Kiku River by Tojiro Ishihara and Yuichi Iwagaki, 1952.

No. 3 Observation of Tidal Strain of the Earth (Part I) by Kenzo Sassa, Izuo Ozawa and Soji Yoshikawa. And Observation of Tidal Strain of the Earth by the Extensometer (Part II) by Izuo Ozawa, 1952.

No. 4 Earthquake Damages and Elastic Properties of the Ground by Ryo Tanabashi and Hatsuo Ishizaki, 1953.

No. 5 Some Studies on Beach Erosions by Shoitiro Hayami, Tojiro Ishihara and Yuichi Iwagaki, 1953.

No. 6 Study on Some Phenomena Foretelling the Occurrence of Destructive Earthquakes by Eiichi Nishimura, 1953.

No. 7 Vibration Problems of Skyscraper. Destructive Element of Seismic Waves for Structures by Ryo Tanabashi, Takuzi Kobori and Kiyoshi Kaneta, 1954.

No. 8 Studies on the Failure and the Settlement of Foundations by Sakurō Murayama. 1954.

No. 9 Experimental Studies on Meteorological Tsunamis Traveling up the Rivers and Canals in Osaka City by Shoitiro Hayami, Katsumasa Yano, Shohei Adachi and Hideaki Kunishi, 1955.

No.10 Fundamental Studies on the Runoff Analysis by Characteristics by Yuichi Iwagaki, 1955.

No.11 Fundamental Considerations on the Earthquake Resistant Properties of the Earth Dam by Motohiro Hatanaka, 1955.

No.12 The Effect of the Moisture Content on the Strength of an Alluvial Clay by Sakurō Murayama, Kōichi Akai and Tōru Shibata, 1955.

No.13 On Phenomena Forerunning Earthquakes by Kenzo Sassa and Eiichi Nishimura, 1956.

No.14 A Theoretical Study on Differential Settlements of Structures by Yoshitsura Yokoo and Kunio Yamagata, 1956.

No.15 Study on Elastic Strain of the Ground in Earth Tides by Izuo Ozawa, 1957.

No.16 Consideration on the Mechanism of Structural Cracking of Reinforced Concrete Buildings Due to Concrete Shrinkage by Yoshitsura Yokoo and S. Tsunoda. 1957.

No.17 On the Stress Analysis and the Stability Computation of Earth Embankments by Kōichi Akai, 1957.

No.18 On the Numerical Solutions of Harmonic, Biharmonic and Similar Equations by the Difference Method Not through Successive Approximations by Hatsuo Ishizaki, 1957.

No.19 On the Application of the Unit Hydrograph Method to Runoff Analysis for Rivers in Japan by Tojiro Ishihara and Akiharu Kanamaru, 1958.

No.20 Analysis of Statically Indeterminate Structures in the Ultimate State by Ryo Tanabashi, 1958.

No.21 The Propagation of Waves near Explosion and Fracture of Rock (I) by Soji Yoshikawa, 1958.

No.22 On the Second Volcanic Micro-Tremor at the Volcano Aso by Michiyasu Shima, 1958.

No.23 On the Observation of the Crustal Deformation and Meteorological Effect on It at Ide Observatory and On the Crustal Deformation Due to Full Water and Accumulating Sand in the Sabo-Dam by Michio Takada, 1958.

No.24 On the Character of Seepage Water and Their Effect on the Stability of Earth Embankments by Kōichi Akai, 1958.

No.25 On the Thermoelasticity in the Semi-infinite Elastic Soid by Michiyasu Shima, 1958.

No.26 On the Rheological Characters of Clay (Part 1) by Sakurō Murayama and Tōru Shibata, 1958.

No.27 On the Observing Instruments and Tele-metrical Devices of Extensometers and Tiltmeters at Ide Observatory and On the Crustal Strain Accompanied by a Great Earthquake by Michio Takada, 1959.

No.28 On the Sensitivity of Clay by Shinichi Yamaguchi, 1959.

No.29 An Analysis of the Stable Cross Section of a Stream Channel by Yuichi Iwagaki and Yoshito Tsuchiya, 1959.

No.30 Variations of Wind Pressure Against Structures in the Event of Typhoons by Hatsuo Ishizaki, 1959.

No.31 On the Possibility of the Metallic Transition of MgO Crystal at the Boundary of the Earth's Core by Tatsuhiko Wada, 1960.

No.32 Variation of the Elastic wave Velocities of Rocks in the Process of Deformation and Fracture under High Pressure by Shogo Matsushima, 1960.

Bulletin No. 32 Published March, 1960

昭和 35 年 3 月 12 日 印刷
昭和 35 年 3 月 15 日 発行

編輯兼発行者 京都大学防災研究所

印刷者 山代多三郎

京都市上京区寺之内通小川西入

印刷所 山代印刷株式会社