STUDY ON EXCAVATION DISTURBANCE IN THE KAMAISHI MINE, JAPAN

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INTRODUCTION

An extensive geoscientific study program is being carried out to characterize the geological environment in Japan and to understand processes which occur in the geological environment[1]. This study contributes to the establishment of a scientific basis for the research and development work on geological disposal of high level radioactive waste. In this connection, in-situ experiments are underway to investigate the underground environment in granitic rock in the Kamaishi Mine, which was formerly one of the largest iron mines in Japan[2]. Existing shafts and drifts permit access to the deep geological environment. There is also information on geological structure, which we can use as the basic information for the in-situ experiments.

One of the main issues to be studied by the in-situ experiments is the mechanical and hydrological disturbance due to drift excavation. The EDZ(=Excavation Disturbed Zone), where rock properties are changed due to excavation, is considered to be physically less stable and a possible path for solute transport. Detailed estimation of the EDZ is essential for adequate design and safety assessment of underground excavations. The objectives of our study on excavation disturbance are:

1) to obtain data on rock properties and extent of the EDZ,
2) to develop investigation methods for characterizing the EDZ,
3) to improve our understanding of the generating mechanism of the EDZ and
4) to estimate the effects of excavation method on excavation disturbance.

This paper describes the results of our study on excavation disturbance carried out around an old mine drift in the Kamaishi Mine in 1993 and 1994.

OUTLINE OF IN-SITU RESEARCH PROGRAM IN KAMAISHI MINE

The Kamaishi Mine is located about 600 km north of Tokyo. The geology in the area consists of Paleozoic and Cretaceous sedimentary rocks and two igneous complexes, Kurihashi granodiorite and Ganidake granodiorite (Figure 1).

The in-situ research program in the Kamaishi mine is divided into two phases of five years each. Phase I was started in 1988 and completed in 1992. Phase II was started in 1993 and will end in 1997. The Phase I research was carried out in the EL.550m drift, which is 550 m above sea level and about 260 m below the surface. The Phase II research is being carried out in both the EL.550m drift and the EL.250m drift, located 250 m above sea level and about 730 m below the surface. Both drifts are located in the Kurihashi granodiorite, as shown in Figure 1. Table 1 shows average laboratory-derived rock properties of Kurihashi granodiorite.

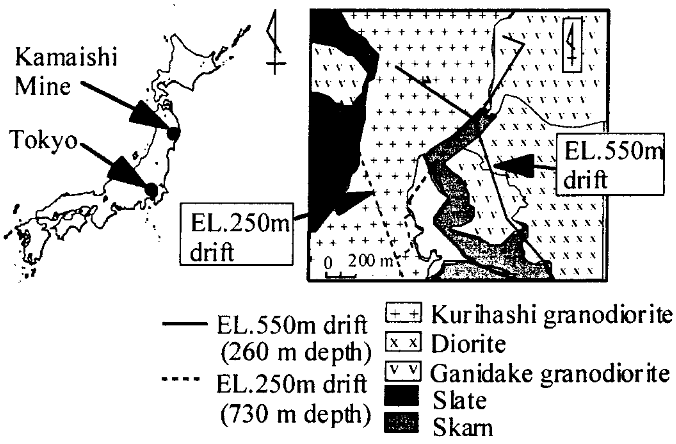


Figure 1 Location Map and Geological Setting of the Kamaishi Mine

Table 1 Rock Properties of the Kurihashi Granodiorite

Natural Density	2.71	g/cm^3
Effective Porosity	1.3	%
P-wave Velocity	5.8	km/s
Unconfined Compressive Strength	144.4	MPa
Indirect Tensile Strength	6.9	MPa
Deformation Modulus	58.2	GPa
Poisson's Ratio	0.25	
Cohesion	23.3	MPa
Internal Friction Angle	52.6	°

The Phase I study of excavation disturbance was carried out in 1988 and 1989 with the excavation of a new drift. The study of excavation disturbance in Phase II is being carried out in the EL.250m drift, based on the results of Phase I. The Phase II study consists of two stages; investigation of the EDZ around an old mine drift in 1993 and 1994, and experiments to be conducted with the excavation of a new drift from 1995 to 1997.

The main objective of the investigation in 1993 and 1994 was to assess the capability of the available measuring methods to characterize the EDZ. The measuring methods that will be used in the experiment from 1995 to 1997 will be selected on the basis of the results obtained from the investigations of 1993 and 1994. The site selected for the investigation is the EL.250m drift, which was excavated by conventional drill-and-blast method. It was expected that the capability of measuring methods would be easily demonstrated under deep and stable rock conditions, as the drift was excavated about twenty years ago at a depth of about 730 m.

DETAILS OF INVESTIGATION IN 1993 AND 1994

Figure 2 shows the drift and borehole layout for the investigations conducted in 1993 and 1994. Geological features of the investigation site were characterized by fracture mapping along the drift wall, core logs and borehole television(BTV) observations. The rock properties and extent of the EDZ were estimated from seismic surveys, borehole jack tests and laboratory rock property tests on core samples.

Geological Observations

Drift wall observation was carried out along the EL.250m drift and fractures with a length of over 3 m were mapped. Core logs and BTV observations were carried out in all boreholes to record rock types and fracture orientations.

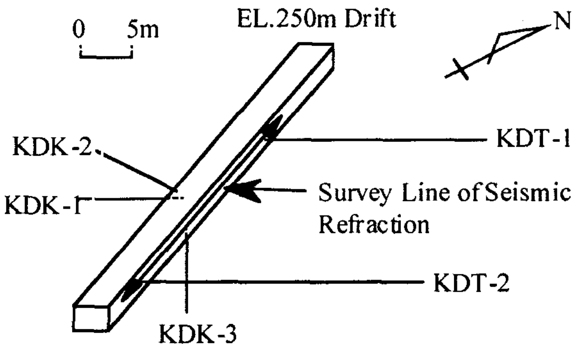


Figure 2 Layout of Drift and Boreholes for Investigation

Seismic Surveys

The seismic surveys include PS logging, a refraction survey and a tomography survey. Two horizontal 20 m long boreholes , KDT-1 and 2, were drilled 20 m apart along the drift wall. PS logging was performed in KDT-1 and 2, and a seismic refraction survey was performed along the drift wall between the KDT boreholes. The seismic tomography survey was performed between KDT boreholes and the drift wall.

PS Logging. P and S waves were generated with a hammer source and the dominant frequency of P and S waves was 200~500 Hz. A receiver was set in KDT-1 or 2, and measurements were carried out every 25 cm up to 5 m from the drift wall and every 50 cm farther from the drift wall.

Refraction Survey. A hammer source was employed and P waves refracted at a velocity boundary were received by geophones set every 50 cm in a line 11.5 m long along the drift wall.

Tomography Survey. A sparker was used as the source for the tomography survey and the dominant frequency of P wave was 3000~4500 Hz. Geophones and hydrophones were used as the receivers which were emplaced along the drift wall and in the boreholes, respectively, and the span between the receivers was 0.5 m. The cell size for back analysis was 1 m and the velocity distribution was calculated with back-projection(BTP) and algebraic reconstruction(ART) methods.

Bolehole Jack Tests

Bolehole jack tests were performed in three 10 m long boreholes, KDK-1,2 and 3, which were drilled horizontally, 45 degrees upward and vertically downward, respectively. The tests were performed under cyclic loading conditions, to a maximum pressure of 30 MPa, which is 20 % of the unconfined compressive strength. Tangential deformation and elastic modulus of in-situ rock were obtained for each stress level.

Laboratory Tests

The samples for laboratory rock property tests were recovered from the cores of the KDK boreholes and two other boreholes drilled in the investigation area of the EL.250m drift. Unconfined and triaxial compression tests, Brazilian tests and measurements of saturation, porosity and elastic wave velocity were performed.

Microscopic observation of seven thin sections of rock samples, recovered from borehole KDK-1, was also carried out in order to determine the extent of the excavation damaged zone. The specimens were treated with fluorescent resin, which is a mixture of acrylic resin and fluorescent paint, so that microcracks were easy to distinguish under ultraviolet light.

INVESTIGATION RESULTS AND DISCUSSION

Geological Observations

Drift wall observations, core logs and BTV observations revealed that the geology is granodiorite and the frequency of fractures with a length of over 3 m is 0.8/m in the investigation site. Figure 3 shows a sketch of the drift wall in the investigation area.

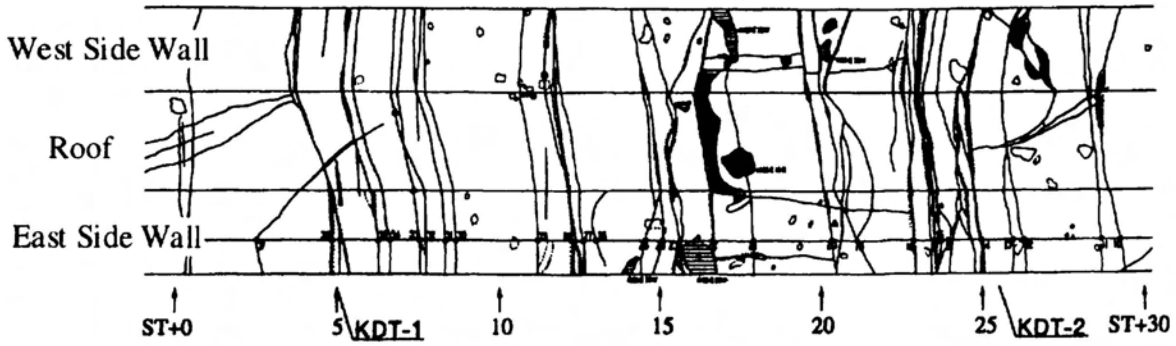
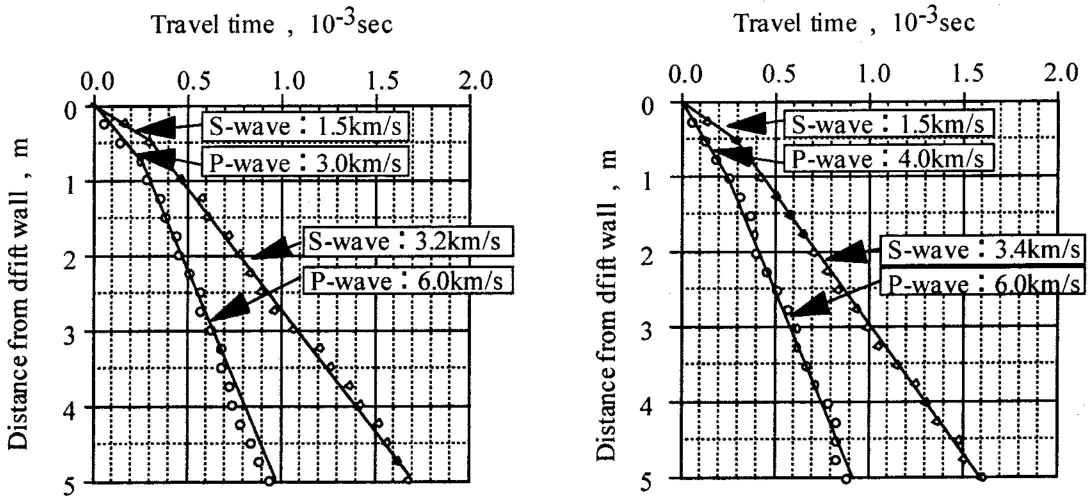


Figure 3 Fracture Map of Drift Wall in Investigation Area

Seismic Surveys

PS Logging. Figure 4 shows the results of PS logging. P wave velocity of the rock mass within about 75 cm of the drift wall is 30-50 % lower than that of intact rock. S wave velocity decreases by 60% within about 50 cm of the drift wall. S wave velocity decreases more



[KDT-1]

[KDT-2]

Figure 4 Seismic velocity estimated by PS logging

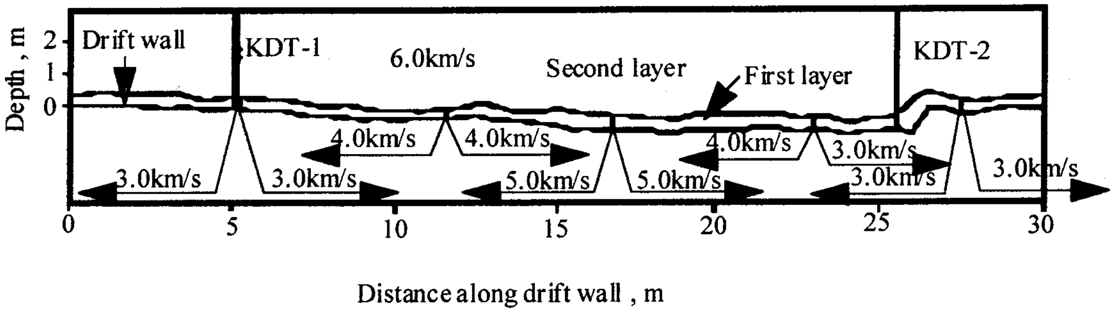


Figure 5 Seismic velocity along drift wall estimated by refraction survey

clearly than P wave velocity. P logging is supposed to be less accurate than S logging because of very high P wave velocity(about 6 km/s).

Seismic Refraction. Our interpretation of the results of the seismic refraction survey is shown in Figure 5. P wave velocity structure of the rock mass along the drift wall is composed of two layers. The first layer has a width of about 50 cm and a P wave velocity of 50~80% of the intact rock, which forms the second layer.

Seismic Tomography. P wave velocities within about 2 m of the drift wall are lower than that of the intact rock (Figure 6). However, the cell size of the tomographic reconstruction is 1 m2, so that the resolution of the velocity distribution is not sufficiently high to resolve as narrow a EDZ as interpreted from the PS logging and seismic refraction surveys. Therefore , the extent of the low velocity zone is probably overestimated in the tomogram. Other low velocity zones were also detected parallel to borehole KDT-2 and near the ends of boreholes KDT-1 and 2.

The low velocity zone along KDT-2 may correspond with a highly fractured zone revealed by the drift wall observations. Porosity in the alteration zone is about 2 times higher than that of the intact rock, and the higher porosity possibly accounts for the lower P wave velocities, particularly if the rock is unsaturated. Therefore, the low velocity zone along KDT-2 may indicate that the zone extends along natural fractures.

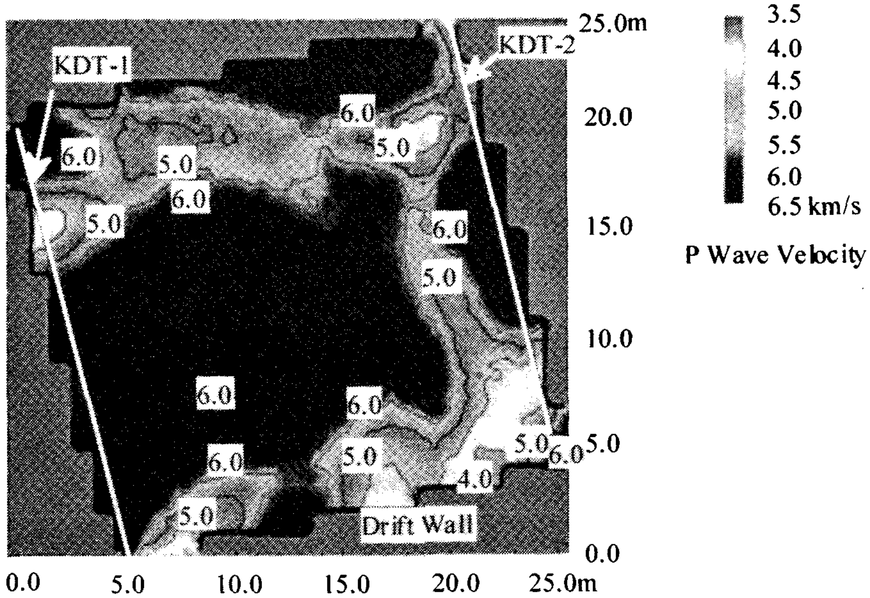


Figure 6 P Wave Velocity Distribution between KDT-1,2 and Drift Wall Estimated with Seismic Tomography

As for the low velocity zone around the ends of the boreholes, there is no known geological feature which accounts for the lower P wave velocities. As the main purpose of the seismic tomography was to understand the P wave velocity distribution near the drift wall, the ray path density is lower and angular coverage poorer around the ends of the boreholes than near the drift wall. Therefore, estimation of P wave velocity around the ends of the boreholes has low accuracy and the low velocity zone is likely an artifact.

Bolehole Jack Test

Figure 7 shows the deformation modulus values measured by the borehole jack test. Low deformation modulus were measured 0.5 m for the drift wall, in contrast to the higher deformation modulus values obtained in the area between 1 m and 6 m of the drift wall.

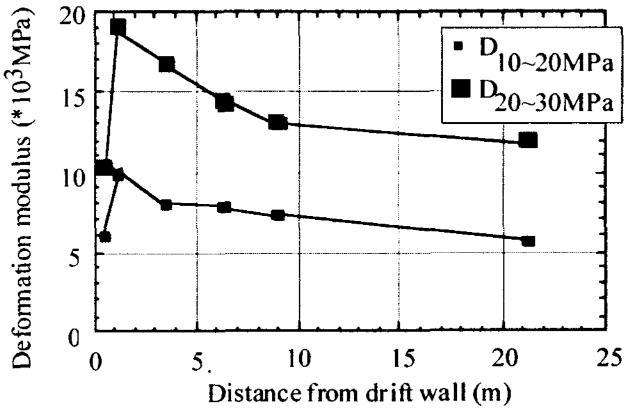


Figure 7 Deformation Modulus Variation with Distance from Drift Wall

Laboratory Tests

There was no clear relation between mechanical rock properties and distance from the drift wall. As an example, the distribution of elastic wave velocity is shown in Figure 8. However, the majority of the laboratory velocity measurements were made on cores taken at distances greater than 3 m, where little excavation disturbance is expected.

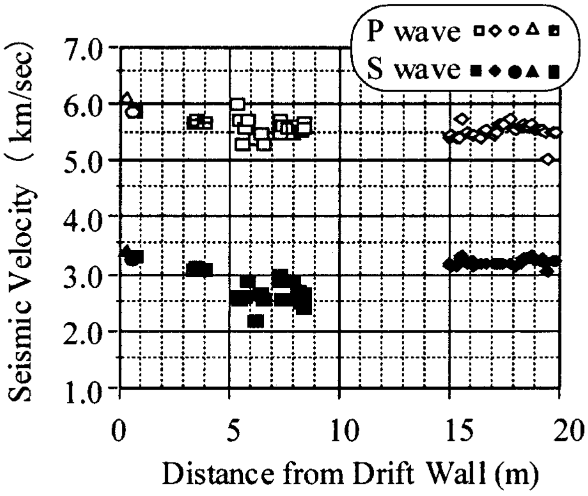
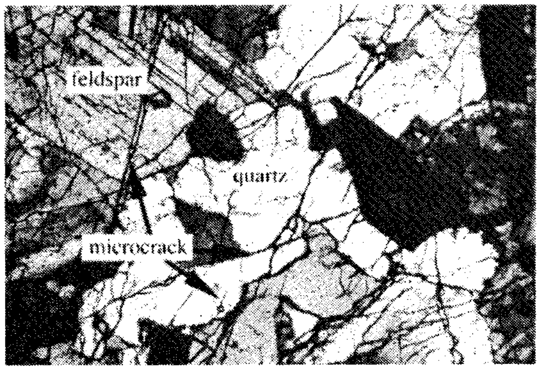
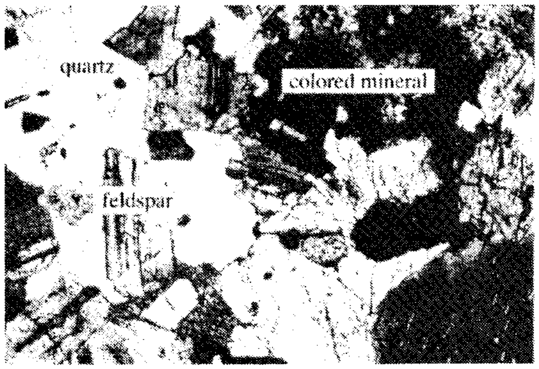


Figure 8 P and S Wave Velocity Distribution with the Distance from The Drift Wall



(a) Distance from Drift Wall = 0.25 m



(b) Distance from Drift Wall = 3.00 m

Figure 9 Microscopic View of Thin Section

Figure 9 shows microscopic views of thin sections made from cores taken 0.25 m(Figure 9(a)) and 3 m(Figure 9(b)) from the drift wall. The difference between two photos is clear, and at 0.25 m, many intragranular microcracks are observed within grains of quartz and feldspar and there are also some intergranular microcracks. In order to evaluate the number of microcracks in each mineral type, the number of microcracks which cross a scanline drawn on each thin section were counted. Length of a scanline was 20 mm. As Kurihashi granodiorite consists mainly of quartz, feldspar and colored minerals such as biotite and hornblende, the counted microcracks were classified into 5 categories: (1) inside quartz, (2) inside feldspar, (3) inside colored minerals, (4) co-incident with grain boundaries, and (5) crossing more than 2 minerals(intergranular). Figure 10 shows the relationship between distance from the drift wall and the number of microcracks. The number of microcracks at 0.25 m exceeds those at the other points. Microcrack frequencies were calculated as follows in order to remove the error due to differences in relative abundance of each mineral:

$F=X/l$

where F =frequency of microcracks, l =total length of scanlines crossing each type of mineral, X =the number of microcracks of each type. l was used for the total scanline length of types (4) and (5).

Figure 11 shows the relationship between microcrack frequencies and distance from the drift wall. The following is derived from the relationship:

1) Frequencies for quartz and feldspar intragranular cracks are relatively high and vary

widely. The large frequency for feldspar intragranular cracks is thought to be due to blasting damage and chemical alteration.

2) Frequencies for intergranular cracks are very low overall, but may show a significant rise at 0.25 m compared with samples taken farther from the drift wall.

3) Frequencies of microcracks inside colored minerals and on grain boundaries are constant.

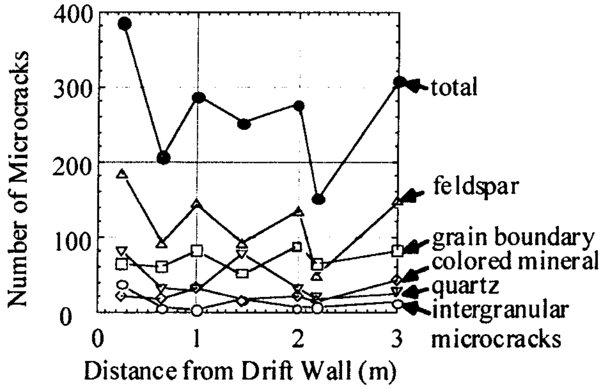


Figure 10 Relationship between Number of Microcracks and Distance from Drift Wall

It is indicated that the zone with high frequency of microcracks extends 0.5 m into the drift wall. In this zone, microcracks were mostly found inside quartz and feldspar, and there were also some microcracks which cross more than two mineral grains. Considering the strength and depth of the rock mass around the investigation area, the microcracks are believed to be generated by blasting operations.

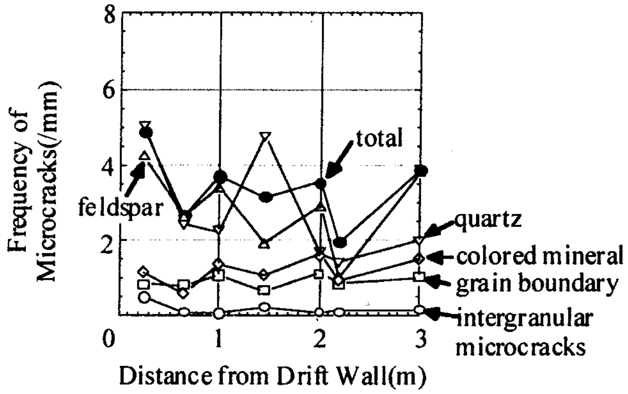


Figure 11 Relationship between Frequency of Microcracks and Distance from Drift Wall

Crack counting work is continuing and scatter may be reduced when more material is sampled.

Low Velocity Zone of P and S Waves in the Vicinity of the Drift Wall

The low velocity zone is considered to extend within about 0.5 m into the drift wall based on the seismic surveys. Comparing with the results of core logs and BTV observation, the low velocity zone corresponds to the rock zone where open cracks with an aperture of 1 to 3 mm exist. Moreover , in this zone, low deformation modulus has been measured with the borehole jack test. On the other hand , elastic wave velocity of intact rock is not changed with depth from the drift wall according to the laboratory tests, whereas high frequency of microcracks has been estimated in the same zone.

These results indicate that the decrease of in situ elastic wave velocity and deformation modulus in the vicinity of the drift is mainly due to open cracks, rather than microcracks. However, the microcracks possibly affect the elastic wave velocity of rock considering that the extent of rock portion with high microcrack frequency is consistent with that of the low velocity zone and the number of samples for the laboratory velocity measurement was small. The causal mechanism of the decrease of elastic wave velocity will be studied further in our next experiment.

SUMMARY

Investigation of excavation disturbance has been carried out around an old mine drift excavated by drill and blasting about 20 years ago at a depth of 730 m in granodiorite, i.e. hard rock, in the Kamaishi Mine. The results of investigation are summarized as follows:

1) Seismic surveys, which include PS logging, a refraction survey and a tomography survey, have detected a low velocity zone around the drift. The PS logging and the refraction survey have indicated that the low velocity zone has a width of about 0.5 m and a P wave velocity of 3~5 km/s, whereas the P wave velocity of the intact rock is about 6 km/s.

2) Core logs, BTV observation and microscopic observation of thin sections have indicated that there are many microcracks and open cracks in the low velocity zone, although the core samples collected near the drift wall have the same rock mechanical properties, including P wave velocity as the intact part of the rock.

3) Low deformation modulus was measured within 1 m of the drift wall in borehole jack test, but the variation of deformation modulus with distance from the drift wall is not so obvious as the variation of P wave velocity.

4) It is supposed that blasting damage to rock is the major cause of the low velocity zone.

5) PS logging and refraction surveys are the most effective methods for detection of the EDZ.

FUTURE PLAN

Based on the results of the investigation of excavation disturbance around an old mine drift, an experiment with the excavation of a new drift has been planned and is underway in the Kamaishi Mine. The new drift for the experiment will be excavated in FY 1996 and the experiment is planned to be completed in FY 1997. Objectives of the experiment are:

1) to determine the rock properties and the extent of the EDZ around a new drift,

2) to understand the processes such as excavation damage and stress redistribution which relate to the generation of the EDZ, and

3) to understand the dependency of excavation damage on excavation methods (conventional blasting versus smooth blasting) .

Figure 12 shows the configuration of drifts and boreholes, and measurements for the experiment. The direction of the test drift is almost perpendicular to the strike of the dominant fractures and perpendicular to the direction of the maximum principal stress for better understanding of such processes as excavation damage and stress redistribution. Vibration and AE monitoring, microcrack observation of thin sections and seismic surveys will be performed mainly for the estimation of excavation damage. Measurements of strain and displacement of rock mass and fracture, convergence, and hydraulic conductivity will be carried out mainly for the estimation of stress redistribution.

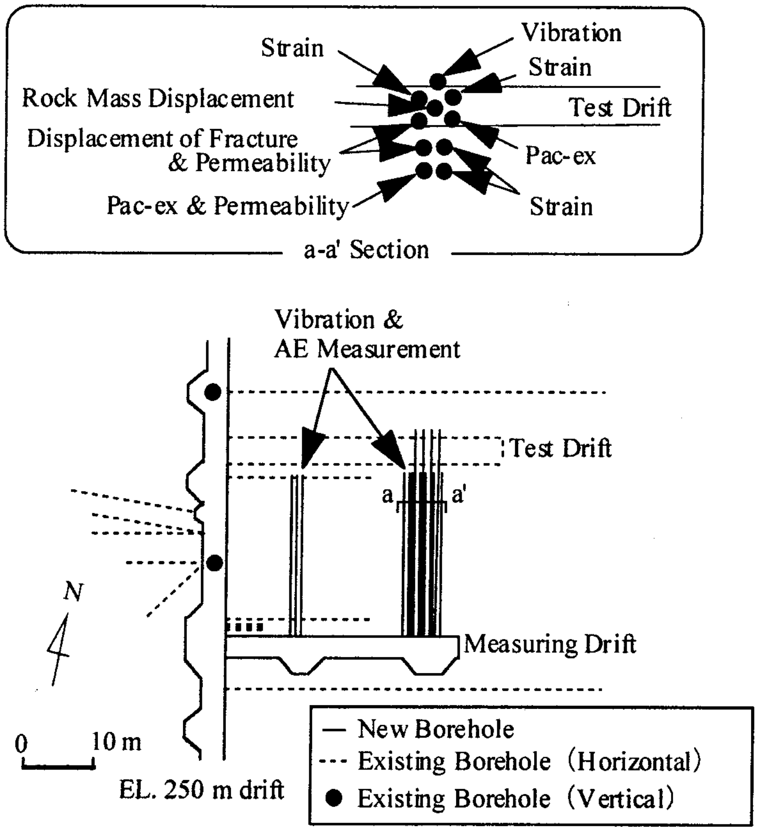


Figure 12 Configuration of Drifts and Boreholes, and measurements of the Excavation Disturbance Experiment in Phase II

ACKNOWLEDGEMENTS

The authors acknowledge that many works of this study were carried out by the staff of Obayashi Corp. and Shimizu Corp. The authors are also grateful to Dr. Steven R. Carlson for his technical comments and advice for improvement of our English text.

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