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The Observation of Crack Development Around an Underground Rock Chamber by Borehole Television System

By

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Summary

Phenomena caused by stress redistribution in a granitic rock as a result of the excavation of a large underground powerhouse were observed using a borehole television system. The observations were carried out five times at regular intervals and at different stages of the excavation. They clearly revealed that microcracks had been progressively generated in the wall area. The majority of these cracks were not initiated from the pre-existing mineral filled joints, but appeared at locations where no joints had been present earlier. It was also found that the summed-up value of the apertures of the microcracks has accounted for more than thirty percent of the resulting wall displacement toward the chamber. From the measured orientations of the generated cracks it can be concluded that the directions of the principal stress axes rotate during the progress of the excavation.

Introduction

Due to the excavation of a large underground chamber relaxation phenomena occur in the surrounding rock mass manifesting themselves in the generation of cracks and displacements. The investigation of these phenomena is of great interest concerning the stability of the opening. One method of elucidating this question in relation to the stress redistribution at different stages of excavation consists of direct observations by means of a borehole television (BTV) system (Hori, 1976). The method has already been successfully applied at different sites of underground powerhouses for hydroelectric schemes in Japan. By observing cracks and joints and measuring the change in their aperture the extent of the relaxed area around the cavern wall could be identified (Hori and Miyakoshi, 1976; Inoue, 1981). In the present paper the results of observations with the BTV-System carried out at the site of the Matanogawa hydroelectric powerhouse in southwestern Japan, are reported. The rock cavern is located near to the Matano river at a depth of about 500 m. It measures 23.5 m in width, 46.3 m in height and 155.5 m in length. The excavation was completed between August 1980 and October 1981. The main part of the cavern is located in granitic

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rocks which are intruded by dikes of dioritic porphyrite or aplite. Hornfels occurs above an elevation of 192 to 200 m in full contact with the granitic rocks. BTV observations were performed in the two boreholes No. 10 and No. 11 shown in Fig. 1. They were drilled at right angles to the axis of the powerhouse from the upper working adit. The boreholes dip 13⁰ from the horizontal having a length of 23.5 m and a diameter of 76 mm. They are separated from each other by a distance of 41.5 m. The BTV observations were carried out five times at regular intervals in the following stages of excavation:

Observation	Stage of excavation
1	excavation not yet started
2	crown drift just completed
3	roof excavation completed down to 183.0 m elevation
4	bench excavation completed down to 173.3 m elevation
5	excavation of the whole cavern completed

Parallel to these boreholes at a distance of 2 m and 3 m respectively the boreholes No. 9 and No. 12 were drilled and installed for borehole extensometer measurements. In this way an independent monitoring of the rock displacements could be performed.

The Borehole Television System (BTV)

It consists basically of a probe with a diameter of 50.8 mm housing the TV camera and a control unit installed in a motor vehicle. The two parts are connected by a 400 m long cable allowing observations to be carried out in boreholes up to this depth. The orientation and the focus of the camera are adjusted by remote control and the corresponding values are displayed on the TV screen (Fig. 2). The pictures can be recorded by means of a video recorder. The TV screen shows the image at a magnification of five times the actual size. Since the aperture of cracks is measured on the picture with an accuracy of approx. 1 mm, the error in the actual value of aperture is less than 0.2 mm.

Discussion of Results

Firstly the pre-existing discontinuities encountered in the boreholes were mapped by the BTV-observation No. 1 and by inspecting the drill cores. These were classified according to the following scheme:

- Continuous joints with calcite filling and a width of 0.1 to 5 mm.
- Continuous joints with a small degree of persistence with chlorite filling and a width of 0.1 to 50 mm.
- Narrow hair cracks.
- Joints filled with clays but not calcite or chlorite, of a few millimeters width.

It is worth mentioning that none of the joints encountered were open; all of them were tightly packed. The number of joints was less than 10 per meter, however their frequency varied along the boreholes.

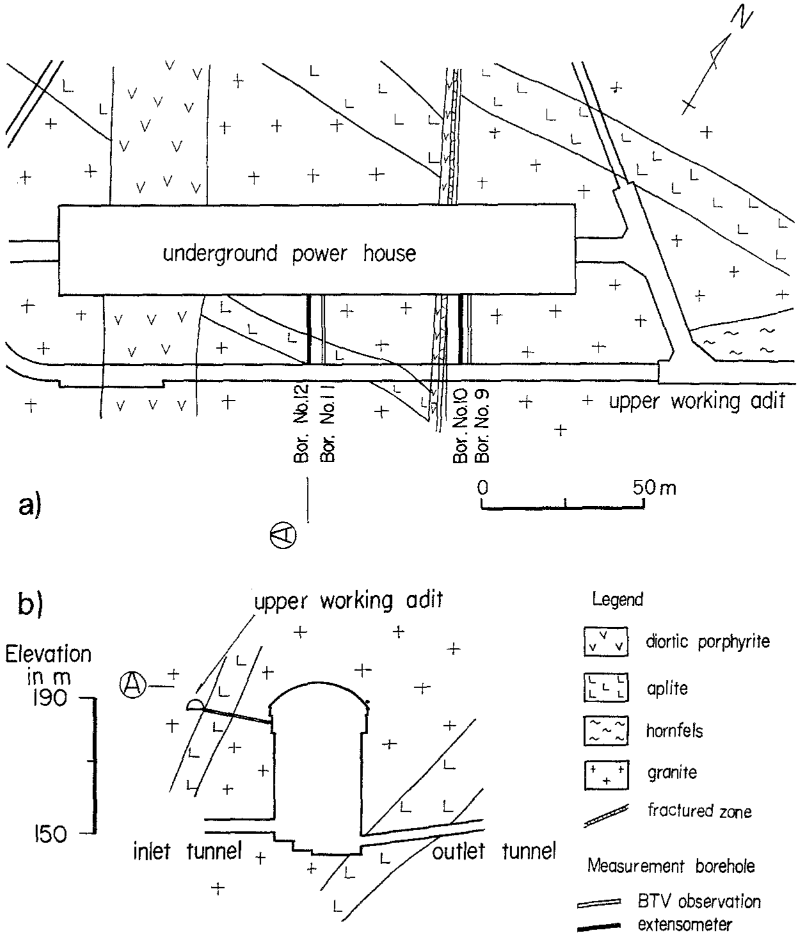

Fig. 1. Matanogawa powerhouse and its geology
a) Horizontal section at an elevation of 185.25 m. b) Cross section A-B

Until observation No. 3, i. e. before the excavation of the cavern has reached the level of the boreholes, no microcracks generated by the excavation could be detected. New microcracks were at first recognised during the observation No. 4. Typical examples for the pictures obtained are shown in Fig. 2. The depth of an observation, the number of the borehole and the direction of the TV camera are clearly indicated on each of the photographs. The scale appearing on the pictures represents 10 mm. Two main groups of the new microcracks could be distinguished:

MA: Microcracks appearing at places with no presence of pre-existing joints.

MB: Microcracks appearing almost in coincidence with the pre-existing joints.

The surfaces of all these microcracks were found to be highly irregular and their aperture was the same all around the inside wall of the boreholes. The photograph in Fig. 2b reveals that an irregular MA-type microcrack

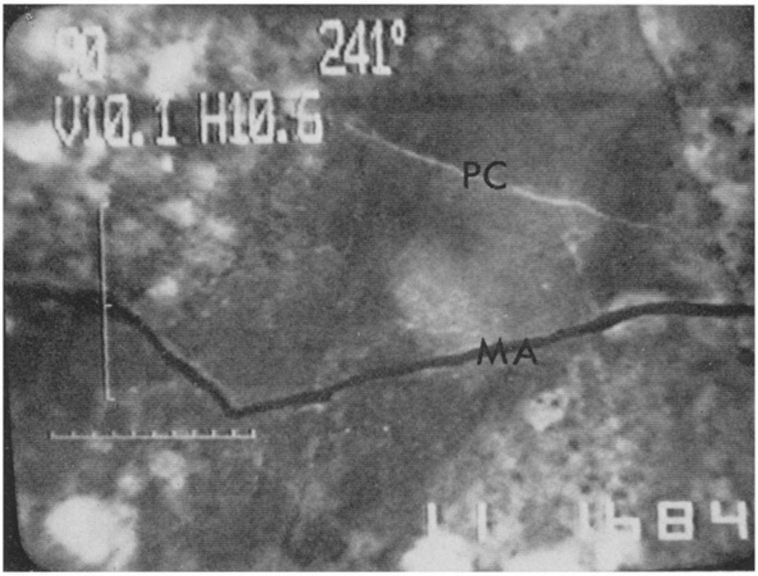

Fig. 2a

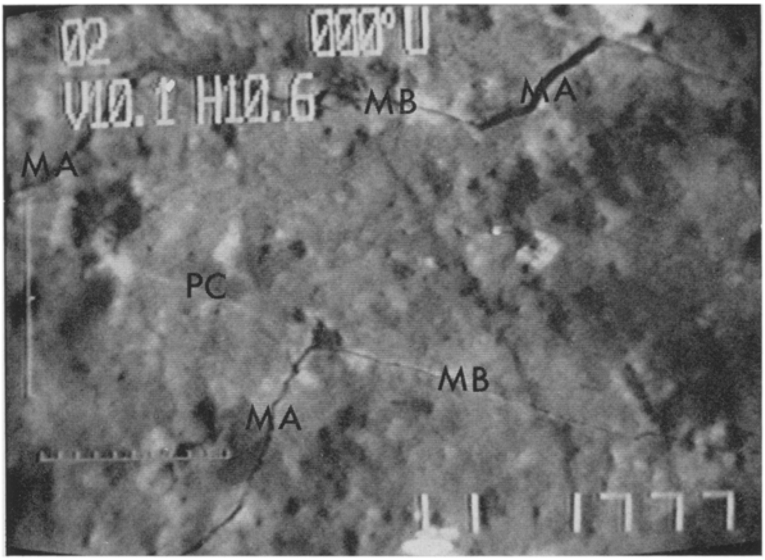

Fig. 2b

Fig. 2. Photographs of the borehole wall with indication of the depth in cm (lower right), MA, MB: Generated microcracks. PC: Pre-

connects two microcracks which appeared along the two pre-existing joints about 20 mm apart. It was observed (Fig. 2 c) that some of the MA-type microcracks were arranged in echelon and connected by an MB-type micro-

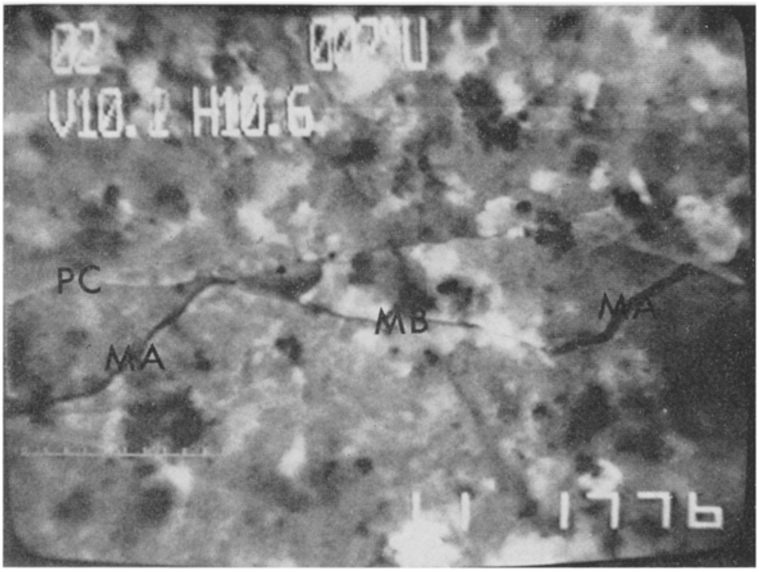

Fig. 2c

Fig. 2d

number of the borehole (lower centre), direction of the TV camera (upper centre). existing joint, filled by calcite. Scale: 10 mm crack. Some MA-cracks branched in two as shown in Fig. 2 d. MB-cracks were not entirely coincident with the pre-existing joints, but broke partially into the rock mass in the vicinity of such joints.

The microcracks in the rock mass which were caused by stress release during the excavation of the chamber are similar to those observed with the scanning electron microscope by Kranz (1979 a, b). Kranz showed such microcracks in granite under compressive stresses just before failure of the test specimen. Although it is difficult to recognise displacements along

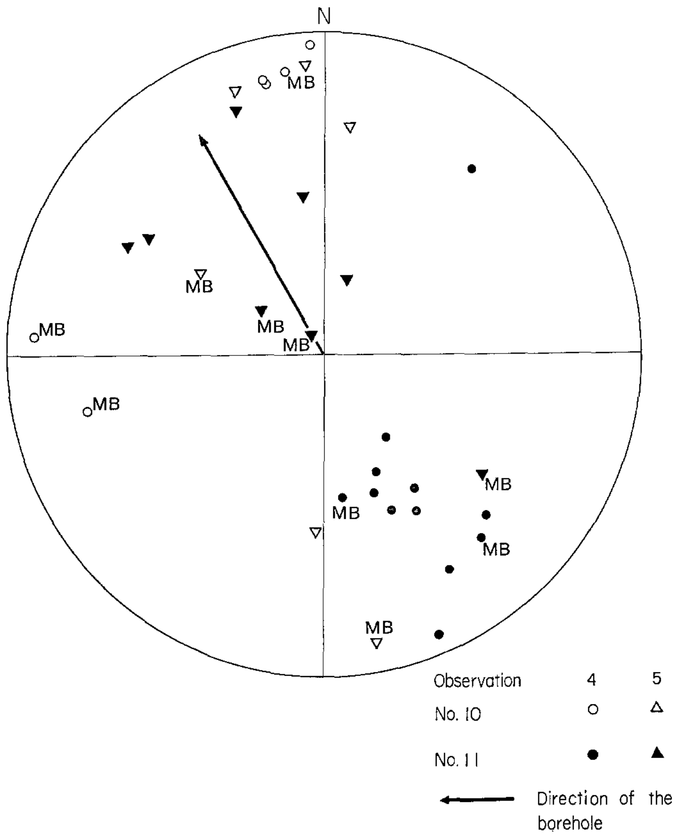

Fig. 3. Orientation of generated microcracks in Wulff's net, upper hemisphere MB type microcracks are denoted as such, others are MA type microcracks

a microcrack surface by BTV observation, there are some indications leading to the assumption that they originate from tensile fractures: firstly because of their irregular surfaces and secondly because their aperture is almost constant along the crack.

In observation No. 4, except for a few microcracks generated along the pre-existing joints, the majority of the generated microcracks belong to the MA type. However, it is also true that microcracks of a width outside the resolution of the BTV system may exist along pre-existing minor joints.

For example, it has been suggested that microcracks were generated along grain boundaries or LARCs (low aspect ratio cavities), which have been presented in electron scanning micrographs by Sprunt and Brace (1974) and Tapponnier and Brace (1976). In observation No. 5 a few more MB-type microcracks appeared than in observation No. 4. Several microcracks

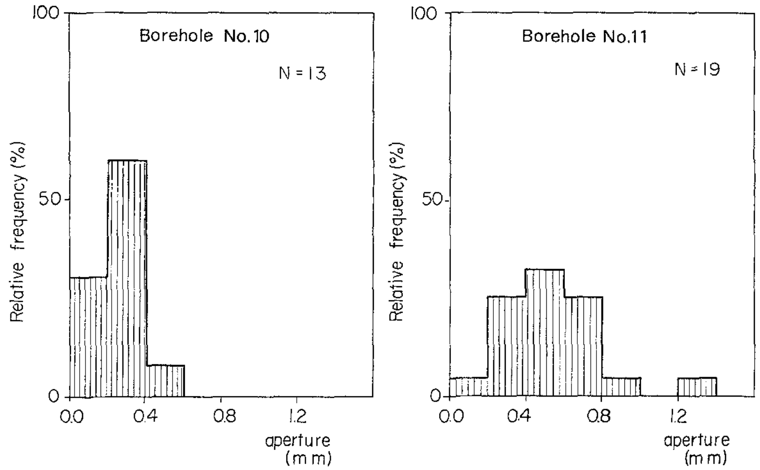

Fig. 4. Histograms of aperture of microcracks

appeared to have complicated connections with one another, forming a so-called cracked zone at a distance of 20 cm from the wall of the chamber in borehole No. 10 and 150 cm in borehole No. 11. This zone may have been directly influenced by blasting.

Fig. 3 shows the representation of the generated microcracks in spherical projection using the upper reference hemisphere. The strikes of the microcracks are almost parallel to the axis of the powerhouse. There is a difference in the dips between observation No. 4 and those of No. 5 especially for the borehole No. 11. Fig. 4 shows histograms of the aperture of the microcracks. The apertures ranged in size from 0.2 to 0.6 mm and reached a maximum value of 1.2 mm.

Total Aperture of Microcracks and Displacement of the Cavern Wall

The boreholes drilled for the extensometers were very close to those of the BTV observations and therefore no difference in the behaviour of the rock mass between the corresponding boreholes may be assumed. Hence, it is justified to compare the total aperture of microcracks (TA) measured in the boreholes No. 10 and No. 11 with the wall displacement of the chamber (ED), measured by extensometers in the boreholes No. 9 and No. 12. The ratio TA/ED ranged from 0.2 to 0.8 as indicated in Table 1. These ratios are in good agreement with the values 0.3 to 0.6 found by Inoue (1981) for the excavation of the Takami underground powerhouse in Hokkaido, Northern Japan. If the displacement of the cavern wall was caused entirely by microcracks the ratio TA/ED would be equal to 1. The fact that the ratio is less than 1 suggests that other factors might be responsible for the displacement ED as well. Part of the displacement could be caused by deformation of the rock itself and by the opening of minor microcracks having apertures outside the resolution of the BTV system. Taking into account that about thirty to forty percent of the displacement ED was caused by microcracks, it is obvious that various phenomena which occur in rocks just before failure, including dilatancy, can be explained by the presence of generated microcracks (Kranz, 1979 a, b).

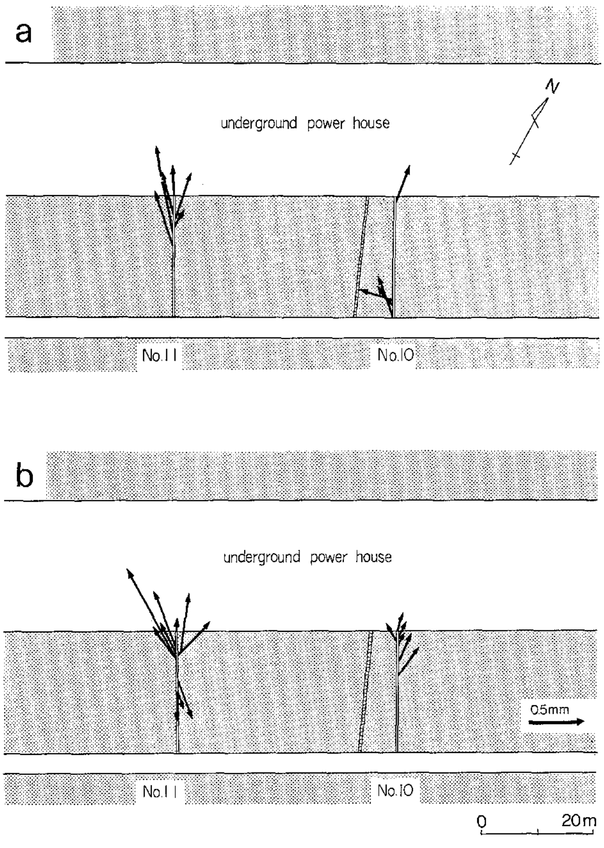

Fig. 5. Directions perpendicular to the microcracks in plan view
a) Observation No. 4; b) Observation No. 5

The direction and the aperture of the microcracks along the boreholes No. 10 and No. 11 as they appeared in the observations No. 4 and No. 5 are indicated in Fig. 5 and Fig. 6. In these Figures the length of the arrows is proportional to the aperture and the directions are normal to the crack surface. Arrows pointing towards the powerhouse indicate generation

Table I. *Total Aperture and Displacement by Extensometer*

A. BTV observation of the borehole No. 10 and extensometer measurement of the borehole No. 9

Observation	Total aperture (TA) in mm	Displacement by extensometer (ED) in mm	Ratio TA/ED
4	1.2	5.70	0.2
5	2.5	8.20	0.3

B. BTV observation of the borehole No. 11 and extensometer measurement of the borehole No. 12

Observation	Total aperture (TA) in mm	Displacement by extensometer (ED) in mm	Ratio TA/ED
4	5.2	6.88	0.8
5	8.2	14.77	0.6

of microcracks and the opposite direction stands for their diminution. From Fig. 5 it can be seen that the strike of the crack surfaces is orientated more

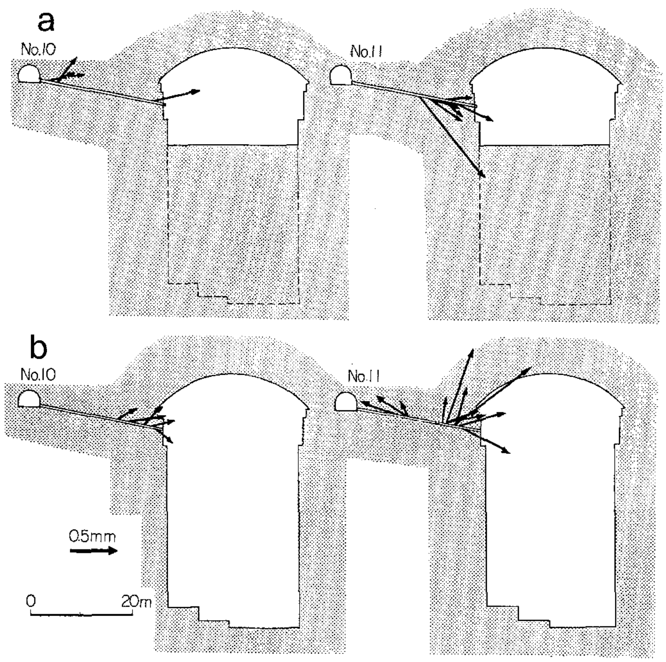

Fig. 6. Directions perpendicular to the microcracks in the cross-section
a) Observation No. 4; b) Observation No. 5

or less parallel to the axis of the powerhouse. Its dip (Fig. 6) varies for the two observations. This may indicate that the directions of the principal stress axis rotate during excavation.

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