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Abandoned roadways aged up to 50 years observed in Kushiro Coal Mine, Japan

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ABSTRACT: 95 abandoned old roadways up to 50 years old and 300 m deep were observed at Kushiro Coal Mine. Large plastic deformations as roof deflection and/or floor heave closed most roadways although a few roadways were remain open. Such in-situ measurements as Rayleigh wave velocity, permeability etc. were carried out. Rayleigh wave velocity in the closed roadway was approx. half the virgin rock mass. Permeability of closed roadway was 40 times greater than that for virgin rock mass. This suggests that 1/40 sealability can be expected even a rock cavern in clastic rocks completely collapsed. This would be much better than rock cavern in crystalline rocks in which much less sealability is expected when completely collapsed.

SUBJECT: Site investigation and field observations

KEYWORDS: case studies, coal mines, field measurements, lab testing, monitoring, nuclear repository

1 INTRODUCTION

Excavation Damaged Zones (EDZs) (Tsang et al., 2005) appear around deep rock repositories for geological disposal. Permeability in EDZs would be much higher than in intact rock masses, and the sealability of a rock cavern is supposed to be significantly compromised by high permeability. Mechanical properties of crystalline rocks, rock salt and, indulated and plastic clays in EDZs were summarized in the above reference; those for medium-hard clastic rocks, however, are unknown. The objective of this research is to clarify the sealability of abandoned and closed rock caverns in clastic rocks in which rock repositories can be constructed.

To accomplish the objective, old roadways were observed at 95 sites during the mining of longwall panels in Kushiro Coal Mine. Comparisons will be introduced between Rayleigh wave velocities and permeabilities in abandoned and closed roadways as old as 50 years, which can be regarded as very severe EDZs with zero initial sealability, and those in virgin rock mass in clastic rocks as deep as 300 m at Kushiro Coal Mine.

Kushiro Coal Mine is excavating Eocene coal seams, which remained from the past excavation by Taiheiyo Coal Mine, toward shallower levels. Roadways as old as 50 years appear at mining faces and sidewalls at the Kushiro Coal Mine under the special circumstances. Old roadways were back filled by (1) thickened waste water from coal

processing, (2) a mixture of fly ash and water, (3) a mixture of fly ash, cement and water or (4) a mixture of rock powder, cement and water. The slurry for back filling was made thin for workability. For example, water comprised 50% of the volume for the mixture of fly ash and water.

The ground-water level deepened with increases in depth from further excavations after the old roadways were excavated by Taiheiyo Coal Mine. It was confirmed that the ground water level was deeper by 50 m or more than at the sites of observation. Seawater never invaded the underground workings, although the excavation was carried out under the Pacific Ocean.

2 IN-SITU TESTS

2.1 Field observation

From the observation of closed roadway, it was clarified that most roadways were completely closed by deflection of roof (Fig. 1, see the last page) and/or floor heave due to plastic deformation of clay and siliceous rock. There observed no significant fractures in the closed parts. On the other hand, a few roadways were left open by the wooden support. No back filling was reached to the open roadways.

2.2 Rayleigh wave measurement

To measure Rayleigh wave velocity, Holes 300 mm deep with diameters of 24 mm were drilled at the apices of two rectangles with side lengths between 1.5 m and 3 m on the sidewall or roof. Rock bolts 300 mm long were grouted by resin. One of the rectangles was drawn on the closed old roadway surface and the other rectangle on the surface of the virgin rock mass. One of the rock bolts was hit by the impulse hammer, and an elastic wave was received by accelerometers fixed by magnet mounts at the heads of the other rock bolts. Signals were amplified, recorded and analyzed. Rayleigh wave velocity in the closed roadway and virgin rock mass both in the present EDZs are in the range of 0.3-1.2 km/s and 1.1-1.8 km/s, respectively.

2.3 Lugeon test

For Lugeon test, two horizontal boreholes with 55 mm diameters were drilled at the closed old roadway and into the virgin rock mass. Gas pipes with 20 mm diameters were inserted into the drill holes and grouted with a hard-formed resin, except for the deepest 1-m part for pressurizing. The deepest 1-m part was pressurized by air pressure and then water pressure while recording flow rate Q . Permeability in the closed roadway and virgin rock mass were in the range of 5 to $6 \times 10^{-14} \text{ m}^2$ and $1.4 \times 10^{-15} \text{ m}^2$ in EdZ, and 1.8 to $10 \times 10^{-13} \text{ m}^2$ and $5.3 \times 10^{-15} \text{ m}^2$ in EDZ, respectively.

2.4 Steel arch removal test

Steel arch removal test at tailgate was conducted by removing steel arches at the tailgate just next to the longwall coal face, and rock mass collapses were observed. A small roof fall occurred when three steel arches were removed (an unsupported span of 3.4 m). The tailgate was completely collapsed by fallen rock blocks up to 1 m in size due to a large roof fall that occurred when two more steel arches were removed (unsupported span of 5.1 m). Those rock blocks were obviously from EDZ around the tailgate under the abutment pressure of the longwall mining panel.

Steel arch removal test was also conducted at a test roadway which was located 239 m below sea level, away from mining areas. The test was carried out on May 24, 2006. There was no large roof fall, even after 15 steel arches were removed; the unsupported span reached 16 m without large roof falls, except for rather small falls of loosened rocks that were as large as tens of centimeters. The EDZ around the test roadway seemed to be smaller than that around the tailgate because the test roadway was far away from mining areas. A few months later, in August and September, humid summer air flowed into the site; dripping water was seen on the rock surface, and several large rock falls, as large as 2 m, occurred. It is estimated that the rock mass was weakened by the humid-air inflow and the large-scale roof falls were induced.

2.5 Stress recovery at longwall goaf

Test on stress recovery at longwall goaf was conducted. The floor of a tailgate was smoothed, and a pressure sensor was placed on the smoothed surface, covered by gravel. The pressure sensor was a 30 cm x 30 cm flat jack sandwiched by a pair of 1-mm thick steel plates. A spring-driven nonelectric data recorder was placed at a safe place, and a

100-m long stainless steel tube connected the pressure sensor and the recorder. Monitoring started when the face was 3.5 m behind the sensor. The face position was 5.4 m ahead of the sensor on Sept. 21, the day after the installation. The mining was finished on Sept. 28, when the face was 34 m ahead of the sensor, and monitoring was continued for 2 months longer. The resolutions of the recorders for both the pressure and time were not precise enough, however, it can be at least said that the pressure recovered to approximately 0.3 MPa by Sept. 28 and kept an almost-constant value.

2.6 Permeability distribution

Permeability distribution along a borehole was measured. The instruments were almost the same as Lugeon tests in 2.3, but a double packer was used to divide the pressurized part at 0.5 m. The test was carried out in a 15-m long and 15-degree upward borehole drilled in the sandstone seam at a tailgate before the abutment pressure appeared. Permeability was on the order of 10^{-11} m^2 less than 4 m deep and on the order of 10^{-12} m^2 or less for depths more than 4 m (Fig. 2). It is estimated that the rock mass within 4 m from the sidewall was an EDZ. It was impossible to carry out the test due to borehole collapse when the face reached 5 m to the borehole.

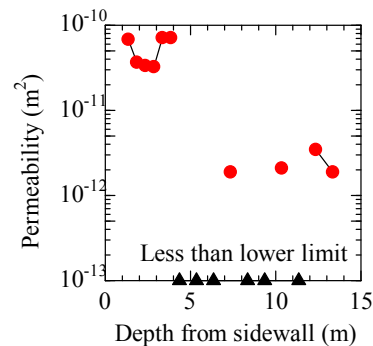


Figure 2. Permeability distribution along a borehole.

2.7 Borehole deformability

Distribution of Young's modulus along boreholes was measured with a Goodman jack. Tests were carried out at a tailgate. The first test was carried out for a horizontal borehole drilled from the sidewall into the virgin field of siliceous rock. The UCS and the Young's modulus of the intact saturated specimen were 52 MPa and 12 GPa, respectively. Loading was carried out in three directions: vertical and 120 degrees and 240 degrees from vertical. A significant anisotropy was not observed in this plane (Fig. 3). Young's modulus for rock mass within 1 m from the sidewall was much smaller than that for rock mass deeper than 1.5 m. The EDZ boundary was estimated to be between 1 m and 1.5 m from the sidewall. The second test was carried out in the sandstone borehole for a Lugeon test by air for measuring a permeability distribution, when the face approached 5 m to the borehole. Loading was carried out only in the EDZ. Small values of Young's moduli were obtained showing yielding of rock mass around the tailgate.

3 LABORATORY TEST

Variation in permeability in triaxial compression was examined for a sandstone core sampled from the roof of one of the sites was carried out. The sample was vacuum-packed at the site, and a 60-mm long, 30-mm diameter cylindrical rock core was taken immediately after unpacking. The core was vacuum-saturated in pure water. End pieces were installed into it, and the core and end pieces were jacketed by heat-shrink tubing. The jacketed specimen was inserted into an ultra-compact triaxial vessel (Fujii & Kondo, 2010). The specimen was consolidated for 10 hours under a hydrostatic pressure of 5 MPa and pore pressures of 2 MPa (upstream) and 1 MPa (downstream). The platen was stopped for 1 week after the specimen was compressed axially to show peak stress and residual state under the drained condition. Slight stress relaxation was observed during the week. The confining pressure was increased to 11 MPa for a week and then decreased to 5 MPa for a week. Permeability increased with specimen failure (Fig. 4); however, it gradually decreased with time in the residual state and reached almost the same level as that for the intact rock specimen. Permeability decreased with the increase in confining pressure and then increased with its decrease. The variation of permeability with confining pressure looked reversible and associated with elastic deformation of the rupture plane. Similar results on Kimachi sandstone can be seen in Takada & Fujii (2009). Fracture closures and poorly connected tortuous fractures were observed in the thin section (Fig. 5). These were likely the causes of the decrease in permeability with time in the residual state. Fracture closure occurred mainly by crushing of the mineral particles and visco-elastic deformation around the rupture plane and not by the pressure solution.

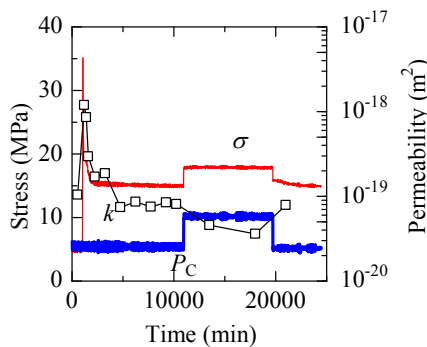


Figure 4 Axial stress (σ), confining pressure (P_C) and permeability (k) versus time obtained under the triaxial compression test using sandstone.

4 DISCUSSION

Main reason for roadway closure can be considered not to be a large stress concentration but large deformation of clastic rocks, which contained smectite, due to water supply by slurry filling under stress which is similar to the overburden pressure from the observation of closed and open roadways, steel arch removing tests and stress recovery test.

Results of the in-situ Rayleigh wave velocity denote that stiffness of rock mass which was 0 when the roadway was abandoned recovered to approx. half that of the virgin rock mass under the overburden for 300 m deep for as long as 50 years. The permeability tests denote permeability recovery to 40 times greater than that in virgin rock mass. Not only roadway closure by large deformation but also closure of fracture are required for sealability recovery. Fracture closure was partly due to clay and back filling materials and partly due to crushing of mineral particles at and viscous deformation of rupture plane.

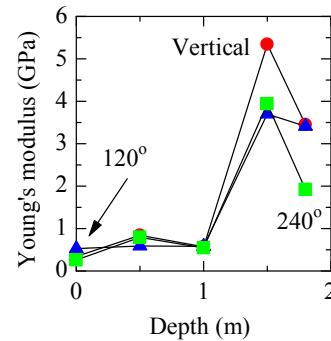


Figure 3. Distribution of Young's modulus along the borehole in siliceous rock.

5 CONCLUDING REMARKS

95 old roadways were observed at Kushiro Coal Mine. Such in-situ measurements as Rayleigh wave velocity, permeability etc. were carried out. Permeability of closed roadway was 40 times greater than that of virgin rock mass. This suggests that a 1/40 sealability can be expected even a rock cavern in clastic rocks completely collapsed. This would be much better than rock cavern in crystalline rocks in which much less sealability is expected when completely collapsed.

Mechanical and hydraulic tests were first conducted for abandoned roadways aged up to 50 years in clastic rocks. Sealability for such roadway is clarified first and the advantage of rock repository in clastic rock is discussed.

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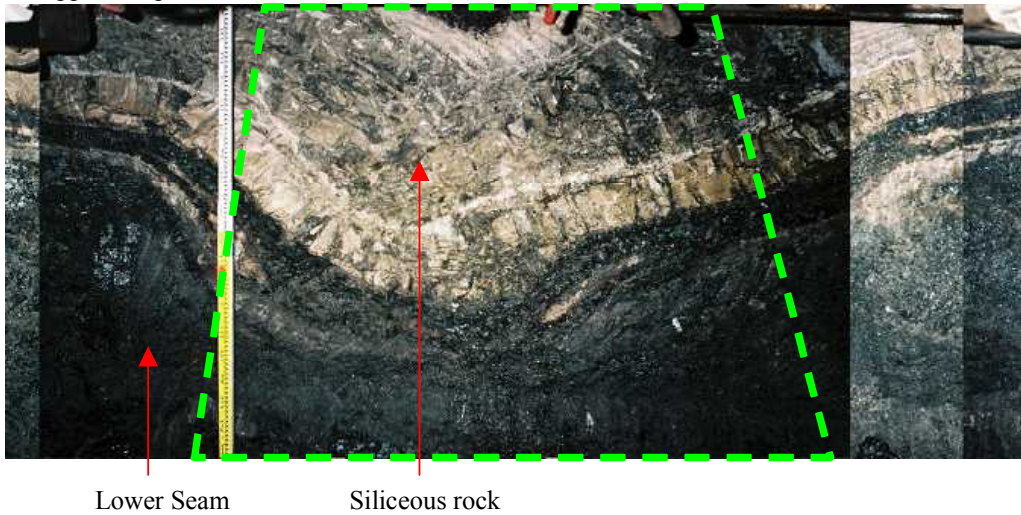


Figure 1. Old roadway observed in Kushiro Coal Mine. Roadway which is denoted by the green line was closed by the deflected and sagged roof. Height of old roadways is approx. 2.5 m.

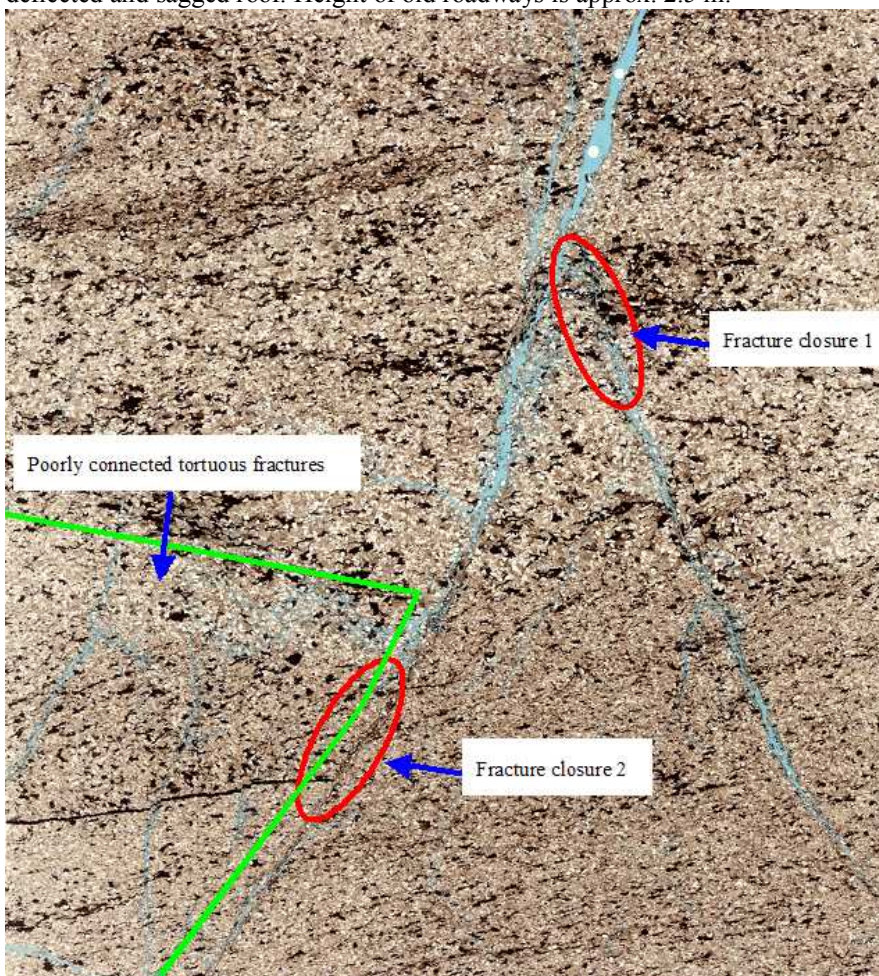


Figure 5. Micrograph of the thin section prepared from the rock specimen used for the triaxial test. The photo corresponds to the thin section of 23 mm wide. Vertical direction of the photo coincides with the loading axis. Test piece was impregnated with blue resin before preparation of the thin section.