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Gas permeability in the excavation damaged zone at KURT

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ABSTRACT

An in-situ experiment to measure the gas permeability using nitrogen gas has been carried out at KURT (KAERI Underground Research Tunnel) to investigate the change of permeability in the EDZ (excavation damaged zone). The results showed that the permeability decreases with an increasing distance to a location about 2 m deep from the tunnel wall, and then maintains a somewhat constant value. The size of the EDZ can be estimated to be about 2 m from the viewpoint of permeability, and in the EDZ, the permeabilities seem to be increased up to 2 orders of magnitude compared with those in the intact rock. The EDZ was estimated to be 1.2 m from the tunnel wall on the basis of the deformation modulus measured through a Goodman jack test. The EDZ size estimated based on the permeability is larger than that from the Goodman jack test. The fractures have a more significant influence on the hydrological properties compared with the mechanical ones because a fluid flow occurs principally through fractures in the crystalline rock.

1. Introduction

The promotion of a nuclear energy program results in the generation of a significant amount of nuclear waste. A geological repository has been considered one of the most promising options to isolate nuclear waste from the biosphere within its harmful period. A geological repository would be located in a bedrock at a depth of several hundred meters below the ground surface, and expected to be of a room-and-pillar design. During the construction of a geological repository in a crystalline rock such as granite, the excavation does considerable damage to the rock close to the tunnel wall.

An EDZ (excavation damaged zone) is a zone around the tunnel where the rock properties and conditions have been changed owing to the excavation. The three mechanisms involved in the development of the EDZ are the excavation impact, the stress redistribution around the newly excavated opening, and the back-pressure on the rock deformation by the emplacement of the rock support (Tsang et al., 2005). The EDZ has an influence on the groundwater flow characteristics as well as the stability of the rock mass. In the EDZ, the permeability of the rock increases because of the creation of new fractures and the opening of pre-existing ones. The annular EDZ surrounding the tunnel may act as a continuous and high-permeable pathway for the groundwater flow, which accelerates the intrusion of groundwater into the repository and increases the release of radionuclide into the biosphere from the repository. Therefore an investigation on the change of permeability in the EDZ has been important from the viewpoint of radiological safety for a geological repository.

The magnitude of an EDZ and the degree of permeability increase in the EDZ depend on the rock conditions and the method of excavation, i.e. whether by blasting or by the use of a TBM (tunnel boring machine). In general, TBM generates a smaller EDZ and a lesser increase of permeability than blasting. In the ZEDEX experiments at Äspö HRL where both TBM and blasting were used, no significant increase of permeability in the EDZ was observed (Emsley et al., 1997). In the FEBEX project, it was concluded that the permeability in the TBM-induced EDZ is comparable to that of the undisturbed rock (Sabet et al., 2005). Liedtke (2005) reported however that the permeability of a TBM-induced EDZ was three orders of magnitude higher than that of the undamaged rock in the Äspö Prototype Repository.

The size of the EDZ and the effects of excavation on the permeability are remarkable in a blast-induced EDZ. Tsang et al. (2005) reported that the permeability increased one or more orders of magnitude in an EDZ induced by blasting. Martino and Chandler (2004) reported that in the URL, the blast-induced EDZ extended to a depth of 0.3 to 0.4 m, and the permeability increased by less than three orders of magnitude relative to that of intact rock. In the Stripa mine and Äspö HRL, the blast-induced EDZ was generated more than 1 m from the periphery of the tunnel and the permeability was increased by two to three orders of magnitude (Pusch and Stanfors, 1992). In the Kamaishi mine where the blasting was used, the EDZ had an extent of about 1 m from the tunnel wall, and the permeability in the EDZ increased two orders of magnitude compared with that of the undamaged rock at the floor of the tunnel, but a permeability change was not observed at the side walls of the tunnel (Sugihara, 2009). The in-situ investigation on the sedimentary rock in the Tono

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mine showed that the permeability increased two orders of magnitude in the EDZ with a size of 0.5 to 1 m (Sato et al., 2000).

In this study, an in-situ measurement to investigate the permeability in the EDZ was performed at KURT (KAERI Underground Research Tunnel), which is a small scale generic underground research laboratory at the Korea Atomic Energy Research Institute (KAERI). A previous study (Kwon and Cho, 2008) on the mechanical properties of EDZ at KURT showed that the average RQD (Rock Quality Designation) in the 0–2 m range from the tunnel wall, where the blasting impact is significant, was decreased by about 17%. From the Goodman jack test before and after blasting, it was observed that the deformation modulus after blasting was lower than that before blasting. The deformation modulus was more or less consistent to 1.5 m from the wall, and increased with the depth. The average vertical deformation modulus, 16 GPa, was about 25% higher than the horizontal deformation modulus, 12 GPa. This might be related to the characteristics of the fracture network in the test area such as the closure of a micro crack, a shear effect, and non-elastic deformation. From the laboratory tests, the EDZ size could be estimated to be around 1.1–1.5 m, and the elastic modulus and rock strength in the EDZ were decreased by about 50% and 15%, respectively.

The gas permeability was measured using nitrogen gas in consecutive small intervals from the tunnel wall to the deep intact rock to investigate the change of permeability in the EDZ. The gas permeabilities in the test interval are expressed along the distance from the tunnel wall. The relation between gas permeability and water permeability was also discussed.

2. Overview of KURT

KURT (KAERI Underground Research Tunnel) is located in a mountainous area at the Korea Atomic Energy Research Institute (KAERI). The geological conditions around KURT were reported by Kwon et al. (2006) and Cho et al. (2008). The major rock type at KURT site is granite. A 252 m long declined borehole with a slope of −10% was drilled to investigate the geological characteristics. 1–3 m wide andesite dikes were encountered at five locations, 28 m, 47 m, 118 m, 124 m, and 235 m from the surface. Observable pegmatite veins were also found. At two locations, 70 m and 75 m from the surface, 0.8 m and 2 m wide faults were identified, respectively. At 180 m, the major water conducting zone was observed (Figure 1). The primary and secondary local fractures are in the NW and NE directions, respectively. Three faults and fracture zones cross the declined borehole at an angle of inclination and at a right angle. The RMR (Rock Mass Rating) was estimated from the uniaxial compressive strength of the intact rock, RQD (Rock Quality Designation), the discontinuity spacing, the condition of discontinuity surfaces, the groundwater conditions, and the orientation of the discontinuities, which were obtained from the drilling of the borehole and the construction of the tunnel. The variation of the rock condition along the declined borehole can be described with a variation of the RMR, as shown in Fig. 2. It is possible to observe that the rock quality improves with the borehole depth. The weak rock zone in the range of 80–100 m is due to the 20 m thick fault zone. The range with an RMR of higher than 41 is 85% of the whole range, and about 24% of the whole range shows an RMR of over 81. The average RMR of the rock zone is calculated as 64. The joint spacing in the rock zones varies from 0.028 to 0.80 m. The RQD varies from 35 to 79 and its average is 71.

KURT consists of two main parts, namely an access tunnel and research modules (Cho et al., 2008). To achieve the maximum depth of the research modules, and to limit the length of the access tunnel, the tunnel portal is located at the end point of the valley at the site. Fig. 3 shows a schematic layout of KURT. The access tunnel has a −10% downward slope to place the research modules as deeply as possible with a limited length of the access tunnel. The length of the access tunnel is 180 m, and the turning shelter is installed at the location, 70 m from the entrance. Two research modules are located at each side of the access tunnel at the tunnel dead end. The lengths of the research modules are 45 m (research module 1) and 30 m (research module 2), respectively, and an upward slope of about 2% is applied. The research modules are located 90 m below the surface in a hard granite formation. The access tunnel and research modules are all horseshoe shapes, and their tunnel size is 6 m × 6 m. The research modules are located in relatively good conditioned rock with an RMR of over 70. From the rock mass quality, the research modules are maintained safely with a limited rock support, including rock bolts and a wiremesh. In the research modules, the rock surface including the floor was opened for the in-situ experiments. A controlled blasting technique was applied for the excavation of the tunnel to minimize the disturbance of the rock around the tunnel.

3. In-situ experiments

To investigate the change of permeability in the EDZ, 6 boreholes were drilled into the wall of research module 1 (Figure 3). There was no water flow through the wall of the boreholes, and the inside of boreholes was under almost dry condition. Because the EDZ is limited to a narrow range of a few meters from the tunnel wall surface, an in-situ permeability measuring system using nitrogen gas was developed to measure the permeability in the EDZ. The use of gas as a fluid instead of water allows an easy and accurate measurement of the low permeability in the small test interval of the borehole. Nitrogen gas is chemically inert,

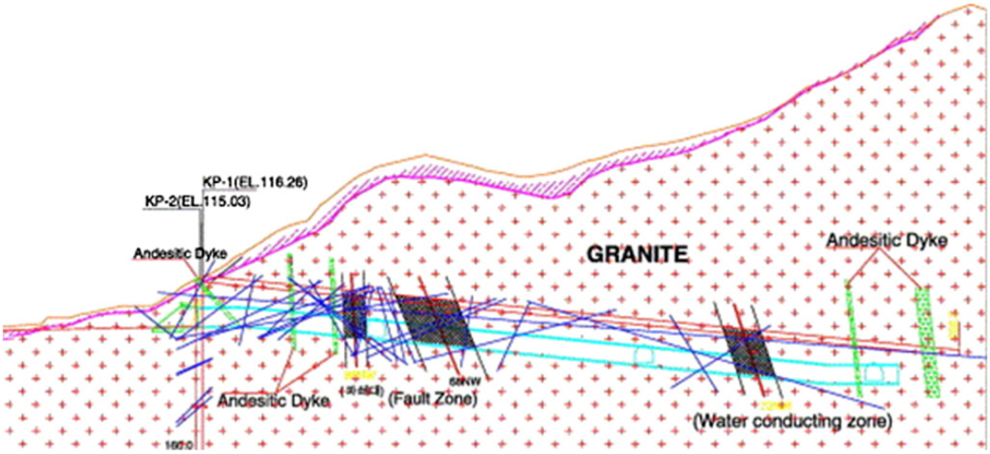

Fig. 1. Geological conditions of the KURT site.