Stress-dependent hydraulic characteristics of natural barrier fractures: A compilation of lab experiments and in-situ tests

Chae-Soon Choi [a*], Yong-Ki Lee [a], Kyung-Woo Park [a]
[a]*Disposal Performance Demonstration R&D Division, Korea Atomic Energy Research Institute*
[*]*Corresponding author: cschoi@kaeri.re.kr*

***Keywords: Stress, Natural rock fractures, Fracture properties, Transmissivity, Hydraulic aperture**

1. Introduction

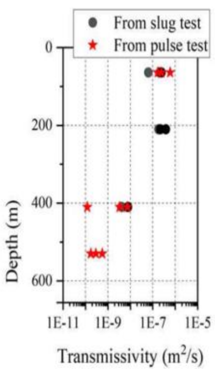
Field hydraulic tests, such as slug and pulse tests, provide valuable information about the in-situ hydraulic properties of fractured rock. In a way, laboratory experiments including core transmissivity measurements and property characterization techniques, allows for controlled experiments under various conditions. Several challenges and differences can arise when comparing field and laboratory data for fractured rock permeability [1]. The most representative cases are scale discrepancy, sample representation, spatial variability and boundary conditions. This study aims to compare the field and laboratory test results for hydro-mechanical boundary conditions, which may be a priority consideration for radioactive waste disposal environments.

2. Borehole in-situ test

Fracture transmissivity analyzed through several slug and pulse test long the depth at KURT site. The results showed a tendency to decrease with depth. This is believed to be due to the closure of the fracture aperture according to an increase in in-situ stress with depth [2]. Corresponding maximum and minimum horizontal stress increase from 10 MPa to 45 MPa and from 5 MPa to 35 MPa [3].

Table I: Summarization of field hydraulic tests

Depth (m)	Test method	Transmissivity (m^2/s)
54 ~ 74	Slug	$2.080e^{-7}$
	Slug	$2.431e^{-7}$
	Pulse	$2.428e^{-7}$
200 ~ 220	Slug	$1.805e^{-7}$
	Slug	$2.179e^{-7}$
400 ~ 420	Slug	$4.134e^{-9}$
	Slug	$7.829e^{-9}$
	Pulse	$3.323e^{-9}$
	Pulse	$7.326e^{-9}$
520 ~ 540	Pulse	$2.924e^{-10}$
	Pulse	$1.732e^{-10}$
	Pulse	$5.603e^{-10}$



3. Sampling of rock specimen

We examined drilling core specimens obtained from the boreholes to sample natural fractures. The sampled specimen is a coarse-grained granite with a single fracture parallel to the long axis. Typically, they are between 5 ~10 cm long and about 5.5 cm diameter.

4. Laboratory experimental method

Contact area, roughness, stiffness and aperture of the fracture are decisive parameters in determining the hydro-mechanical characteristics. Contact area and roughness between fracture surfaces can be analyzed using 3-dimensional geometrical data obtained from 3D-laser profile line scanner. And using MTS 816 rock test system, stiffness can be examined through an axial loading during displacement measurement of fractures. Lastly, constant water injection test was conducted to measure the flow rate under various stress condition. The fluid flow experiment also used the triaxial compression chamber of the MTS rock test system. We improved confidence in the experimental data because MTS is the leading provider of rock test systems that can be configured to hydro-mechanical rock properties.

5. Intensive analysis

In the case of the laboratory test scale, the hydraulic test is conducted in only one fracture and boundary conditions are properly controlled. Based on flow rate data, the fracture hydraulic aperture can be easily obtained from the cubic law.

$$Q = We\frac{ge^2}{12v}\frac{\Delta h}{L}$$

Here, Q is the volumetric flow rate, g is the acceleration of gravity, v is the kinematic viscosity of the fluid, h is the hydraulic gradient and e is the hydraulic aperture of the fracture. A variation of hydraulic aperture was observed according to the applied stress condition. Especially when the depth corresponded stress magnitude was increased, it was confirmed that the aperture size decreased nonlinearly. We compared the lab-scale aperture to the local scale aperture, which can be estimated from field hydraulic test data. Then, the field hydraulic test section contains more than one fracture. Therefore, the specific suggested methodology for the use of these field hydraulic tests to obtain the aperture was adopted [1]. As a result, this bilateral comparison research made it possible to determine the importance of the stiffness and roughness effect analyzed at the laboratory scale on the aperture.

6. Conclusion and plan

This study will be applied to research on upscaling of the fracture properties. It will also be progressive research for determining the aperture properties required for numerical modeling studies at a block scale.

REFERENCES

[1] Y. B. Cao, X. T. Feng, E. C. Yan, G. Chen, F. F. Lu, H. B. Ji, K. Y. Song, Calculation method and distribution characteristics of fracture hydraulic aperture from field experiments in fractured granite area, Rock Mechanics and Rock Engineering, Vol 49, pp.1629-1647.

[2] S. Choi, E. Kwon, B. H. Park, K. W. Park, Evaluation of hydrogeological and hydro-chemical characteristics of the deep borehole, KAERI/TR-9648. 2022.

[3] Y. Jo, C. Chang, S. H. Ji, K. W. Park, In situ stress states at KURT, an underground research laboratory in South Korea for the study of high-level radioactive waste disposal, Engineering Geology, Vol. 259, 105198.

Acknowledgment

This work was supported by the Institute for Korea Spent Nuclear Fuel (iKSNF) and National Research Foundation of Korea (NRF) grant funded by the Korea Government (Ministry of Science and ICT, MSIT) (No.2021M2E1A1085200)