Hydraulic response of excavation-induced disturbed zone in jointed rock masses

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１．INTRODUCTION

Flow in jointed rock mass is of great importance in a risk or reliability analysis for a geological disposal of a high-level nuclear waste. Meanwhile, the flow in the jointed rock mass is highly dependent on in-situ stress condition and its change due to tunnel excavation. The primary objective of this study is to evaluate the excavation-induced change in hydraulic characteristics of the jointed rock mass upon the creation of excavation.

２． METHODOLOGY

The present method is based on the relationship between mechanical deformation (e.g. normal stress and shear displacement) and anisotropic transmissivity of individual joints in jointed rock masses. The jointed rock mass is represented by a network of discrete joints. Thus, in this study, the transmissivity of a single rough rock joint and its anisotropic transition induced by the mechanical deformation is first examined and then the established relation is utilized in performing flow analysis in the joint network. Excavation analysis is conducted and corresponding deformations of individual joints are obtained using the Micromechanics-Based Continuum (MBC) model. For the flow and particle transport analysis in jointed rock mass, the FracMan/Mafic code is selected. These two finite element codes are connected through separate computational module in which the transmissivity modification is executed.

３．ANALYSIS IN A SINGLE ROCK JOINT

Flow analysis in a single rock joint with rough surfaces is performed numerically and analytically so as to understand the transition of equivalent joint transmissivity and its characteristic anisotropy due to mechanical deformation. Special interface element is employed to simulate contact problem under normal load and to obtain aperture distribution by finite element technique. The obtained aperture distribution is used in solving the Reynolds equation in order to derive the equivalent joint transmissivity. Analytical approach is also executed to derive more general conclusion on joint transmissivity and its deformation-induced change. Using the

$$\frac{\partial}{\partial x}\left(\frac{\rho g\, a(x,y)^3}{12\mu}\frac{\partial h(x,y)}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{\rho g\, a(x,y)^3}{12\mu}\frac{\partial h(x,y)}{\partial y}\right)=0 \quad (;\mathrm{Re}\,ynolds \quad equation)$$

$$\overline{K}_{ij}^{eff}=Coeff.\overline{A}^3\left[\left(1+3\frac{\sigma^2}{\overline{A}^2}\right)\delta_{ij}-9\alpha_{ij}\frac{\sigma^2}{\overline{A}^2}+9\left(\alpha_{ij}-3\alpha_{ij}^{\ 2}+9\gamma_{ij}\right)\frac{\sigma^4}{\overline{A}^4}\right](;equivalent\ permeability)$$

$$Cor_A(x,y)=2Cor_Z(x,y)-Cor_Z(x-d_x,y-d_y)-Cor_Z(x+d_x,y+d_y)\ (;correlation\ function\ of apertures)$$

$$\sigma_A^{\ 2}=2\sigma_Z^{\ 2}\left[1-Cor_A(x,y)\right](;\mathrm{var}iance\ of\ aperture\ distribution)$$

where,

$a(x,y)$ *; apertures at each local point*

$\overline{A}$, $\sigma_A^{\ 2}$ *; mean and variance of aperture distribution*

α , γ *; coefficient depending on correlations of apertures*

d_x , d_y *; shear displacement*

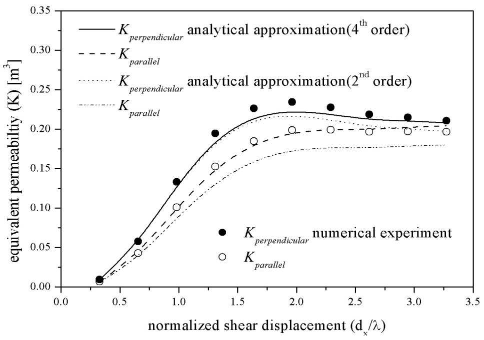

Figure 1. Numerical and analytical results on equivalent permeability in a single rough joint under deformation

Perturbation expansion method, the above Reynolds equation can be solved in an analytical manner. The solution is the function of statistical moments (e.g mean, variance, and auto-correlation) of aperture distribution. The statistical moments of the aperture distribution can also derived analytically using the available probabilistic information of the surface roughness of joints. It is noted that the well-known increment of joint transmissivity due to shear dilatancy and origination of anisotropy are effectively reproduced both numerically and analytically.

キーワード　excavation-induced, anisotropic transmissivity, single joint, jointed rock mass
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4．ANALYSIS IN JOINTED ROCK MASS

Based on the excavation-induced transmissivities of a single joint, flow analysis around a circular tunnel in a jointed rock mass is performed. Within a model of cube, measured by 15 m x 15 m x 15 m, random discrete joints are generated (Figure 2), and then a circular tunnel with a diameter of 5 m is excavated (Figure 3). The deformation of individual joints due to the excavation-induced redistribution of in-situ stresses around the excavation is calculated by the MBC model analysis, with which initial transmissivities are modified to excavation-induced transmissivities. The characteristic results of the present approach are following.

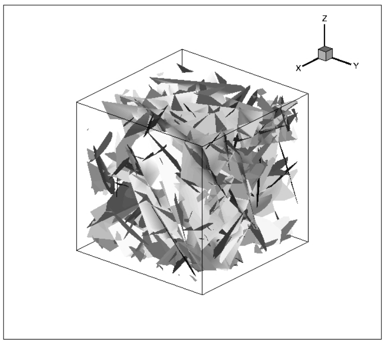

Figure2. Examples of discrete network of generated joints

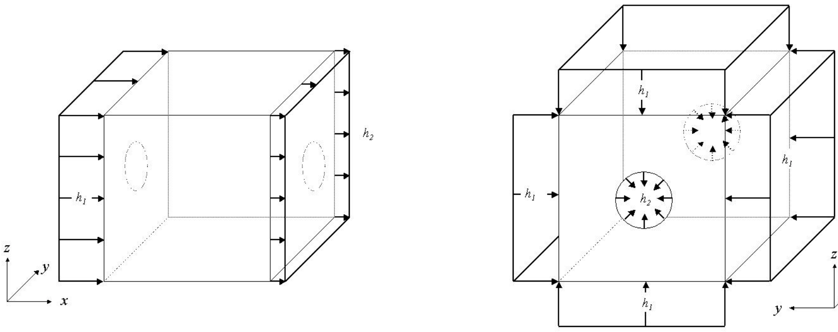

Figure3. Excavation of tunnel with flow boundary conditions; left-axial flow, right-radial flow

5．REPRESENTATIVE RESULTS

Through Figure 4 to 5, typical estimations by present approach were introduced. Figure 4 indicated the frequency histogram of flow rate obtained as a result of hundred of iterative Monte Carlo Simulation and is fitted to Gaussian distribution. It is noted that the flow rate increase in axial flow is much significant rather that that of radial flow. Figure 5 illustrates the particles, at several time steps, transported through the network by advective flow. It shows that the increment of excavation-induced transmissivity concentrates around the tunnel boundary, so that the particle movement is greatly enhanced.

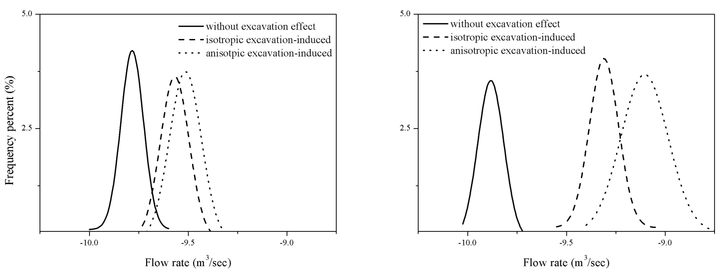

Figure 4. Frequency histogram of flow rate (left;radial, right;axial)

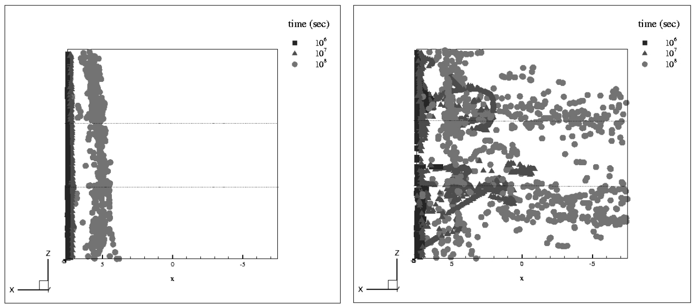

Figure5. Particle positions at different time steps (left; without excavation effect, right; with excavation disturbance)

6．SUMMARY AND CONCLUSION

To understand the excavation-induced changes in the hydraulic characteristics of a jointed rock mass, equivalent transmissivity of a single rough rock joint under deformation was examined, and the understandings are further implemented into the flow analysis through a discrete network of joints. Typical predictions obtained in a test simulation by present method were introduced. The increment of flow rate and particle transport in the direction parallel to tunnel axis were noticeable. However, quantitative verifications are still expected.

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