Study on Flow Characteristics of Fluid through a Rock Fracture Network

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1. Research background and objective

In recent years, more and more large-scale rock engineering projects such as dam foundations, underground storage caverns, submarine tunnels and waste disposal facilities are under design and construction. The fluid flow behaviour of rock fractures in rock mass is one of the crucial issues in the safety assessment of these projects. Previous experimental and analytical studies have focused on the flow behavior of single rock fractures, with little attention paid to the flow behavior of a rock fracture network. In this study, fluid flow tests were conducted on an artificial rock fracture network by means of a fractured glass plate. Various hydraulic heads were applied on the inlet of one fracture and the flow rates at the outlets of other fractures were measured. Numerical simulations applying Cubic law on each fracture were then carried out on the same model of the experiment to verify the validity of the cubic law and to assess the response of the flow rate to the hydraulic head. The flow behavior through single fracture and fracture network was compared to estimate the influence of the junction of multiple fractures on the flow behavior of a fracture network.

2. Laboratory experiment

An intact rock such as granite has extremely low permeability and water can hardly get through it. In this study, a fractured glass plate was used to represent a rock, with the cracks being regarded as rock fractures as shown in Fig. 1. There are three fractures in the model jointing at a point near the centre of the model. Various hydraulic heads were applied on the inlet of one fracture and the flow rates at the outlets of other fractures were measured, based on which their flow velocities can be calculated. The situation of experiments are shown in Figs. 2 and 3.

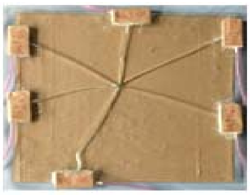


Fig.1 Experimental model

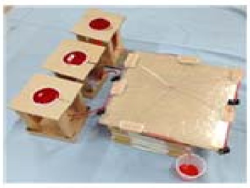


Fig.2 Situation of experiment

Fig.3 Water collection

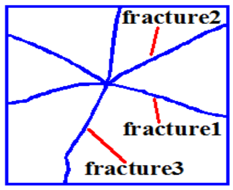


Fig.4 Numerical model

3. Numerical simulation

3.1 Modeling and meshing

Software autoCAD was used to establish the numerical model based on the experimental model as shown in Fig. 4. Then, a meshed model based on Fig. 4 was constructed in FLAC^{3D} , and flow simulation was conducted.

3.2 Govern equation of fluid flow

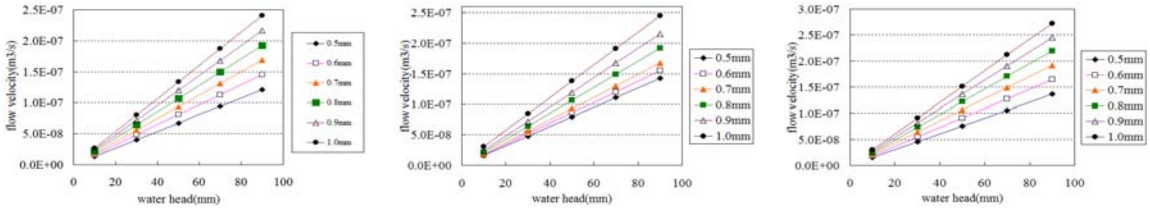
Fluid flow is described by Darcy's law through the following govern equation:

$$q_i = -k_{il}\hat{k}(s)\left[p - \rho_f x_j g_j\right]_{,l} \tag{1}$$

where q_i is the specific discharge vector, p is pore pressure, k is the tensor, $\hat{k}(s)$ is the relative mobility coefficient, ρ_f is the fluid density, and g_i , i = 1,3 are the three components of the gravity vector.

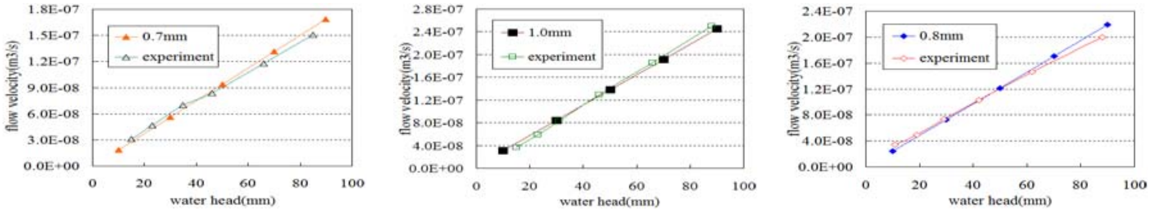
3.3 Relation between flow velocity and fracture aperture

Flow tests were conducted on the three apertures respectively by sealing other two when testing one aperture, under various water heads. The numerical simulation results of the relation between flow velocity with water head for the models with different apertures are shown in Fig. 5, and the comparison of experimental and simulation results is shown in Fig. 6. With the increment of water heads and apertures, fluid flow velocities increase proportionally which follows the Cubic law. According to the comparisons, flow velocity-water head curves of fractures 1 2 and 3 agree with the numerical models with apertures of 0.7mm, 1.0mm and 0.8mm respectively. By doing so, the hydraulic apertures of each fracture in the experimental model were quantitatively estimated.



(a) fracture 1 (b) fracture 2 (c) fracture 3

Fig. 5 Flow velocity under different apertures and water heads



(a) fracture 1 (b) fracture 2 (c) fracture 3

Fig.6 Comparison between laboratory experiment and numerical simulation

3.4 Flow characteristics of a fracture network

Numerical simulations were further conducted on fracture networks with a number of combinations of inlet and outlet as shown in Table 1 and Table 2. The flow velocities at each outlet were recorded for all the cases and their relations with water head are shown in Fig. 7 and Fig. 8. At here, case 1-1 stands for the flow velocity at the outlet of fracture 1 in case 1, while case 1-a stands for the total flow velocity at every outlets in case 1. Fig.7 shows the cases with one inlet (fracture 1) and several outlets. The more outlets the model has, the slower the flow velocity at the outlet of fracture 1 becomes, due to the distributary of flow at the joint of fractures. The increase of outlet will also increase the total flow velocity of the fracture network.

In the cases of Table 2, the water head applied on fracture 1 was kept constant as 10mm and various water heads were applied on the other two apertures simultaneously to represent the situations of fractures in a network subjected to different water heads. As shown in Fig. 8, the flow rate at the outlet of fracture 1 drops when fracture 2 is involved in the model, compared to the value when fracture 3 is involved in the model because fracture 2 has a larger aperture than 3. The increase of inlet and outlet will also increase the total flow velocity of the fracture network.

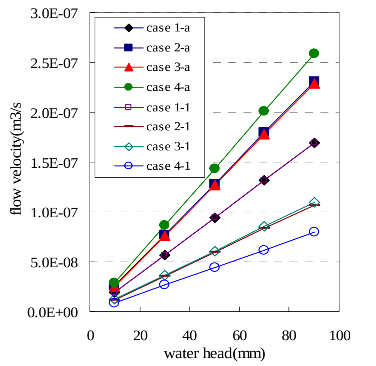


Fig.7 Flow velocity of fracture1 in a single fracture

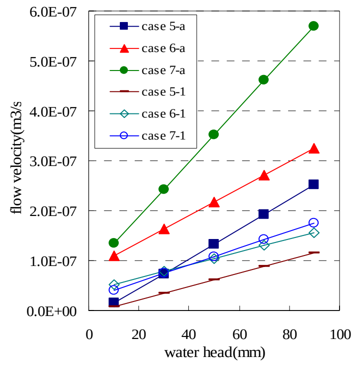


Fig.8 Flow velocity of fracture1 in cross fractures

Table1 Cases with one inlet and several outlets

Case	inflow	outflow
1	fracture 1	fracture 1
2	fracture 1	fracture 1 and 2
3	fracture 1	fracture 1 and 3
4	fracture 1	fracture 1, 2 and 3

Table2 Different cases of cross fractures

Case	inflow	outflow
5	fracture 1 and 2	fracture 1 and 2
6	fracture 1 and 3	fracture 1 and 3
7	fracture 1, 2 and 3	fracture 1, 2 and 3

4. Conclusions

In this study, flow behavior of a fracture network was investigated through laboratory experiment and numerical simulation. The simulation using the Darcy's law has good consistency with the experimental results. Compared to a single fracture, fluid flow is more complex in a rock fracture network, which is significantly affected by the interaction of different fractures especially at the junction. Such interaction will be investigated in detail in the future study.

References

Hakami E. Aperture distribution of rock fractures [Doctoral Thesis]. Stockholm:1995.