Evaluation of Hydromechanical Behaviour of Single Rock Joint with a Newly Developed Shear-Flow Test Apparatus

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1. INTRODUCTION

In recent years, the management of radioactive waste becomes an important environmental issue in all countries operating nuclear power plants. Experiments are necessary to determine the physical, mechanical, thermal and hydraulic properties of the proposed rock masses. In this study, a new hydromechanical behavior test apparatus is developed which could apply shear-flow coupling test under both constant normal load (CNL) and constant normal stiffness (CNS) boundary conditions with regulable hydraulic gradients. A series shear-flow coupling tests under both CNL and CNS boundary conditions were carried out to estimate the hydraulic behaviour of rock joints during a shear process.

2. EXPERIMENTAL STUDY

In this study, a laboratory visualization system of shear-flow tests under CNS boundary condition is designed. The outline of the fundamental hardware configuration of this apparatus is described in Figure 1. One advantage of this apparatus is that the flowing image in rock joint can be monitored with a CCD color camera placed above the transparent replica at interval times after trace flow is injected into the joint. Acquired images are then analyzed by an image processing program within a PC.

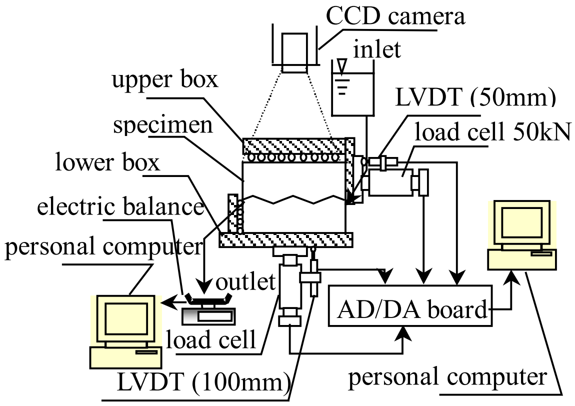

Fig. 1. Schematic view of the visualization system and shear-flow test apparatus.

The experiment process in this study could be divided into three categories. (1) setting contact areas on two smooth parallel plates with uniform aperture, by changing the distribution pattern and contact ratio (the ratio of contact area to the whole flow area) to test the response of flow to the contact area (see Figure 2). (2) applying normal loads on the rock specimens from natural ground, by doing increasing and decreasing cycling loading to examine the influence of joint surface characteristics on the flow (i.e. friction). (3) shear-flow coupling tests on artificial rock specimens under different boundary conditions (CNL and CNS) to give a general estimation. Herein, test (1) was done on idealized fracture with contact area and test (2) and test (3) were tested on artificial rock joints.

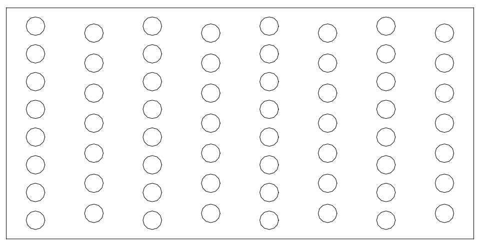

Fig. 2. One example of the arrangement of contact area (15%).

One example of the transmissivity with contact ratio of 15% is shown in Figure 3. There are not obvious differences among different patterns with the same contact ratio. The distribution of contact areas seems to have negligible influence on the transmissivity of a fracture, whereas the transmissivities are different in various contact ratios. Therefore, contact ratio could be expected as a simple factor to estimate the effect of contact area on the transsimisivity of a fracture.

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Shear test results are shown in Figure 4. The change in normal displacement in CNS tests is small in comparison with that in CNL tests, hence, CNS condition inhibits the increase of transmissivity during shearing.

3. NUMERICAL SIMULATION

Assuming the following geometric and kinematic conditions: 1) the fractures consists of two smooth parallel plates with uniform aperture, 2) the fluid is incompressible and fluid flow is laminar in the steady state, the governing equation for fluid flow in a single fracture is derived from the mass conservation equation and Darcy's law as follows:

$$\frac{\partial}{\partial x}\left(T_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(T_{yy}\frac{\partial h}{\partial y}\right)+Q=0 \qquad (3)$$

where Q is an initial source and sink taken to be positive when fluid is slowing into and negative when flowing out of the fracture, and T_{xx} and T_{yy} are called the fracture transmissivity in x and y-directions, respectively, defined by the cubic law expressed as following equation:

$$T_{xx}=T_{yy}=T(x,y)=\frac{\rho g e^3}{12\mu} \qquad (4)$$

where μ is dynamic viscosity. The FEM code developed in this study uses linear quadrilateral elements to solve the equations mentioned above.

As shown in Figure 5, during shearing, the joint will dilate and so does the mechanical aperture, which induces the increase of transmissivity. Dilation also causes the contact areas of the joint walls decreasing, which, furthermore has a positive effect in increasing the transmissivity. The numerical simulation results distribute upon the experimental ones after a shearing offset around 8mm, before which, simulation gives good predictions.

4. CONCLUSIONS

Normal displacement is the dominant parameter in evaluating the hydraulic behavior of rock joints during shearing. If a joint is sheared under CNS boundary condition, comparing to the CNL condition (under the same initial normal stress), the contact area will decrease slower and smaller and the conductivity will increase in a lower magnitude. Numerical simulation, in some degree, could give good prediction to the hydraulic conductivity if the fracture apertures were accurately modeled.

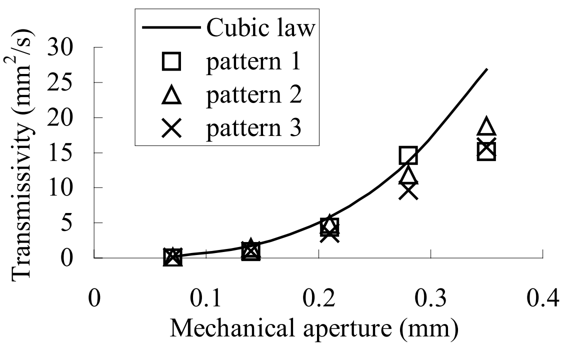

Fig. 3. Transmissivities of the fractures with contact ratio of 15%. Herein, pattern 1, 2 and 3 have the same contact ratio and size of contact area but different arrangements.

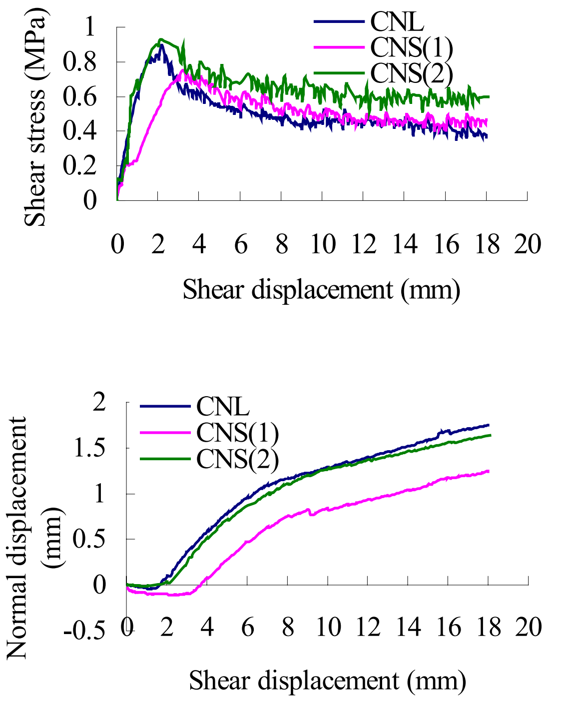

Fig. 4. Shear test results under CNL (σ_n =1MPa), CNS(1) (k_n =200Mpa/m) and CNS(2) (k_n =500MPa/m) boundary conditions.

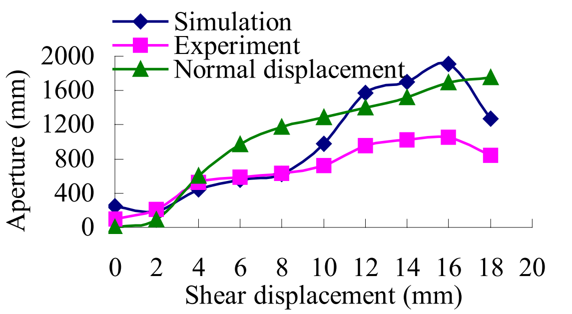

Fig. 5. Change of aperture during shearing from experiment and simulation. (CNL, σ_n=1MPa).