Fluid flow and solute transfer through a fracture step: mixing models at intersections and retardation effect of a step structure

N. D. KHANG, MEMBER OF JSCE, DOCTORAL STUDENT, SAITAMA UNIVERSITY
K. WATANABE, MEMBER OF JSCE, PROFESSOR, SAITAMA UNIVERSITY

Abstract Fluid flow and solute transport in fracture structure step are investigated by the mean of numerical simulation. It is found that complete mixing occurs only in cases of T-intersections while streamtube routing model is observed in through-going intersections. Both geometric models and splay fracture types of the fracture step significantly influence to solute spreading patterns.

Keywords. fracture intersection, flow and solute mixing, fracture step, retardation effect.

1. Introduction

Fracture network model has been widely used when simulating fluid flow and solute transport within a fractured rock mass. The problems remain when adopts the discrete network to the analysis of solute transport are (a) how to simplify a complicated fracture system; (b) how solute are transported through fractures and mixed with fluid in the fracture intersections. The purposes of this study are (1) to examine fluid flow and solute mixing at intersections, and (2) to analyze the retardation effects of step structure in fractures. This study is the base for the analysis of solute transport in a large rock mass (network scale).

2. Methods

2.1 Idealization of a major fracture: In order to simulate flow and solute transport in a natural complex fractured rock mass by numerical codes, simplifications are needed. Figure 1a shows an idealization model proposed by Mazurek et al (1) where a major fracture is represented by master fractures and several connecting splays. Three possible types of a common fracture or splay are presented in figure 1b, they are the models of *shear fracture*; *hydrothermally altered fracture*; and *open fracture*. Figure 1c shows three basic types of fracture intersections: *T-intersection* (**Ia**) where one fracture terminates against another; *displacement fracture* (**Ib**) formed when a fracture displaced along another; and *through-going intersection* (**Ic**) where one fracture crosses a second fracture. We intentionally restricted our investigation to the idealized geometry shown in Figure 3 where all intersections among fracture are of type **Ia**.

2.2 Numerical model: Flow and solute transport within above fracture is modeled as a two dimensional process. In this study a two dimensional Galerkin finite element model is used to obtain flow and solute transport solution by directly solving advection-dispersion equation. Flow is assumed to be laminar regime. Two-dimensional studies provide insight to the factors influencing transport process.

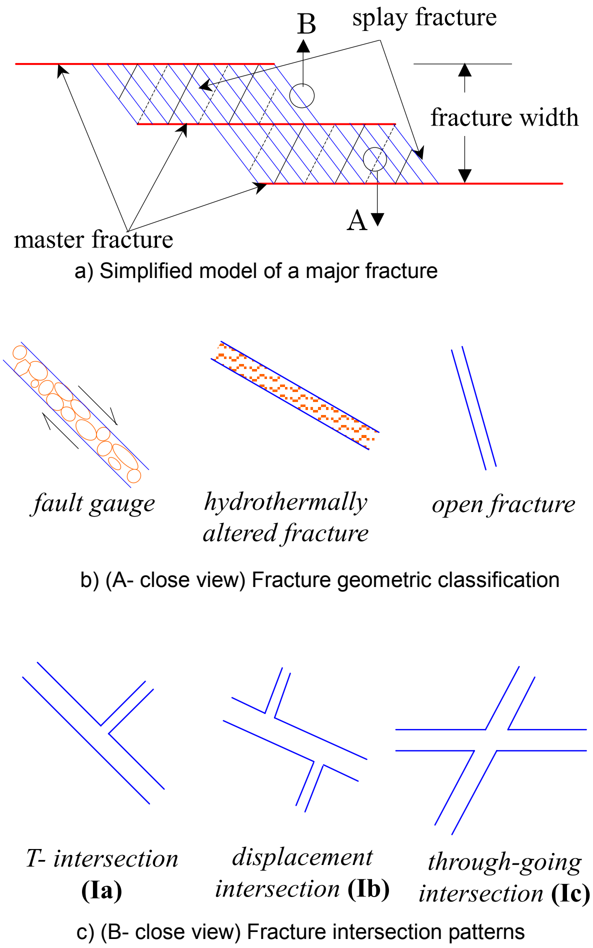

Figure 1. Idealized fracture at fault step (fracture step)

3. Results of numerical investigation

Three models have been proposed to describe the manners in which fluid and solute are transferred through fracture intersections: (i) streamtube routing; (ii) streamtube routing with diffusion within fracture intersections; and (iii) complete mixing. The majority of model studies at the network scale use complete mixing model where mass is transported away from intersection in proportion to the discharge in each outflow branch. However, in our study the concept of complete mixing is not properly observed in various cases. This assumption is acceptable only for the case of T-intersection. Figure 2 shows a typical example where most of contaminant is mainly transported into branch 3 (figure 2b) even the out discharge Q4 in branch 4 is quiet greater than out discharge Q3 in branch 3. In the most cases, the streamtube routing model is often observed. Our results agree with many other studies in the past (2).

At the larger scale flow and solute transports within a fracture steps in three geometric models as shown in figure 3 are simulated. At first we investigate the case where all master, splay fractures and microcracks are hydrothermal altered fracture (low hydraulic conductivity). The plot of breakthrough curves at downstream boundary in those cases (figure 4a) shows that a step fracture when

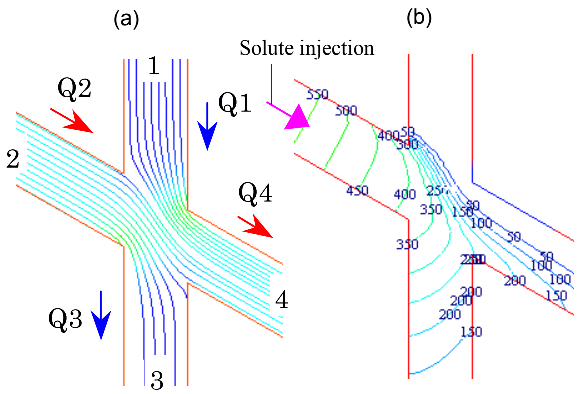

Figure 2. Example of flow and solute mixing at a through-going intersections: (a) Stream tube configuration (b) Concentration contour plot at a certain time (constant contaminant source C_o=1,000ppm at upstream boundary of branch 2, contours in ppm, Q2=Q4 > Q1=Q3 (Q1/Q2=3/5))

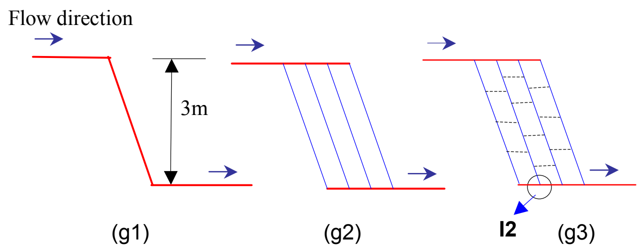

Figure 3. Geometries of three fracture step models: (g1) one connecting splay (g2) multi-connecting splays (g3) multi-connecting splay with micro-cracks

modeled as several splay fractures will result in longer arrival time and transit time. The introducing of microcracks that are not aligned in the flow direction into step structure also leads to longer in both arrival and transit time. In the later cases of numerical calculation, the same fracture geometries as above are used but now all connecting splays and microcracks are assumed as open fracture (high hydraulic conductivity). As shown in figure 4b, the change in permeability of connections strongly influences to spreading pattern. Both arrival and transit times are reduced significantly, especially in the case of microcracks introduced into step structure (g3-b) the arrival time is much earlier in comparison with the other cases (g1-b, g2-b). It is clear from above results that the introducing of connecting splays and microcracks into step structure leads to longer transit time or greater macroscopic dispersion. This means that when model a fractured rock mass as a discrete network, one must be very careful in idealization step structures in fractures both for geometric model and fracture type.

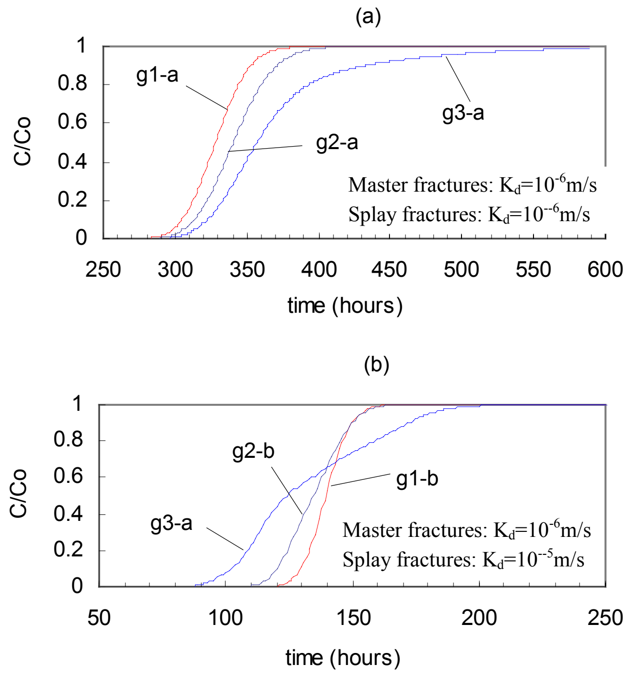

Figure 4. Breakthrough curve at downstream boundary: (a) all fractures are hydrothermal altered fracture (low hydraulic conductivity); (b) master fractures are hydrothermal altered when splay and micro-fractures are opening (high hydraulic conductivity)

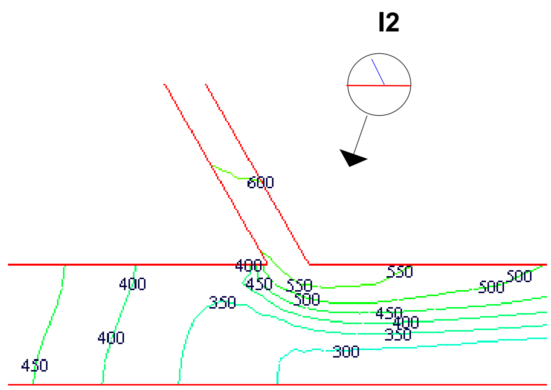

Figure 5. Concentration contour plot at intersection **I2** (figure 2-g3) at time t=290 hrs in the case g3-a (constant contaminant source C_o=1,000ppm at upstream boundary, contours in ppm)

4. Conclusions

It is found that complete mixing occurs only in the cases of T-intersections while streamtube routing model can be observed in the through-going intersections. The fracture steps play an important role to spreading pattern of solute in fracture networks. More research works on the general geometry of fracture should be conducted.

REFERENCES

1). M. Mazurek, P. Bossart, T. Eliasson, Classification and characterization of water-conducting features at Aspo: results of investigation on the outcrop scale, the report for Aspo HRL joint project, Switzerland, 1996.

2). J. Bear, C. F. Tsang, and G. Marsily, *Flow and Contaminant Transport in Fractured Rock*, Academic Press Inc., Sandiego, 1993.