NUMERICAL INVESTIGATIONS OF FLUID FLOW AND SOLUTE TRANSPORT IN A SELF-AFFINE FRACTAL FRACTURE WITH NONLINEAR HYDROMECHANICAL EFFECT

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Faults and fractures play an important role in the transport of fluid and solute through rocks with low permeability. Under a wide range of circumstances these transport processes are concentrated onto a network of interconnected individual fractures and thus it is important to analyze the fluid flow and solute transport in a single fracture. The flow and transport behaviors in a fracture depend significantly on the distribution of void spaces between two opposing fracture walls and also on the roughness of the fracture surface (Gentier, 1986). It is well recognized that the fractures include closed regions where two walls are in contact each other, as well as opened regions where two walls are separated by a distance that is varied from point to point. The aperture and contact area distributions in the fracture depend significantly on the normal (e.g. Durham and Bonner, 1995) or shear stress (e.g. Yeo et al., 1998) acting on the fracture. In general, the effect of both stresses has a tendency to decrease the void spaces offered to the fluid flow and solute transport due to the increase of contact areas.

In the present work, the flow and transport behaviors in a variable-aperture fracture subjected to only normal stresses are numerically analyzed. The variable aperture distribution in the fracture is generated by using the self-affine fractal model and the fracture surface roughness is represented by the fractal dimension. In order to represent a nonlinear relationship between the effective normal stress and the fracture aperture, a simple mechanical model is adapted and combined with the local flow model. The effect of the fractal dimension on the flow and transport behaviors is also examined.

Flow and transport simulations were carried out in 10 independent aperture distributions at each level of the effective normal stress and all of results correspond to mean values for 10 realizations. We can observe that the flow paths in $D = 2.5$ is more tortuous than those in $D = 2.0$.

The effective permeability decreases non linearly, but the fracture of $D = 2.2$ is slightly more permeable than that of $D = 2.5$. This result is the same as that by several researchers such as Moreno et al.(1988), Ewing and Jaynes(1995). We also compared with results obtained from Zimmerman and Bodvarsson's analytical model (1996). As a result of the comparison, a relatively good agreement between the numerical model and Zimmerman and Bodvarsson's model is obtained for both $D = 2.5$ and 2.2.

The mean transit time in both cases of D increases non-linearly with the effective normal stress and the case of $D = 2.5$ increases faster than that of $D = 2.2$. However, the difference between two values of D is gradually increased with the effective normal stress. This result is due to the fact that the particle pathway in the fracture with $D = 2.5$ is more tortuous flow path than that in the fracture with $D = 2.2$. Consequently, the solute transport in a single fracture is influenced by the effective normal stress as well as the fracture surface roughness.

We can expect that the results obtained from these numerical studies will be helpful to describe the characteristics of flow and transport with the hydromechanical effect for each element consisting of the three-dimensional fracture network.

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