Correlation between physical and hydraulic properties of rock fractures constrained by surface geometry: Digital rock physics approach

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Fracture flow and fracture aperture distribution are of great interest to evaluate the mechanism of earthquake and fractured reservoirs. To predict and image the subsurface fluid-flow behavior, geophysical observations, such as seismic and electromagnetic methods, and classical rock physical models have been broadly applied. However, there is no established rock physical model to estimate the fluid-flow behaviors (e.g., permeability) in the fracture from resistivity or elastic wave velocity, and thereby fluid-flow behavior in the fracture are difficult to be precisely interpreted by geophysical data. To reveal the fluid-flow behavior in the fractured zone, we need to establish the rock physical model for the fracture. In this study, to establish the rock physical model which can correlate fracture aperture, fracture permeability, elastic wave velocity and resistivity, we measured and calculated them by using real rock and digitalized rock fractures.

We conducted laboratory fluid-flow test by using fractured Inada granite (50 mm in a diameter, 80 mm in a length) which have single tensile fracture with different roughness. For the numerical model, we digitalized this real rock fracture (0.1 mm grid resolution) to calculate fluid-flow, resistivity and elastic wave velocity under the same condition with experiment. A series of 3D fracture flow simulations was revealed by using Lattice Boltzmann method and we applied finite element analysis to calculate resistivity and elastic wave velocity after this fluid-flow simulation.

As the results of experiments and simulations, we clarify the changes in fracture aperture, fracture permeability, elastic wave velocity and resistivity associated with increasing effective normal stress. Moreover, changes in the permeability and the resistivity were not affected by the roughness, whereas velocity change shows roughness dependency. This roughness dependence of velocity change can be explained by the distribution of asperities. We also correlate the changes in permeability, resistivity and elastic wave velocity. The relationship between permeability and resistivity can be modeled regardless of the roughness, while the relationship between permeability and elastic wave velocity change depend on the roughness. Our results suggest that the resistivity survey is effective for estimating the change in permeability, whereas elastic wave velocity may need to be modeled in consideration of the asperities. As the results of further studies using synthetic fracture, fracture geometry (e.g., asperity) affects these relationships.

Keywords: digital rock physics, elastic wave velocity, resistivity, permeability, fracture flow, Lattice Boltzmann Method