ABSTRACT

Choi, Min-Kwang, Ph.D., Purdue University, August 2013. Characterization of Fracture Stiffness Subjected to Normal and Shear Stress. Major Professor: Antonio Bobet and Laura J. Pyrak-Nolte.

A series of laboratory experiments is presented on characterization of specific stiffness for a fracture subjected to shear and normal stress. The experimental works focus on seismic behavior of a fracture to provide the relationships between normal and shear fracture specific stiffness and between spatial distribution of fracture stiffness and fluid flow.

The ratio of shear to normal fracture specific stiffness is proposed when a fracture is subjected to shear as well as normal stress. Synthetic fractures made of gypsum and lucite are prepared to have different fracture surface conditions; well-mated or non-mated. For well-mated fracture surfaces, asperities were created by casting gypsum against sandpaper. After the first block hardened, the second block was cast against the rough surface of the first block such that the two contact surfaces are well-mated. Non-mated fracture surfaces are fabricated with two lucite blocks that were polished (lucite PL) or sand-blasted (lucite SB) along the contact surface. In the experiments, each specimen is subjected to normal and shear loading while the fracture is probed with transmitted and reflected compressional and shear waves. Shear and normal fracture stiffnesses are calculated using the displacement discontinuity theory. The stiffness ratio obtained from the experiments is compared to a theoretical ratio that is determined assuming that the transmission of compressional and shear waves is equal. The experimental results show that the fracture roughness of the non-mated fractures affects the stiffness ratio in the low range of normal stress and that the shear fracture specific stiffness for well-mated fractures is sensitive to the applied shear stress.

Spatial variability of fracture specific stiffness is investigated seismically on lab-scale natural fractures. Seismic measurements for intact and fractured granite specimens are obtained as a function of stress. The granite matrix shows stress-sensitivity due to existence of micro-cracks and a fracture behaves as a low-pass filter by reducing the transmission of high frequency components in transmitted seismic wave. From the measurements of transmitted waves, fracture specific stiffness is calculated by the displacement discontinuity theory. Estimated fracture specific stiffness shows that the fracture stiffness is non-uniformly distributed on the fracture plane and changes locally as a function of stress. It is found that fracture specific stiffness is dependent upon fracture geometries, i.e., distribution of asperity height and micro-slope angle. The more uniform the asperity heights the stiffer the fracture is and magnitude of shear fracture stiffness is sensitive to high micro-slope angle though the area with the high micro-slope angle is very small.

Seismic behavior of rock matrix and fracture upon saturation is utilized to correlate fluid flow with fracture specific stiffness. Experiments of fluid invasion into rock matrix and fracture show increase of wave velocity and decrease of wave amplitude. Invasion velocity into void spaces in a fracture is found to be much faster than that into rock matrix, such that propagation of the fluid in a fracture is seismically detectable first during the early stage of fluid invasion. The detected fluid front advances non-uniformly throughout the fracture plane and the non-uniform propagation of fluid is correlated to the spatial distribution of fracture specific stiffness. The fluid first invaded portions of the fracture that had a relatively low fracture stiffness and then spread to the regions with higher stiffness. Along with the fluid invasion, fluid flow through a fracture is measured and found to be stress-dependent. The stress-dependent flow is correlated to fracture specific stiffness measured at the same normal stress. Fluid flow is stiffly decreases compared to the increase of fracture stiffness. This fluid flow - fracture specific stiffness behavior gives an implication that the fracture seems to have spatially correlated aperture distribution from the comparison with data of literature.