Fracture process and macroscopic strength of rocks under axial loading of compression

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The fracture strength of rock specimens under loading of compression decreases with an increase in specimen size. This size effect is one of the factors that should be taken into consideration on discussing the strength of faults. Here, a model based on the shear micro-fracture process is introduced to elucidate the macroscopic strength of compression and its size effect.

By analyzing the published P-wave velocity data for rock specimens under axial loading of compression, the density c of tensile cracks is found to be expressed by c = f(p)G(r), where p is confining pressure and r is applied stress difference normalized by the macroscopic strength of the specimen. Since r is proportional to the applied shear stress, G(r) is proportional to the density of shear cracks in a specimen. The expression means that the macroscopic fracture occurs when shear crack density reaches at a critical value. Assuming that micro-fracturing obeys the Coulomb criterion, G(r) can be rewritten as g(t), where t is shear stress normalized by the macroscopic shear strength. (Yamamoto, 1995, Fracture Imaging, 3rd SEG/SEGJ Int. Symposium, 327- 334.)

For the above fracturing process, the following model has been proposed: A specimen consists of small volume elements of the same size called physical elements. Shear fracture strength is assigned to all the elements. Rupture originating at an element propagates over a number of the elements to make the elements lose their strength. Here, the assemblage of the elements that have lost the strength is called a microfracture element. The strength of a microfracture element is thus equal to that of the weakest physical element in the microfracture element.

A variable u is defined as the applied shear stress normalized by the macroscopic strength for a constant normal stress on the fracture surface. Taking a power function of its value ranging from 0 to 1 as the strength distribution function for the microfracture elements, a function gm(u) is derived on the condition that fractured volume do not support the load at all. The function gm(u) is a two valued function of u and u is defined for u.LE.U at a critical value gc of gm(U). U represents the macroscopic strength and gc is the fraction of fractured volume. The macroscopic fracture occurs at the time when fractured volume reaches at the critical value gc. This is coincident with the experimental result above. (Yamamoto, 1998, Zisin 2, 50, 169 - 180; Yamamoto et al., 2002, EPS, 54, 1181 - 1194)

The size of physical elements is invariant for the same rock. If larger microfractures occur for larger specimens in size, the strength of microfracture elements decreases. This makes the specimen weaken. In order that a specimen completely fractures, the strength of physical elements should be 1 in u at most and the largest macroscopic strength is determined on the condition of microfracture elements equal in size to physical elements. The strength thus calculated is about 0.55 in u for m = 5 and about 0.72 in u for m = 10, where m is the power of the strength distribution function. These values of u identical to the internal friction coefficient are found to be close to those for specimens in laboratories.

The size effect theoretical determined is compared with the published data for the size ranging from a few cm to about 1 m in length. The theory is seen to well explain the data in this size range and the internal friction coefficient of 1 m size specimens is smaller than 0.15. (Yamamoto, 1996, SSJ, Fall Meeting, A34)

The above results suggest the possibility that the strength of faults generating earthquakes is small. Further, they suggest that there are some mechanisms to make the shear strength small without highly pressurized pore fluid in rocks. The key to solve this problem is expected to be in fault structure.