S044-001 Room: Convention B Time: May 29 13:45-14:00

A generalized fracture process model for brittle rocks under true tri-axial compression

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INTRODUCTION: The stresses measured around a fault suggest that the damaged zone is in the post-failure state under the normal stress to the fault plane. Fracture density or crack density can be estimated for the zone from the stresses in or around the zone through the fracture process model, assuming that stresses equilibrate to the strength. The elastic constants of the damaged zones can be calculated for the estimated crack density using the theories of the effective elastic constants. Following this procedure, it has been shown that damaged zones have a large Young modulus and a small rigidity to the stresses on the fault plane. It has been pointed out further that this elastic property can make the faults weak. This implies that the elastic anisotropy of damaged zones causes the anisotropy of fault strength and this anisotropy can be known from the stresses in or around damaged zones. In order to know the strength anisotropy from the stresses, it is necessary to generalize the fracture process model so as to provide the fracture density for arbitrary applied stresses, because the existing model has been derived from the data for rock specimens under the axial loading in confining pressure. The purpose of this study is to present a generalized fracture process model that is applicable to an arbitrary stress field.

MODEL: Consider a rock specimen under the applied compressive stresses, s1, s2, and s3 (s1.gt.s2.gt.s3) to the directions x1, x2 and x3, respectively. Two modes of microfractures are produced in the specimen by the stress differences (s1-s3) and (s2-s3). Here, provided that the respective modes of microfractures are not interactive each other, we formulate the relationship of fracture density to applied stresses for only one mode of microfractures due to (s1-s3). We define an axis xr in an arbitrary direction orthogonal to x1. The model for the formulation is as follows: 1) A specimen consists of small volume elements of the same volume. 2) An element can fracture once and the fracture forms a surface whose normal is in the plane (x1, xr). 3) The number density of the potential surfaces with their normal in (x1, xr) is constant for any direction of xr. 4) Fracture of an element obeys the Coulomb criterion, where the normal stress is given by (s1+sr)/2. 5) Shear strength ts of an element is expressed by us = ts/tr, where tr is a reference strength. 6) The number of fracture elements is proportional to te**m when applied shear stress is increased from 0 to te. 7) s1=sr=(s1+sr)/2 in a fractured volume element.

ESTIMATION OF ULTIMATE STRENGTH: It is difficult to solve the equations for arbitrary stresses. Here we calculate the ultimate strength of a rock specimen on the condition of s2=s1, assuming that xr is in either direction of x2 or x3. This assumption probably overestimates the number of fractured element and thus underestimates the ultimate strength. The shear strength thus calculated is larger than that for s2=s3 by about 5.9% for m=4 and by 7.5% for m=4. These correspond to the increases of about 16 % and about 21 % in the compressive strength, respectively.

COMPARISON WITH EXPERIMENTAL DATA AND CONCLUSION: Mogi (1971) and Takahashi et al. (1983) measured the ultimate compressive strength of some kind of rocks by true tri-axial compression test. The strength increases with an increase in s2 up to a certain magnitude of s2 and is rather constant for larger magnitude of s2 (Takahashi et al., 1988). For trachyte, chart and sand stone, the increment of the strength is 15 to 30 % of that under s2=s3 when s3 is larger than 10 MPa. The calculated strength is seen to be slightly smaller than the observed ones. Taking account of the assumption for the orientation of fractured planes, it is reasonably concluded that the model well explains the data of the strength under true tri-axial loading of compression, although more exact calculation might be required to establish the present model.