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SOME SIZE DEPENDENT PROPERTIES OF JOINTS AND FAULTS

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Abstract. Marked strength-size effects are observed when joints are subjected to shear. This is due to the mobilization of larger, but less steeply inclined asperities as sample size is increased. The displacement required to mobilize strength is also increased by the changing size of sample. These observed size effects indicate that large scale tests should be performed to obtain realistic data concerning shear behavior, dilation, and associated permeability changes.

Introduction

A simple empirical method of characterizing the shear behavior of rock joints was developed some years ago. It consists of three components: ϕ_b, JRC and JCS. A basic or residual friction angle (ϕ_b or ϕ_r) for flat non-dilatent surfaces in fresh or weathered rock, respectively, forms the limiting value of shear strength. To this is added a roughness component (i). This is normal stress dependent and varies with the magnitude of the joint wall compressive strength (JCS), and with the joint roughness coefficient (JRC). The latter varies from about 0 to 20 for smooth to very rough surfaces respectively. The peak drained angle of friction (ϕ') at any given effective normal stress (σ'_n) is expressed as follows:

$$\phi' = \phi_r + i = \mathrm{JRC}\ \log(\mathrm{JCS}/\sigma'_n) + \phi_r \qquad (1)$$

Each parameter can be quantified by simple index tests: tilt or self-weight sliding tests for JRC, and Schmidt hammer rebound tests for JCS and ϕ_r. Details are given by Barton and Choubey (1977). When a joint is unweathered or the strength of a fresh fracture or laboratory "fault" is of interest, the value of the unconfined compression strength (σ_c) is used in place of JCS. At extremely high normal stress, confining effects increase the value of JCS to $\sigma_1 - \sigma_3$, the differential stress. This form of equation fits high pressure triaxial strength data for "faults" extremely closely, as shown by Barton (1976).

The anticipated scale dependency of JRC and JCS deduced when analyzing large scale shear tests of joints in quartz diorite (Pratt, et al., 1974) has recently been confirmed in a comprehensive series of tests reported by Bandis, et al. (1981). Figure 1 illustrates diagramatically how the dilation component (d_n) and the strength component (S_a) of asperities reduce with increasing scale. Both these components vary with the values of JRC and JCS.

Repeated tests on cast model replicas of a wide variety of joint surfaces indicate that JRC and JCS reduce most strongly when joints are rough. Planar joint surfaces exhibit only minor scale dependent properties. As a result of this work it is now possible to predict the approximate reduction of ϕ' with increasing scale for a wide variety of surfaces, by substituting scaled values of JRC and JCS in equation 1. Tentative application of scaled values of JRC and JCS to fault-size surfaces indicate that even a rough, jagged failure surface (i.e. a recent fault) may

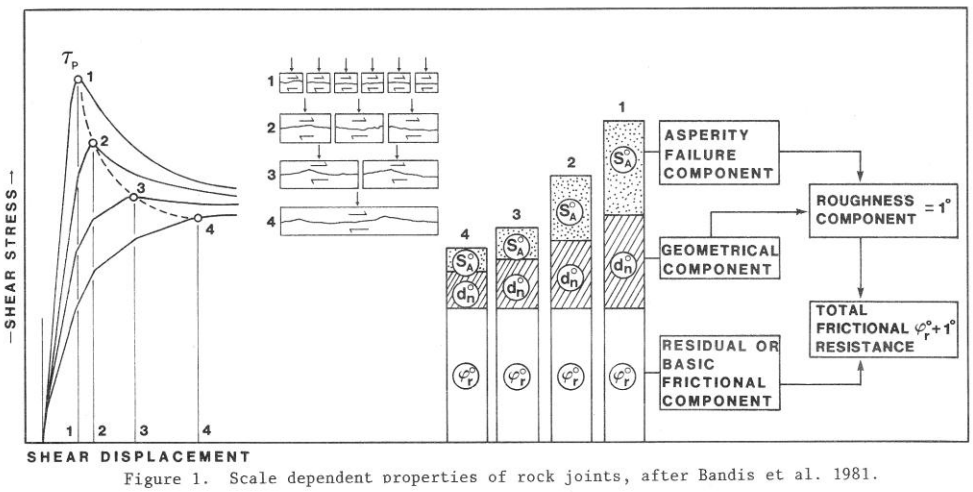

Figure 1. Scale dependent properties of rock joints, after Bandis et al. 1981.

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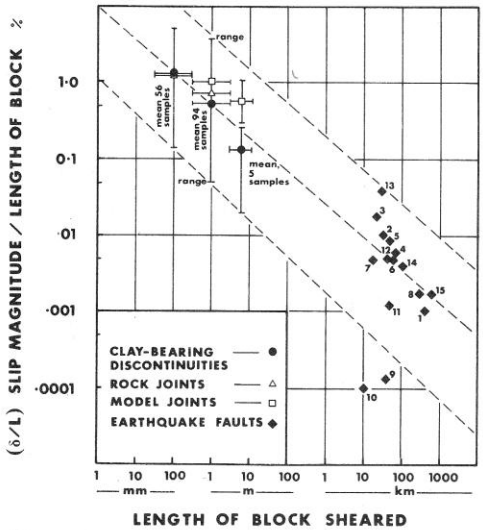

Figure 2. Slip magnitude depends on block size.

have very low effective JRC and JCS values, due to the enormous size involved. In view of the assumed low shear strength of a fault surface, this is obviously a qualitatively reasonable result.

Scale Dependency of Slip Magnitudes

The slip or shear displacement that occurs before peak strength is mobilized is actually the factor which causes the scale effect. A review of some 650 test results on joint surfaces ranging from 40 mm to 12 metres lengths indicates quite consistent scale dependency as shown in Figure 2. The fifteen data points on earthquake fault slip magnitudes were average values derived from a review paper by Nur (1974). The average slip (40 estimates from a total of 15 earthquakes) was 3.85 meters.

An analysis of the data which is reported elsewhere, indicates that the following equation gives a reasonable approximation to the observed values.

$$\delta = \frac{L}{500} \cdot \left(\frac{JRC}{L}\right)^{0.33} \qquad (2)$$

where δ = slip magnitude required to mobilize peak strength, or remobilize residual strength

L = length of joint or faulted block (m)

Example 1. Laboratory Specimen.

Assume: JRC = 15 (rough), L = 0.1 m
Equation 2 gives δ = 1.0 mm.

Example 2. Earthquake Fault.

Assume: JRC = 1 (close to residual), L = 100 km
Equation 2 gives δ = 4.5 meters.

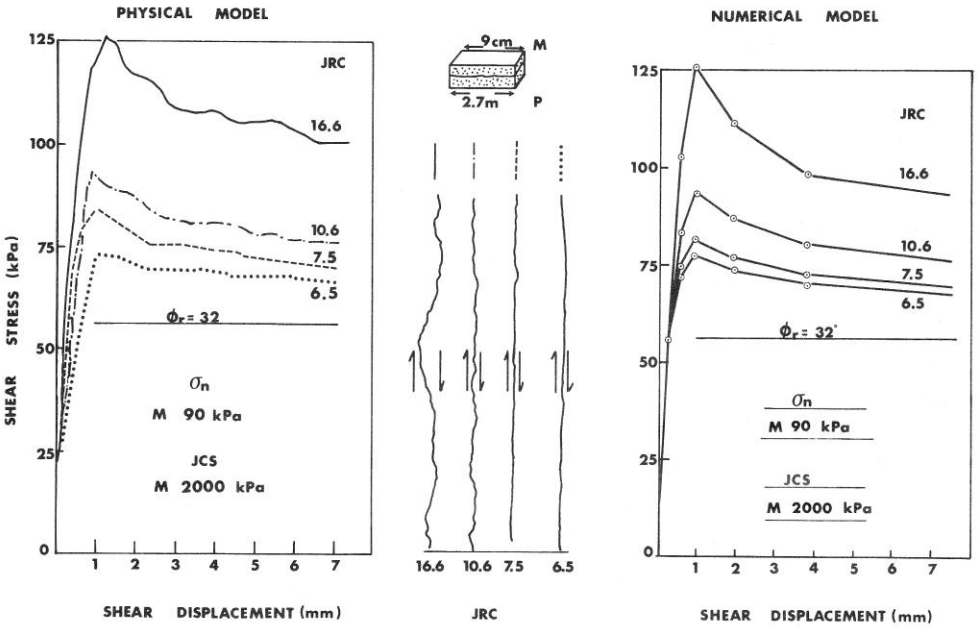

Figure 3. Numerical model of joint behavior compares closely with measured behavior.

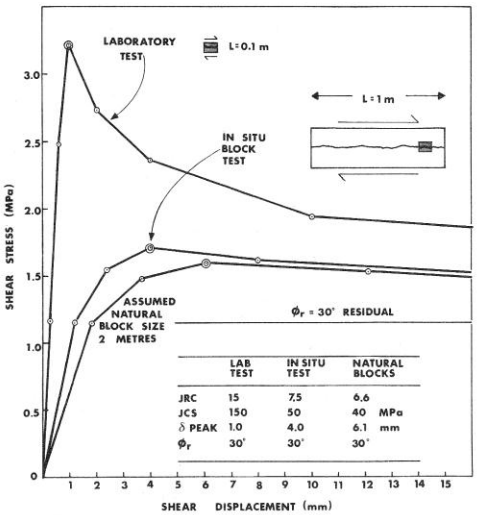

Figure 4. Modelling shear strength scale effects.

Modelling Joint Behavior

The value of large scale tests is greatly enhanced when data can be extrapolated to other rock types, other stress levels, and other sample sizes. This ability is crucial in design problems involving joints at depth, since site specific data is likely to be in short supply. A case in point is the design of mined nuclear waste repositories, probably at depths on the order of 1 to 2 km.

Naturally occurring joints show much greater variations in their shear strength properties than laboratory induced "faults" of a few cm^2 in area. Consequently, it may not be sufficient to try to describe rock joints by a law of the type proposed by Byerlee (1978), unless normal stress levels are considerably higher than the 0-25 MPa encountered in rock engineering problems.

Recent developments reported elsewhere (Barton, 1981) allow the modelling of not only peak shear strength, but the complete shear stress-displacement history of a shearing event.

Figure 3 illustrates how the method produces a realistic simulation of shear test results, spanning a wide range of surface roughness. Changes in normal stress, and changes in scale are treated in a similar manner.

The potential consequences of the scale effect on shear stress-displacement behavior, particularly at low stress levels, is illustrated in Figure 4. A rough joint in competent rock (i.e. a tension joint in granite) may show quite artificial behavior at laboratory scale.

Potential Scale Effects on Joint Permeability

The possibility of a scale effect on joint permeability has been suggested by Witherspoon et al. (1979). At present the data base is too limited and diverse to make definite conclusions possible. It is obviously unreasonable to compare the permeabilities of rough, fresh, artificial fractures with those of weathered natural joints

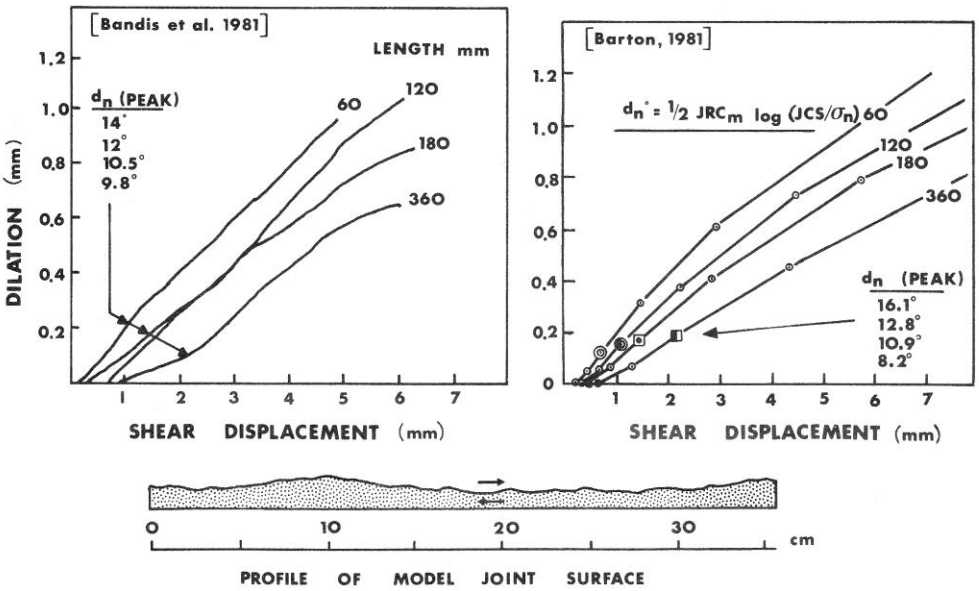

Figure 5. Modelling scale effects on dilation suggests scale-dependent permeability.

of different roughness, since the degree of aperture closure under a given stress level will vary in each case.

Recent work by Bandis (1980) has shown that initial joint apertures (a_j) tend to be larger when joints are weathered, with low JCS values. The closure occurring under a given level of normal stress (i.e. 20-50 MPa) is found to depend on the values of JCS, a_j and JRC. It is therefore clear that care must be taken when permeability data from different joints are compared, as demonstrated by Voegele et al. (1981). Intuitively, samples of different size taken from the same joint would not seem likely to exhibit different permeabilities if subjected to the same levels of normal stress, since pure normal closure will depend on the properties of the small, steeply inclined asperities at all scales. Thus, small scale values of JCS and JRC are likely to have more relevance in this particular case. However, when shearing of the joint is included, the scale dependent properties of JRC and JCS must be considered. Their variation with sample size immediately introduces a potential permeability scale effect.

The reason for this is seen in Figure 5. The numerical modelling of shear stress-displacement behavior for different sizes of joint surface has been extended to the modelling of dilation. It is seen that even a small shear displacement of 0.5 mm may nearly mobilize peak strength, and cause significant dilation across a small sample, before dilation even begins on the longer sample. Thus, joint permeability seems likely to be a scale dependent property when shearing of a non-planar joint occurs, but not when normal closure alone is considered.

Conclusions Concerning Large Volume Experimentation

The advisability of large volume experimentation will clearly vary within the different disciplines of geomechanics. From the foregoing review of rock engineering scale effects it is apparent that large scale tests are essential when shearing of joints, dilation, and permeability changes are of concern. It is also felt that in-situ testing rather than laboratory testing is easier when a large jointed block needs to be characterized. The 8 m^3 heated block test of jointed gneiss performed for the Office of Nuclear Waste Isolation by Terra Tek involves some 30 discrete interlocked blocks, which would be impossible to test in the laboratory without serious sample disturbance. It is envisaged that this type of site specific in-situ test will be an important source of hydro-thermal-mechanical input data when evaluating a nuclear waste repository site, prior to licensing (Voegele et al., 1981).

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