REMR Technical Note GT-RE-1.4

USE OF FRACTAL DIMENSION TO CHARACTERIZE SURFACE ROUGHNESS OF ROCK MASSES

PURPOSE: To describe the use of fractal dimension for classifying the surface roughness of rock masses.

APPLICABILITY and LIMITATIONS: A fractal dimension can be calculated from the profile of a rock-joint surface and can be used to estimate the Joint Roughness Coefficient (JRC). The use of fractal dimension characterization is not intended to replace classic surface-roughness evaluation techniques but to supplement them.

DESCRIPTION: For the purposes of this technical note, fractal dimension is a method of characterizing the scale-independent roughness of a rock-joint surface. A fractal dimension characterization may be obtained by measuring the length (L) of a profile of a rock surface several times with a ruler length, y , that is progressively decreased (e.g. a smaller unit of measurement each time) and then counting the number, N , of these y-length segments to approximate the total length, L , of the profile.

$$L = Ny \quad (1)$$

The increasing resolution of the measurements reveals an increasing number of microvariablilities in the rock-joint profile; thus Equation 1 should be expressed as

$$L \cong Ny \quad (1a)$$

An interesting phenomenon is that as y decreases, L increases. The plot of $\mathrm{Log}_{10}(N)$ versus $\mathrm{Log}_{10}(y)$ is a straight line. The negative of the slope of this line is the fractal dimension (D). The fractal dimension can be incorporated into Equation 1 to become

$$L = Ny^{D} \quad (2)$$

RELATIONSHIP BETWEEN THE FRACTAL DIMENSION AND JOINT-ROUGHNESS COEFFICIENT: Joint roughness (and the roughness of bedding planes) is a factor in the sliding stability of rock masses. The rougher the surface of the joint, the greater stability it has against sliding. An accepted value which describes the roughness of rock surfaces is known as the Joint Roughness Coefficient or JRC (Ref a). Typical roughness profiles for various JRC values are shown in Figure 1.

It is an exercise in judgment to use Figure 1 to assign a JRC value to a specific cross section. A less subjective procedure is a calculation based on laboratory shear tests of rock samples (Ref a):

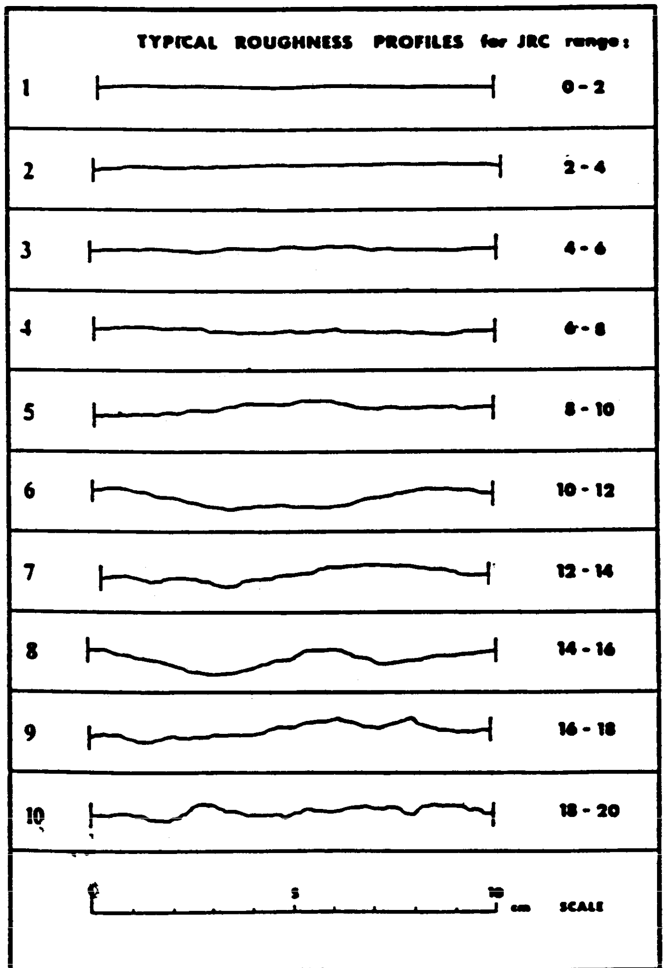

Figure 1. JRC profiles (Ref a), reprinted with permission

$$JRC = \frac{\arctan(\tau/\sigma_N) - \phi_b}{\text{Log}_{10}(JCS)/\sigma_N)} \qquad (3)$$

where

τ = shear stress

σ_N = effective normal stress

ϕ_b = basic friction angle of smooth rock in radians

JCS = joint wall compressive strength

A relation between the fractal dimension and the JRC was developed from a regression analysis on the data obtained from several rock surface profiles. The method of least squares was used to develop the following regression equation:

$$JRC = -1022.55 + (1023.92)D \qquad (4)$$

For this equation, D must be represented by at least four-digit precision after the decimal point. This equation is empirical and is forwarded only as a procedure for estimating the JRC.

A rough approximation of Equation 4 is developed as

$$\mathrm{JRC} \cong 1000(\mathrm{D} - 1) \tag{5}$$

This equation is more conservative than Equation 4; that is, a lower estimate of JRC results from Equation 5. Moreover, this equation is useful in the calculation of other rock surface parameters, such as shear stress. For example, from Equation 3, the shear stress, τ , based on a known JRC value, can be calculated,

$$\tan^{-1}(\tau/\sigma_N) = JRC\left[\log_{10}(JCS/\sigma_N)\right] + \phi_b \tag{6}$$

or

$$\tau = \sigma_N \tan\left\{JRC\left[\log_{10}(JCS/\sigma_N)\right] + \phi_b\right\} \tag{7}$$

Incorporating the fractal dimension, D , into the equation is most easily done with the use of equation 5

$$\tau = \sigma_N \tan\left\{1000(D - 1)\left[\log_{10}(JCS/\sigma_N)\right] + \phi_b\right\} \tag{8}$$

Equation 8 is an expression for the calculation of shear stress as a function of the fractal dimension.

REFERENCES:

a. Barton, N., and Choubey, V. 1977. "The Shear Strength of Rock Joints in Theory and Practice," Rock Mechanics, Vol 10, pp 1-54.

b. Carr, James R. 1990 (Mar). "Surface Roughness Characterization of Rock Masses Using the Fractal Dimension and the Variogram," Technical Report REMR-GT-14, US Army Engineer Waterways Experiment Station, Vicksburg, MS.