5. Shear Stress on the Rock Side

In order to pace the jet, the cutting surface must be in a continuous state of incipient failure. The purpose of this section is to set forth a failure criterion to complement the friction law (14) and close the problem.

An obvious possibility is that the surface fractures when the shear stress reaches some definite value

$$\tau = \tau_o , \tag{16}$$

where τ_o is the force required to shear off a grain, divided by a typical grain area. Equation (16), however, is overly simple. The normal force on a grain tends to keep it in place, so the right-hand side of (16) must be augmented by a term proportional to normal pressure:

$$\tau = \tau_o + \mu_r p_s . \tag{17}$$

The failure criterion (17) is due to Coulomb and is discussed in great depth by Jaeger and Cook [10]. μ_r is the coefficient of internal friction for the rock. Generally $\mu_r \approx 1.0$.

Equations (14) and (17) are similar in structure, and a closer inspection reveals that the similarity means trouble. The coefficient μ_w of Coulomb friction between water and rock should not be more than 0.6 according to (15), and certainly μ_w should be less than the coefficient μ_r of friction internal to the rock itself. The shear stress required for fracture according to (17) appears to exceed the stress available from the flow according to (14). A jet should be quite incapable of cutting rock!

The resolution of the dilemma lies in the finite permeability of the rock. The high surface pressure p_s forces water through the pores of the cutting surface, creating a precursor of saturated rock as shown in Fig. 6. The pore pressure p within the saturated region ranges from p_s at the cutting surface CS down to p_a at the interface WD between wet and dry rock. The pore pressure relieves the internal friction and results in a failure criterion

$$\tau = \tau_o + \mu_r (p_s - p) , \tag{18}$$

also discussed at length by Jaeger and Cook.