A Theory of Hydraulic Rock Cutting

by

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Abstract

Water jets having total pressures above 1000 atm are attractive tools for cutting rock. Here a theory is developed to explain the cutting action. The rock is assumed to translate at a speed v under a continuous jet. The problem is to determine the depth h of the resulting slot as a function of feed rate v, diameter d_o and total pressure P_o of the jet, and the relevant properties of the rock.

The jet exerts traction against a cutting surface at the leading edge of the slot, and the traction induces continuous fracture. Cavitation tends to sheath the cutting surface in vapor, but curvature of the jet stream causes a high surface pressure, which closes the cavity bubbles and exposes the grains to direct impact from the water. The surface pressure would suffice to keep the grains in place, but permeability allows the water to penetrate beneath the cutting surface and relieve the pressure across the grains.

Permeability gives rise to an intrinsic speed for rock cutting, $c = k\tau_o/\mu_r g$, where k is the permeability, τ_o the shear strength, and μ_r the coefficient of internal friction of the rock, and g is a typical grain diameter. For Wilkeson sandstone, c is found to be 17.2 in/sec. If the feed rate v is considerably less than c, then the slot depth h is unaffected by permeability and has a value $1.01\, d_o P_o/\tau_o$ for an optimum angle of jet impingement. The slot depth h decreases as v becomes comparable to c, but the rate of slot-area creation hv rises toward a maximum value $1.47\, k d_o P_o/\mu_r g$, proportional to permeability but wholly independent of shear strength. At feed rates exceeding $(0.42P_o/\tau_o - 1)c$, the jet stream no longer exerts sufficient traction to fail the rock, and efficient cutting ceases.

The theory is compared to preliminary data spanning a three-decade range of v, and the comparison is highly encouraging.

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