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A new method for calculating the mean aperture of fractures in rocks: The dual mean

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The intrinsic permeability or hydraulic aperture of single fractures can be determined with the Local Cubic Law, LCL, $F(x,y) = -\left(H^3/12\mu\right)\nabla P$ where, F is the vector of the flow flux, H is the separation distance or local aperture of the fracture, ∇P is the local pressure gradient applied to the fluid and μ is the dynamic viscosity of the fluid. Fracture wall roughness should cause an overestimation of this permeability if it is of the same order of magnitude as fracture aperture variation. However, in laminar flow systems (to which the majority of subsurface flow belongs), roughness will not affect the mean flow velocity or flux as viscous drag near the fracture walls dampens the effect of roughness (Reynolds Number < 1). Predictions of the LCL worsen as the fracture surfaces are brought together due to an increase in in-plane toruosity. Overestimations of fracture permeability are often due to inappropriate averaging of the separation between fracture walls, the mechanical aperture, H. All mean values depend upon the mean surface heights of the two surfaces used to define the fracture aperture. However, it is common to quote the mean aperture for the scenario where the relative mean surface heights of the two surfaces used to define the fracture aperture are such that the fracture surfaces just touch. The simple arithmetic mean aperture, H_a, is well defined, but of little practical use for fluid flow calculations. The geometric mean aperture, H_g, is well defined if the surfaces do not touch, but collapses to zero if the surfaces touch at one or more points even if the rest of the aperture is patent to flow. The harmonic mean aperture, H_h, is also well defined but again it collapses to zero if the surfaces touch. To overcome the problem, we define the dual mean, H_{dm}. This is the arithmetic mean of the geometric mean apertures along all fracture profiles in the direction of presumed fluid flow through the fracture. It has a physical basis, and is sensitive to anisotropy in the plane of the fracture, i.e., it has different values in different directions through the fracture. We use the dual mean in the two cartesian directions in the plane of the fracture x and y. For the x-direction this is defined as, $H_{dmx} = (1/N_y)\sum_{j=1}^{N_y}\exp\left(\sum_{i=1}^{N_x}(\log A_{ij}/N_x)\right)$, where N_x, N_y are the dimensions of the measurement grid in the $x$and $y$directions, respectively, A_{ij} is the value of the fracture aperture at the grid point with indexes (i,j), and H_{dmx} is the dual mean aperture computed with respect to x-direction (of the flow). We have tested the dual mean by finite element modelling and applied it to five rough fractures for which the physical and hydraulic aperture are known. The dual means in both directions across the fracture apertures show a much better correlation to the modelled hydraulic apertures than standard arithmetic mean apertures. We conclude that this is a pragmatic approach to calculating the mean aperture of a fracture where the surfaces touch at at least one point.