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

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\textbf{INTRODUCTION}

The intrinsic permeability or hydraulic aperture of single fractures can be determined with the Local Cubic Law,

\[ F(x,y) = \frac{H^3}{12\mu} \nabla P \]

where, \( F \) is the vector of the flow flux, \( H \) is the separation distance or local aperture of the fracture, \( \nabla P \) is the local pressure gradient applied to the fluid and \( \mu \) is the dynamic viscosity of the fluid. Fracture wall roughness should cause an overestimation of this permeability if \( H \) 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 damps the effect of roughness (Reynolds Number \( \sim 1 \) ). Predictions of the LCL worsen as the fracture surfaces are brought together due to an increase in plane botum. Overestimations of fracture permeability are often due to inappropriate averaging of the separation between fracture walls, the mechanical aperture, \( A \). 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, \( H_d \). This is the arithmetic mean of the geometric mean apertures along any 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,

\[ H_d = \frac{1}{N} \sum_{i=1}^{N} \exp \left( \frac{\log A_x}{N} \right) \]

where \( H_x \), \( A_x \), and \( N \) are the dimensions of the measurement grid in the x and y directions, respectively. \( H_x \) is the value of the fracture aperture at the grid point with indices \( i \), and \( A_x \) 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 modeled hydraulic aperture than any standard arithmetic mean aperture. We conclude that this is a pragmatic approach to calculating the mean aperture of a fracture where the surfaces touch at least one point.

\[ \text{FINITE ELEMENT MODELLING} \]

Fluid flow was modelled in 2D plan view in the measured rock fractures in a FEABA\textsuperscript{\textsuperscript{**}} environment. The image analysed surface topography and aperture maps of Isakov et al. (2001) and Ogilvie et al. (2002) were used to define the physical boundaries of the model. Presuming validity of Local Cubic Law, LCL, for flow flux, Ge's equation was used to compute the pressure field (Ge, 1997). We have defined a new type of average (the dual mean) that takes into account the variation element within the fracture. We defined the dual mean for hydraulic aperture by applying it to the fluid flow problems. The dual mean aperture, \( H_d \), was calculated from the modelled data (i.e., from the integral of flux and pressure head) as in close agreement with the profiled mechanical apertures, \( A_m \) resulting from a dual mean (Figure 1). This is a better correlation than when using an arithmetic mean aperture. It is therefore possible to continue using the LCL to predict hydraulic aperture when approximating a dual mean mechanical aperture. This constant ratio allows large-scale fracture networks to be populated with plates of the effect of roughness (Brush & Thomson, 2003).

\[ \text{RESULTS} \]

The performance of Reynold's equation for flow within a channel of constant aperture in which there is embedded a constriction. The effect of the pore is not taken into account by Haymery's equation.

\[ \text{MEAN APERTURES} \]

An integral of the flow flux across the flow direction yields overall flux or flow charge. The ratio of the flow change to the pressure head applied to the fracture characterizes the fracture transmissibility. This value was computed for every fracture type and for every flow direction in order to derive hydraulic aperture of the fracture.

\[ \text{REFERENCES} \]


\[ \text{CONCLUSIONS} \]

1. There exist a number of ways of obtaining an average value for the aperture of a rock fracture (e.g., arithmetic, geometric, harmonic).

2. Each of these methods has its disadvantage when used for flow modelling.

3. One of the most important disadvantages is that these averages are independent of direction whereas the effective mean aperture of a fracture should be dependent upon the flow direction for anisotropic fracture.

4. When there has been a collision of average (the dual mean) that takes into account the requirements of flow modeling, particularly that \( H_a \) (average) does not collapse when the fracture surface touch (i.e., the aperture is zero) at one or more points, and \( H_h \) (average) has different values depending on the direction of fluid flow.

5. We have tested the dual mean by finite element modeling and applied it to five rough fractures for which the physical and hydraulic apertures are known.

6. The dual means in both directions across the fracture apertures show a much better correlation to the modeled hydraulic apertures than any standard arithmetic mean aperture.

7. We conclude that this is a pragmatic approach to calculating the mean aperture of a fracture where the surfaces touch at least one point.