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Macroscopic properties of fracture networks from the percolation threshold to very large densities

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Progress has been made possible thanks to a very versatile numerical technique based on a three-dimensional discrete description of the fracture networks. Any network geometry, any boundary condition, and any distribution of the fractures can be addressed. The first step is to mesh the fracture network as it is by triangles of a controlled size. The second step consists in the discretization of the conservation equations by the finite volume technique. Two important properties were systematically studied, namely the percolation threshold rho_c and the macroscopic permeability K_n of the fracture network. Dimensionless quantities are denoted by a prime.
The numerical results are interpreted in a systematic way with the concept of excluded volume which enables us to define a dimensionless fracture density rho' equal in the average to the average number of intersections per fracture.
1. Isotropic networks of identical fractures
The dimensionless percolation threshold rho'_c of such networks was systematically studied for fractures of various shapes. rho'_c was shown to be almost independent of the shape except when one has very elongated rectangles. A formula is proposed for rho'_c.
The permeability of these networks was calculated for a wide range of fracture densities and shapes. K'_n(rho') is almost independent of the fracture shape; an empirical formula is proposed for any value of rho' between rho'_c and infinity.
For large rho', K_n is well approximated by the Snow formula initially derived for infinite fractures.
2. Anisotropic networks of identical fractures
The fracture orientations are supposed to follow a Fisher distribution characterized by the parameter kappa; when kappa=0, the fractures are isotropic; when kappa=infinity, the fractures are perpendicular to a given direction.
rho'_c does not depend significantly on kappa and the general formula proposed in 1 can be used as a first approximation.
A considerable simplification occurs for permeability. The dependence on kappa can be determined analytically for infinite fractures as an extension of the Snow formula and is a tensor K'_S. Numerically, K'_n is equal to the product K'_n,i K'_S.
3. Extensions
Two important extensions were already worked out.
rho'_c and K'_n were determined for fracture networks with power law size distribution wether they are anisotropic or not.
So far only fractures which are uniformly distributed in space were considered. However, in Excavation Damaged Zones, the density decreases exponentially from the wall. The previous analysis has been recently extended to this case.
Results for both extensions are conveniently analyzed in the same framework.
4. Conclusions
Our studies can be summarized as follows. rho'_c and K'_n(rho') do not depend significantly of the fracture shape. Moreover, semi empirical formulae are proposed to predict these quantities for all densities.
Further studies closer to geophysical reality will be performed.