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AN INVESTIGATION OF THE RELATION BETWEEN FISSURE FLOW AND DEGREE OF CONTACT AREA BY AN ELECTRIC ANALOGUE MODEL

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ABSTRACT

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The degree of contact area in a fissure plane is a function of the rock stress across the plane and the elastic properties of the rock surface. A knowledge of the relation between fissure flow rate and the contact area of a fissure is very important, especially when dealing with soft rocks.

An extremely simple and effective method to study the above relationship is to use an electric analogue model. Such studies obtained results that showed that the existence of contact areas across a fissure results in a decrease of flow rate and that this decrease is a function of the contact area between the rock surfaces.

INTRODUCTION

Fissures in rock masses are a common feature in the near-surface layers of the Earth's crust, and in many situations they form the primary conduits for water movement.

The hydraulic behaviour of these fissure systems is very important to many geotechnical activities such as pumping, where it is important to know how the fissure's hydraulic properties will change under conditions of increasing effective stress and thus increasing contact area.

Although some empirical relations have been presented (Lamb and Whitman, 1969) correlating the degree of contact area with normal stress, very few attempts have been made to examine the relation between degree of contact area and fissure permeability. Louis (1969) assumed that the flow rate reduces in proportion to the ratio between the open surface of a fissure plane and the total surface, although he did not present any proof for the

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linearity of this reduction effect. Sharp (1970) predicted a less significant effect for contact area on flow rate. Katsuhiko (1975) was the first to investigate in detail the effect of contact area upon flowrate by using a numerical model; he concluded that the flow rate decreases in a hyperbolic manner as the effective area of contact increases.

This paper reports a simple way to study this problem, using an electric analogue model to investigate the relation between flow rate and contact area.

PRINCIPLE

It is well known (Davis and DeWiest, 1966) that the general problem of the steady state flow of fluids through plane conduits, may be reduced to the solution of Laplace's equation with the appropriate boundary conditions, which in its Cartesian co-ordinate form may be expressed as:

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} = 0 \tag{1}$$

where h is the function of hydraulic potential, x and y being the conventional coordinate directions.

This equation is one of the most well-known partial differential equations in other branches of physics and in some cases the solutions for a number of flow problems may be taken over from those that have already derived for other purposes in other branches of physics, by simply translating them into their proper hydrodynamic equivalent. For the special case of the flow through a fissure with a degree of contact area different than zero, the boundary conditions imposed make any attempt to solve eqn. (1) analytically very difficult and in some cases impossible.

The method used here, makes use of the fact that a flow of current through a thin, uniform conducting sheet produces a potential distribution that satisfies the two dimensional form of Laplace's equation:

$$\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} = 0 \tag{2}$$

where v is the function of the electrical potential. The obvious similarity between eqns. (1) and (2) is based on the following principles: Principle of continuity (fluid flow, current flow); principle of conservation (fluid mass, electric charge); and principle of linear flow (Darcy's law, Ohm's law).

Thus by using a system of flow nets constructed from the flow of electric current through an electric conductive paper analogue, it is possible to calculate the water discharge for specific boundary conditions.

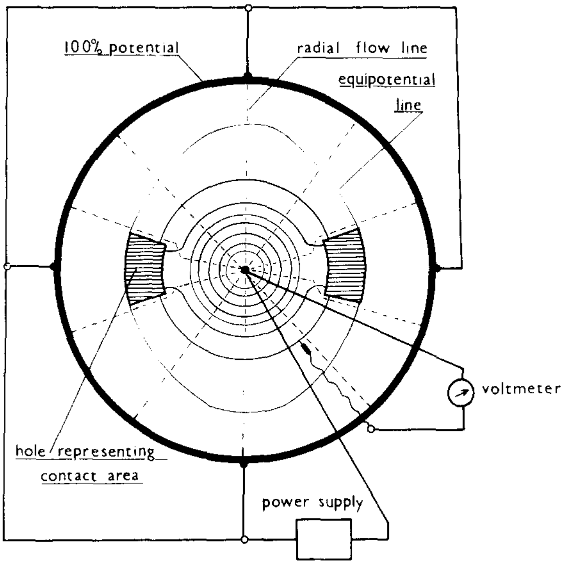

Fig. 1. Arrangement used for the experiment.

EXPERIMENT

A 30 cm diameter circle of electrically conductive paper was used to represent a fissure (Fig. 1), in which horizontal radial flow moves from a recharge boundary at its circumference to a discharge boundary at its centre. This can be thought of as radial flow to a pumped well. The pumping process was modeled by driving electric current from the perimeter of the circle towards its centre which represented the well. The effect of contact area was simulated by cutting holes in the conductive paper: no current can cross this, but must flow around it, hence simulating the effect of fissure contact on flow. To model, increased areas of contact sections of increasing area both laterally and radially were removed from the paper.

On energising the model the current flowing obeys eqn. (2). After plotting the equipotential lines with the help of a standard Wheatstone bridge the flux lines were drawn in such a way as to form a continuous network of curvilinear squares. The particular advantage of plotting and sketching such a network is that a solution to the Laplace equation can be found which satisfies the very complicated boundary conditions imposed by the nature of the contact area of the fissure, which frequently cannot be expressed in mathematical terms.

DISCUSSION OF THE RESULTS

Figure 2 shows the equipotential and flow lines obtained for various

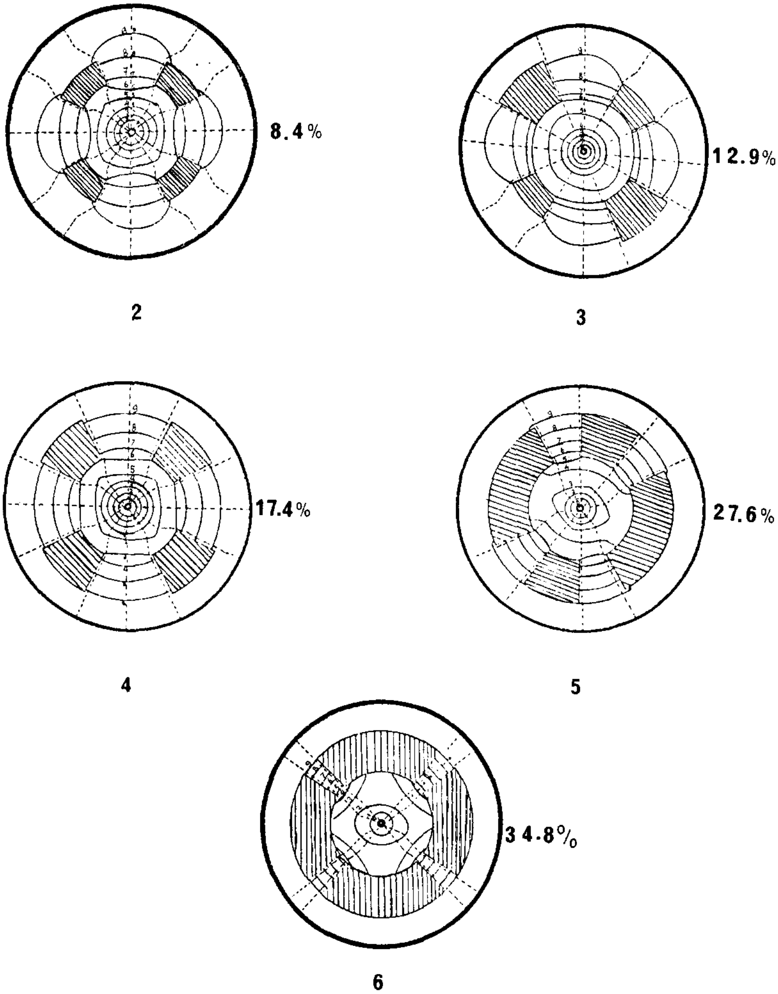

Fig. 2. Flow-line patterns as were calculated from the electric analogue model for different contact areas.

degrees of contact area. If dQ is the discharge per single stream tube then one can write:

$$\mathrm{d}Q = K \cdot A \cdot \mathrm{d}h/\mathrm{d}r \tag{3}$$

where K is the conductivity, dh/dr is the head drop and A is the cross section of the stream tube. Assuming a unit value of K and summing the discharge of all the individual stream tubes it is possible to obtain an estimate of the total fissure discharge in units of flow rate. Table I shows the results obtained for various degrees of contact area.

Figure 3 is a graph of the results obtained. From this one can see the

TABLE I
Discharge versus contact area

	Analogue No.					
	1	2	3	4	5	6
Contact area (%)	4.2	8.4	12.9	17.4	27.6	34.8
Discharge in units of flow rate	25.7	21.9	20.6	18.2	14.1	6.6
Change in discharge per unit of increase of contact area (%)		90.4	28.8	53.3	40.2	104.6

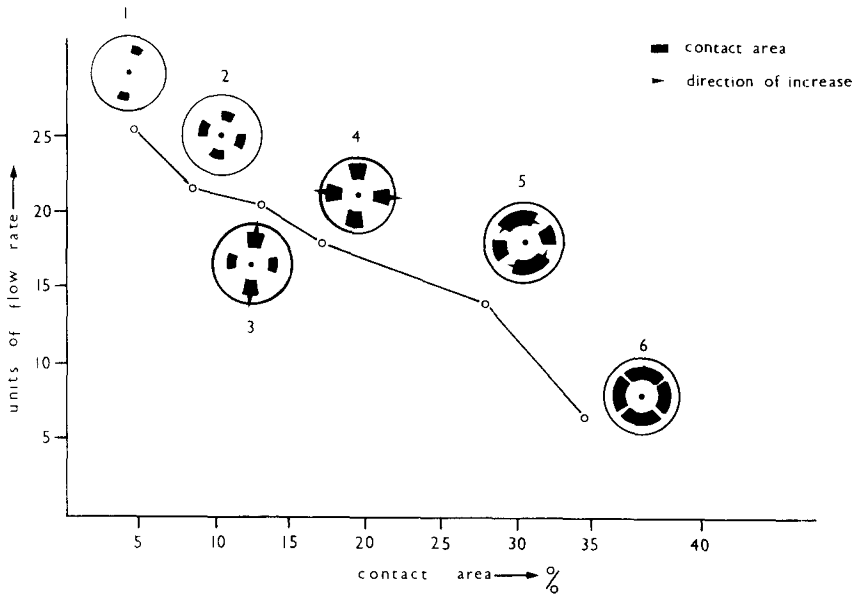

Fig. 3. Flow rate as a function of the degree of contact area.

general trends of the relation between flow rate and contact area. One important conclusion that can be drawn from this diagram is that the flow carried by a fissure decreases with increasing contact area and that the decrease is a function of the contact-area distribution; in other words, it depends on the path of fluid flow.

These simple electrical analog experiments suggest that the location of the contact area is very important in estimating the flow characteristics of a natural fissure. Figure 3 shows that when going from case (1) to case (2) there is a 90.4% (see Table I) decrease in the flow rate per unit of increase of the contact area of the fissure, while when going from case (2) to case (3) there is only a 28.8% decrease in flow rate. The large decrease in flow rate which corresponds to an increase of the contact area of the fissure close to the borehole is due to the high hydraulic gradient occurring near the hole. However, by considering the same total contact area away from the borehole, the hydraulic gradient is comparatively small, and the effect of flow rate is correspondingly small.

These results must always be kept in mind when interpreting results from packer tests since the process of drilling may disturb the fissure close to the well and the data from tests may underestimate the flow rate of the corresponding fissure zone. This may happen because of partial plugging of portions of the fissure by small rock particles, which may be permanently lodged close to the borehole.

CONCLUSIONS

In the present paper an electrically conductive paper analogue was used to simulate fluid flow through a partially closed fissure and the flow rate for various degrees of contact area was estimated.

The results obtained showed that the fissure discharge decreases with increasing contact area and that it also depends upon the way with which the contact area is distributed.

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