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Contribution for a better understanding of flow in fractured rock masses based on new field test techniques

Contribution pour une meilleure compréhension des écoulements dans les massifs rocheux fracturés à partir de nouvelles techniques d'essais en place

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ABSTRACT: Two new field test techniques carried out in the field are helpful in understanding how water flows in fractured rock masses and in determining their hydraulic properties. The results of these tests, performed in a borehole located at the site of the Santa Isabel Dam to be built on the Araguaia River in Central Brazil, are presented in this paper.

1 INTRODUCTION

The flow in fractured rock masses has been studied by means of conceptual models based on the geometric shape of these structures. For this reason, the researchers generally idealized a fractured rock mass crossed by plane joints grouped in families.

There are three types of models, as follows:

a. Plane fracture model with rock matrix of reduced permeability (Sion 1965), (Serafim 1968), (Louis 1968 and 1974) and (Sharp 1970).

b. Plane fracture model with rock matrix of significant permeability (Witherspoon et al. 1974).

c. Small conduit model (Londe 1973).

Based on the analysis of test results, this paper proposes a new model that, although close to the first one, differs from it in that the flow does not pass through families of plane fractures. In this model, the water flows through a reduced number of paths, such as discontinuities, joints, etc., which allow easier flow due to less resistance.

Underground water flows through the main discontinuities at velocities frequently around 10,000 times greater than those reached in rock masses and consequently, exerts contour pressures on the flow in these subdomains.

2 FIELD TESTS TO DETERMINE THE HYDRAULIC PROPERTIES OF FRACTURED ROCK MASSES

The Water Pressure Test, known as the Lugeon Test, consists of injecting water under pressure into a borehole at a certain depth and measuring the volume of water absorbed into the ground.

The interpretation of the Lugeon Test has led several authors, such as Guerra et al (1967), Lancaster-Jones (1985), Gomes et al (1982 and 1985), Houlsby (1985), C.Kutzner (1985), Louis and Maini (1979), etc., to suggest graphs correlating flow x pressure and comparisons with laminar and turbulent flows. The interpretation of the Lugeon Test is quite difficult since it requires assumptions on data that cannot be determined by the test. These assumptions are made due to the uncertainty of how and where the injected water flows underground.

In addition, when a flow pattern is defined,

the flow gradient will depend on the assumed values for the range of action and pressure difference. However, the proposed and assumed values were not confirmed in practice. This is why the Lugeon Test is founded on four important unknown quantities:

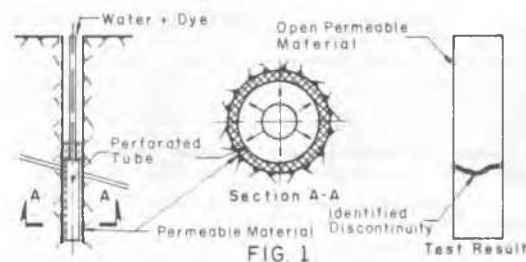
- Where does the water flow in the packed section of the borehole?
- Which is the flow pattern?
- What value should be assumed for the pressure difference if the action radius is unknown?
- What is the action radius of the test?

In an attempt to answer these questions, two different tests were idealized, one called the Hydraulic Register Test - TRH, that will define through which discontinuities water loss occurs, and how the water-bearing discontinuities are. The other, called Water Injection Test under Decreasing Pressure - EIPD, that will define in every water-bearing discontinuity, for a given pressure P and in a laminar flow pattern, over an action radius R , the hydraulic properties, such as conductivity, nominal discontinuity aperture, etc., related to the gradients used in the test, or another reference.

2.1 The Hydraulic Register Test - TRH

When the Water Pressure Test, or Lugeon Test, is performed, one section of the borehole is packed and the water injected under pressure. As previously mentioned, it is not clearly defined how and where there is a water loss.

The TRH will determine how and where the injected water is lost. For this purpose, the walls of the borehole section under test are wrapped in a permeable material (fig. 1) then coloured water will be injected. When the test is



finished, the material is lifted out and it can be observed that the material has been stained only where the water has flowed. This test can indicate where the water flows and also the form of the water-bearing discontinuity.

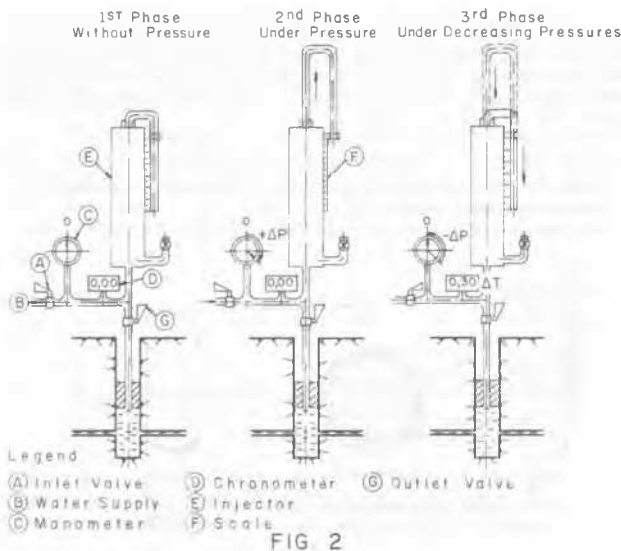
The identification of water-bearing discontinuities on the core will identify all points where the water flows.

The tests carried out on the sites of Cachoeira Dourada Dam (CELG), São Domingos (DAE-Goiás) and Santa Isabel Dam (ELETRONORTE), all in Central Brazil, show that the number of water-bearing discontinuities is smaller than those identified on the cores, and that some of the discontinuities already affected by oxidation are no longer water paths, even under high water pressures. These conclusions confirm our proposed model that the flow passes through fewer discontinuities instead of through groups of plane fractures, and also show that the only way to learn about the exact seepage path is with the help of the TRH tests.

2.2 The Water Injection Test under Decreasing Pressure - EIPD

After identifying the water-bearing discontinuities using TRH tests, one can now determine their hydraulic properties by undertaking the EIPD test. The EIPD test consists of injecting water under pressure through a discontinuity identified by the TRH, and at a certain moment, suddenly stopping the water injection under pressure, making the discontinuity absorb, for a certain time, a known rate of flow over a certain range of decreasing pressure. With this information, the type of flow through the discontinuity can be defined or, in other words, laminar flow can be maintained through controlling the water injection rate.

Fig. 2 shows the three phases of the EIPD test. The first, when water is injected into the system without pressure, the second phase when the system is pressurized with pressure P_2 , and the third when the inlet water valve is closed, letting the pressure decrease until P_1 , while the time spent, ΔT , is recorded and the rate of water flow absorbed by the discontinuity at this time is obtained. The water volume is supplied by the injector.



Thus, with this procedure, all the discontinuity's hydraulic properties can be determined. The differences in pressure exerted on the discontinuities are constant, but always obtained in gradually increasing pressure range tests. Several points can then be obtained to plot a curve, where the aperture of the discontinuity and its conductivity for certain gradients can be observed (Andrade 1986) (Andrade 1987).

3 THE FLOW IN FRACTURED ROCK MASSES BASED ON THE APPLICATION OF THE TRH AND EIPD TESTS

In 1988, J.B. Franciss was already saying that the underground water flow was through cracks in the rock mass foundation.

Now it can be proved, by using the TRH test, that there are few water-bearing discontinuities and it can be verified by using the EIPD, that the flow rates in these discontinuities are high in relation to those occurring in the rock mass between them. If we imagine a rock mass foundation as shown in figure 3, and to give a better idea of the phenomena we assume that the reservoir fills immediately, we can understand that the water flows downstream through the main discontinuities.

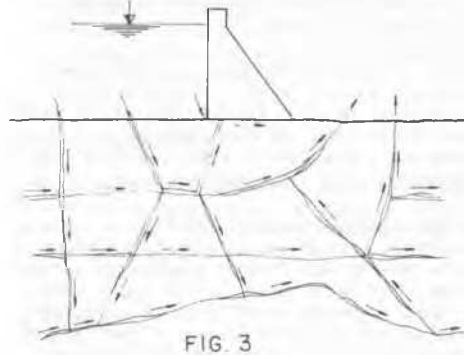


FIG. 3

Under those conditions, these are the discontinuities which establish the pressures inside the rock mass foundation. In the parts between these discontinuities (subdomains), the pressures are established from them, as a consequence of the contour condition, and are equalized within it (see fig. 4).

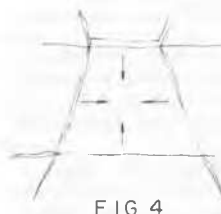


FIG. 4

So we can understand that in the subdomains there may be percolations in the upstream direction when the pressures are being equalized. This simple model can be used as a basis for understanding the flow through fractured rock mass foundations. By analyzing the underground water flow using the Nodal Point Method (MEPON), described by the author in other publications

(Andrade 1984, 1986 and 1988), it is easier for us to understand and control the phenomena of percolation in fracture rock mass foundations.

4 A CASE STUDY

On the Santa Isabel Dam site whose foundation rock is a micaschist with 30° dip schistosity planes, tests were performed in a 10.07 m deep vertical borehole.

The TRH indicated two water-bearing discontinuities, the first at 2.41 m and the second at 6.30 m, both along the schistosity.

No other water losses were detected along the borehole wall. Figure 5 shows the pattern of discontinuities.

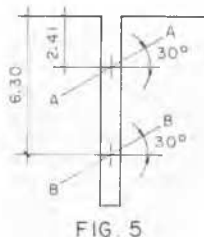


FIG. 5

After detecting the depth and attitude of the water-bearing discontinuities, the EIPD was carried out at both levels in order to determine the hydraulic properties. The tests were performed with different injection pressures varying from 0.6 kgf/cm^2 to 2.1 kgf/cm^2 and it was possible to determine the hydraulic properties of both discontinuities, as shown in figure 6. Line A represents the discontinuity at 2.41 m and line B at 6.30 m.

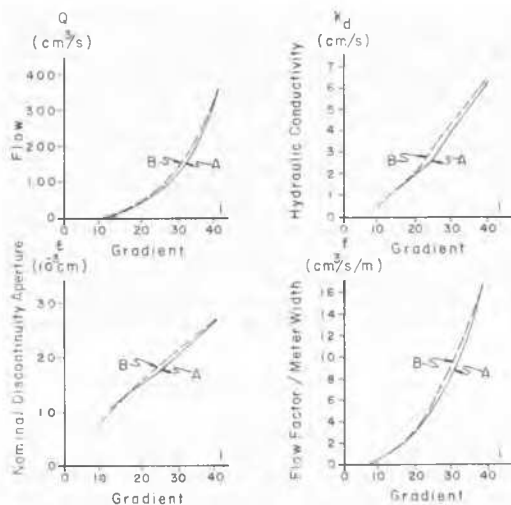


FIG. 6

5 CONCLUSIONS

Through the use of the TRH and EIPD tests, the fractured rock mass foundation can be mapped in its hydrogeotechnical aspects to be able to understand how the flow occurs.

In figure 6 it can be seen that the conductivity reaches 4 cm/s for a gradient of 30. On the other hand, it is known that fractured rock masses have an average conductivity of around 10^{-2} cm/s to 10^{-4} cm/s , so it can be said that speeds in these discontinuities can be from 4.000 to 40.000 times higher than in the frac-

tured subdomains. For these reasons, this proposed model is upheld which assumes that the rock mass is crossed by main discontinuities where the flow occurs, leading to pressures inside the subdomains as a consequence of contour conditions.

The Nodal Point Method-MEPON presented by the author in other publications (Andrade 1984, 1986, 1987), is based on this conviction and has been applied in several designs of dams already built, which proves its worth in explaining and understanding the water flow in fractured rock mass dam foundations.

REFERENCE

- Andrade, R.M.de (1980). Cálculo da subpressão em estruturas assentes em maciços permeáveis anisotrópicos, 71 pp, Engevix, Brazil.
- Andrade, R.M.de (1982). A drenagem nas fundações das estruturas hidráulicas, 437 pp, Engevix, Brazil.
- Andrade, R.M.de (1983). Controle da subpressão pela drenagem horizontal, 251 pp, Engevix, Brazil.
- Andrade, R.M.de (1984). Hidrogeotecnia nas barragens, 437 pp, Engevix, Brazil.
- Andrade, R.M. de & Boal, M.A. (1985). Numerical method in hydrogeotechnical analysis of dam foundations. Commission Internationale des Grands Barrages XV Congrès des Grands Barrages, Q.58, R.11:191-208, Lausanne.
- Andrade, R.M.de (1986). Propriedades hidráulicas de maciços fraturados e sua aplicação em projetos, II South American Rock Mechanics Symposium, Porto Alegre, Brazil.
- Andrade, R.M.de (1987). New techniques for the determining of the hydraulic properties of fractured rock masses, 48 pp, Engevix, Brazil.
- Andrade, R.M.de (1988). Mechanics of the flow in fractured rock masses applied to dams, 324 pp, Engevix, Brazil.
- Gomes, L.G., Alonso F., M. & Romero H., J.L. (1985). Seepage control in Spanish dams, XV Congrès des Grands Barrages, Icold, Q.58, R.55:921-935, Lausanne.
- Guerra, J.R., Weyermann, W.S. & Mota, O. (1967). Les caractères de la percolation d'une roche d'après les observations préalables faites pour le projet de l'éclan d'étanchéité, IX Congrès des Grands Barrages, Icold, Q.32, R.8, 109-122, Istanbul.
- Kutzner, C. (1985). Considerations on rock permeability and grouting criteria, XV Congrès des Grands Barrages, Icold, Q.58, R.17, 315-328, Lausanne.
- Louis, C. (1974). Introduction a l'hydraulique des roches, BRGM, 114 pp.
- Louis, C. & Maini, Y.N. (1970). Determination of in situ hydraulic parameters in jointed rock. 2nd Congress of International Society of Rock Mechanics. Belgrade.
- Londe, P. (1973). Rock mechanics and dam foundations design. International Commission on Large Dams, Paris.
- Lugeon, M. (1933). Barrages et géologie. Dunot, Paris.
- Witherspoon, P.A., Gale, J.E., Taylor, R.L. & Ayatollahi, M.S. (1974). Investigation of fluid injection in fractured rock and effect on stress distribution. Geotechnical Engineer: Report no. TR-74-4. Berkeley, University of California.