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THE OTHER SOLUTION OF A ROCKS FRACTURING AS A RANDOM EFFECT

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ABSTRACT. Fracturing is one of the natural processes which exhibits some random features and may, therefore, be studied using statistical methods. The most suitable description of the fracturing effect is that of a log-normal distribution. A fracture is taken orientation and location a field example is given to describe the possibility of evaluation of fracturing in hard-rock massifs, in which in situ measurements are limited. In the paper the other possible procedure is derived for a rocks fracturing evaluation.

1. INTRODUCTION

Massifs with fracture permeability have attracted attention during recent years, due to their advantages in environmental constructions where minimum inflows are demanded. The search for suitable types of rock massifs is not straightforward, even though the rocks are generally classified as "non-pervious". The basic feature by which fracture groundwater differs form porous groundwater is given by their specific filtration environments. The rock environment with fracture permeability is characterized by highly variable heterogeneity and anisotropy; from evenly fractured rocks, through quasi-homogeneous and isotropic rocks, to massifs with pronounced heterogeneity and anisotropy. From a regional point of view, rocks with fracture permeability form the major part of many hydrogeological massifs. This term includes rock massifs which form a basement, and those which are overlapped by other aquifers in a near-surface zone. The evaluation of hydrogeological relationships inside hydrogeological massifs presents a more complex problem, because groundwater flow is influenced in a specific manner by several factors, including: the nature and type of fractures; the fracture fill; the intensity of massif deformation; variations in deformation in both horizontal and vertical directions; and the mutual position of fractures and fractured zones.

2. EVALUATION OF THE FRACTURED ENVIRONMENT

A principal pre-requisite for groundwater discharge from a hydrogeological massif is that the rock must have been deformed so that a network of interconnected fractures is generated. This includes deformation of rocks in a near-surface environment. Tectonic relationships are the decisive factor in determining groundwater storage and flow in rocks of low primary porosity. Rock deformation may either reduce permeability (sealing) or enhance permeability, and participates in the differentiation of groundwater discharges. Measurements of minimum groundwater runoff allow evaluation of the effects of fracture pathways on groundwater flow, even outside fractured zones which constitute preferred flowpaths. From a hydrogeological point of view, a fracture may be defined as every plane of discontinuity in a rock, independent of its origin, orientation and location. Therefore, the hydraulic function of every fracture in the massif is decisive.

The groundwater flow is defined by the two basic parameters – storativity (or effective porosity) and hydraulic conductivity. From this point of view the problem has been taken into account how to determine the volume of free spaces within fractured massif.

The evaluation of fracturing as one of the significant factors in the creation of hard-rock aquifers, is often restricted by limited possibilities for measurement and description in situ.

Deformation of rock units by fracturing takes place by the action of natural processes, which can be studied by statistical methods. The parameters used to characterize fracturing (size, aperture, frequency) can be expressed by a log-normal distributions [Hatle and Likeš 1974]. The fractures must be mutually interconnected so that water can flow in them (Fig. 1a). The measured aperture of fractures with groundwater flow was reported to be 100–300 μm in the granite massif Albtal in Germany, and 20 μm for carbonate aquifers [Himmelsbach 1992; Jandová 1989].

The initial shape of the fractures can best be simulated by an ellipsoid, as this permits an approximation of a wide set of shapes from spherical bodies through cylindrical canals to very narrow and elongated slits. The distribution of fracture frequency in relation to width (x) (Fig. 1a) is described by a log-normal distribution (LN(μ, σ)).

$$f(x) = \frac{1}{\sigma\sqrt{2\pi x}} e^{-1/2((\ln x - \mu)/\sigma)^2} \tag{1}$$

where μ is the natural logarithm of the centre of gravity coordinate of surface area $f(x)$ and σ is the natural logarithm of the standard deviation of the log-normal distribution.

The plot of this dependence is shown in Fig. 1b. There is no general procedure to determine the characteristics σ and μ and therefore it is necessary to treat each case separately. Generally, we can estimate with sufficient accuracy the values x_m and x_0, or their ratio x_0/x_m, where x_m is the size of fractures with maximum probability of occurrence. The value x_0 is the size of fractures with maximum change in the probability of their occurrence. Both values x_m and x_0 are determined from the conditions for the maximum and point of inflection in the $f(x)$ curve. If it is possible to determine reliably only the ratio x_0/x_m, we can calculate only the standard deviation, according to the formula:

$$\sigma = \frac{|\ln x_0/x_m|}{\sqrt{(1 - \ln x_0/x_m)}} \tag{2}$$

It follows that $x_0, x_m > 0$. The second characteristic, μ, can be calculated according

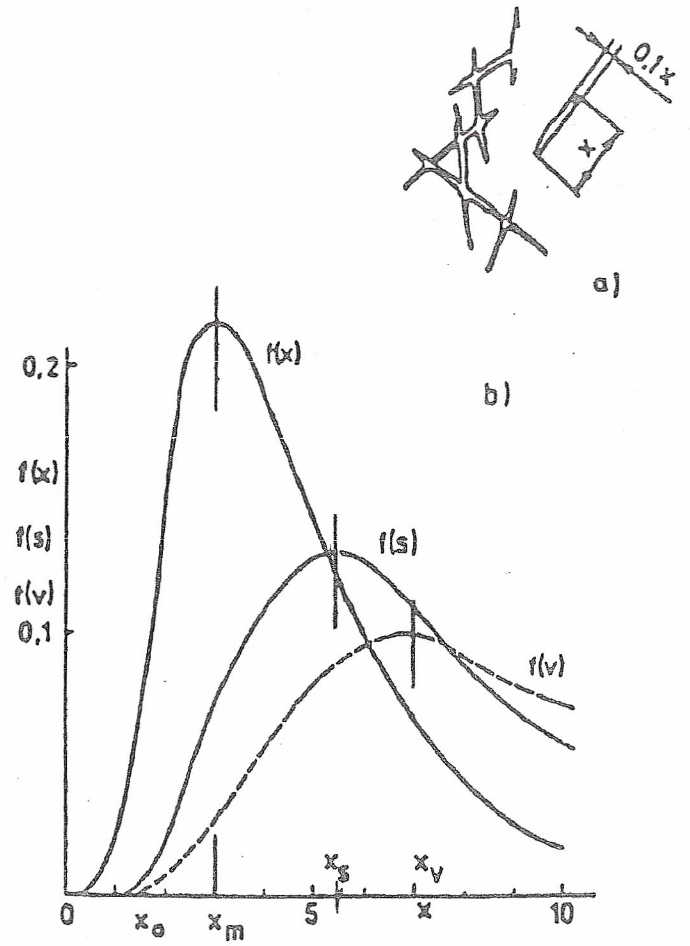

FIG.1 a) Schematic representation of interconnected and isolated fractures.
b) Relative frequency of fractures according to their width x at log–normal distribution ($f(s)$ – surface, $f(w)$ – volume; x_m, x_s, x_v – modus)

to formula:

$$\mu = \ln x_m + \sigma^2 \tag{3}$$

In the article (1993) the authors described the method using statistical methods as a possible approach to the valuation of fractured hydrogeological massifs [Hanzlík, Jahoda 1993]. Nevertheless there has been found out, if a set of fractures is classified into classes with the large range then by this way a quantity of fractures can be determined smaller than the real number of fractures in some cases. Such result would determine a negative quantity of the fine fractures or very great ones. This shortcoming of solution can be solved on the assumption that a measured number of fractures is always smaller than the real one, maximally this number can be identical. Our solution is based on the use of a distribution function $\varnothing Z$ of a log-normal distribution. The variable Z is transformed from parameters x, σ, μ of a log-normal distribution which express the formula:

$$Z = \frac{\ln x - \mu}{\sigma} \tag{4}$$

3. EXAMPLE OF UTILIZATION

The extensive Borský massif is located in the western part of the Bohemian Massif between the Mariánské Lázně spa to the north and the town of Dehetná to tho south. It is composed mainly of porphyritic biotite granite and granodiorite of Hercynian age. The study profile is located in the area of the town of Tachov. Sorting the fractures according to their widths (i.e. the size of the fracture on a profile, not its aperture) was carried out on a profile of dimensions of 50 × 20 m, regardless of the fractures orientation (Table 1). Fractures smaller than 0,05 m could not be reliably identified, and therefore the data on their frequency, width or surface area were gained by statistical estimates. The total number of fractures m is not known so far, because the data on fractures smaller than 0,05 m are not available.

TABLE 1. Measured data on fractures

Width of fractures [m] from–to	Number (m_1)	Mean width [m]
0,05–0,30	260	0,175
0,30–0,40	256	0,35
0,40–0,60	210	0,50
0,60–0,80	125	0,70
0,80–1,20	80	1,00
Totals:	931	—

The statistic characteristics of the log-normal distribution can be calculated from equations (2), (3) and have these values $\sigma = 0{,}41$ and $\mu = -0,88$. A quotient of fractures from a total number of fractures m has been sea chedrin the width interval from $0,175 \leq x \leq 1$ (Fig. 2).

On this figure the interval of the transformed variable Z has been demonstrated which is corresponding to the mentioned interval. The points Z_1 and Z_2 are calculated from the formula (4). The values $\varnothing(Z_1)$ – (0,03) and $\varnothing(Z_2)$ – (0,98) are determined graphically. The number of fractures, which were measured in situ, is 931 and this one makes 95% of fractures for the mentioned interval. The total number of fractures $\underline{m}$ comprehends 980 of fractures. In the first solution the number of fractures $\underline{m}$ was determined 1016, which was the value of median as a standard deviation to exclude the effect of extreme values. The difference between these numbers of fractures is relatively low 4%. This result is satisfactory in spite

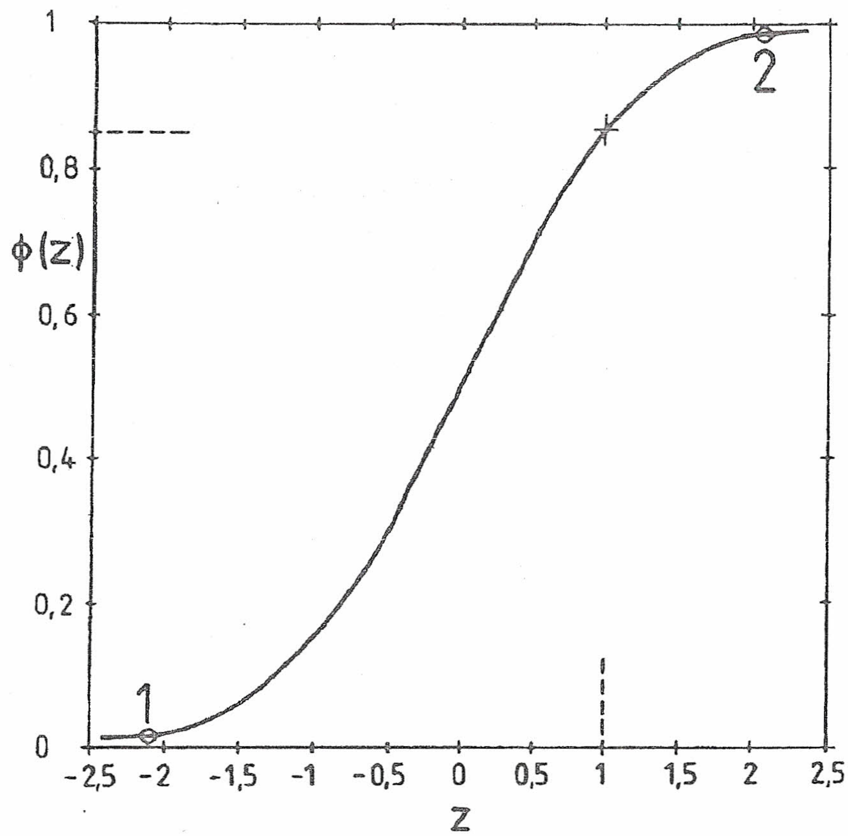

FIG.2 Graph of the distribution function $\Phi(Z)$ (Z – transformed variable)

of the mentioned fracture set into classes with a large range. This procedure with the aid of the distribution function $\varnothing(Z)$ is plausible and likely.

4. CONCLUSIONS

The description and evaluation of a hydrogeological massif requires the application of a range of methods, due to the considerable variability and complexity of the fracture environment. The approach to evaluation of fractured hydrogeological massifs given in this paper differs from the classical geological description of fracturing. This approach is based on statistical methods, which provide us with a more objective idea of the studied feature, i.e., fracturing, in contrast to empirical estimates, which are based upon professional skill, education and intuition. The results also permit a certain quantification of the fractured aquifer, and have applications to the solution of groundwater flow problems.

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