3-D network simulation technique of rock mass joint and of analysis of permeability tensor

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Abstract: On the basis of field geology survey, the probability distribution function of joint aperture is fitted and the availability of the fitting is verified. We can generate the circles with thickness to simulate the joint. The permeability tensor of rock mass is direct ratio to the third power of joint aperture. It is more reasonable and feasible to analyze the permeability tensor of rock mass when combining the simulated 3-D net work with joint aperture, for thee calculated method of permeability tensor comprehensively considered the effect of joint's orientation, aperture, scale and their distribution.

Key words: rock mass joint, joint aperture, 3-D simulation, permeability tensor

1 INTRODUCTION

It was concluded after a long-term study that to deposit the high level radioactive nuclear waste in the deep stratum is strictly feasible. It is necessary to precisely make certain the three dimension network of rock mass joint for locating the high level radioactive waste repository , conceiving the conceptual repository, studying the migration law of nuclide and appraising the stability of the repository. Most rock mass are inhomogeneous, discontinuous and anisotropic material in the nature. There is many discontinuities among the rock mass, which shape, scale and attitude are dissimilar. It posses complicated network character in the three dimension space. It is the foundation of estimating the engineering mechanics character of rock mass to effectually describe and quantitatively analyze the structural character of rock mass based on field geology survey. Remarkable progress have been made in quantitatively describing and analyzing the structural parameter of rock mass with statistical method and in simulating the joint network of rock mass with Monte-Carlo method[1-4].

However, during simulating the three dimension network of rock mass joint, we still presume that the joint are smooth plane without thickness at present. Actually the geometry shape of joint is complicated. Joint possess aperture and the joint plane are mostly undulant and rough. The smooth plane without thickness can not present the factual status. The aperture, undulation and roughness of rock mass joint and the status of joint fillings have a great effect to the character of joint and the quality, stability and permeability of rock mass. Joint distribution and its aperture control the friction coefficient, cohesion and permeability of rock mass. The study of paper 5, 6 indicated that the permeability tensor of rock mass is direct ratio to the third power of joint aperture. Very slow infiltration may result in severe nuclear pollution; therefore, when simulating the joint network, the model with joint aperture will accord with the actual situation much more and will precisely grasp the infiltration law of under ground water and will afford credible basis for effectively control the migration of nuclide .

2 THE MODEL OF 3-D NETWORK WITH JOINT APERTURE

The three dimension network numerical simulation of rock mass joint involved with many complicated geometry parameter. The process is listed below:

(1) The detailed field geology survey. Generally, the windows statistical method was used to attain the geometry parameter of outcrops and joints. The data attained by field geology survey are: the outcrop's type, the outcrop's attitude, the outcrop's scale, the scan-line's location, the scan-line's attitude and the geometry parameter of joint that list in the table 1.

(2) The division for rock mass structure. The differ pattern of rock mass joint result in the unhomogeneity of rock mass. The boundary of similar structure of rock mass is making certain through the division of statistical homogenous region.

(3) The delineation cluster of rock mass joint. The data of rock mass joint was projected to the Wolf's Stereographic Projection Net and the cluster of joint was delineated by .

(4) The correctness of the error that exist in the measurement of the length, space and attitude of rock mass joint. There is always error in the measurement of joint's data, the correctness of the data must be complete before the statistical inference of rock mass joint's geometry parameter.

(5) The fitting of the probability distribution function of joint's diameter, density and attitude. The measurement data is divided into some section and the relative frequency of every section is calculated. The probability distribution function is fitted and the availability of the fitting is verified after the frequency histogram is made.

(6) The three dimension network of rock mass joint is generated with Monte-Carlo method according to the probability distribution function that attained in the fifth step.

The three dimension network simulating techniques don't posses the function of simulating joint aperture at present. In order to well simulating the true status and exactly reflecting the structural character of rock mass, the joint aperture must be simulated while simulating the three dimension network. After the measurement error correctness and the distribution function fitting during the simulation of joint network, the circular plane with thickness may be generated by Monte-Carlo method to simulate the joint. The actual joint aperture is variable and it is difficult to precisely express the variation with mathematic formula. When measuring the joint aperture and fitting its distribution function, we presume that the joint aperture is invariable.

We make careful exploration and select thirty-nine outcrops in the 1.5 square kilometers scope near the NO.1 borehole in Beishan Area, Gansu province----- the preselected area for China's high level radioactive waste repository. Then we carefully lay the scan-line, measure the attitude of outcrop, measure every joint and note the location, attitude, length, aperture and fillings of every joint. Aimed at the situation that the study of joint aperture is not adequate, we detailedly noted the joint aperture and fillings when we measured the joint in field. Some measurement results are listed in Table 1.

We select 1265 pieces of joint of 14 contiguous outcrops and fit the distribution function of the joint aperture. The statistical results of the joint aperture and the simulative curve are shown in Fig.1. The statistical results and the simulative curve indicate: the small aperture joint occupies a large proportion and the joint which aperture is 2 millimeter hold 50 percent. The proportion is decreased as the joint aperture increase. The probability distribution of joint aperture may be precisely fitted by negative exponential function. The fitted formula is: $y = 0.9450\mathrm{e}^{-0.3379x}$ the standard deviation is: S=0.0364. The availability of the fitted distribution function is verified by the K-S method which is detailedly narrated in paper 2. the confidence level is set as: α=0.05 . The threshold of D_n^{α} is 0.111 .The calculated actual maximum D_n^{α} is 0.0441. $D_n < D_n^{\alpha}$, So we accept the fitted exponential distribution function at the confidence level of 0.05. This result is similar to the result gained by Call etc (1976), Barton (1978), Xu guangli (1993).

Table 1 The field survey data of outcrop joint

location (m)	dip (o)	Angle of dip (o)	length (m)	aperture (mm)	fillings
0	235	76	5.59	6	
1.72	313	74	0.8	8	
2.41	314	81	4	4	
2.9	316	83	4	2	
3.4	313	82	4	4	
3.9	341	82	1.6	2	
4.2	358	81	1.9	2	
4.45	316	80	4	4	
4.5	285	82	4.55		

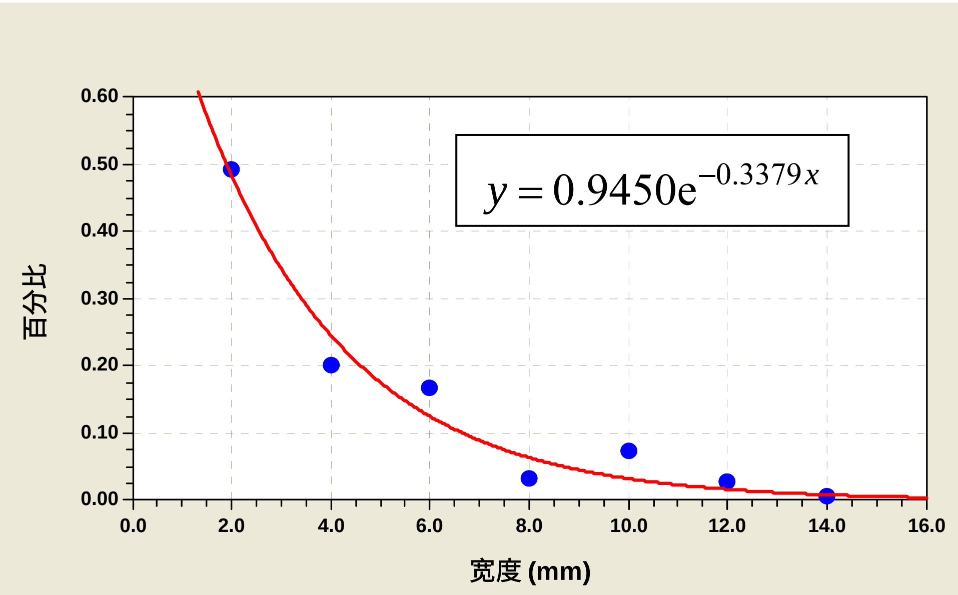

Fig.1 The statistical results of joint aperture and the simulative curve

3 PERMEABILITY TENSOR OF ROCK MASS ANALYSIS

Generally the joint network of rock mass is consisted of many set of different orientation joint. The underground water flow by the connected network. After the connected network generated, the permeability index of rock mass can be calculated by the relevant formula[7]. The scalar is not sufficient to reflect the permeability of the rock mass for the rock mass is inhomogeneous, discontinuous and anisotropic material. The tensor can reflect the permeability of each orientation[8].

3.1 Invariable width smooth joint model

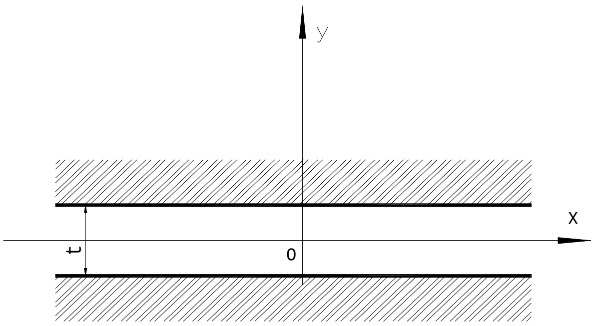

Fig.2 Invariable width smooth joint model

Modeling the invariable width smooth joint. Suppose the aperture width is *t* and infinitely extend. Set up the coordinate that shown in Fig.2.The steady seepage equation of the flow in *xy* plane is:

$$\rho(\frac{\partial}{\partial x}u_x^2+\frac{\partial}{\partial y}u_xu_y)=-\frac{\partial\vec{P}}{\partial x}+\frac{\partial\tau_{xx}}{\partial x}+\frac{\partial\tau_{xy}}{\partial y} \tag{1}$$

$$\rho(\frac{\partial}{\partial x}u_xu_y+\frac{\partial}{\partial y}u_y^2)=-\frac{\partial\vec{P}}{\partial y}+\frac{\partial\tau_{xy}}{\partial x}+\frac{\partial\tau_{yy}}{\partial y} \tag{2}$$

Where u_x and u_y are the projection of velocity tensor in the coordinate axis, τ_{xx}, τ_{xy} and τ_{yy} are the component of viscous resistance tensor.

Its continuity equation is:

$$\frac{\partial u_x}{\partial x}+\frac{\partial u_y}{\partial y}=0 \tag{3}$$

Boundary equation is:

$$y=\pm\frac{t}{2},\ \ u_x=0 \tag{4}$$

Study out the basic equation of the flow movement's average velocity is:

$$u=-\frac{t^2}{12\mu}\bullet\frac{\Delta\vec{P}}{\Delta x} \tag{5}$$

3.2 THE DEFINATION AND DETERMINATION OF CRACK TENSOR

When Oda analyzed the hydraulic character of rock mass in 1985, he defined the crack tensor as:

$$P_{ij} = \frac{\pi\rho}{4}\int_o^{r_m}\int_0^{t_m}\int_\Omega r^2 t^3 n_i n_j E(n,r,t)d\Omega drdt \qquad (6)$$

Where *r, t* is the diameter and thickness of the circular plane that simulate the joint of rock mass. n_i, n_j are the component of joint's unit normal tensor in the coordinate axis x_i, x_j.

E(n, r, t) is the united probability density function about the joint's unit normal tensor, diameter and aperture. *p* is the quantity of joint in unit volume. is the unit solid angle of the sphere's surface.

Being divided into enough even set, the variable *n, r, t* is irrelevant, viz.

E(n, r, t) = E(n) f(r) g(t) (7)

Where *E(n), f(r)* and *g(t)* are the probability density function of joint's dip, radius and aperture. When the probability density function of joint's aperture is negative exponential function, the crack tensor is:

$$P_{ij} = \frac{3\pi\rho}{2} t^3 < r^2 > N_{ij} \qquad (8)$$

where t is the average aperture of joint, $< r^2 > = \int_0^{r_m} r^2 f(r)dr$, $N_{ij} = \int_\Omega n_i n_j E(n)d\Omega$.

3.3THE DEDUCEMENT OF PERMEABILITY TENSOR

Suppose the average velocity of the flow in rock mass is:

$$\bar{v} = \frac{1}{V}\int_V v dv = \frac{1}{V}[\int_{V^I} v^I dV^I + \int_{V^J} v^J dV^J] \qquad (9)$$

where superscript *I, J* denote to rock mass and joint respectively. V is the total volume. v is the velocity of flow.

Generally, the permeability of rock mass is $10^3 \sim 10^9$ times higher than that of the intact rock. So the permeability of the intact rock can be ignored. The analysis of permeability tensor always aimed at the joint network. Hence, the formula(9) may approximate as:

$$\bar{v} = \frac{1}{V}\int_{V^J} v^J dV^J \qquad (10)$$

suppose dN as the quantity of joint which centre lies in the flow field, so

$$dN = 2N^{(V)}E(n,r,t)d\Omega drdt \qquad (11)$$

the interspaces' volume of each joint is $\frac{\pi}{4}r^2 t$, so the total interspaces' volume is

$$dV^J = \frac{\pi N^{(V)}}{2} r^2 t E(n,r,t)d\Omega drdt \qquad (12)$$

where $N^{(V)}$ is the total joint quantity in the volume V.

the distribution of hydraulic head in the seepage field completely decided by the hydraulic echo of rock mass joint system. When there is a great number of joint in the rock mass, we presume that the hydraulic head linearly decrease, that is the hydraulic gradient $\vec{J}$ is even in the whole seepage field. Suppose $\vec{J}^J$ is the component of J in the joint plane, that is

$$J_i^J = (\delta_{ij} - n_i n_j) J_j \tag{13}$$

considering the status of the real joint, suppose the velocity of the flow is

$$v_i = \lambda \frac{g}{\mu} t^2 J_i^J \tag{14}$$

where λ is amendatory constant, $0 \le \lambda \le \frac{1}{12}$, and as the scale and quantity of joint increasing λ approach to $\frac{1}{12}$.

Import formula (12), (13), (14) into formula (10), we receive:

$$\bar{v} = \lambda \frac{g}{\mu} [\frac{\pi\rho}{4} \int_0^{r_m} \int_0^{t_m} \int_\Omega r^2 t^3 (\delta_{ij} - n_i n_j) E(n,r,t) d\Omega dr dt] J_j \tag{15}$$

Contrast formula (15) and the Darcy's law: $\bar{v} = -\frac{g}{\mu} K_{ij} \frac{\partial \varphi}{\partial x_j} = \frac{g}{\mu} K_{ij} J_j$

We received the equivalent permeability tensor of the joint network.

$$K_{ij} = \lambda (P_{kk} \delta_{ij} - P_{ij}) \tag{16}$$

where P_{ij} is the crack tensor that obtained from the calculation by formula (8), $P_{kk} = P_{11} + P_{22} + P_{33}$ is the sum of crack tensor's diagonal component.

This calculated method of permeability tensor comprehensively considered the effect of joint's orientation, aperture, scale and their distribution. When simulating the three dimension network of rock mass joint, we recode the geometry information of each joint at the same time and calculate the permeability of rock mass according to the formula (16) with repeated adding method.

4 CONCLUSIONS

It is more reasonable and feasible to analysis the permeability tensor of rock mass when combining the simulated 3-D net work with joint aperture according the method in the section 3, for the calculated method of permeability tensor comprehensively considered the effect of joint's orientation, aperture, scale and their distribution. So the tensor more externally reflect the permeability of rock mass than ever and provide credible proof to precisely master the law of underground water flow and to effectively control the migration of nuclide. At the same time, we don't consider the effect of the variability of joint aperture and the wave character of the joint surface to the permeability. It is valuable to study the variability of joint aperture and the wave character of the joint surface, when simulating the three dimension network and analyzing the permeability of rock mass.

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