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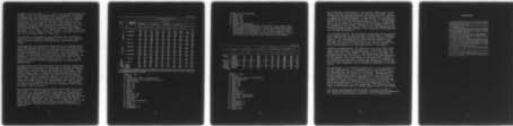
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DETERMINATION OF THE PERMEABILITY OF THE FROZEN FISSURED ROCK M--ETC(U)  
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IN THE VICINITY OF  
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M.I. Pogrebiskiy and S.N. Chernyshev

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CORPS OF ENGINEERS, U.S. ARMY  
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DETERMINATION OF THE PERMEABILITY OF THE FROZEN  
FISSURED ROCK MASSIF IN THE VICINITY OF THE KOLYMA HYDROELECTRIC  
POWER STATION

M. I. Pogrebiskiy, S. N. Chernyshev      *Kolyma*, Vol. 39, No. 1  
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The granite foundation of the Kolyma Hydroelectric Power Station is broken up by fissures of considerable width (up to 10 cm), suggesting that the rock is highly permeable. In addition, the permanently frozen condition of the massif (and the filling of the fissures with ice) rules out hydrodynamic testing for a considerable part of it without thawing the rock beforehand. Experimental pumping and pressurization carried out by Lengidroproyekt in the bed of the Kolyma River, where the massif is in a thawed condition, confirmed theories on the high permeability

of the granite. However, in areas adjoining the site of the future dam, similar filtration tests were carried out following a costly and lengthy process of preliminary thawing of the massif. The only method of predicting the permeability of the thawed state of the massif is calculating the filtration coefficient from the geometry of the fissures. This makes it possible, incidently, to calculate the filtration coefficient of the massif in the frozen state.

The determination of the permeability of the rock massif on the basis of the parameters of the fissures was made possible by the work of G. M. Lomize [2] and Ye. S. Romm [5], who determine the characteristics of the movement of water in the fissures and the dependence of the hydraulic resistance upon the parameters of the individual fissures as well as on the mutual orientation of the latter. Experience gained in the use of the relationships obtained by Ye. S. Romm, as they apply to the actual geological conditions at Nurek and Ust'-Ulimsk Hydroelectric Power Stations [3, 4, 6] has demonstrated the promising nature of the method and indicated that it should be developed further. The same conclusion has been reached abroad [7, 8, 9, 10]. The authors made changes in Romm's model which made it possible to take into account the loose fill present in the fissures [6], the statistical distribution of the fissures in terms of their orientation, density\*, width, and so on. As a result, it became possible to determine the filtration coefficient of granite for various parts of the foundation as well as the characteristics of the filtration inhomogeneity and anisotropy of the massif. It should be pointed out that the dynamics of the thawing process or formation of ice during filtration are outside the scope of the present paper.

In conjunction with the approximate method of calculation of a number of parameters of the network of fissures and the low accuracy of measurement of the width of the fissures, these estimates of permeability may be viewed as correct according to the modulus within the limits of one order, and the estimate of anisotropy may be viewed as correct within the limits of whole values of the coefficient of anisotropy.

The vicinity of the Kolyma Hydroelectric Power Station is composed of Upper Paleozoic granite from the intrusion known as the Great Threshold of the In'yali-Debinsk synclinorium of the Kolyma folded zone. At the periphery, this area is in contact with sandstone and shale of the Verkhoyansk formation.

The parameters of more than 1000 fissures were measured in the area (orientation, width, density, and length). An analysis of

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\* The term "density of fissures" refers to the distance between the cracks in the system.

the results of the measurements carried out primarily in mine workings, showed that three systems of fissures enjoy preferred development in this area. Two of them (I and III) are characterized by steep dip angles and have sublatitudinal (along the river) and submeridional strikes, respectively. System II consists of shallow fissures with dip angles of no more than 20° on the average. As indicated by Table I\*, in terms of its orientation the network of fissures is completely uniform for the entire area. This cannot be said of other parameters: the same table shows that the subvertical fissures on the left bank are characterized by average distances which are greater than on the right bank, in other words, the left bank differs from the right bank in having a sparser network of fissures.

The fissures were divided into six groups on the basis of the type of fill. The authors proceeded on the assumption that the fissures were completely filled with ice, as well as those fissures that were filled with ice and some kind of material, do not filter in the frozen (contemporary) state of the massif. In the thawed massif the fissures that are filled with ice are considered open. The following classes of fill were identified in the thawed massif: (1) open fissures; (2) fissures with rinds, deposits, and films of ferric hydrate, etc. on the walls; (3) fissures with filtering sandstone-clay filler. In the frozen massif there were: (1') fissures filled with ice; (2') the same, as in Class 2, but with ice; (3') fissures with sand and clay ice-saturated fill. In conjunction with the system of computation described below, the fissures were combined into two groups, those that were open and those that filled with filtering material. In the thawed massif, the open fissures made up about 68% of all the fissures measured in the area, while the amount that were in the frozen state was 92%. It should be pointed out that in the thawed massif on the left bank there were a great many more open fissures. In completing the characterization of the filling of the fissures, we must provide information on the ice content of the fissures: on the left bank, there were considerably more fissures that were filled with ice and ice-saturated permeable fill than there were on the right bank.

The width of the fissures varies within quite broad limits, from hundredths of a centimeter to several centimeters, and the fissures containing fill usually have greater widths than open fissures. An analysis of the width of the fissures indicates that there is a tendency for them to expand toward the surface,

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\* Here and in the following, the actual material is presented in generalized form, since it is impossible to present the primary material here owing to the limited scope of the work at the present time. In this article, we have used primarily data from the Lengidroyekt expedition and the authors' own material.

(2) Таблица 1

a	b	c	d					
			I		II		III	
Берег р. Колымы	Общее число из- меренных трещин	Выработки	e ориентирова- ния трещин (азимут и угол падения), град	f среднее рас- стояние меж- ду трещинами, мм, см	g ориентирова- ния трещин (азимут и угол падения), град	h среднее рас- стояние меж- ду трещинами, мм, см	i ориентирова- ния трещин (азимут и угол падения), град	j среднее рас- стояние меж- ду трещинами, мм, см
k Правый	772	m Штольня и шурфы	0 / 76	68	180 / 9	68	96 / 81	63
l Левый	230	n Штольня в шурфы	174 / 76	178	212 / 29	75	283 / 85	170
		o Обнажение	6 / 87	121	223 / 12	71	102 / 83	195
		p Штольня, шурфы и обнажение	6 / 81	154	222 / 12	73	228 / 85 102 / 84	187

- TABLE 1. Key.
- a, Coast of Kolyma River
  - b, Total number of measured fissures
  - c, Mine workings
  - d, Fissuring parameters for the following systems of fissures:
  - e, Orientation of fissures (asymuth and dip angle), degrees
  - f, Average distance between fissures, cm
  - g, Orientation of fissures (asymuth and dip angle), degrees
  - h, Average distance between fissures, cm
  - i, Orientation of fissures (asymuth and dip angle), degrees
  - j, Average distance between fissures, cm
  - k, Right
  - l, Left
  - m, Adits and test pits
  - n, Adits and test pits
  - o, Outcropping
  - p, Adits, test pits, and outcroppings

and this tendency is intensified primarily as a result of those fissures that are filled with permeable material and have developed mostly at the surface of the ground. The open fissures do not expand as they approach the surface (Table 2).

Table 2 presents the actual material with gives some idea of the relationship between the average values for the widths for the systems of fissures on both banks of the river. On the basis of these data, we see that the left bank of the Kolyma River is characterized by much wider fissures than the right bank. This situation holds for open and filled fissures in the thawed and frozen state in the adits. It is only in the case of filled fissures in the test pits that we see the reverse picture, which we feel is due only to the nonrepresentative

Таблица 2

a Состояние массива	b Тип запол- нения трещины	c Выс- ботки	d Средняя ширина трещины, см						
			e правый берег			f левый берег			
			g системы трещин						
			i	ii	iii	iv	v	vi	
Тунис	Открытые	Устья							
		штолен	0.18	0.05	0.03	0.29	0.33	0.15	
		Забои							
	Заполненные	Устья							
		штолен	0.15	0.17	0.13	0.21	0.23	0.21	
		Шурфы	0.15	0.03	—	—	0.04	—	
Алжир	Открытые	Устья							
		штолен	1.92	2.50	1.15	5.00	1.86	1.25	
		Забои							
	Заполненные	Устья							
		штолен	0.49	0.11	—	—	1.40	—	
		Шурфы	4.93	1.52	1.15	0.84	0.80	0.61	
Алжир	Открытые	Устья							
		штолен	0.09	0.05	0.03	0.19	0.15	0.15	
		Забои							
	Заполненные	Устья							
		штолен	0.13	0.17	0.13	0.07	0.17	0.12	
		Шурфы	0.15	0.03	—	—	0.04	—	
Заполненные	Устья								
	штолен	0.22	—	—	8.92	0.38	—		
	Забои								
Алжир	Заполненные	штолен	0.12	0.14	—	—	—	—	
		Шурфы	1.92	1.17	—	—	—	—	

TABLE 2. Key.

- a, State of massif  
b, Type of filling of fissures  
c, Mine workings  
d, Average width of fissures, cm  
e, Right bank  
f, Left bank  
g, Systems of fissures  
h, Thawed  
i, Frozen  
j, Open  
k, Filled  
l, Open  
m, Filled  
n, Mouths of adits  
o, Bottoms of pits  
p, Test pits

nature of the actual material as it pertains to the test pits on the left bank. Since the degree of influence of the width of the fissures on the permeability of the fissured massif is quite significant (and is much greater than the influence of the density), we can expect that the rocks on the left bank will have greater permeability than the rocks on the right bank.

The most difficult technical task was the measurement of the length of the fissures in the towpath on the left bank. They indicate that the horizontal fissures, which are the longest, serve as the basic filtration pathways and can also serve as a connecting link between the fissures of the first and third systems.

Now let us move on to the discussion of the method of calculating the filtration coefficient of granite on the basis of the fissuring parameters. In order to estimate permeability, the granite massif was represented as follows. The granite, in blocks, is assumed to be impermeable and incapable of transmitting hydrostatic pressure. Those fissures that were open and filled with permeable loose material were considered permeable. The consumption of water that could pass through the massif under these conditions was equal to the sum of the flows conducted by the fissures.

The expression below [5] makes it possible to estimate the filtration coefficient of a massif for the direction which coincides with the direction of the pressure gradient when there are fissures in the system:

$$K_{\phi, n} = \frac{g}{12\nu} \sum_{i=1}^n \frac{b_i^2}{a_i} \left\{ 1 - \left[ \sin \beta_i (\cos \alpha_i \cos \varphi + \sin \alpha_i \cos \rho) - \cos \beta_i \cos \gamma \right]^2 \right\} \quad (1)$$

where  $g$  is the acceleration due to gravity,  $m/sec^2$ ;  
 $\nu$  is the kinematic viscosity coefficient,  $m^2/sec$ ;  
 $b_i$  is the width of the cracks,  $m$ ;  
 $a_i$  is the average distance between fissures,  $m$ ;  
 $\alpha_i, \beta_i$  are the asymuth and dip angle of fissures in system  $i$ , degrees;  
 $\rho, \varphi, \gamma$  are the angles between the direction for which the filtration coefficient is estimated and the corresponding coordinate axes, degrees.

For a massif with fissures that are filled with permeable material [6]

$$K_{\phi, n} = \sum_{i=1}^n \frac{b_i K_{\phi, i}}{b_i + a_i} \left\{ 1 - \left[ \sin \beta_i (\cos \alpha_i \cos \varphi + \sin \alpha_i \cos \rho) + \cos \beta_i \cos \gamma \right]^2 \right\} \quad (2)$$

where  $K_{f,t}$  is the filtration coefficient for the filler in the fissures.

Both expressions are valid for similar conditions when the fissures in the system are strictly parallel, have a constant width for their entire length, and the distances between them are assumed constant while the lengths are infinite. These conditions result in a considerable limitation of the area of applicability of formulas (1) and (2), but the authors disregarded them in estimating the permeability of the granite. In writing the computer program, the filtration coefficient of the massif was calculated as the sum of (1) and (2). Hence, both the empty crack and the cracks that were filled with permeable filler were taken into account simultaneously.

It was arbitrarily assumed that each system was represented by only one fissure, which made it possible to take into account not only the distribution of the orientation but also the changing width of the fissures. The latter is especially important, since the calculation based on the average values of the width, as practice has shown, is responsible for lowering the value of the results several fold. When there is one fissure in the system, the distance between the fissures in the system becomes indeterminate and for an unlimited volume of the massif. Therefore, the authors considered those massifs that were bounded by the walls of mine workings. The analysis was conducted on the basis of the following coordinate axes (X - eastward, Y - northward, Z - toward the zenith) with dimensions x, y, and z. The linear dimension of the cross section of the working in a direction perpendicular to the fissure was used as the arbitrary density of the fissures in system (A), represented by one fissure. This value, in the case of a vertical shaft with a slanting location of the fissure, is calculated according to

$$A_i = z \cos \beta_i + d \sin \beta_i \quad (3)$$

To determine the rectangular cross section in the general case

$$A_i = (x \sin \alpha_i + y \cos \alpha_i) \sin \beta_i + z \cos \beta_i \quad (4)$$

where d is the diameter of the shaft.

Note that  $\alpha_i$  in formula (4) may be considered to be the asymuth of the dip of the fissure only under the conditions pertaining in the vicinity of the Kolyma Hydroelectric Power Station, where the mine workings are oriented latitudinally or meridionally.

With a different orientation of the workings, the azimuth of the dip in expression (4) would have to be replaced by angle  $\alpha_1$  between the strike of the dip of the fissure and the direction of the wall of the working, coinciding with axis Y:

$$\alpha'_1 = \alpha_1 - \delta, \quad (5)$$

where  $\delta$  is the azimuth of the wall of the working, coinciding with axis Y.

Readings measured clockwise from the meridian are considered positive and those measured counterclockwise are considered negative. The condition  $\delta < 45^\circ$  is introduced and determines which of the walls of the adit must coincide with the Y axis. Equations (3) and (4) are useless for sloping workings.

This method of estimating A can be used for systemic and random networks of fissures. In the case of systemic networks, when calculating on the basis of individual values, it is possible to use the simpler and less accurate method of estimating  $A_i$ :

$$A_i = \bar{a}_i \cdot n_i, \quad (6)$$

where  $\bar{a}_i$  is the average distance between the fissures in the system;  
 $n_i$  is the number of fissures in the system.

Computation using formula (6) requires isolation of the systems of fissures and calculation of  $\bar{a}_i$ , while formulas (3) and (4) allow this work to be avoided. The use of formulas (3) and (4) is particularly effective when using a computer. For this work, the arbitrary density was calculated in two ways (without any significant differences in the results).

Hence, the filtration coefficient of a fissured massif was calculated separately for each mine working (a total of four adits and nine test pits, whose total length was about 500 m). The program written for the BESM-4 computer was the work of V. A. Pyrchenko. The geological material for each working was viewed as an individual massif of actual data.

The calculations performed for two opposite states of the massif fail to take any kind of intermediate situations into account: for current frozen condition of the massif, when a portion of the fissures are filled with ice, and for the melted state, when the ice is completely gone from the fissures.

The calculation were performed according to formula (1) to estimate the filtration coefficient of open and equivalent fissures

(classes of filler were 1, 1', 2 and 2' in the thawed state and classes 1 and 2 in the frozen state of the massif. According to formula (2), the coefficient of filtration of the fissures was calculated when the latter had permeable filler (classes of filler 3 and 3' in the melted state and class 3 in the frozen state of the massif). As the filler material for the fissures in carrying out computations using formula (2), the following values for the filtration coefficient were used: rotten stone (debris) - 100 m per day, rotten stone (debris) and sand - 80 m, sand - 50 m, sandy loam - 1 m, loam, clay, and mylonite - 0.1 m, mineral filler, calcite, ice and filler with ice (in the frozen state), 0 m per day.

The estimate of permeability was performed using fractional values for the fissuring parameters ( $\alpha_i$ ,  $\beta_i$ ,  $A_i$ ,  $b_i$ ) individually for each fissure in the thawed ( $K_T$ ) and frozen ( $K_M$ ) states.

Then summation was carried out according to the program using both computational formulas in order to obtain the total permeability individually for the rock massif in the melted state and for the massif in the frozen state. For each fissure, the filtration coefficient was calculated in three coordinate planes: the horizontal and two vertical ones (latitudinal and meridional) and in four directions in each of them, any one of which is characterized by three angles --  $\rho$ ,  $\phi$ ,  $\gamma$ . This makes it possible to obtain characteristics of anisotropy of permeability.

The directions used for calculating the filtration coefficient coincide with the strikes of the principal fissure systems and, supposedly, with the axes of anisotropy of the massif. Inasmuch as the individual directions coincide in different coordinate planes, Table 3 shows the values obtained for the filtration coefficients (in meters per day) for nine different directions. Table 3 shows the results, but not for all workings. The lines in the table indicate that the values for the filtration coefficient in the frozen massif are equal to zero, since all of the fissures are filled with ice. The results are given individually by adit for the weathering zone (mouth) and massif itself (bottom).

The values obtained for the filtration coefficient vary within wide limits -- from thousandths to 22 m/day. The filtration test which was performed by the Lengidroyekt expedition in the river bed yielded filtration coefficients that were much greater than those obtained by the authors (on the basis of the data from the expedition, the filtration coefficient varies from 0.005 to more than 1200 m/day). It is obvious that in the river bed the fissures are filled with loose material to a lesser degree, although other reasons for the difference are possible.

Таблица 3

Плоскость	Направление, угол к горизонту	Коэффициент фильтрации пород К									
		шахта									
		штольня 99		штольня 100		штольня 763		штольня 777		шурф 770	шурф 731
		устье	забой	устье	забой	устье	забой	устье	забой		
Горизонтальная	Восток, 0°	0.2	3.3	0.1	9.7	1.2	5.0	0.3	0.2	—	0.2
		0.3	3.5	5.6	10.3	3.1	11.9	6.6	15.7	0.08	0.8
	Север, 0°	0.04	2.7	0.0	8.5	0.8	7.3	0.04	1.1	—	0.1
		0.1	2.8	2.2	8.8	5.2	22.0	3.8	12.2	0.07	0.8
	С.-в., 0°	0.1	2.7	0.04	9.2	1.7	6.1	0.2	0.3	—	0.2
0.2		2.8	5.8	9.8	6.8	21.4	5.1	13.6	0.06	0.6	
Ю.-в., 0°	0.1	3.3	0.06	9.0	0.3	6.1	0.2	1.1	—	0.1	
	0.2	3.5	1.9	9.2	1.6	12.5	5.3	14.4	0.04	0.6	
Вертикальная	Земл., 90°	0.2	2.6	0.1	1.8	1.8	2.3	0.3	1.2	—	0.2
		0.3	2.8	5.5	2.4	5.9	17.9	3.1	6.3	0.03	1.1
	Запад, 45°	0.2	2.9	0.1	5.5	1.4	6.9	0.3	0.5	—	0.2
		0.3	3.1	6.4	6.2	5.2	19.2	5.0	10.9	0.06	1.0
	Восток, 45°	0.2	3.0	0.1	6.0	1.6	0.4	0.3	1.0	—	0.2
0.3		3.3	4.6	6.6	3.8	10.6	4.6	11.0	0.06	0.9	
Вертикальная меридиональная	Север, 45°	0.1	2.4	0.06	5.5	1.5	4.8	0.2	1.1	—	0.2
		0.1	2.6	1.6	5.7	5.6	21.4	6.4	14.0	0.06	1.1
	Юг, 45°	0.1	2.9	0.04	4.8	1.1	4.6	0.1	1.3	—	0.1
		0.2	3.0	5.9	5.5	5.6	18.5	0.5	4.5	0.04	0.9
	Степень анизотропии	4.0	1.4	2.2	5.4	5.8	20.0	7.8	5.8	—	3.0
		2.8	1.4	3.8	4.2	4.4	2.1	18.0	3.4	2.7	1.4

З. - Примечание. В числителе даны значения коэффициента фильтрации мерлых пород, в знаменателе — талых. Значения коэффициентов фильтрации округлены до первого знака после запятой. Степень анизотропии получена по более крупным значениям коэффициентов фильтрации.

TABLE 3. Key.

- a, Plane
- b, Direction, angle to horizontal
- c, Coefficient of filtration of rock, K
- d, Mine working
- e, Adit 99
- f, Adit 100
- g, Adit 763
- h, Adit 777
- i, Mouth
- j, Bottom
- k, Test pit 770
- l, Test pit 731
- m, Horizontal
- n, Vertical
- o, Vertical meridional
- p, East, 0°
- q, North, 0°
- r, Northeast, 0°
- s, Southeast, 0°

Table 3, key, continued.

t, Zenith, 90°

u, West, 45°

v, East, 45°

w, North, 45°

x, South, 45°

y, Degree of anisotropy

z, Note: the numerator gives the values of the coefficient of filtration of frozen soil, while the denominator gives the values for thawed soil. The values of the filtration coefficients are rounded off to the first decimal place. The degree of anisotropy is determined on the basis of the most fractional values of the filtration coefficients.

Таблица 4

Плоскость	Направление, угол к гориз. (град)	Работы								ширф 731
		ШТОЛБ 99		ШТОЛБ 100		ШТОЛБ 763		ШТОЛБ 777		
		устье	забой	устье	забой	устье	забой	устье	забой	
Горизонтальная	Восток 0°	1,7	1,1	70,0	1,1	2,5	2,4	21,0	71,5	3,5
	Север. 0°	3,0	1,0	538,0	1,0	7,0	3,0	96,0	10,8	10,0
	С.-В. 0°	1,8	1,0	146,0	1,1	4,0	3,5	28,0	47,0	4,0
	Ю.-В. 0°	2,0	1,1	38,2	1,0	5,0	2,0	29,6	13,6	7,8
Вертикальная шуртовая	Зенит. 90°	1,4	1,1	61,0	1,3	3,3	7,8	11,0	5,1	5,4
	Запад 45°	1,4	1,1	88,0	1,1	3,6	2,8	17,5	23,8	4,6
	Восток 45°	1,5	1,1	58,0	1,1	2,4	29,0	15,2	71,5	4,0
Вертикальная меридиальная	Север. 45°	1,2	1,1	33,0	1,0	3,8	4,4	28,0	12,7	6,6
	Юг. 45°	2,2	1,1	148,0	1,1	5,2	4,0	5,2	3,6	6,6

TABLE 4. Key.

a, Plane

b, Direction, angle to horizontal

c, Mine workings

d, Adit 99

e, Adit 100

f, Adit 763

g, Adit 777

h, Mouth

i, Bottom

j, Test pit 731

k, Horizontal

l, Vertical, latitudinal

m, Vertical, meridional

n, East, 0°

o, North, 0°

p, Northeast, 0°

q, Southeast, 0°

r, Zenith, 90°

s, West, 45°

t, South, 45°

The filtration coefficients in the current frozen state of the massif are less than they will be after the ice thaws. Table 4 shows the relationship between the coefficients of filtration of thawed and frozen massifs. In some places, the increase in permeability following thawing of the ice will be insignificant (adits 99 and 100, outside the weathering zone). In individual areas, we can expect an increase in the filtration coefficient by a factor of 100 or more. Evidently, as a result of the increased filling of the fissures with ice in the weathering zone, the differences between the  $K_f$  of the thawed and frozen massifs will be more significant.

In the thawed massif, the filtration coefficients reach particularly high values for the deep parts of the massif. Evidently, this indicates the presence of wide fissures, currently filled with ice. In the parts of the adits near the mouths of the tunnels, there are fissures which are as large if not larger, but they are filled with loose material, and this markedly reduces the permeability of the upper parts of the massif.

Contrary to expectations, the granite on the right bank, which looks "more fissured" to the naked eye, is actually less permeable than the "less fissured" granite on the left bank. As mentioned earlier, the width of the cracks plays the most important role in the formation of the filtration characteristics of the granite, and it is greater on the left bank. However, it is possible to estimate visually the degree of fissuring on the basis of the size of the blocks and the density of the fissures. These parameters are of secondary importance in estimating  $K_f$ .

The anisotropy of the fissure permeability is very significant; in the frozen massif, it is greater than in the thawed part. In some workings, the filtration coefficient differs in different directions by the factor of 20 or more. The maximum filtration coefficients usually are associated with the YZ plane in the selected system of coordinates, i.e., the one which is directed along the river at various angles to the horizon and vertically. The only exception in this regard is adit No. 763, where the permeability in a direction perpendicular to the river is higher than in other directions. The degree of anisotropy in the frozen state is usually greater than in the thawed.

The results we obtained must be viewed as rough estimates of the actual coefficients of filtration, since some of the parameters of fissuring were assigned arbitrarily in the computations.

## REFERENCES

1. Жилевков В. Н. и др. О влиянии на водопроницаемость трещин шероховатости их стенок. Тр. коорд. совещ. по гидротехнике. Вып. 48. Л., 1970.
2. Ломизе Г. М. Фильтрация в трещиноватых породах. М., Гостэнергиздат, 1951.
3. Потребиский М. И., Колычко А. Б. Исследование тектонической трещиноватости и ее влияние на условия строительства крупных гидроэлектростанций на р. Вахш. Мат. к науч.-техн. конф. ПНИИИИАС. М., 1969.
4. Рац М. В., Чернышев С. Н. Трещиноватость и свойства трещиноватых горных пород. М., «Недра», 1970.
5. Ромм Е. С. Фильтрационные свойства трещиноватых горных пород. М., «Недра», 1966.
6. Чернышев С. Н. Коэффициент фильтрации скального массива с рыхлым заполнителем трещин. Инженерные изыскания в строительстве. Реф. сборник № 3 (11). М., 1971.
7. Louis A. Etude des écoulements d'eau dans les roches fissurées et de leurs influences sur la stabilité des massifs rocheux. Electricité de France, № 3, 1965.
8. Proceedings of the Symposium «Percolation through fissured rock». Int. Soc. Rock Mech. and Int. Ass. Eng. Geol., Stuttgart, 1972.
9. Snow D. T. Rock fracture spacings and porosities. Jour. Soil Mech. and Found. Div., v. 94, № 1, 1968.
10. Wittke W. Durchströmung von klüftigen Fels. Theorie, Experiment, Anwendung. Versuchsanst. für Wasserbau und Kulturtech. H-153, 1969.