RELATION OF LINEAR BLOCK DIMENSIONS OF ROCK TO CRACK OPENING IN THE STRUCTURAL HIERARCHY OF MASSES

M. V. Kurlenya, V. N. Oparin, and A. A. Eremenko

UDC 622.831+553.434

1. *Experience in experimental investigations* in the field of geomechanics and earth physics, which has been accumulated preferentially in the last two to three decades, definitely supports the hypotheses advanced by Academician M. A. Sadovskii in his own time concerning the structural hierarchy of rock masses [1]. These notions were extremely contradictory in the theoretical explanation of a number of interesting experimentally observed geomechanical effects. It is also possible to classify among these geomechanical effects, for example, the comparatively recently exposed phenomenon of the alternating-sign reaction of rock under dynamic effects [2, 3], which has high potential both in the field of theoretical investigations, and also for practical applications. We will devote an independent series of studies to the individual aspects of this kind of results and to applications of the observed effect. The present paper, however, dwells on study of such an important structural factor of geomaterials as the ratio of the linear block dimensions of rock to crack operning, and the individual dimensions of the blocks in the structural hierarchy of masses. Without going into detail on the basis of the significance of this factor, let us point out only its fundamental role in the prediction of the linear parameters of hidden tectonic fractures and geoblocks of corresponding rank, and in the study of the rapid dispersion of different types of elastic waves, as well as in the energy exchange between impulse-type sources and the block medium with which they interact.

As far as we know, there are currently few systematic investigations on the factor that we have pointed out. Available information either pertains very indirectly to this factor (as a rule, in the geological literature), or is absent altogether.

But then, this is hardly astonishing. Strictly speaking, however, determination of a crack opening of some rank in its "classical" understanding is not a simple problem not only because by itself, the parameter is extremely variable (proof of this exists in the mass of mining geologic literature) even for one recorded crack, but also because it is extremely difficult to make direct measurements in the field. If, however, the concept of "crack opening" is looked upon from more general positions, it is found that variations of the noted parameter are not as arbitrary as would be indicated at first glance. Moreover, suspicions arise concerning the fact that this "will" is dictated by the nesting factor of the blocks in the structural hierarchy of the mass.

By its own nature, the following rather simple fact is the basis for use of these generalized positions on the concept of "crack opening": quite often in nature, a crack is filled to some degree with slightly cohesive fractions of matrix, products of their dynamometamorphism, or by fluids (which can also possibly be crystallized out) and so forth. In this case, it is possible to point out a number of geomechanical processes for which it is not so much the character of the crack filler, as the distance between the edges of the cracks that are determining.

We performed a rather emitted analysis with consideration of the above-indicated discussions for ore and rock masses basically on a sample from the Tashtagol Mine in Shorii Mountain and ore samples from the Talnakhsko-Oktyabr'skii deposit (Noril'sk) to attract the attention of experimenters to the question that has been raised, and to fill to any degree the gap created here. The individual knowledge of the authors was extracted from publications at their disposal, which are related by some means or other to the subject of the investigation.

Mining Institute, Siberian Branch, Russian Academy of Sciences, Novisibirsk. Translated from Fiziko-Tekhnicheskie Problemy Razrabotki Poleznykh Iskopaemykh, No. 3, pp. 3-10, May-June, 1993. Original article submitted January 29, 1993.

2. Method Used to Process Field Data. If the average distance between crack edges δ_i for geoblocks of the rocks on a fixed hierarchical level (i) is employed as an indicator of "crack opening," irrespective of the character of the crack filler, in this case for blocks represented by the characteristic linear dimension Δ_i , therefore, an indicator, which can be denoted here by the symbol

$$^{i}\mu_{\Delta}(\delta)=\delta_i/\Delta_i \tag{1}$$

is sought experimentally.

Use of the subscript i in (1) is necessary, generally speaking, because in no way does it yet follow that the quantity $\mu_{\Delta}(\delta)$ is a certain invariant. If this is so, however, the indicator $\mu_{\Delta}(\delta)$ will merit introduction as a "universal" rating characteristic of geomaterials on a level with familiar mechanical constants. As will be demonstrated below, these recommendations are, in reality, not devoid of certain bases.

Consequently, two questions arise in connection with Eq. (1): How is the quantity δ_i determined; and 2) what is understood to be Δ_i, and, accordingly, how can this characteristic be measured under field conditions?

Recommendations concerning direct measurement of the distance between the edges of open cracks of a different level could serve as a "trivial" method, but one that is essentially difficult to implement in the field. The difficulties in this case are coupled, above all, with the fact that the cracks frequently are filled, by some means or other, with a different kind of material, and vary with respect to thickness, moreover, in space. To overcome these difficulties, we propose to use the generalized concept of crack opening, and to employ statistical evaluation on the basis of general data samples to account for the nonsteady state (variation) of this characteristic in space. The matter of answering the second question is more difficult, because real blocks of rock are, as a rule, nonisometric. The shape factor (ratio of maximum to minimum dimension) of the blocks, however, frequently does not exceed 2-3. In this connection, the following could be a sufficiently general, universal characteristic of the linear dimensions:

$$\Delta_i=\varkappa\cdot V_i^{1/3}, \tag{2}$$

where V_i is the volume of a block at the i-th hierarchical level, and $\varkappa$ is a generalized shape factor, which depends on available a priori information on symmetry components of the geoblocks. In the case of cubic symmetry, for example, it is convenient to set $\varkappa = 1$; in the case of spherical symmetry, $\varkappa = (6/\pi)^{1/3}$, and so forth.

Unfortunately, Eq. (2) can seldom be used under field conditions for a number of obvious reasons. Situations where there is the possibility of estimating either the distance between subparallel disjunctives separating the blocks of a certain rank, or the distance between "branching points" of cracks in plan or a certain section of the rock mass are the most typical. In our study, we will use both parameters when necessary; in a general sample, the averaged "diameter" of the blocks will therefore, by nature, serve as a linear dimension Δ_i of the blocks with allowance for the heterogeneity of the data statistics:

$$\Delta_i\simeq\frac{1}{N}\sum_{j=1}^{N}l_j, \tag{3}$$

where l_j are linear dimensions of the sides of the blocks or their diameters, and N is the volume of the data set. In this aspect, the dispersion caused by the potentials of the experiments will assume the values of the estimated parameter in (3) when necessary. As a closing remark, it should also be pointed out that the information of interest to us on the scale of tectonic geoblocks can, as represented, be obtained from certain quantitative parameters associated with analysis of such forms of manifestation of fracture tectonics as injective formations: intrusive bodies, dikes, sills, quartz–carbonate streaks, or veins, etc. For understandable reasons, the thickness and lengths of these bodies provide notions concerning the values of δ and Δ, respectively, for tectonic disjunctions of a different scale level, which had formed in the geological past. The width and expanse of zones of vigorous shattering of rock in the immediate vicinity of tectonic fractures distinguished by extremely weak coupling (or by its absence) between rock fractions can be considered another alternate scheme for estimating the desired parameters δ and Δ, respectively. Both of the above-cited will "elicit" that situation where the interval δ between geoblocks is filled to some degree with the crushing products of the rock mass of these blocks, or by inclusions of a different geochemical composition, which have penetrated through fractures that had once formed with the parameters δ and Δ. It is important that the width of the zones of vigorous shattering around disjunctions be evaluated with a sufficient degree of

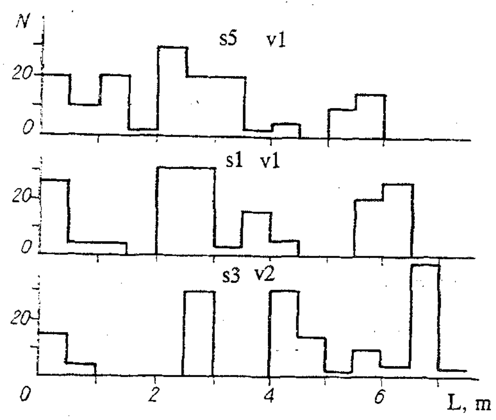

Fig. 1. Histograms of rock-crack distribution along hole according to data of periodic observations at Taimyrsk Mine (working at −1050 horizon).

reliability and immediately during the opening of mine workings, for example, from the linear parameters of the rock failure beyond the boundary around workings at points of intersection with disturbances.

3. Talnakhsko-Oktyabr'skoe Site. The walls of holes are visually inspected using an RVP-451 instrument. The width of the crack opening was determined with an accuracy to 0.2 mm. In interpreting the results, the number of cracks was reduced to this value. For a width of opening of 1 mm, for example, we took five cracks each 0.2 mm for plotting the type of histograms shown in Fig. 1. As visual observations indicated (Taimyarsk Mine, −1050 horizon), open systems of cracks exist essentially over the entire length of the holes. Unfortunately, the holes could be inspected at depths to 8 m from the perimeter of the workings due to the technical limitations of the RVP-451 instrument. The results of periscope observations over six holes, for example, at long-range observation stations (LROS-1 and -2) in the Taimyrsk Mine are cited in Table 1. As is apparent from Table 1, the ratio of interest to us $\delta/\Delta = 2.7 \cdot 10^{-2}$ on average. The small number of similar observations in continuous sulfide ores at the Oktyabr'skoe Noril'sk deposit made it possible to estimate this ratio within the range $(0.5\text{-}1) \cdot 10^{-2}$. It should also be pointed out that comparison of data derived from electrochemical logging and their spectra, which make it possible to isolate blocks ranging from 0.25-0.5 to 3 m in size for the cases in question [5], with corresponding histograms of crack openings for these same holes provides the bases for the conclusion that the above-cited estimates based on the parameter $\mu_\Delta(\delta)$ apply precisely to blocks of the noted type size: 0.25-3.0 m.

In estimating the parameter $\mu_\Delta(\delta)$ for blocks on a lower level in conformity with the classification proposed by Rats [6], let us revert to familiar structural-tectonic data for the deposit under consideration.

According to data provided by geologists [4], the thick Noril'sko-Kharaelakhsk deposit with a deep fracture, which has a north-northeast strike, and the system of parallel or subparallel tectonic cracks associated with it, is the basic structural component of the Talnakhsk deposit. In this case, all large-scale tectonic disturbances are characterized by the development (along their axis) of crushing zones, the thickness of which fluctuates from 0.2-0.5 to 5-8 m. If the average distance between subparallel fractures (the average sections are determined by the starting and ending "points" of the branching of disjunctive in plan) on the chart of the geological section of the Talnakhsk deposit is taken as the linear dimensions Δ of the structural geoblocks, this quantity is grouped within the limits ~35-50 and ~200 m. Setting $\delta_1 = 0.2\text{-}0.5$ m, $\delta_2 = 5\text{-}8$ m, $\Delta_1 \simeq 35\text{-}50$ m, and $\Delta_2 \simeq 200$ m, we have

$$\frac{\delta_1}{\Delta_1} \simeq (0.4 - 1.4) \cdot 10^{-2}; \ \frac{\delta_2}{\Delta_2} \simeq (2.5 - 4) \cdot 10^{-2}.$$

As experience gained with geomechanical observations of the edge displacement of supported rock strata indicates, the relative compressive deformations do not, as a rule, exceed the values of those cited.

4. Tashtagol Mine. The core-drilling method is used in the stage of possible recognition of potentially dangerous segments of the rock mass in the Tashtagol deposit as a function of effective stresses and degree of tectonic disturbance. The state of the mass is evaluated on the basis of core disking in accordance with a procedure developed by the All-Union Scientific-Research Institute of Mine Surveying. Holes of different orientation are drilled with a diameter of 59 mm to a

$$\begin{Vmatrix} \sigma_{1\kappa}^{g'} & 0 \\ 0 & \sigma_{2\kappa}^{g'} \end{Vmatrix} = \begin{Vmatrix} \sigma_z & \tau_{xz} \\ \tau_{zx} & \sigma_y \end{Vmatrix}, \tag{23}$$

where

$$\sigma_z = \frac{1}{2}\left(\sigma_{1\kappa}^{g'} + \sigma_{2\kappa}^{g'}\right) + \frac{1}{2}\left(\sigma_{1\kappa}^{g'} - \sigma_{2\kappa}^{g'}\right)\cos 2\Theta_2,$$

$$\sigma_x = \frac{1}{2}\left(\sigma_{1\kappa}^{g'} + \sigma_{2\kappa}^{g'}\right) - \frac{1}{2}\left(\sigma_{1\kappa}^{g'} - \sigma_{2\kappa}^{g'}\right)\cos 2\Theta_2,$$

$$\tau_{xz} = \tau_{zx} = \frac{1}{2}\left(\sigma_{1\kappa}^{g'} - \sigma_{2\kappa}^{g'}\right)\sin 2\Theta_2.$$

For the third sensor oriented along the x axis we have

$$\begin{Vmatrix} \sigma_{1\kappa}^{g''} & 0 \\ 0 & \sigma_{2\kappa}^{g''} \end{Vmatrix} = \begin{Vmatrix} \sigma_y & \tau_{yz} \\ \tau_{zy} & \sigma_z \end{Vmatrix}, \tag{24}$$

where

$$\sigma_y = \frac{1}{2}\left(\sigma_{1\kappa}^{g''} + \sigma_{2\kappa}^{g''}\right) + \frac{1}{2}\left(\sigma_{1\kappa}^{g''} - \sigma_{2\kappa}^{g''}\right)\cos 2\Theta_3,$$

$$\sigma_z = \frac{1}{2}\left(\sigma_{1\kappa}^{g''} + \sigma_{2\kappa}^{g''}\right) + \frac{1}{2}\left(\sigma_{1\kappa}^{g''} - \sigma_{2\kappa}^{g''}\right)\cos 2\Theta_3,$$

$$\tau_{yz} = \tau_{xy} = \frac{1}{2}\left(\sigma_{1\kappa}^{g''} - \sigma_{2\kappa}^{g''}\right)\sin 2\Theta_3.$$

Here and above θ_1 is the angle between the x axis and $\sigma_{1k}{}^{g}$; θ_2 is the angle between the z axis and $\sigma_{1k}{}^{g'}$; θ_3 is the angle between the y axis and $\sigma_{1k}{}^{g''}$. It can be seen from the equations that values of σ_x, σ_y, and σ_z are monitored mutually for three sensors.

Values of $\sigma_1{}^0$, $\sigma_2{}^0$ and $\sigma_3{}^0$ may be found from the well-known cubic equation [14]:

$$\sigma^3 - \zeta_1\sigma^2 + \zeta_2\sigma - \zeta_3 = 0,$$

where ζ_1, ζ_2, ζ_3 are stress tensor invariants.

Directional cosines for $\sigma_1{}^0$, $\sigma_2{}^0$ and $\sigma_3{}^0$ may be determined from the following set [14]:

$$\begin{aligned} &\left(\sigma_x - \sigma_i^0\right) l_i + \tau_{xy} m_i + \tau_{xz} n_i = 0, \\ &\tau_{yx} l_i + \left(\sigma_y - \sigma_i^0\right) m_i + \tau_{yz} n_i = 0, \\ &\tau_{zx} l_i + \tau_{zy} m_i + \left(\sigma_z - \sigma_i^0\right) n_i = 0, \end{aligned} \tag{25}$$

by taking here any two equations, adding as a third

$$l_i^2 + m_i^2 + n_i^2 = 1$$

and by placing instead i = 1, 2, 3.

A special case of the method of an advance sensor may be considered as the following method. A borehole is drilled and a sensor is installed in it. Then over a central borehole in a section in front of the sensor a large diameter borehole is drilled (see Fig. 2b) or an annular slot is drilled with removal of the core (see Fig. 2c), but it is not drilled beyond the sensor. As drilling occurs stresses arise in the sensor caused by stress concentration in front of the face of the large-diameter borehole. Since the additional stress field ahead of the face of this borehole is generally speaking similar to the original field, from the optical picture in the sensor it is possible to determine the direction of quasiprincipal stresses for the original field and the value of their ratio.

If the original stress field in a uniform rock mass is only caused by the weight of the rock, then one of the axes of symmetry for the optical picture, and in fact axis I (see Fig. 1), will be oriented over the vertical, and coefficient λ determined from the pattern of the optical picture will correspond to the Dinnik side thrust factor:

$$\lambda = \frac{\sigma_2^{\kappa}}{\sigma_1^{\kappa}} = \frac{\nu_r}{1 - \nu_r}, \tag{26}$$

where ν_r is Poisson's ratio for rock.

TABLE 1. Results of Periscope Observations Along Holes at Long-Range Observation Stations (LROS-1 and -2): Taimyrsk Mine, −1050 horizon

No. of hole	Length Δ of hole, m	$\sum_i \delta_i$, m	$\frac{\delta}{\Delta} \times 10^{+2}$
1	6,0	0,153	2,6
2	6,5	0,162	2,5
3	7,5	0,152	2,0
4	8,0	0,322	4,0
5	7,5	0,218	2,9
6	7,0	0,156	2,2
		Average ...	2,7

TABLE 2. Data on Crack Opening from Core Descriptions of Magnetite Ores and Rock from Tashtagol Mine

Hole number	Length Δ of hole, m	$\sum_i \delta_i$, m	$\frac{\delta}{\Delta} \cdot 10^2$	Hole number	Length Δ of hole, m	$\sum_i \delta_i$, m	$\frac{\delta}{\Delta} \cdot 10^2$
2	68	1,5	2	30	63	0,81	1,0
3	47	2,5	5	31	70	1,0	1,4
4	28	0,5	2	32	71	3,5	5,0
5	84,8	0,8	0,9	33	22	1,0	4,0
6	22,2	0,2	0,9	34	73	0,5	0,7
7	80	0,5	0,6	35	50	1,5	3,0
8	85	0,4	0,5	36	70	0,5	0,7
9	85	0,8	0,9	37	30	2	6,0
10	85	0,2	0,2	38	23	1	4,0
11	85	1,7	2	39	70	4,5	6,0
12	100	0,3	0,3	40*	45	3,5	7,0
13	22	1,5	7	41	71.5	7	9,0
14	64	1,0	1,5	42*	9	1	10
15	22	1,0	4	43*	9	2	20
16	63	0,1	0,1	44	70	0,1	0,1
17	66	0,5	0,7	45	70	0,5	0,7
18	66	0,5	0,8	46	20	0,1	0,5
19	22	0,1	0,3	47	21	0,05	0,2
20	7	0,01	0,1	48	70	1,5	2,0
21	70	0,03	0,04	49	30	0,2	0,6
22	6	0,1	0,1	50	47	0,3	0,6
23	23	0,02	0,1	51	16	0,5	3,0
24	40	0,12	0,3	52	56	0,7	1,0
25	7	0,5	7,0	53	17	0,3	1,0
26	19	1,5	8,0	54	85	0,3	0,3
27	22	0,5	2,0				
28	83	1,5	2,0				
29	22	0,1	0,4			Average ...	2,0

*Anomalous values can be linked to blocks of a lower rank.

where the coefficient θ frequently falls within the interval 0.5-2. The following question arises in this connection: what could explain this "peculiarity"? The linear factor of block nesting* λ in the structural hierarchy of rock masses, which can be estimated [1] by the range 3-5 may serve as a possible, from our standpoint, explanation of precisely this value of $\mu_\Delta(\delta)$, i.e., if Δ_i and Δ_{i+1} are characteristic linear dimensions of the blocks of adjacent ranks i and $i + 1$,

*Our term: introduced by analogy with the concept of the "nesting type of structure" in [5]. The area and volume nesting factors are obviously proportional to the second and third powers of the linear factor, respectively.

$$\lambda_i = \Delta_i/\Delta_{i+1} \simeq 3 - 5 \quad \forall (i). \tag{5}$$

According to data derived from analysis of seismic energy liberation and the characteristic features of the reaction of rocks to blast effects under conditions in the Tashtagol deposit, we obtain $\lambda \cong 4.5$ (to be addressed in greater detail in one of the papers devoted to this subject matter). It is readily seen that

$$\Delta_{i+3} \simeq \mu_\Delta(\delta) \cdot \Delta_i \quad \forall (i), \tag{6}$$

i.e., the width of cracks separating blocks of i-th hierarchical rank from one another is determined by the size of the blocks of a rank three numbers higher.

Unconditionally, where it is also possibly to agree with the explanation of the order of the quantity $\mu_\Delta(\delta)$, to state that we understand how the number three is arrived at would elicit strong self-confidence on our part! However, certain analogies are offered in connection with studies performed by Shemyakin [8-9].

5. In conclusion, let us indicate one of the applied aspects of relationship (1), which may find broad application for evaluation of mineral resources, say, of hydrothermal or magmatic origin in cases when it is difficult to do this by direct (drilling) or geophysical methods.

According to Lapin [7], the Tashtagol deposit is an ore body with an expanse of approximately 1 km and thickness to 100 m, and dips subvertically to a depth of more than 2 km. Until now, there have been essentially no more precise estimates of the expanse of the ore body. In this connection, the above-derived relationship (1) can be used, as presented, for this kind of estimate, if we set $\delta \cong 100$ m, and Δ applies to the overall expanse of the ore body (up to the next "branching point"):

$$\Delta \simeq \Theta^{-1} \cdot 10^2 \simeq \left(\frac{1}{2} - 2\right) \cdot 10 \text{ km},$$

i.e., the average estimate yields an ore-body expanse of the order of 10 km. Proceeding from this, the special work required to estimate the potential reserves of workable mineral resources is not presented. If relationship (1) is correct, the ore reserves expected here would remain at least an order higher than what has been extracted to the present time since the start of work on the magnetite deposit (since the 1930s).

According to Egorov and Sukhanova [4], the Noril'sk deposit is a thick inclined ore body. The value cited for the parameter $\mu_\Delta(\delta)$ may, unconditionally, also be of direct interest to both miners, and also geological organizations of the Noril'sk Combine: for estimating promising reserves of copper–nickel ores, and, among other things, for organizing studies devoted to the survey of ore bodies. Actually, if $\delta \cong 50$ m is adopted as the average thickness of the ore body (high-grade + high-grade-impregnated ores) in the exploited horizons of the deposit, it is easy to see that the expanse of the sheet deposit Δ prior to the next "branching point" is $\Delta \cong (0.5\text{-}2) \cdot 5$ km, i.e., $\Delta_{avg} = 5$ km. Knowing the geometric bedding parameters of the ore body, consequently, it is possible to indicate rather simply the areas for hole drilling for geological prospecting or detailed geophysical studies to search for an alternate "nodal point" of the deposit, and so forth. Considering this, the reserves of sound sulfide ores at Taimyr are quite imposing; the basic mass, however, lies at a depth of more than 2 km.

The examples that we have cited do not, unconditionally, exhaust the possible diversity of applications of the empirical $\mu_\Delta(\delta)$ relationship under discussion here. In the general case, the latter should probably be treated as a certain statistical distribution function, the estimate of the mathematical expectancy ($\bar{\theta} = 1?$) and dispersion of which could be the focus of intense attention in future studies.

REFERENCES

1. M. A. Sadovskii, "Natural lumpiness of rock," Dokl. Akad. Nauk, **247**, No. 4 (1979).
2. M. V. Kurlenya and V. N. Oparin, "Some characteristic features of the reaction of rocks under blast effects in the neighboring zone," Preprint, Mining Institute, Siberian Branch, Academy of Sciences of the USSR, Novosibirsk, No. 10 (1984).
3. M. V. Kurlenya and V. N. Oparin, "Phenomenon of alternating-sign reaction of rock under dynamic effects," Fiz.-Tekh. Probl. Razrab. Polezn. Iksop., No. 4 (1990).

4. V. N. Egorov and E. N. Sukhanova, "Talnakhskii ore-bearing intrusive on the northwestern Siberian platform," Razved. Nedr., No. 1 (1963).
5. V. N. Oparin, "Fundamentals of geophysical flaw detection in holes. Part 1: Spectral analysis and measures of defectiveness," Fiz.-Tekh. Probl. Rzazrab. Polezn. Iksop., No. 5 (1985).
6. M. M. Rats and S. N. Chernyshev, Jointing and Properties of Fissured Rock [in Russian], Nedra, Moscow (1970).
7. S. S. Lapin, Magnetite Ore Bodies, Their Structure and Magnetic Properties [in Russian], Nauka, Novosibirsk (1976).
8. E. I. Shemyakin, "Unrestrained failure of solids," Dokl. Akad. Nauk SSSR, **300**, No. 5 (1988).
9. E. I. Shemyakin, "Unrestrained failure of solids, II," Dokl. Akad. Nauk SSSR, **316**, No. 6 (1991).

METHOD OF ANNULAR PHOTOELASTIC SENSORS AND ITS PROSPECTS FOR GEOMECHANICAL MEASUREMENTS

G. I. Kulakov

UDC 622.831.3

Borehole photoelastic sensors [1-8] are used in laboratory and full-scale studies of the stress–strained state and mechanical properties of a rock mass with introduction of underground mining and also in operational monitoring of rock mass stressed state and rock burst hazard.

The sensors are prepared from silicate optical glasses and other optically sensitive materials, i.e. polystyrenes, synthetic rubbers, and epoxy gels.

An annular cylindrical sensor installed in a borehole drilled in the test rock and glued to its walls deforms together with the surrounding rock mass. During any change in the stress–strained state of the rock mechanical stresses arise in the sensor. Information from it which develops as a result of deformation of the molecular-atomic structure of the sensor material is recorded by means of a beam of polarized light transmitted to recording equipment, i.e. a polariscope, in which the interference of light beams is transformed into a visually observed optical picture (Fig. 1) with a characteristic pattern from which there is evaluation of the magnitude, orientation, and ratio of quasiprincipal stress (strain) field and the increase in stresses or strains in the rock in a plane normal to the longitudinal exit of the sensor.

More then ten varieties and fifteen standard sizes of annular photoelastic sensors have been developed and are used at the Institute. The variety of them makes it possible using similar instruments to carry out quite an extensive set of geomechanical measurements. In the simplest structural case an annular photoelastic sensor is a glass cylinder with an axial hole of small diameter fitted with a mirror layer over one of the end surfaces. In mine measurements it is normal to use a sensor with an outer diameter of 40 mm with a length of 30-40 mm and rarely 10 mm.

The glass sensor provides measurement of an increase in stresses up to 8-10 MPa, and with stresses up to 30 MPa glass sensors with a metal frame are used, but up to 100-200 MPa the sensors used are in the form of a metal cylinder with an axial hole supplied with a photoelastic coating over the end face.

The information from an annular photoelastic sensor includes five parameters: the angle determining the orientation of quasiprincipal stresses in the rock, the order of bands at the point of reading the optical picture proportional to the greatest quasiprincipal stress in the rock, and parameter $\lambda = \sigma_2^k/\sigma_1^k$ which specifies the pattern of the optical picture (σ_1^k, σ_2^k are greatest and least quasiprincipal stresses).

Institute of Mining, Siberian Branch, Russian Academy of Sciences, Novosibirsk. Translated from Fiziko-Tekhnicheskie Problemy Razrabotki Poleznykh Iskopaemykh, No. 3, pp. 10-21, May-June, 1993. Original article submitted January 14, 1993.

1062-7391/93/2903-0203$12.50