Problems of Seismic Safety of Ore Mining

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Abstract—**The issues of seismic and geodynamic monitoring and constructive seismic safety of the development of rock ore deposits are considered. Some aspects of the interaction of natural and technical systems that ensure the geomechanical balance of ore-hosting massifs are detailed. The possibilities of control of massif geomechanics with the filling of technological interstices with multi-strength mixtures and tailings of underground leaching are investigated. The results of the study of the state of the massif by modeling on low molecular weight materials are presented. A model of the dependence of field development indicators on the parameters of geomechanical processes is given. A dependence of seismic velocity on the weight of the charge is investigated. The formulas for determining the safe spans of a flat shape are recommended. The typification of processes is given and distinctive signs of underground leaching are formulated in the aspect of control of massif geomechanics. A fundamental assessment of the combined technologies with rationalization of the use of the properties of a massif to control the sign and value of the stresses in natural and artificial massifs is given. The conclusion is made about the effectiveness of the controlled interaction of natural and technical systems that ensure the geomechanical balance of the massifs and the ground surface in the area of subsoil development for an indefinitely long time.**

Keywords—geodynamics; seismic impact; development; ore deposits; massif; blasting; underground leaching

I. INTRODUCTION

In case of a technogenic intervention in the subsoil, the general question of the development of ore deposits is the interaction of natural and technical systems that ensure the geomechanical balance of the massifs in the area of the subsoil development with the possibility of monitoring the state of the rock mass for an indefinitely long period of time. Each mountain object has its own field and responds to external influences [1-4].

A zone where displacements and deformations exceed permissible values is distinguished under the influence of mining in the upper layers of the lithosphere. Mining carries out two functions simultaneously. They can initiate an earthquake by combination of technological interstices. The existence of interstices in the earth's crust "excites" seismic phenomena (up to the level of earthquakes) in the zone of works.

There is no model that would describe the mechanism of the induced seismicity properly.

The state of the rock mass in the process of mining ores is corrected by the phenomenon of relaxation. Conversion of the massif to a guaranteed stable or unstable state and limiting the convergence of exavation contours is provided by optimizing the load-carrying capacity of anthropogenic structures by comparing the strength of anthropogenic processes with geological processes under natural conditions and optimizing the reliability coefficient.

Geodynamic processes increase with time. Thus, in the depths of the Sadon deposits (North Caucasus), up to 5 million m3 of unfilled technological interstices have been accumulated over two centuries of development. Such a volume of interstices is involved takes part in changes of the geodynamic and seismic conditions in the crust. The hypothesis that dynamic processes in their interstices are the cause of catastrophic processes (for example, the glacier Kolka fall in the Karmadon gorge of North Ossetia) has the right to existence [5-9].

Therefore, the study of the mechanism of the occurrence and redistribution of stresses is important for functioning of the mining region.

II. Model of natural and anthropogenic stresses

Reduction of the level of stress up to a safe value is provided by engineering measures that contribute to the movement of rocks without destroying integrity [10-12].

The strength condition of the natural-technogenic system is described by the model of Vetrov-Golik:

$$\sigma_1 \pm k\sigma_{2,3} \le \sigma_{st} =$$

$$= \begin{cases} \sigma_{st}^{0} = \int\limits_{0}^{Z_{0\max}} fx(dx_1, dx_2 ... dx_n) \rightarrow \begin{cases} \sigma_{stow} = \int\limits_{0}^{Z_{0\max}} fx(dH_S) \\ \sigma_{stow} = \int\limits_{0}^{Z_{0\max}} fx(dH_S + dH_C) \end{cases} \\ \sigma_{st}^{rem} \quad \text{for } \mathrm{H_C} = \mathrm{H} \rightarrow \sigma_{stow} = \int\limits_{0}^{B} fx(dH) \end{cases}$$

where σ_1 is the vertical principal stresses; $\sigma_{2,3}$ are horizontal principal stresses, MPa; k is the coefficient of geological conditions; σ_{st} are stresses in the upper layer of host rocks, MPa; σ_{st}^{0} are stresses in the vicinity of mine, MPa; σ_{st}^{rem} are residual strength of rocks, MPa; Z_0 is flat span of roof rocks, m; $x_1, \ldots x_n$ are characteristics of rocks; σ_{stow} is the strength of the stowing mass, MPa; B is span of the caving zone; H is height of the caving zone, m; h_c is height of the zone of influence of exavation, m; h_S is the height of stowing mass, m.

The state of massifs is described by the Hooke condition:

$$\Sigma \sigma = T_e \times \Sigma \varepsilon \times \kappa$$

$$\Sigma \varepsilon = T_c \times \Sigma \sigma \times \kappa$$

where σ is stresses; ε is deformations; T_e and T_c are effective tensors of elasticity and compliance, respectively; κ is coefficient of discreteness.

Zones of rock fracture appear in the massif; they are characterized by rock weakening. In the zone of disturbed rocks with thickness of 0.5 to 10 m, the attenuation coefficient decreases from 0.25 to 1.15. The zone of enhanced attenuation has a capacity of 0.5-1.5 m. The coefficient of structural attenuation increases to the periphery to 0.15, which means a decrease in strength in contrast to the undisturbed massif from 1.5 to 6.0 times.

A. *Seismic blasting*

The mechanism and scale of induced seismicity in rock massifs are associated primarily with the parameters of using the explosion energy during blasting of minerals by explosive charges.

The presence of elements with different physicomechanical properties in the massif leads to the attenuation of the explosion energy, which is accompanied by uneven crushing of the rock mass and labor and energy costs associated with this.

The most important dynamic characteristic of ore-bearing rocks, which determines the indicators of blasting, is the speed of propagation of longitudinal blast waves. It varies for most rocks from 1000 to 9000 m/s. No less important parameter is the strength of rocks, which, varies irregularly with the increase of the depth of mining operations.

The effectiveness of the development of deposits of complex structure depends on seismic influence of the explosion. The purpose of most studies is relationship of the seismic velocity of rock particles and the weight of explosives. One of the main objectives of the research is to determine velocity of seismic vibrations of rock particles depending on the parameters of blasting.

Technologies of ore blasting by explosives ensure the controllability of stresses only in case of maintenance of the limiting parameters of blasting. Uniform crushing of ores is achieved by optimizing the size of the line of minimal resistance. Optimal interval is equal to a time of formation of cracks.

Changing the acoustic impedance of a medium, changes of the parameters of the secondary stress field are made. Quantitative parameters of the seismic impact of an explosion are determined on the basis of a consistent pattern of the propagation of seismic explosion vibrations in various media at an acceptable displacement rate.

The maximum of seismic energy is associated with horizontal vibrations in the longitudinal wave. The prevailing intensity is also a longitudinal wave, the main energy of seismic vibrations of which is associated with the horizontal component of the vibration velocity. The speed of seismic vibrations of rock particles depends on the weight of the charge:

$$v = k\left(\frac{\sqrt[3]{Q}}{r}\right)^{n}$$

where K is coefficient depending on the geological and technological conditions and energy characteristics of explosives; n is an indicator depending on the nature of seismic waves and the distance to an explosion.

Seismic vibrations in rocks with high acoustic impedance penetrate into considerable distances in the depths of the rock mass, and the deformation is elastic. Deformations are characterized by elastic - plastic and plastic features when the distance from the center of the explosion is up to 15m.

If the stresses and deformations from individual explosions are not accompanied by the formation of cracks in the rock mass, short-delay blasting will ensure the stability of exavation. Otherwise, the blasting of subsequent slowing down groups leads to the growth of cracks.

Short-delay blasting is successful in terms of reducing the seismic effect of an explosion in cases where the explosives are divided into groups, each of which generates insufficient for destruction stress waves.

Most commonly, all the wells of one drill ring are blown up with one slowdown. Better fragmentation and maximum risk reduction is achieved by applying stress fields. Therefore, in case of sequence blasting it is recommended to blast at one time up to 5-6 drill rings with slowdowns between them of 25-35 ms.

The speed of the massif displacement reaches maximum values at a distance of up to 70m from the charge and is considered as the most dangerous from the point of view of maintaining the stability of underground mine workings and injuries of workers. In this zone, the deformations are formed, accompanied by "balmstone".

When mass-breaking of ore is carried out, the stress wave does not violate the continuity of the rock mass until it reaches the interface of media with different acoustic impedance. The presence of a free surface generates a reflected wave and creates conditions for the destruction of underground excavations.

Seismic influence of the explosion is estimated by the speed at which the safety of structures is guaranteed and the deformations do not exceed the predicted ones. The speed above which the safety of structures is estimated with a probability of less than 0.5 is considered as critical.

Quantitative parameters of seismic influence of an explosion are established on the basis of a consistent pattern of the propagation of seismic explosion vibrations in various media at an acceptable displacement rate (Table 1).

Permissible deformation of rocks within the limits of elasticity is established in accordance with the classification of the protected structures according to their responsibility and service life (Table 2).

B. Use of residual strength of disturbed rocks

The stresses in the disturbed massif are determined by the ability of the structural blocks to self-wedging due to the residual strength of the rocks:

$$\sigma_{r.s} = f(\sigma^{rem}, d_1, d_2, R_{st}, H, h_{arc}, ..., x_n) = \int_{\min}^{\max} f(x_1, ..., x_n)$$

where $\sigma_{r.s}$ is a residual strength of rocks, MPa; X_n is filling and massif parameters.

Parameters of the limiting body of self-wedging of structural blocks of rocks are:

$$\alpha = d_I\left(\frac{10R'_{st}}{KHV_c} - 1\right) \Rightarrow [\sigma]_{cr} < [\sigma]_{p.n}^{rem}$$

where α is the half-span of the limiting arch of wedging, m; 10 is conversion factor kg/cm^2 to t/m^2; V_c is rock mass, t/m^2; H is depth of the arch abutment, m; K is a safety factor.

TABLE I. PERMISSIBLE DISPLACEMENT RATE OF STRUCTURES FOR THE MAIN TYPES OF ROCKS

Type of rocks	Longitudinal wave speed, m/s*10^3	Permissible displacement rate of structures by classes, cm/s			
		I	*II*	*III*	*IY*
Loose debris and sediment	1-2	4.08	8.2	12.2	20.4
Badly fractured ground with clay and high porosity	2-3	6.8	13.6	20.3	34.0
Rock with natural fracture	3-4	9.5	19.0	28.4	47.5
Relatively monolithic with single cracks	4-5	12.2	24.4	36.7	60.0
Monolithic, weakly fractured	5-	14.9	29.8	44.6	74.5
Very strong and solid without cracks	6-7	17.8	35.6	53.3	89.0

TABLE II. PERMISSIBLE DEFORMATION DEPENDING ON THE CLASS OF STRUCTURES

Class	Characteristics of buildings and service life	Life time	Permissible deformation	Level of a reliability	Reliability coefficient
I	Particularly responsible buildings	≥20	0,0001	0,99	1,52
II	Responsible buildings with a lifetime of more than 5-10 years	10÷ 12	0,0002	0,94	1,44
III	Short-term facilities	5÷7	0,0003	0,89	1,36
IV	Irresponsible buildings with a lifetime of up to 1 year	1÷3	0,0005	0,84	1,3

The safety of the massif is provided by its dividing into areas where the strength is determined by the stresses of the rocks not in the massif (up to the surface), but only in its lower layer, the height of which depends on the width of the flat span of the massif underworking. If this condition is not fully ensured, interstices are laid.

Seismically safe technology is subjected to the restrictions:

- seismic explosion vibrations do not exceed the permissible limits of the velocity of displacement for objects from 1.0 cm/s to 3.0 cm/s.
- shielding of seismic explosion waves;
- limiting the mass of a charge per explosion of 1500 kg;
- limiting the number of simultaneously exploding blocks to two;

- application of a delay interval between explosions of at least 50 ms.

III. MANAGEMENT OF MASSIF GEOMECHANICS WITH THE HELP OF FILLING WITH HARDENING MIXTURES

A. Model of control of geomechanics with different strength mixtures

Density of epoximal is 1.2 g/cm^3, modulus of elasticity is 2.7 MPa.

Geomechanical balance of the massifs in the area of the subsoil development is ensured by replacing the ores being extracted with an artificial massif [13-14].

The degree of deformation of natural and anthropogenic structures and the earth's surface under the influence of mining was assessed by simulating the methods of extinguishing technological interstices by the method of photoelasticity.

The deposit which is about 2500 m in size, 500 m in uprising and 10 m in thickness with a scale of 1: 20000, was identified by the model 125 × 25 × 5 cm. The volume weight of epoximal is 1.2 g/cm3, the elastic modulus is 2.7 MPa.

The massif was accepted as a homogeneous and disturbed fracture and a large crack, which corresponds to the conditions of metallic deposits. In the first series of models, interstices were left open; in the second they were filled with discrete rocks; in the third - with a hardening mixture of low strength; and in the fourth - filled with a solid hardening mixture. Figure 1 presents stress shapes in a homogeneous massif, and in group 2 they are presented in a fault-broken massif.

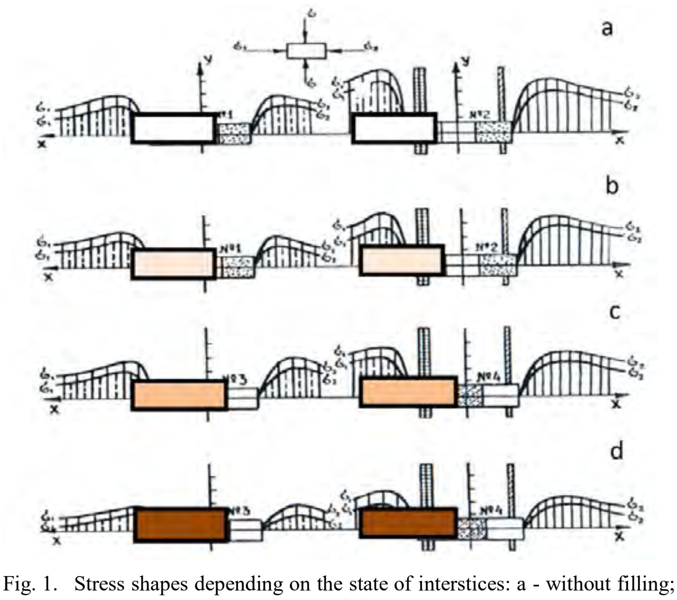

Fig. 1. Stress shapes depending on the state of interstices: a - without filling; b - filling with loose rocks; c - filling with low-strength mixtures; d - filling with strong mixtures. On the left - in the hanging side, on the right - in the heading side

Depending on the state of technological interstices and the place of measurement of stress in the massif vary from 1.0 to 9.2 MPa (Table 3).

The stability condition is:

$$\sigma_1 - \sigma_2 \geq \sin\delta(\sigma_1 + \sigma_2) + \sigma_{сж} + (1 - \sin\delta)$$

where σ_1 is horizontal stresses; σ_2 is vertical stresses; δ is angle of internal friction, degree; $\sigma_{сж}$ is strength of rocks, MPa.

TABLE III. STRESS VALUE DURING MODEL DEVELOPMENT, MPA

Massif elements	Without filling	With filling		
		Discrete mixture	*Low strength mixture*	*Solid mixture*
Hanging side				
σ_x	8.9	5.4	5.0	3.8
σ_y	7.8	5.0	4.4	3.2
Heading side				
σ_x	7.7	4.8	4.8	3.6
σ_y	6.9	4.7	4.7	3.0

Stress in the massif:

$$G_H = \gamma H \frac{G_m}{\sigma_e}$$

where γ is the density of rocks, t/m^3; H is the depth of the point, m; σ_e is stress in the model.

Side thrust is 0.5, 1.0, 1.5; the angle of inclination of the force vector to the vertical axis is α= 0; the filling module is 0.1 MPa, the module of host rock - 1.4 MPa;

Stresses in the model are:

$$\sigma_m = \sigma^{1.0} \times n$$

where $\sigma^{1.0}$ = 0.1 kgf/cm^2 per strip; n is the strip number at the model point.

Variants of the state of access chambers: without filling and with it.

With a lateral spread factor λ = 0.5, the maximum stresses in the zones of the key stones and the walls of the chambers are 7.6 x 7.5 = 57 MPa, and the top of the ceiling vault is 7.6 x 2 = 15 MPa. In an intervening pillar the maximum compressive stresses were 7.6 x 6.5 = 49 MPa (Fig. 2).

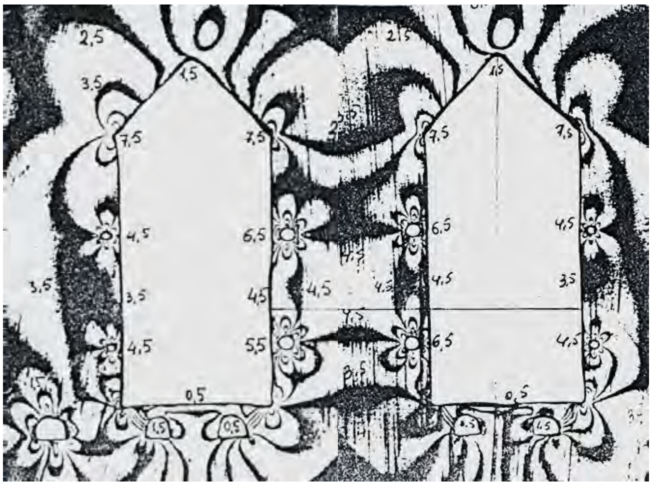

Fig. 2. Stresses at lateral thrust coefficient of 0.5: on the left - an open chamber; on the right - filled one.

With a lateral thrust coefficient λ = 1.0 in the zones of key stones, ceiling and the walls of the chamber, the stresses are 7.6 x 6.5 = 49 MPa. In the pillar, the maximum stresses decrease to 7.6 x 5.5 = 42 MPa (Fig. 3).

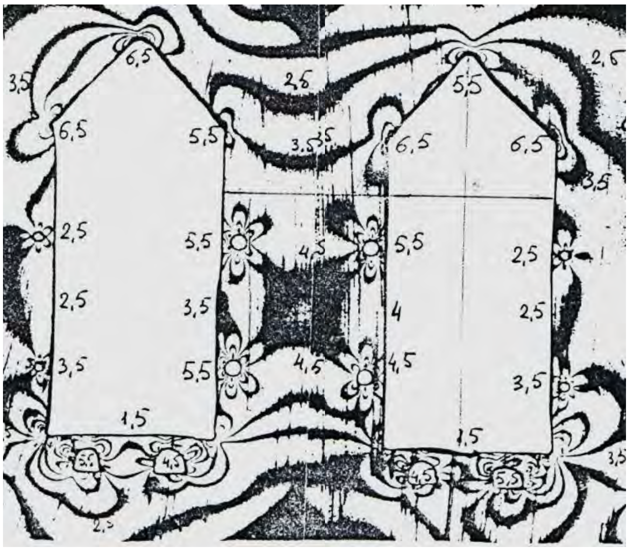

Fig. 3. Stresses at lateral thrust coefficient of 1.0: on the left - an open chamber; on the right - filled one

With a lateral thrust coefficient λ = 1.5, in the zones of key stones, ceiling and the walls of the pressure chamber are 7.6 x 6.5 = 49 MPa, and in the ceiling up to 7.6 x 8.5 = 64 MPa 15 with a coefficient of lateral thrust coefficient of 0.5 (Fig. 4).

When the lateral thrust coefficient was changed from 0.5 to 1.5, the stresses in the ceiling increased from 41 MPa to 140 MPa.

Filling of chambers with hardening mixtures reduces the level of stresses in the ceiling by about 2 times. With options without filling in intervening pillars, the value of the stresses increases.

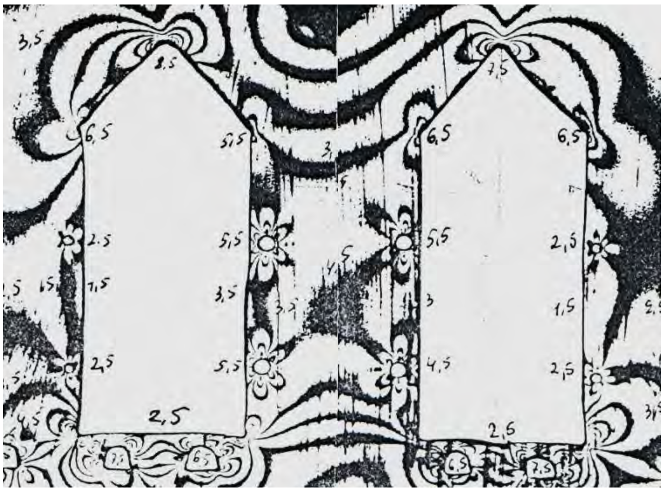

Fig. 4. Stresses at lateral thrust coefficient of 1.5: on the left - an open chamber; on the right – filled one

The results of modeling are as follows:

- when interstices are filled with hardening mixtures without stress relief, sedimentation of the roof reaches 105 mm in terms of nature;
- when interstices are filled with hardening mixtures, lower stresses occur during single-stage mining with unloading of the massif by dredging ores;
- stresses during unloading on the roof and soil differ by 20-30%, but unloading on the soil is preferable.

Mining in the first stage unloads the roof with the transfer of pressure on artificial massifs. A new arching is being created above the excavation site.

During the explosive blasting of ore in artificial massifs, deformations occur and they can lead to ore dilution by filling material and loss of stability. The dependence of vibration velocity on the weight of the charge, obtained experimentally and by calculation, have good convergence (Fig. 5).

Dependence of the vibration velocity of rock particles on the distance to the center of the explosion is illustrated in Fig. 6

The seismic velocity of the particles of material:

$$V_3 = 90 \cdot \rho^{2.25} \cdot 10^{-2}, m/s$$

where $\rho = \frac{\sqrt[3]{Q}}{r}$ is reduced weight of explosive charge.

The artificial pillar is stable until the stresses at the wave front exceed the maximum strength of the filling material [15-16].

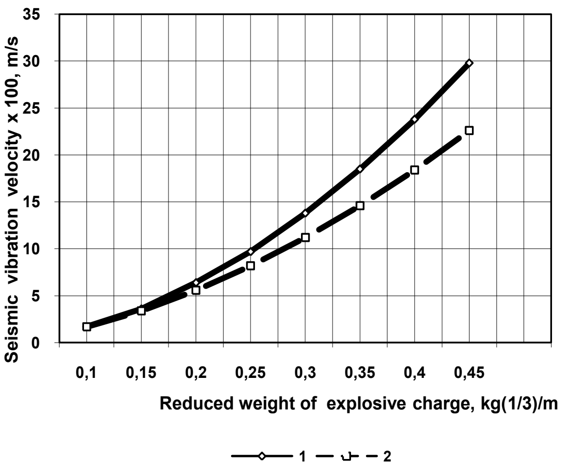

Fig. 5. The dependence of seismic velocity on the weight of the charge: 1 - obtained by correlation analysis by processing the experimental data; 2 - obtained by calculation

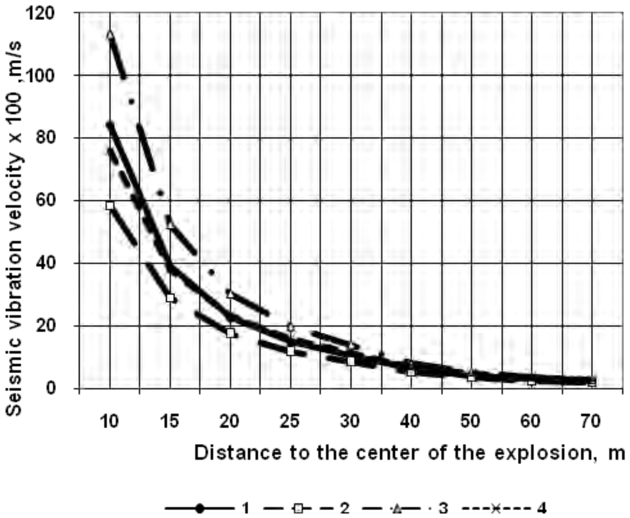

Fig. 6. Dependence of the velocity of seismic vibrations of rock particles on the distance for the conditions: 1 – mine 1; 2 - mine 2 at Q = 500 kg; 3 – mine 1 and 4 – mine 2 at Q = 800 kg.

B. *Technologies of model implementation*

The model of interaction between natural and technical systems is based on replacing rock massif by a massif of consolidated hardening mixtures, the strength of which is comparable or a few lower than strength of rock massif.

Unloading massif from hazardous stresses is carried out by working on the roof of the excavation or underworking on the soil. The safety of the massif and the area of the earth's surface above it are estimated by comparing the size of the zone of dangerous influence of workings with the depth of work.

Dependence of the quality indicators of the field development on the parameters of geomechanical processes is described by the model:

$$\sigma \cdot K_s = \int_{l_{\min}}^{l_{\max}} fx(dx_1, dx_2 .....dx_n) \to \Pi, R = \int_{l_{\min}}^{l_{\max}} f \cdot x(dh_s + dh_n)$$

$$\sigma \cdot k_s = \int_{l_{\min}}^{l_{\max}} fx(dx_1, dx_2 ....dx_n) \to P, R = \int_{l_{\min}}^{l_{\max}} f \cdot x(dh_s + dh_n)$$

where σ are stresses in the influence zone of workings, MPa; Ks is correction factor of stresses; l max, l min are outcrop spans, m; x1 ... xn are technological, physicomechanical and other characteristics; Π is ore loss, fraction unit; R is ore dilution by rocks, fraction unit; hs is a height of filling mass, m; hп is a height of the influence zone of mine workings, m.

Disturbed rocks within the resulting arch can form a solid structure [17-18]:

$$\alpha = d_1 \left(\frac{10 R_{st}}{K H \gamma} - 1 \right)$$

where a is the half-span of the arch of rocks wedging in the roof, m; d1 is a horizontal size of the structural block of rocks, m; Rst is rock resistance to compression, kg/cm2; 10 is conversion factor kg/cm2 to t/m2; γ is volume weight of rocks, kg/m3; H is depth of the arch abutment of the rock wedging in the roof, m; K is a safety factor.

Backing of rocks with a filling provides the conditions for triaxial compression to increase its strength 1.2÷1.4 times. Protection of the filling mass from the seismic action of the explosion is made by shielding.

The dependence of the vibration velocity of rocks on the weight of the explosive charge, obtained experimentally and obtained by calculation, has good convergence (Fig. 7).

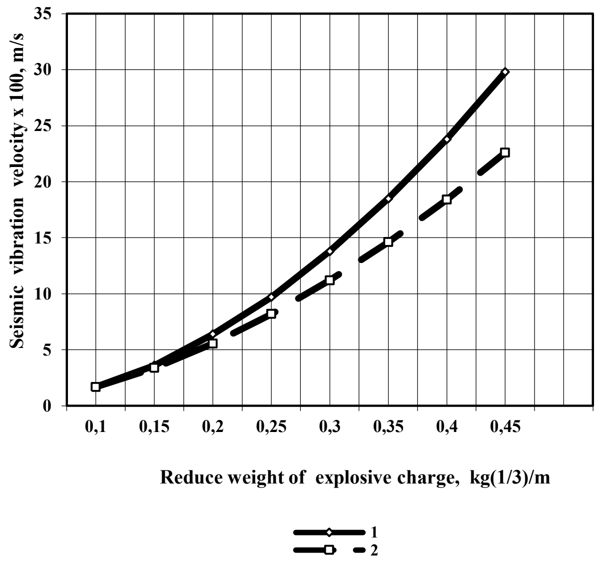

Fig. 7. Dependence of seismic vibration velocity on the weight of the explosive charge: 1 - obtained by correlation analysis by experimental data processing; 2 - obtained by calculation

The nature of the dependence of rock particle vibrations at the seismic wave front on the distance to the center of the explosion is interpreted in Fig. 8.

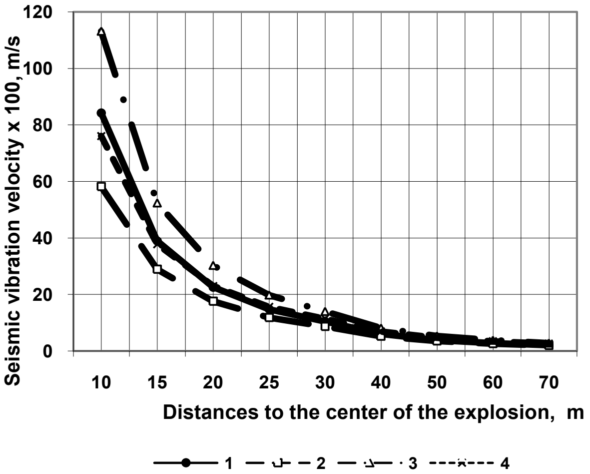

Fig. 8. Dependence of the velocity of seismic vibrations of rock particles on the distance for the conditions: 1 – mine 1; 2 - mine 2 at Q = 500 kg; 3 – mine 1 and 4 – mine 2 at Q = 800 kg

IV. Control of Massif Geomechanics during Underground Leaching

A. The model for control of geomechanics

The development with the help of underground leaching differs from traditional technology by the following:

- filling of the interstices with the rock mass (separated from the massif) participating in the preservation of geomechanical stability;
- issuing to the earth's surface only part of the rock mass to provide a compensation space during ore blasting;
- extraction of metals from ores in underground workings.

The stability of the ore-bearing massif is determined by the presence of a natural self-supporting arch (Fig.9).

Maximum natural self-supporting arch:

$$L_n = 2d_2\sqrt{\frac{10R_{st}}{K_2\gamma d_1}}$$

where d_1 and d_2 respectively are horizontal and vertical dimensions of the structural blocks, m; γ is volume weight of rocks; k_2 is a safety factor.

If the roof comprises rocks, the deformations in which do not exceed the plastic boundaries, the permissible span of the flat form of the main roof:

$$q = \frac{2}{3}\frac{L_0}{2}h_0; \qquad h_0 = \frac{L_0}{2V_0};$$

$$q = \frac{L_0}{2V_0}; \qquad M_q = \frac{L_0\gamma}{18V_0};$$

$$T = \frac{10R_{st}}{R_c}\frac{1}{2}d_{oc};$$

$$M_T = T\frac{5}{2}d_{oc} = \frac{10R^o_{st}\cdot 5d_{oc}}{18K_2}; \quad R_{st} = R'_{st} = R''_{st};$$

when $V_0 = 1$ $\quad L_0 = 1{,}71\sqrt[3]{\frac{10R_{st}\cdot d^2_{oc}}{K_2\gamma}}$.

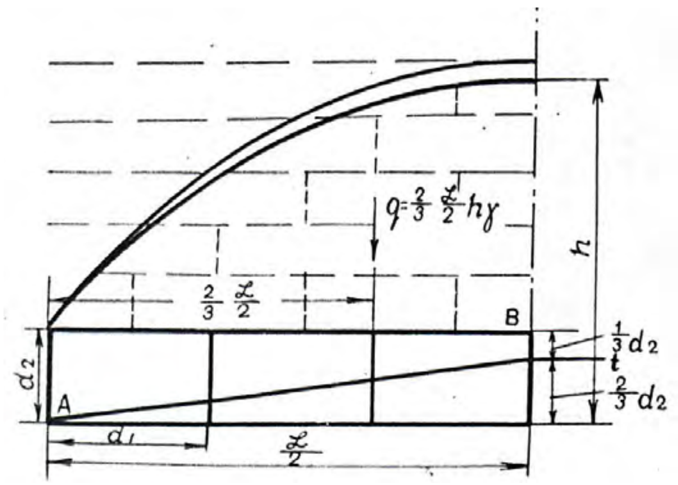

Fig. 9. Diagram of the formation of the bearing stratum: h is the height of the arch; L is the width of the span; d1 is horizontal size of structural blocks; d2 is the vertical size of the structural blocks; γ is the volume weight of rocks; t is closing point of structural blocks; q is moment of force

If there is a part of the ore-conducting seam in the roof, the self-wedging ability is reduced, and the permissible span of the flat roof is determined from the expression:

$$q_{\text{н}} = \frac{L}{2}\text{в}\gamma; \qquad M_{q\text{н}} = \frac{L}{2}\text{в}\gamma\frac{L}{4} = \frac{L^2\text{в}\gamma}{8};$$

$$T = \frac{10R_{st}}{K_2}\frac{1}{3}d\text{н}_2; \qquad M_T = T\frac{3}{6}d\text{н}_2 = \frac{10R_{st}\cdot 5d^2\text{н}}{18K_2};$$

$$L = 1{,}48d\text{н}_2\sqrt[3]{\frac{10R_{st}}{K_2\gamma\text{в}}}.$$

A flat span can be increased by fastening structural blocks by increasing the moment of expansion force:

$$q_{\text{н}} = \frac{L_3}{2}\text{в}\gamma; \qquad M_q = \frac{L_3}{2}\text{в}\gamma\frac{L_3}{4} = \frac{L_3{}^2\text{в}\gamma}{8};$$

$$T = \frac{10R_{st}}{K_2}\frac{2}{3}d\text{н}_2; \quad M_T = T\frac{2}{3}d\text{н}_2 = \frac{10R_{st}\cdot 10d^2\text{н}_2}{18K_2};$$

$$L_3 = 298d\text{н}_2\sqrt{\frac{10R_{st}}{K_2\gamma\text{в}}}.$$

During the two-stage development, the reference pressure is redistributed to the chambers of the second stage, and the load on the structures is determined by the mass of rocks within the natural self-supporting of rocks. Disturbed rocks within the arch are deformed, but can form a solid structure and do not interfere with the leaching process [19-20].

Prospective technologies are those in which rich ores are discharged to the surface, and the rest of the ore is processed at the place of occurrence (Table 4).

TABLE IV. TYPIFICATION OF PROCESSES OF UNDERGROUND BLOCK LEACHING OF ORES

Processes	Process parameters	Process implementation conditions
Crushing ore	Ensuring the size of + 20mm - 50mm	Uniform ore density. The possibility of creating a compensation space for an explosion
Ore irrigation	Well in an Intact Massif Splashing from the surface of the ore Wells in destroyed ore with casing Use of fine-grained materials Hydraulic rock breaks	Lack of impermeable zones and channels in broken ore
Collecting production solutions	Anti-filtration curtains Waterproofing leaching sites Electrovacuum drainage of solutions Use of synthetic polymeric materials	Elimination of leaching products in the environment
Process Intensification	Physical methods: injection of compressed air, blasting of ores, reduction of particle size in proportion to the concentration gradient, breaking out of layers with a variable line of least resistance, shaping the ellipsoid of release, ultrasonic vibrations, electromagnetic treatment of solutions; Chemical methods: washing with water with activating additives, the introduction of chemical compounds; Biological methods: the use of bacterial strains.	Obtaining a given loosening. The increase in the content in the solution to an acceptable value
Leachability control	Borehole methods: rock drilling for the introduction of monitoring devices, drilling of broken ore with sampling. Cutting workings with sampling	Representativeness of samples and measurements for the entire block

B. Model implementation technologies

The development of deposits by underground block leaching involves the creation of areas with rocks of varying strength in a massif:

- the blocks are filled with ore material, which is mobile and prone to caking;
- blocks are characterized by water saturation and weakening of rock strength;
- in the leaching process, the mineral particles move.

The creation of such sites provokes an increase in tensile stresses and loads on the elements of the natural-anthropogenic system.

The balanced state of the ore-bearing massif is ensured if the leaching blocks are unloaded from critical stresses by artificial and natural massifs.

Within the block, rich ore in the amount of about 40% of the reserves is extracted and delivered to the earth's surface, and the rest is leached in the block.

The issues of saving massifs are dealt by leaching without destroying the massif due to the injection of reagents under high pressure on the one hand and the trapping of solutions on the other.

V. COMBINED CONTROL OF MASSIF GEOMECHANICS

A. The model for combined control of massif geomechanics

Combined methods for controlling the massif geomechanics are based on the joint use of various types of technologies with the rational use of the properties of the massif to control the sign and magnitude of stresses in natural and artificial massifs.

The best are combined technologies, in which poor ore is processed in-situ (Fig. 10).

The peculiarity of the method is the collective control of mining seismicity within the entire field, as some areas of the ore field and separating and protecting their natural and artificial pillars are interdependent on anthropogenic stresses.

The stress level in the system is regulated by engineering measures:

- the slope of the artificial massif on the ore massif reduces the dilution of ore by a stowing;
- the safety stowing massif at the border of the ore deposit is a protective wall, allowing the extraction of the main reserves in the best conditions;
- hardening of unstable rocks with anchors and steel ropes provides the best extraction performance.

B. Model implementation technologies

The combined control of geomechanics is used in the production of multi-grade ores, for example, after the extraction of rich ores with a collapse system, the poor ores are modified by leaching in blocks [21-22].

The geomechanical balance of the massif is ensured by dividing the massifs into limiting conditions for the formation of a set of natural balance and the preservation of a flat roof. Inside the isolated areas, various ore mining technologies can be applied.

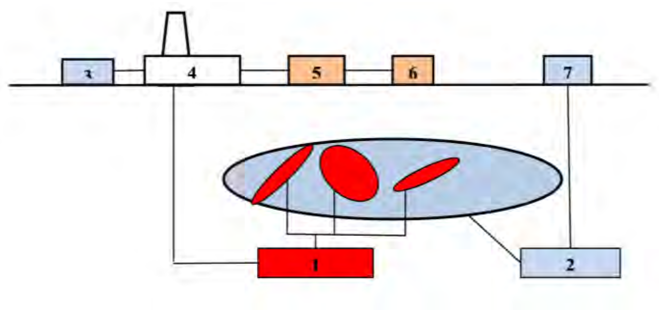

Fig. 10. Combined mining of deposit: 1 - rich ore; 2- poor ore; 3– heap leaching; 4 – ore-control station; 5 - concentration station; 6 - stowing complex; 7 - chemical solution preparation workshop

Protection of the adjacent sites of the field from the seismic impact of the explosion is made by screening.

VI. Conclusion

Induced geomechanical processes correspond with natural geodynamic processes, resulting in an imbalance in the earth's crust.

Ground control by regulating natural and anthropogenic stresses allows increasing the safety of works, reducing the dilution of the ore and improving the enrichment of mined ores.

The hazard of increased stress is revealed when seismic explosive operations are applied to seismicity of the ore-discrete discrete massif and the adjacent site of the earth's surface. The greatest hazard is the destruction of the massif when blasting a large amount of explosives.

The interaction of natural and technical systems that ensure the geomechanical balance of the massifs and the earth's surface in the area of development of the subsoil with the ability to monitor the state of the rock mass for an indefinitely long period of time is controlled by the regulation of ore mining and processing.

In the destruction of artificial massif by explosive works, seismic and explosive vibrations of rocks play a leading role if the velocity of displacement of rocks during explosions exceeds permissible values.

The prevention of hazardous seismic effects is carried out using the slowdown explosives. The seismic action of the explosion is controlled by screening the blast waves and adjusting the blasting parameters.

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