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Array Management Using Ore Processing Tailings

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Abstract: It was shown that the purpose of a rock massif state control is the choice of development technological schemes with the prevention of the earth's surface destruction. The possibility of compound use is substantiated to manage a massif based on ore mine refuse and underground leaching. The features of small fraction weakly active compound components are characterized. The criterion of management economic efficiency by a massif state and the condition of a geomechanical system strength is proposed. The zonality of ore-bearing rocks is described. The method of technology danger assessment is proposed for environment. The combined technology is proposed as the optimum technology for the economic and environmental criteria.

Key words: Array, rock, design, earth surface, tailings, enrichment, leaching, compounds, efficiency criterion, geomechanics

INTRODUCTION

The provision of mining operation safety became an urgent problem because the growth of mineral production volumes increases the risk of rock pressure dynamic manifestations and the destruction of an ore-bearing massif is a threat to people's lives and economy (Golik *et al*., 2015a). This problem is added by an equally important issue of metal ore tailing utilization (Bian *et al*., 2012; Davies and Rice, 2001; Franks *et al*., 2011).

The purpose of a rock mass state control is the choice of development technological schemes which would guarantee the earth surface from damage. The conditions of massif stability are based on the hypotheses that take into account the use of the broken rock bearing capacity by M.M. Protodyakonov, A.A. Borisov, V.D. Slesarev, S.V. Vetrov and others. The preservation of the Earth surface is achieved if a roof of treatment facilities keeps a flat shape without collapsing at uncovering. The stability of a roof for fractured rocks is determined by the natural equilibrium parameters developed by S.V. Vetrov. A flat shape depends on the ability of rock block to self-wedging (Golik *et al*., 2014, 2015b).

MATERIALS AND METHODS

Main part: The preservation of geomechanical favorable conditions allows to use for compound mass control based on enrichment tailings and the underground leaching of ores. Their main drawback is a low strength compensated by the staging of mining, the continuous process of filling, the time of strength increase, the changes of hydration temperature, water-cement ratio and other methods (Gattinoni *et al*., 2014; Golik *et al*., 2015c).

Thus, tailings can be used in hardening compounds only after the extraction of metals from them up to TAC level or up to the background value although, the tailings of ore recycling are applied in practice without any further treatment used as inert fillers (Golik *et al*., 2015d).

When masses are created from leached ores left in situ the natural binders fasten them into a concrete structure, with the strength up to 1 MPa. The strength of a hardening filling with the additives of leaching tailings is above the base strength at the equal flow rate of slag. If the ratio 1/6-1/7 for a filler is an optimal one for a filling compound with crushed rocks at the amount of 30-50% from a filler weight, then the flow rate may be reduced to 150 kg m^{-3} for heap leach tailings at their amount of 30-50%.

More often tails contain the mixture of minerals, the size of which makes up to 0.2 mm. The use of small fraction tailings improves a filling mixture transportability (Golik *et al*., 2015e). The absence of solid component in a mixture weakens its structural skeleton, improves the compression abilities and promotes the deformation of rocks and the migration of mining products.

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Tailing oxides at the amount from 1-10% do not reduce a filling mixture strength. The liquid phase contains sulfate ions up to 17 g^{-1}, so the mixing of tailings with slag containing up to 50% of CaO, develops gypsum which accelerates the hardening of a mixture.

The best results of void filling by hardening mixtures are provided at their volumetric compression. The bearing capacity of void filling material at 2-3 fold volumetric compression is increased 2-3,7 times according to A.L. Trebukov, 2-3 times according to D.M. Bronnikov and 3,5 times according to M.N. Tsygalov.

At a bulk loading the filling structure may be destroyed even but its bearing capacity increases. The specific surface area of tailings is twice larger than the standard sand. During the process of filling crimping the fine particles are "pressed" into the pores and reinforce a filling.

The criterion of economic efficiency for a massif state management is often considered as reduced costs at the filling of voids. The collapse of rocks satisfies this criterion most of all. Such an approach can not be considered as a valid one, since the actual value of damage is not estimated reliably. Due to the criterion of the earth surface preservation from the number of possible ones the ways of management with the collapse of rocks are excluded, the use of which gave rise to insoluble environmental problems in the areas of the KMA, Donbas, Urals and other regions (Onica *et al*., 2006).

The destruction of rocks in the zones of excavation influence occurs in the mode of brittle and quasi brittle destruction mode. The condition of geomechanical system element strength are determined from the condition proposed by Golik:

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

$$= \begin{cases} \sigma^0_{сж} = \int_0^{Z_{0max}} fx(dx_1, dx_2 ... dx_n) \rightarrow \\ \begin{cases} \sigma_{закл} = \int_0^{Z_{0max}} fx(dH_S) \\ \sigma_{закл} = \int_0^{Z_{0max}} fx(dH_S + dH_C) \end{cases} \\ \sigma^{ОСТ}_{сж} \quad \text{При } H_C = H \rightarrow \sigma_{закл} = \int_0^B fx(dH) \end{cases}$$

Where:

- σ_1 = The vertical component of principal stresses
- $\sigma_{2,3}$ = The horizontal component of principal stresses (Mpa)
- k = The coefficient of structural and tectonic condition influence
- $\sigma_{сж}$ = Voltages in the top layer of softened rocks (Mpa)
- σ = The residual strength of oftened rocks (Mpa)
- Z_0 = The span, at which a flat roof is preserved, m
- $x_1,\dots x_n$ = The characteristics of structural rock blocks
- σ_{3akji} = The strength of filling mass at compression (Mpa)
- $\sigma^{ОСТ}_{сж}$ = The width of a collapse zone; H - the height of a collapse zone (m)
- H_c = The height of cleaning work impact area, m
- H_S = The height of filling (m)

The jamming of structural rock blocks in the area of rock softening is provided by roof stresses and the side thrust of structural blocks:

$$\sigma^0_{сж} \le \sigma^{ОСТ}_{сж} + \sigma_r = \int_0^{Z_{0max}} fx(dx_1, dx_2 ... dx_n) \rightarrow \sigma_{закл} = \int_0^{Z_{0max}} fx(dH_S)$$

where, σ_r thrust stress of the lower layer structural units, m. The system bearing capacity increase is adjusted by the following parameter: $k_{уПр}$:

$$\sigma^0_{сж} \le \sigma^{ОСТ}_{сж} + m\sigma_r = \int_0^{Z_{0max}} fx(dx_1, dx_2 ... dx_n) \rightarrow \sigma_{закл} = k_{уПр} \int_0^{Z_{0max}} fx(dH_S)$$

The behavior of the rock mass at the combined impact of natural and anthropogenic factors is described by the following condition:

$$\sigma K_3 = \int_{l_{min}}^{l_{max}} fx(dx_1, dx_2 ..... dx_n) \rightarrow$$

$$П, R = \int_{l_{min}}^{l_{max}} fx(dh_3 + dh_n)$$

Where:

- σ = The stresses in a mining influence zone (Mpa)
- K_3 = Stress correction factor
- l_{max}, l_{min} = Lock exposure spans (m)
- $x_1 ... x_n$ = Technological, physical, mechanical and other characteristics
- П = Ore losses, shares of un.
- R = The dilution of ores by rocks, shares of un.
- h_3 = Filling mass height (m)
- $h_П$ = The height of mining impact (m)

The degree of technology security for the development of critical stresses and strains is estimated by the coefficient K_1:

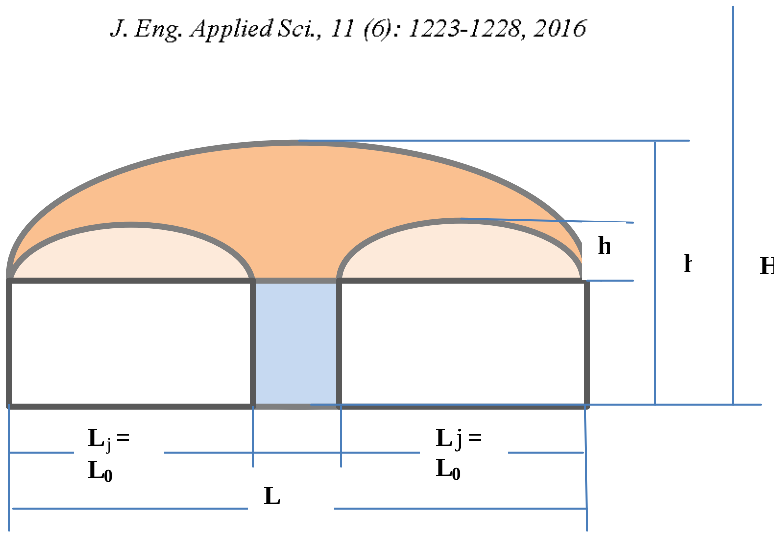

Fig. 1: Massif division scheme into geomechanically safe sites: $L_{Пре}$,$L_{φ}$, L_{i}, the limiting span concerning the condition of a roof natural equilibrium development, an actual one and for a flat roof; H, the depth of works; h_{c}, the height of a natural balance arch for an extreme span; h_1, the height of a new arch

$$K_1 = f(V_0 - V_3 K_T)$$

Where:

- V_0 = The volume of voids formed in the array of voids
- m^3; V_3 = The volume of filled voids
- m^3; K_T = The share of hardening filling (%)

The geomechanical balance of a massif is provided by the separation of massifs into sections, for which $L_б<L_φ<L_{ПреП}$ and $H>h_1$ and inside areas it is separated into spans with a flat roof L_i, where H, h_1 is the depth of works from the surface and the height of a mining influence area, m; $L_φ$, $L_{ПреП}$, L_i, the actual spans respectively, the extreme ones concerning the condition of a roof formation and a flat roof preservation (Fig. 1).

RESULTS AND DISCUSSION

The stability of a hardening filling depends on the compound quality, the curing time and filling feeding mode. The fracture zones, characterized by rock weakening appear around minings. The attenuation coefficient decreases from 0.25-1.15 within the broken rock zone at the power of 0.5-10 m. An increased weakening zone has the power of 0.5-1.5 m. The structural attenuation coefficient increases 1.5 - 6.0 times toward the periphery up to 0.15 which means the reduction of strength as compared to an intact massif. The zones of weak deformations are developed around the minings with the destruction of rocks. The zones differing by stresses and strains are developed downward within deposits:

- The zone of rocks untouched by mining operations;
- The zone of rocks disturbed by mining operations, including mineralization and the subzone of mining influence;
- The area of filling: laying, lining, rock, etc.

The first zone prevents the release of gas and powdered products from the depths and the draining of surface waters. The tectonic disturbances are healed with minerals, the rocks are in a state of compressive stress, so the area acts as a screen. The second zone becomes the source of infection with environment waste as the result of an actual mining. The third zone is dependent on the state of voids. The state of massifs and their mobilization capacity is characterized by the level of stresses:

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

$$= \begin{cases} \sigma^0_{сж} = \int_0^{Z_{0max}} fx(dx_1, dx_2 ... dx_n) \rightarrow \\ \begin{cases} \sigma_{закл} = \int_0^{Z_{0max}} fx(dH_S) \\ \sigma_{закл} = \int_0^{Z_{0max}} fx(dH_S + dH_C) \end{cases} \\ \sigma^0_{сж} \quad \text{При} \;\; H_C = H \rightarrow \sigma_{закл} = \int_0^B fx(dH) \end{cases}$$

Where:

- σ_3 = The vertical component of principal stresses (Mpa)

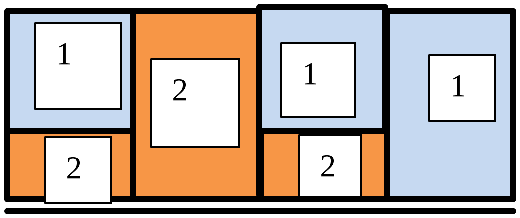

Fig. 2: The combination of technologies with the hardening filling and leaching tailings: 1) leaching tailings; 2) hardening mixtures

$\sigma_{1,2}$	=	The horizontal resulting component of the principal stresses (Mpa)
K	=	The parameter which depends on the degree of stress distortion by structural and tectonic conditions
$\sigma_{ñæ}$	=	Stresses in the upper layer of softened massif elements (Mpa)
$\sigma^0_{ñæ}$	=	The stresses in the zone of mining influence (Mpa)
Z_0	=	The span, at which a planar shape of exposure is preserved (m)
$x_1..x_n$	=	Mechanical and structural characteristics of the building block material
$\sigma_{cæ}^{oct}$	=	The residual strength of softened rocks (Mpa)
$\sigma_{çàêë}$	=	The compression strength of a filling mass (Mpa)
$h_ñ$	=	The height of a mining area influence (m)
B	=	collapse zone width (m)
H	=	The height of rock collapse zone (m)
$h_è$	=	Filling height (m)

The more rock mass is extracted from the subsoil, the greater the inflow of water into the voids, the release of gases from ventilation, the volume of waste dumps, the removal of minerals by waters and wind, the volumes of rocks moving into the voids of the first zone (Ivashchuk, 2013).

The filling of voids by stowing material reduces the stresses in right proportions. A filling mass acts as a control means. The void filling types are combined of (Golik *et al.*, 2015f):

- The first type, the insulation of voids and their filling with hardening mixtures
- The second type, the hardening filling and the underground leaching tailings
- The third type, isolation, the hardening stowing and leaching tailings

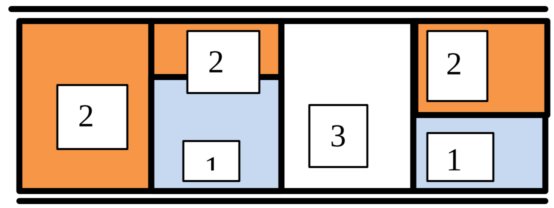

Fig. 3: The combination of technologies with the hardening filling and leaching tails: 1, leaching tails; 2, hardening mixes; 3, empty voids

The degree of technology danger for environment is estimated as the ratio of void volume and the material of their filling:

$$K_1 = \frac{V_{3an}}{V_n}$$

Where:

$V_{3aП}$ = Mine filling volume (m^3)

V_i = Mining volume (m^3)

Leaching tails become the filling material when they acquire a sufficient strength. The combination of technologies with a hardening filling and solidified SP tails is characterized by a danger degree (Fig. 2):

$$K_2 = \frac{V_{3ak} + V_{n\beta}}{V_n}$$

Where, $V_{iâ}$ is the volume of voids filled with SP tails. The combinations of the third type - the filling with hardening mixtures, leaching tailings and insulation - are characterized by the fact that some part of the voids is isolated (Fig. 3).

$$K_3 = \frac{V_{3ak} + V_{\mu}}{V_n}$$

where V_i, the volume of isolated voids. The technologies with the isolation of voids are applied at a massif stability:

$$K_4 = \frac{V_{\mu}}{V_n} K_{\phi 1}^{-1}$$

Where:

V_u = The amount of isolated voids

$K_{\Phi 1}$ = The filtration coefficient on tectonic deformations

At the use of technologies with the collapse of rocks the migration of waste is determined by the filtration ratio through the broken rocks:

$$K_5 = \frac{V_0}{V_n} K_{\phi 2}^{-1}$$

Where:

V_i = The amount of broken rocks
$K_{\Phi 2}$ = The filtration ratio according to broken rocks

The efficiency canned tail stocks with their disposal Ц_y:

$$\Pi_y = \sum_{p=1}^{P}\sum_{o=1}^{O}\sum_{n=1}^{?}\sum_{t=1}^{T}\sum_{f=1}^{F}\sum_{n=1}^{N}\left\{\left(M_{ey}\mathbf{Ц}_{My}+Q_y\mathbf{Ц}_{qy}\right)\right\} - \sum_{з=1}^{з}\left[K\left(1+E_{Hy}\right)+E_q+E_x\right] - \left[\left(M_e\mathbf{Ц}_M+Q\mathbf{Ц}_q\right)+Q_г\mathbf{Ц}_г\right] K_c K_y K_T K_б K_г K_{Bp} K_ч \rightarrow \max$$

Where:

P = Tail utilization products
O = Tail types
Ц = Tail processing processes
T = Processing period
F = The stages of storage existence
N = Tail use stage
M_{ey} = The amount of metals from wastes
Ц_{MY} = Metal price
Q_y = The amount of restored effects
Ц_{qy} = The price of utilized substances
E_q = Utilization loan interest rate ratio
E_x = Loan interest rate ratio for the production of metals
E_{HY} = Interest rate ratio for the environment
M_e = The amount of lost metals
Ц_M = The price of lost metals
Q = The number of lost effects
Ц_q = The price of lost useful substances
Q_R = The amount of effects harmful for environment
$\text{Ц}_г$ = Compensation costs for global destruction factors
з = Management costs
K = Storage facility management costs
K_c = The ratio of tailings self organization
K_y = Leaching product leakage rate
K_T = Solution leakage distance ratio
$K_б$ = The influence coefficient on biosphere
$K_г$ = The coefficient of pollution influence on neighboring regions
K_{bp} = Danger implementation ratio in time
K_r = Environment destruction risk ratio from unaccounted factors

The combined technologies, at which the richest ores are provided for the processing on the surface and the remaining ore is processed on site using the reagents which turn metals into solution are the optimal ones according to economic and ecological criteria (Golik *et al.*, 2015a-f). The process of metal extraction from mine refuses is activated by leaching in a disintegrator. The movement of solutions is carried out in a closed environment of pipelines which excludes the contact with the biosphere.

CONCLUSION

The ecology of mining areas is determined by the upper lithosphere zone safety separating the zone of high deformations with the migration channels from the earth surface. The danger to the environment depends on mechanical and physical processes occurring in the material of void filling and is prevented by the replacement of extracted ores with the structures made of stowing mixtures, the tailings of underground leaching, etc.

The criterion for the correctness of ore mining technologies with the filling of voids by mine refuse and underground leaching processing products is the Earth surface safety as the guarantor of hazardous processes isolation in mines.

The combination of technologies with hardening filling and the solidified tails of underground leaching sets the conditions of volumetric stressed state massifs, increasing the efficient subsoil use factor.

Within geomechanical balanced portions of an ore field the technologies minimized by cost can be used which allow mining enterprises to survive in the mountain conditions of market relation stabilization.

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