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MINERAL MINING TECHNOLOGY

Drainage Efficiency Enhancement for Watered Sludge in Aikhal Open Pit Mine

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Abstract—The authors address the problem connected with gradual rise of sludge level in Aikhal open pit mine. It is found that sludge level has been rising gradually in the course of underground mining under the safety crown meant to prevent inrush of watered mud from the open pit bottom to the underground excavations. The promising approaches to steadying of watered sludge to ensure safe and convenient underground mining are developed.

Keywords: Aikhal open pit mine, sludge, steadying, drainage activities, water removal, hard rock cushion, mechanical support, freezing.

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INTRODUCTION

After completion of surface mining, moist debris and atmospheric precipitates accumulate at the bottom of open pits [1–5]. Aikhal surface mine is currently a mined-out open pit extended from the west to the east, with the bottom height marks of 235 m in the southwest and 195 m in the northeast. In the bottom area of ~8100 m^2, bottom material is accumulated in a volume more than 340 Km^3. This material is water-saturated debris (boulders, break stone, land waste and clay). Moisture of debris depends on the season and amount of precipitation. Underground mining now in progress under the open pit uses the room-and-pillar system with shearing and cemented paste backfill [6–12].

For safe and convenient underground mining, and for safe extraction of ore reserves from the crown pillar (200.0–194.5 m of absolute elevation) up to the safe zone boundary (185–156 m of absolute elevation), it is expedient to undertake measures aimed at stabilization of bottom material in the open pit.

The actual geological and hydrogeomechanical situation analysis in Aikhal open pit mine indentifies the most promising activities toward bottom sediment stabilization, namely:

—drainage for the bottom debris dewatering and water removal;

—doping of the sludge with dry rocks (creation of rock pillow);

—change of physical state of the sludge by freezing in natural cold;

—rock mass reinforcement.

1. DRAINAGE ACTIVITIES

In 2003 Aikhal mine testes a drainage system of tilted raises drilled from underground openings to watered debris on the open pit bottom. During drainage water in drainage boreholes froze under low temperatures of surrounding rock mass.

For reliable and steady-state drainage of watered material on the pit bottom, the borehole drilling and construction technology was changed. Drill rig ULB-130 with two drill columns (outside and inside) was used. The outside column ensures isolation of the inside operating column. As the the required penetration depth is achieved, the inside drill column is removed, while its lock drill is left at the end of the outside column, and a drain column is put into the outside column. Then, the outside column is removed, and the drain column remains in the watered rock mass. In order to eliminate water freezing in the drain column, a heater strip is installed in it by sections of 0.9 m in size. The heater strip ensures positive temperatures lengthwise the drain hole and in adjacent rock mass. Thus, the drain column with the heater strip prevents freezing of water flow and heats the well bore zone. Under conditions of Aikhal open pit, it is efficient to use self-adjusting heater cable RSX 15-2. The design model of watered bottom debris drainage is shown in Fig. 1.

The flow rate of a drainage raise in the system of n drainage raises is calculated from the formula:

$$Q_0 = \frac{2\pi kl}{\ln \dfrac{1.47l}{r}} \left[\frac{akF}{nA} - \left(\frac{akF}{nA} - H_0 \right) e^{-nAt/\mu F} \right], \quad Q_\Sigma = nQ_0 ,$$

where k is the soil permeability; l is the average estimated length of the drainage group of boreholes, m; r is the radius of a drain borehole, m; a is the reduction factor of the atmospheric precipitation period in one year; F is the average area of watered bottom debris, m^2; n is the number of drain raises; $A = (2\pi kl) / \ln(1.47 / l)$; H_0 is the initial head by the end of 2019; μ is the gravitational water yield of soil; Q_0, Q_Σ are, respectively, the single drain raise flow rate and the total flow rate, m^3/day [13].

The time required to drain bottom debris in Aikhal open pit was calculated using the data on: $k = Q / F = 0.012$ m/day; $Q = 100$ m^3/day (average water inflow in underground openings without regard to atmospheric water); $F = 8100$ m^2; $\mu = 0.2$; $Q_1 = akF = 8$ m^3/day (average annual inflow in bottom debris due to atmospheric fallout), $a = t / 365$, t is the annual duration of atmospheric precipitation in the open pit; $H_0 = 45.5$ m; $h = 2.3$ m (drainage standard); $l = 20$ m; $r = 0.063$ m, $A = 0.245$ m^2/day. The calculation results are as follows:

Number of drainage boreholes	20	30	40	50	60
Drainage time, days	1800	700	550	450	350

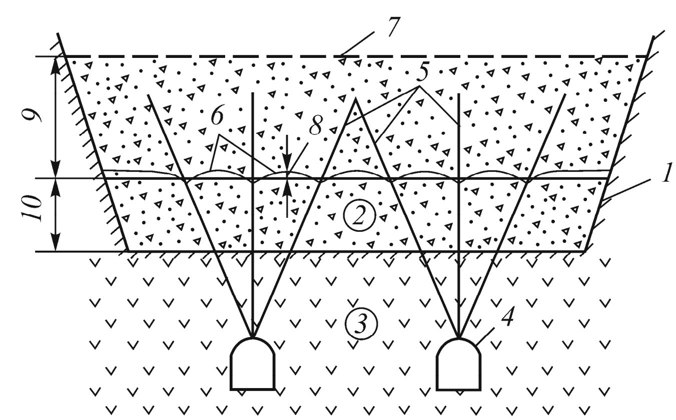

Fig. 1. Watered bottom debris drainage design model: *1*—pit wall; *2*—watered bottom debris; *3*—crown pillar; *4*—underground openings; *5*—tilted drainage raises; *6*—depression curve; *7*—initial hydraulic head in bottom debris (H_0); *8*—excess of actual head over average head (Δh); *9*—time-varied hydrostatic head in bottom debris (S); *10*—time-varied average groundwater level during water drawdown (h).

Bottom debris drainage is a slow process; the low soil permeability and high gravitational water yield of soil dictate drilling of many tilted drainage raises ($n = 60$–50) and long drainage time of 1.0–1.5 year. The average yield of a single drainage borehole is: $Q_0 = 11$ m^3/day and $Q_\Sigma = 660$ m^3/day at $t = 0$ day and $n = 60$ holes; $Q_0 = 0.4$ m^3/day and $Q_\Sigma = 24$ m^3/day at $t = 350$ day and $n = 60$ holes. The yield of the drainage system essentially lowers with time. The layout of the drainage system is presented in Fig. 2.

2. WATER REMOVAL FROM THE SURFACE OF BOTTOM DEBRIS

The adopted water removal system uses drainage cross-cuts sequentially constructed with the increasing level of watered bottom debris. At the present time, drainage cross-cuts 1–3 are filled with sludge, and cross-cut 4 occurs at the same level as the bottom debris horizon.

There are two scenarios of bypass of water and sludge from the pit bottom: construction of drainage cross-cut 5 with water intakes and use of drainage cross-cut 4 with a system of tilted drainage raises equipped with drainage columns. The currently existing water removal system in the open pit mine features high quantity of suspended matter in water being removed, which results in silting of pipelines and induces extra load on a dirt collector of a pumping station on Level +163 m.

In order to remove suspended matter from drainage water, it is suggested to modify the structure of the cross-cuts (Fig. 3). During construction of drainage cross-cut 5 at the height mark of 241 m (above the approach zone between the bottom debris horizon and the drainage cross-cut floor), two perforated metal pipes with diameter of 400 mm are laid so that they protrude in the pit by 10 m. Inside the cross-cut, the pipes are laid so that to pass beyond the waterproof brattice, and are connected via a water stop to a water conduit to water circulation wells and to the pumping station of Level +163 m. At the entry of the drainage cross-cut, a drainage fill is made to enclose the drainage pipes. The drainage cross-cut comes into operation when water in the open pit reaches the height mark of 242 m.

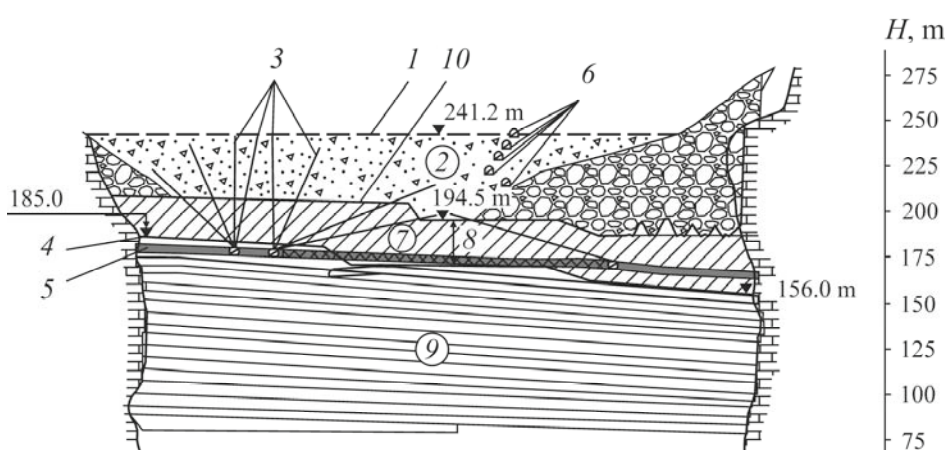

Fig. 2. Layout of bottom debris drainage system: *1*—level of sludge; *2*—watered bottom debris; *3*—tilted drainage raises; *4*—boundary of safe mining depth; *5*—ventilation and backfill drift; *6*—drainage cross-cuts; *7*—safety crown; *8*—crown pillar thickness; *9*—mining layers; *10*—open pit bottom.

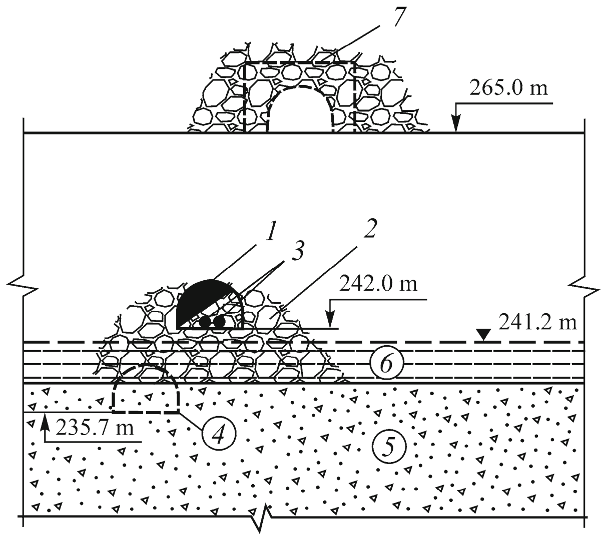

Fig. 3. Water intakes in drainage cross-cut 5: *1*—drainage cross-cut 5; *2*—dry drainage fill; *3*—perforated water circulation pipes; *4*—drainage cross-cut 4; *5*—watered pit bottom debris (silt); *6*—water; *7*—caved portal frame.

For removal of atmospheric water from the pit, it is recommended to make up to 4 water intake boreholes from beyond the concrete brattice of drainage cross-cut 4 using drill rig ULB-130. These boreholes should be equipped with a drainage column with diameter 127 mm and with filter KDF-120 to ensure water clarification before entering the borehole (Fig. 4). The water intake boreholes are also connected via a water stop to a water conduit to water circulation wells and to the pumping station of Level +163 m.

It is found that with increasing level of sludge in the pit, the uncontrolled inflow of open pit waste water in underground openings of Aikhal mine intensifies due to growing hydrostatic pressure on the enclosing structures of the mine protection from ground water. Key point is to stabilize watered bottom debris and also to reinforce and improve the existing system of waterproof and water bypass structures. Inrush-hazardous areas are protected by extra fencing structures—waterproof solid concrete brattices with water outlets. With a view to reducing pressure on the enclosing structures, the faulted waterproof brattices are modified. The controllable water outlets of the brattices, after teardown of out-of-order water stops, can be used as conductors for further construction of drainage and discharge boreholes to the brattice-separated zone.

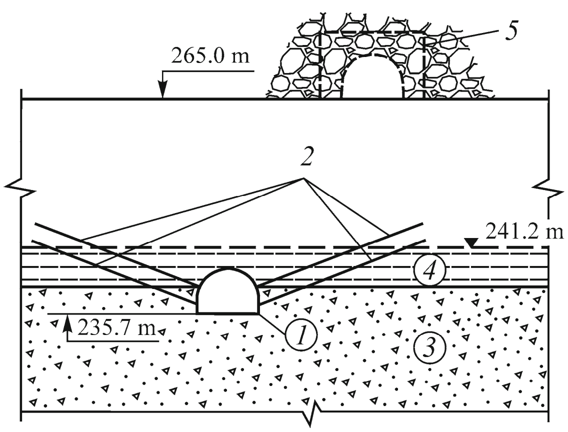

Fig. 4. Water intake boreholes of drainage cross-cut 4: *1*—drainage cross-cut 4; *2*—drainage boreholes; *3*—watered bottom debris; *4*—water; *5*—caved portal frame.

In order to reduce the risk of water and watered sludge inflows from the pit bottom, all boreholes drilled into the pit bottom from the underground openings, as well as all water bypass holes connected with the waterproof brattices-separated and flooded area of the underground mine should be inspected and controlled. The boreholes should be closed using grouting, if necessary.

After water removal from the surface of the bottom debris, and after implementation of all drainage and dewatering activities, the hydrogeomechanical situation in Aikhal mine can change drastically: the hydrostatic pressure on the pit bottom can be removed completely and the rock mass becomes inrush-safe. Actually, the waterfront which affects the top of the crown pillar will be eliminated.

3. CREATION OF ROCK PILLOW ON THE PIT BOTTOM

It is suggested to create a dry rock pillow using dolerite rock blocks to be broken from the pit wall by explosives and to fall to the pit bottom by gravity. The stabilization mechanism consists in penetration of broken rock in the sludge under the action of kinetic energy of fall with overcome with the sludge resistance (viscous friction). The mix of dry rocks and sludge represents a heterogeneous system with much lower mobility and inrush hazard. Excessive rocks create a safety pillow under the sludge, which increases the sludge-generating load and displaces some pore water to the system of drainage boreholes. This contributes to stabilization of rock mass.

The dry rock pillow is better to be created after dewatering of the pit bottom debris. The friction force of the dewatered debris prevents dry rocks from penetration more than by 5 m, and the dry pillow is thus created on the the dry surface. In this case, the pillow closes the entry of drainage cross-cut 5 and represents a reliable barrier passable by atmospheric water flow toward the drainage cross-cut and impermeable for suspended sedimentation.

4. REINFORCEMENT OF TOP ROCK MASS IN THE CROWN PILLAR

For safe and comfortable extraction of ore reserves under the pit bottom and crown pillar, the forepoling approach is proposed. This method consists in early creation of tube umbrella in the roofs of stopes on the upper mining layer under the pit bottom. The tube umbrella represents metal casing tubes. When the tubes are exposed in the course of shearing, they are reinforced by continuous timber frame with grouting in order to eliminate doming (Fig. 5a). The side view of the forepoling system is depicted in Fig. 5b.

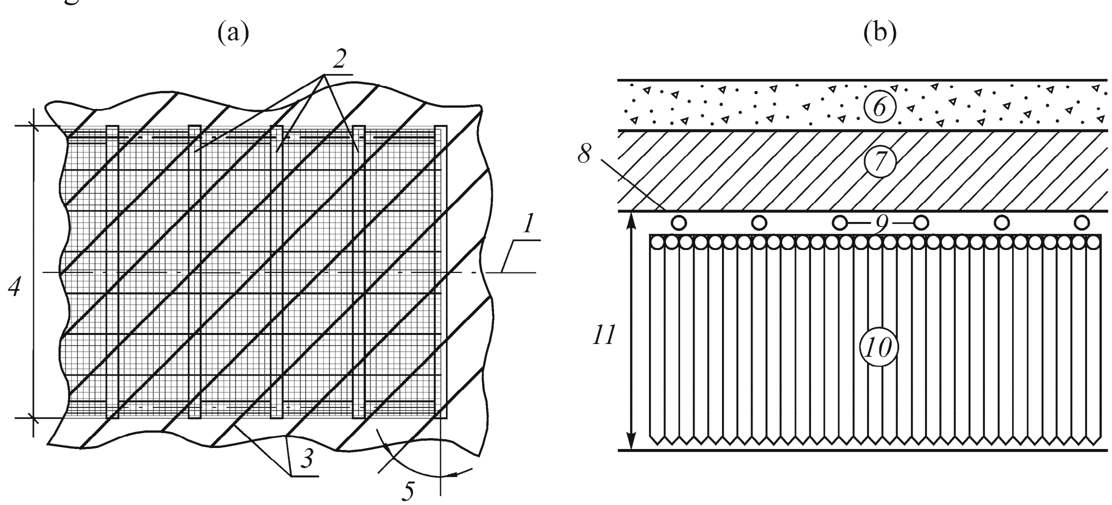

Fig. 5. (a) Tube umbrella and (b) forepoling system side view: *1*—stooping axis; *2*—continuous timber framing; *3*—metal tubes; *4*—stoping width; *5*—angle between axes of tubes and stoping; *6*—watered bottom debris; *7*—crown pillar; *8*—safe mining depth boundary; *9*—tube umbrella; *10*—continuous timber framing; *11*—upper mining layer under pit bottom.

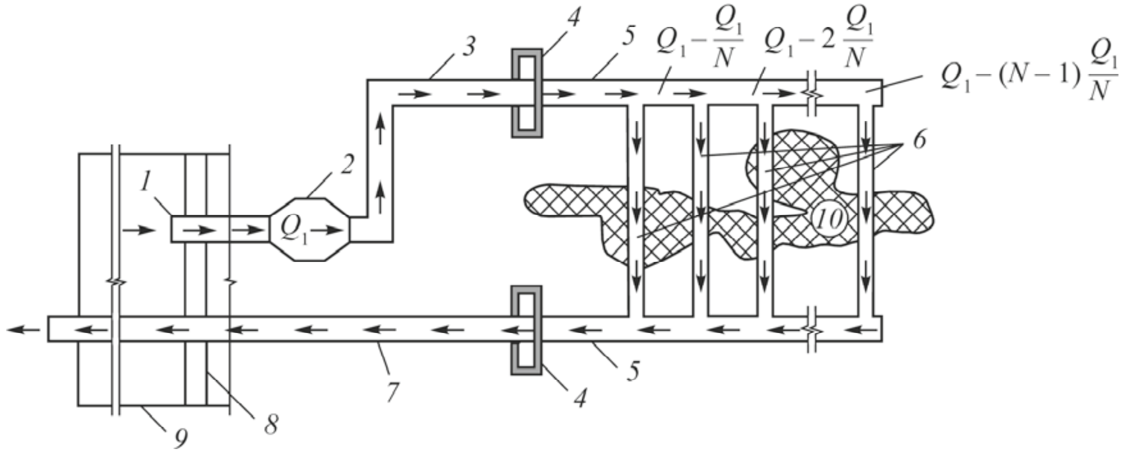

Fig. 6. Air freezing system: *1*—suction pipe line; *2*—centrifugal fan; *3*—air supply pipe line; *4*—airtight brattice in air supply roadway; *5*—air supply roadway; *6*—freezing pipe; *7*—discharge pipe line; *8*—water-resistance brattice in dog heading to open pit; *9*—dog heading to open pit; *10*—ore body; Q_1—cool air flow rate; N—number of pipes.

Forepoling is advisable after dewatering of the watered debris on the pit bottom. Drilling is carried out from a circular process drift around the ore body at the height mark of 200–205 m. Drilling allows creating a plane of parallel load-bearing structures (thick-walled metal tubes) in the roof of stoping on the upper mining layer under the pit bottom.

Drilling by drill rig ULB-130 is carried out inside an opposite-rotating protective column with rock-breaking tool and with wash-out using closed water circulation system, which eliminates extra watering and instability of ore body and rock mass. After drilling completion, the drill rig is removed from the hole, while the protective column remains and serves the prime support element in the stoping roof. The tube umbrella is created in unstable rocks capable of rock falls (contact zone of coarsely clastic rocks and weak watered ore).

5. AIR FREEZING SYSTEM

The use of natural cold to freeze rocks in the roof of the upper stoping layer under the pit bottom allows a safe frozen wall to be created around the tubes in the tube umbrella. This frozen wall has a thickness equal to the spacing of the tubes. The freezing pipes can be the forepoling tubes filled with cold atmospheric air from the pit void (Fig. 6). This method totally eliminates water inflows and risk of inrush of water bottom debris to actual mining area.

CONCLUSIONS

The best promising methods to stabilize bottom debris in Aikhal open pit mine. Dewater of bottom debris via tilted drainage raises is a slow process due to low permeability and high water gravitational yield of water. Water removal from the surface of bottom debris, drainage and dewatering activities can improve the hydrogeomechanical situation: stoping operations can be carried out within the crown pillar. The support design for the stoping areas governs the operation safety. Stabilization of watered sludge on the pit bottom by means of creation of a dry rock pillow is a difficult challenge both this time and in the future in view of the poor quality of pit wall rock mass. The forepoling is advisable in mining in unstable rock mass capable of rock falls. The use of natural cold for rock mass freezing can help create frozen walls around the tube umbrella in the roof of the stoping layer.

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