



INFLUENCE OF MINING-GEOLOGICAL CONDITIONS AND TECHNOGENIC FACTORS ON BLASTHOLES STABILITY DURING OPEN MINING OF APATITE-NEPHELINE ORES

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The paper presents the results of borehole stability research and considers possible causes of emergencies. The features of the blast hole drilling process are analyzed taking into account the properties of the rock. Based on the distribution of speed of drill fines removal from the well, an algorithm for selecting drilling modes is proposed. The nature of change in the size of the holess over time has been analyzed. This paper investigates the influence of rock fracturing and its water content on borehole stability.

Possible options for eliminating the man-made impact on the massif near holes and options for fixing the hole walls with soft shells are suggested. The experimental data on the installation of shells for the conditions of open mining of apatite-nepheline ores are given. The operability and effectiveness of the technology is proved.

Key words: explosive breaking, borehole, roller drilling, water cut, stability, support, soft shells, mining safety

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Introduction. Explosive methods of rock breaking for excavation and processing is one of the most labor-intensive stages in mining cycle. The efficiency of drilling and blasting operations is influenced by many factors, one of which is the field water content [4-8, 11, 12]. In recent years, a new problem has emerged that was previously uncharacteristic for rock massifs, i.e. instability of well bores, causing the need to apply the technology of charging of wells right after drilling. Charging after drilling requires constant presence of additional people and equipment on the bench, which, combined with financial costs, reduces the effectiveness and safety of blasting operations. Thus, the solution of the problem of stability of blastholes becomes very urgent.

Setting of a problem. The Vostochny mine is developing the Koashva deposit of apatite-nepheline ores by open pit methods and is part of the deposits of the Khibiny group. Preparation of rocks for excavation is carried out by drilling and blasting. In recent years the company has mastered the use of emulsion explosives (EE) and non-electric methods of initiation which has significantly increased the safety of blasting operations. Drilling of blastholes is carried out by roller-bit drilling machines SBSH-250. Charging of holes is carried out by Transmanut mixing-charging tucks based on Scania machines. In the process of preparing rocks for excavation, the greatest difficulties arise when drilling holes [2, 4, 12]. The holes are unstable and in several cases it is not possible to obtain the required number of full depth holes due to the difficulty of removing drilling fines. In this case, the wells must be repeatedly drilled anew. At the same time the blasting pattern becomes irregular, drilling time is considerably increased, there is a waste of electricity and, explosives. Because of the short time to maintain the stability of the holes they are loaded right after drilling. This creates considerable inconvenience, leads to appearance of unproductive periods of expensive equipment, and significant increase of production costs.

Methodology. The analysis showed that the greatest impact on the stability of blast holes are mining-geological and human factors.

The physical and mechanical properties of the ore and waste rocks [1, 3, 9] are given in the table.



Physical-mechanical properties of the rocks of the Koashvinsky quarry

Property	Spotted, spotted-banded and banded ores	Lenticular-banded ores	Reticulate ores	Block ores	Waste-rock (urtites, ijolite)
Density, t/m ³	3.1	2.92	2.75	2.94	3.3
Velocity of longitudinal waves, m/s	4500	4300	5200	5350	
Modulus of elasticity, MPa	$6.0 \cdot 10^4$	$5.5 \cdot 10^4$	$8.0 \cdot 10^4$	$7.0 \cdot 10^4$	$8.3 \cdot 10^4$
Poisson's ratio	0.3	0.27	0.2	0.25	0.25
Compressive strength, MPa	110	145	160	160	225
Ultimate tensile strength, MPa	3.0	5.0	9.0	4.0	10.4
Drilling category	–	–	XIII	XIII	XVI
Blasting category	–	–	IV	IV	III

Hard rocks have up to 20 cracks per meter and belong to the medium fracturing level type. The development of the deposit is characterized by a complex hydrogeological situation. The average water inflow is 11,000 m³/h. Water content greatly complicates the process of boreholes drilling. Even dry wells in some cases have poor stability.

Blastholes on the site are divided into the following categories:

- 1) dry;
- 2) flooded, fed with water in filtering mode;
- 3) flooded, fed with flowing water in hydrostatic head mode;
- 4) flooded, fed with water in increased head mode and water flowing.

The waste benches mainly have holes of 1-3 categories, ore benches have all those categories.

Full-scale studies have shown that the flow of water into the drill hole depends on the nature of the fracture and the degree of crack opening at 1.0-1.5 m from the location of the proposed hole placement. Subcapillary and capillary cracks do not interfere with the drilling process. Minor water inflow during drilling has a positive effect as it contributes to the reduction of dust and improves cooling of the drill bit. Super-capillary cracks (opening from 0.2 mm and above) create inflow of water with pressure. When opening is 2 mm or more, the inflow of water becomes significant. In the last two cases, the process of cleaning drill fines from the holes becomes difficult.

An analysis of the reasons for this phenomenon shows that one of the factors that provokes the blocking of the bore with pieces of rock is excessive vibration of the drill string. Vibration during roller-bit drilling is caused by the specific operation of the rolling cutter. As the drill penetrates into the rock during hole collaring, flushing of the drill cuttings does not occur. The video clip of the drilling process shows that in the initial period the rolling cutter vibrates and deforms the surface within a radius of about a meter. In the literature, the question of the influence of the drill string vibrations on the stability of the wells has not been fully investigated. As the drill bit deepens drilling fines become very compact between the drill rod and the borehole wall. With further deepening, the drill bit and pieces of rock are pressed into the surrounding rock. After completion of drilling, the rock hole begins to close and after. A while the cross-section of the well is reduced to a sizes unsuitable for charging.

The onset of vibrations occurs with tool rotation speed increase and depends on the mass and stiffness of the drill string. The larger the mass of the rotational-feeding mechanism, the greater is the vibration of the drill string. It is theoretically calculated that the rotational-feeding mechanism of the machine must have a mass of not less than 3.5 tons at stable 100 revolutions per minute [2].

Drilling is carried out at 150 or more revolutions per minute and an axial load of 30-100 kN. The designed bottom hole cleaning system provides continuous air supply and simultaneous water supply if necessary. It is impossible to disconnect the air supply because of the danger of clogging the scavenging channels in the bit and the drill string. Water is fed at a pressure of 0.35 MPa to the pipeline only when drilling dry wells. One rolling cutter produced by Uralvagonzavod can drill more than 1000 m of wells under the investigated conditions.

The stability of holes is greatly affected by the drilling tool integrity. The main reason for roller cutter failures is jamming and subsequent destruction of bearings installed in the legs. The hard metal hemispherical reinforcing elements wear out due to the chipping of hard alloys and high temperatures during drilling without water. When the bit is rubbed against a hard and abrasive rock, the rolling bit is very hot-sometimes even the color of the metal changes. It is very difficult to determine the beginning of the destruction of bearings and the chipping of hard alloys during drilling. The bearing that breaks down in the initial stage creates an imbalance of the bit, which in turn leads to the vibration of the drill string, curvature of the hole profile and the destruction of the blasthole wall in the drill string impact zone. With complete destruction of one of the bearings, the rate of drilling drops. The average drilling speed achieved at the enterprise with the use of a new bit is approximately 1 m/min.

Observations show that the axial force on the bit is determined by the existing at the plant practice and is not optimal. In foreign mining practices with similar conditions it is recommended, to drill with rolling cutters with axial forces of average 10 kN for every centimeter of the bit diameter, i.e. with an accepted diameter of 8.75 inches, the axial force should be up to 300 kN with the assumed speed of 40-50. The SBSH-250 can develop an axial force of up to 200 kN.

Therefore to improve the stability of boreholes, it is necessary to develop and use optimization algorithm of for drilling rig operation process in relation to the conditions of the Koashva deposit.

Figure 1 shows the distribution of the speeds of the drill cutting's movement in the gap between the walls of the hole and the drill string. The data was obtained based on video analysis of the drilling process. Figure 1 shows only the vertical components of the particle trajectory. In reality, the particles in the gap move in a turbulent flow along a complex trajectory, i.e. chaotically so this data should be considered approximate. In this case, we investigated the process of drilling a 10 m well with a bit with a diameter of 250.5 mm with a drill string diameter of 203 mm. Drilling was carried out on the site with flooded wells, fed with flowing water in hydrostatic head mode.

The analysis of distribution of particle velocities in a gap with a width of 24 mm shows that removal the sludge is possible only in a narrow region of about 1 cm adjacent to the walls of the drill string. When the drilling rig reaches a planned depth of 10 m, the well top diameter increases, and the width of the total gap becomes higher than 60 mm. In the process of drilling, there is a redistribution of the of particle velocities.

The kinematics of particle motion becomes much worse. The velocities of the particles moving near the bore wall fall, and the particle velocities near the wall of the drill string change little. In this case, the width of the speed range where the fines can be removed is about 1.5 cm. Therefore, to improve the process of fines removal, it is necessary either to increase the air flow by about four times, or to reduce the gap between the well wall and the drill string up to 1 cm.

Figure 2 shows the time-based change in cross section of holes drilled through ore and in waste rocks. The data was obtained by recording the control points at regular intervals at a depth of 50 cm. The limiting value is the time at which the borehole section is reduced by 50 % of the initial size. Such a criterion is chosen based on the accepted pipeline diameters, dimensions and technical capabilities of

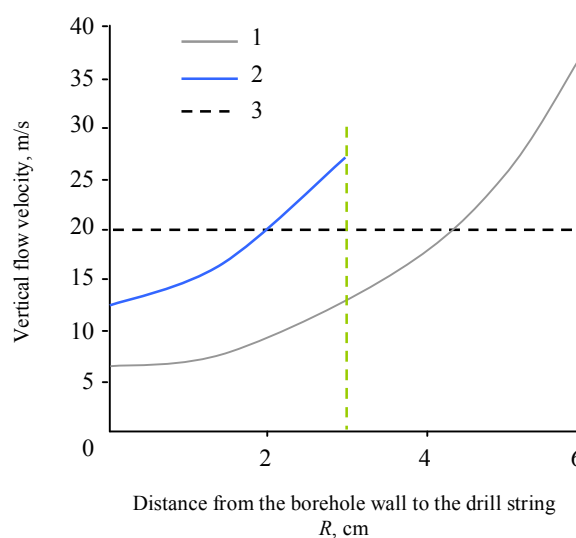


Fig. 1. Distribution of drill fines removal speed at the final (1) and initial (2) stages of drilling; 3 – area of minimally stable removal of drill fines

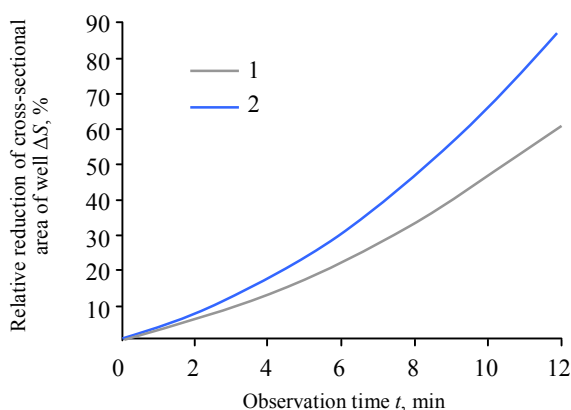


Fig.2. Patterns of wells cross-section changes it time in waste rock (1) and ore (2)

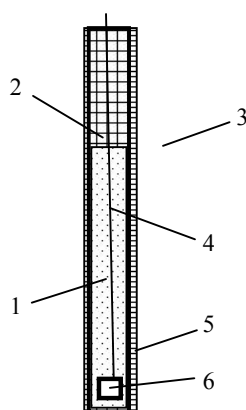


Fig.3 Design of a charge for water-cut rock

1 – waterproof explosive; 2 – soft shell with water in down-hole;
3 – rock massif; 4 – wave-guide; 5 – down-well; 6 – primer



Fig.4. A 10 m well filled with drill fines and water.
Well top is absent

the mixing and charging equipment. Based on these studies, the time limit to produce charging operations at the hole with the installation of an intermediate detonator was established: for the benches of waste rock it equals 9 min and 11 min for ore.

Discussion. To increase the stability of holes we proposed a method that makes it possible to stop the closure of the cross-section for several days. This time is quite enough for charging wells according to the standart process.

The method [10] consists of installing a soft polyethylene shell of the required diameter for the entire depth of the well and filling it with water. The EE is charged inside this shell. The density of EE is higher than the density of water and therefore, as it moves, it displaces water from the inside. Ultimately the explosive charge is formed in a protective envelope and can stay in it for a long time (Fig.3).

To assess the practical applicability of the proposed method, the shells were made of technical polyethylene of thickness of 120 and 200 micron. The coiled material was rolled to the required length, cut into strips of calculated width and glued with double-sided adhesive tape. The strength of the joints was verified by a manual dynamometer. The strength of the seams in the places of gluing proved to be higher than the strength of the whole sheets.

The shells were filled with water through a hose with an internal diameter of 32 mm from a standard vehicle, the water container was placed in the vehicle body (IBC container) with volume of 1 m³. Filling of the shells with water was carried out due to the hydrostatic head. Shells were installed and tested in 13 wells.

To accelerate the time of immersion of the shell in the hole, a stone weighing about 1 kg was placed in it. Time for preparation and placement of the shell in the borehole was 1 min.

Based on the research data, the following was established. Installation of shells in dry holes occurred without any difficulties. Filling of the shells with water is possible both from below and from

above. The time of filling of the shell is the same. Filling the shells from below requires a longer preparation time and placement of a hose of a full length of the hole. This operation takes 2-3 minutes. Further, the shell together with the hose is lowered into the well and then water is supplied. In water filled wells, when the shell is filled with water, it is displaced in the gap between the shell and the well wall. The time for water displacement was 4 minutes for wells with a depth of 10 m. If the

shell is filled with water from above, the filling time is increased to 6-7 minutes due to a slower displacement of water in the gap. Consequently, the shells filled from below are more efficient and reliable. The shells installed in the wells are shown in Fig.4-6. Based on production experiments, the effectiveness of using polyethylene shells for increasing the stability of blastholes is proved.

Conclusion. The testing of the shells in production conditions showed that the effect of creating a counteraction to filling of holes with rock is preserved under condition of their integrity. Any damage to the shells associated with water leakage reduces the effect of maintaining the hole. It was established that shells with wall thickness 120 μm are damaged by abrasive pieces of rock, starting from a depth of 10 m in the area of the bottom hole. Shells with a wall thickness of 200 microns performed reliably without damage over the entire range of operations. The maximum maintenance effect is achieved at a water column height above the well top of 0.2 m. In this case, the wellbore stays undamaged for five days. Based on the production tests of shells installed in all categories of wells, regularities of interaction of shells with enclosing rocks have been revealed.



Fig.5. Shell is installed in a dry well and filled with water



Fig.6. Shell is installed in flooded well and filled with water

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