Development of Complex Ore Zones

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Abstract. The article is aimed at developing a technology for mining valuable ores with maximum preservation of natural contacts of ore zones with empty rocks and reduction of mixing of the rock mass during explosive loosening. A new method for working out local areas of mineralization in strong rocks using explosive loosening of rocks in the conditions of natural "clamping" by a natural array with decelerations between successive bursts of borehole charges above 300 MS is proposed. This allows you to achieve a minimum displacement of the exploded rock mass in both horizontal and vertical directions without any additional costs.

1. Problem statement

When working out valuable ores it is essential to preserve as much as possible the natural contacts of ore zones with empty rocks and reduce the mixing of the rock mass in the process of preparing them for excavation by explosive loosening. This is achieved by special methods of conducting explosive work. Therefore, practical and theoretical studies of the processes of rock destruction by borehole charges, including mathematical and physical modeling, continue [1-9]. Blasting on a buffer of previously blasted rock mass or blasting in an absolutely clamped environment (on a monolithic array) is widely used in quarries). Such blasting provides control of the collapse of the rock mass and the possibility of selective excavation [10].

At the same time, the main attention is paid to buffer blasting with loading from previously exploded rock mass, including special work on the formation of this loading. So in the method of explosive preparation of rock mass for selective excavation, which includes drilling wells, performing block surveying, testing wells with geological and geophysical methods, studying the natural blockage of rocks, contouring high-quality ore, charging wells with explosives, blasting wells, switching well charges and sequential explosion with large decelerations in a clamped environment. On the side of the spent horizon, a buffer is constructed from uncollected rock mass, such as overburden after the past explosion. Boreholes are drilled on the contact of ore-rock from the side of the lying side of the Deposit with high-quality ore at the angle of its occurrence. A number of boreholes are blasted simultaneously. Then the charges of the main wells drilled in the remaining part of the block directly in the ore body and substandard ore are detonated in a compressed medium. [11].

In [12], it is proposed to form a trapezoidal retaining wall from previously blasted rocks using the excavating and loading equipment. The experimental section with a volume of 212 thousand m³ was divided into two equal blocks, in the first of which the retaining wall had a traditional shape formed as a result of the previous explosion, and in the second it was formed in a trapezoidal shape. The parameters of both explosive blocks were adopted as follows: at the height of the ledge of 15 m, the depth of
the wells was 17 m, the grid of wells – 7x7 m. In the first block, the height of the retaining wall was 9 m, and the width below it was 31 m. In the second block, the height of the retaining wall was level with the ledge 15 m, width 24 m. The explosion scheme in both blocks is diagonal, the explosion delay interval between rows is 35 MS, the specific consumption of EXPLOSIVES (nobelan-2080) is 0.63 kg/m³. In the second block with a trapezoidal shape of the retaining walls reduced the speed of movement of the blasted rock mass in the horizontal plane, increased the duration of the explosion on the environment, increased efficiency of use of energy of explosion and better made quality crushing array: the average size of a piece decreased by 29 %, and the number of oversized pieces decreased by 22 %. Increasing the degree of crushing allows you to increase the productivity of excavators by 5 % and reduce the cost of crushing oversized items by 22 %.

Both the first and second examples require significant time and financial expenditures for the construction of a loading buffer from the exploded rock mass, and in the first case, the overburden will also have to be removed after the explosion. Therefore, the cost can be recouped only in the case of mining valuable ores. In addition, buffer blasting on a pre-blasted mountain range requires a significant size of work sites, which is not always feasible.

2. Methods

Methods At the same time, there is a simpler and cheaper method of exploding: on the "clip" from the natural array at the start of the surface scheme of initiating a mass explosion from the back of the exploding block towards the slope of the ledge. It has been used for a long time, but we have obtained significant results only in the last 8-9 years, when we started using large deceleration intervals – 150-200 MS or more. The practice of conducting blasting operations has shown that when the block is located second or third from the rear edge of the exploding block, the release of rock mass for the last row of wells is excluded, since there is a possibility of moving the destroyed mass towards the exploded rock mass of the block. The start of the explosion from the middle of the block reduces the displacement of the exploded rock mass, keeping the contacts of ores and rocks close to natural ones [13, 14].

When the deceleration intervals increase above 150-200 MS, the mechanism of explosion development in the rock mass changes significantly. Long arching impact of the detonation products in the cracks of the previous explosions allows to extend and expand them. K. Hino [15] argues that, in short-delay blasting in the explosion of the charges of the previous turn are formed with additional surface outcrop in which arching action of the gases of explosion subsequent stage lasts from 10 to 100 MS. Therefore, at large deceleration intervals, the time required for the cracks to germinate to the full depth corresponding to the quasi-static stage of destruction under the action of the bursting action of the explosion products of subsequent charges appears.

This interpretation fits perfectly into the concept of rock destruction about the stage mechanism of rock destruction, studied by scientists from the Ioffe Institute of physics and technology [16]. At any mechanical or other method of impact on the rock, regardless of the nature of this impact (surface or local), the process of destruction proceeds in two stages. At the first stage, the processes of generation and accumulation of micro- and macro-cracks and other defects up to a certain concentration occur in the volume of the rock. This stage is preparatory, which is a three-dimensional pre-destruction. At the second stage, there are processes of merging cracks into larger ones and dominating catastrophic local growth of some of them with the formation of separations. This is the pre-collapse stage.

However, the kinetics of destruction of inhomogeneous fractured rocks (and all rock masses are represented by such rocks) the speed and depth of crack germination are significantly affected by the mechanism of development of natural cracks and their germs existing in the medium, and the conditions for the transition of the explosion energy to the energy of formation of new surfaces. Under the action of a cyclic alternating load, energy flows to the crack vertex. The same absolute value of tensile and compressive stress creates an equal flow of energy, however, their impact on crack growth is the opposite: the energy of compressive stresses having hardening effect and the tensile – seeks to break the bonds in the crack tip. Crack growth cannot occur at the stage of compressive load action, despite
the flow of energy to the crack vertex. The process of brittle rock destruction by explosion is characterized from a physical point of view by one type of destruction – separation under the action of tensile stresses from the action of a stress wave in the rarefaction phase. This feature corresponds to the physical nature of the mechanism of bond breaking only under the action of tensile or tangential stresses, and not all the energy of tensile stresses is spent on the crack growth, but only its excess over the energy of medium deformations [17]. Therefore, the time between the impact pulses is a crucial point: the next pulse should follow only after the compression process, in which there is no crack growth, and the passage of the stretching wave, which ensures the growth of cracks. Therefore, the full cycle of "compression – stretching" in the stress wave must pass, taking into account that the time of removing the substance from the state of rest is always less than the time of its return to this state.

In [18], it was found that as a result of cyclic impact of compressive load, the accumulation of destruction occurs from cycle to cycle, and the processes of softening are especially active in the last cycles, when there is a mass accumulation of micro-cracks, a multiple grid of micro-cracks is formed (the intensity and total acoustic emission increases sharply). As a result of such actions, multiple destruction is observed with the formation of a surface several times larger than in normal (non–cyclic deformation), while the energy stored (or required for destruction) under cyclic action is reduced by 1.3-1.4 times.

In [19], it is emphasized that micro cracks in the elastic deformation region develop under the action of a tensile pulse in an elastic wave. The determining parameters are the magnitude of the stretching impulse, its duration and the rate of onset of micro cracks, and with a certain ratio of the values of these parameters, natural germinal micro cracks can grow by a certain amount. Thus, in [17] it is shown that the increment of the crack length for one cycle of "compression-stretching" is 10 mm, which is phenomenologically interpreted as a pre-fracture of the rock.

Let's consider the dynamics of loading a conditional rock mass with the most common parameters of the speed of sound in it (CP), equal to 3-4 km/s – this is the speed at which the stress wave moves along such an array. At an average sound speed of 3.5 km/s, the compression wave passes 3.5 m in 1 MS. Let's consider the scheme of exploding borehole charges with a diameter of 200 mm, located on a grid of 6×6 m, with a deceleration of 25×42 MS. After the explosion of well 1 for 25 MS (before the explosion of well 2), the voltage wave will go 87.5 m – outside the block. With some delay, let's say 1 MS, the action of the stretching phase will begin in this wave, causing the formation of cracks. When cracks develop at a rate of 0.4 CP per 1 MS, the crack will grow by 1.4 m, taking the size of the fracture zone r at 40 charge radii (4 m), and the pre – fracture zone R at 200 charge radii (20 m), we get the time to form the fracture zone ~3 MS and the pre-fracture zone-14 MS. Already this enlarged calculation shows that the formation of a pre-collapse zone is possible at decelerations of more than 14 MS between successive bursts of borehole charges. It is obvious that schemes with 25×42 MS decelerations cannot provide sufficient time to complete the growth and fusion of micro cracks into the cracks that form the parts of the array. Only circuits with decelerations greater than 100 MS can provide sufficient time to form not only a failure zone, but also a pre-failure zone.

A deceleration of more than 100 MS allows each well charge to be blasted separately, not to open the crack, as with decelerations of up to 100 MS, but to a free surface. An experimental mass explosion with a deceleration of 150 MS in the in the direction of the cutting slotand and 200 MS in the perpendicular direction starting from the middle showed that each well charge explodes separately [14]. Only the first cutting charge is triggered in the conditions of " hard clamping" of an intact rock mass and the deformation of rocks is possible only in the direction of the open surface of the ledge site. The next two downhole charges of the series explode after 150 MS in a situation when the rock mass already has significant differences from the intact one: a zone of crushing from the explosion of the first charge is formed, which serves as a free surface, towards which the movement of the destroyed rocks is also possible. In addition, both of these charges are located in the zone of strong influence of the first charge voltage waves, which caused an increase in the disturbance of the rock mass. This disturbance, in the form of cracks opened by a certain amount, allows a part of the strongly compressed products of the explosion of the second-stage charges to penetrate into these cracks and devel-
op their growth by a wedging action. 50 MS after the explosion of a pair of vrubovyh charges triggered charges on a number of wells. Neighboring wells have three times the impact of stress waves and, consequently, a more developed disturbance, which will penetrate even more products of the explosion and strengthen this disturbance. And so with each next pair of borehole charges, the disturbance of the pre-collapse zone increases and, accordingly, the possibility of the active phase of splitting cracks with the products of the explosion increases. So, by 550 MS from the beginning of the explosion, charges are triggered, through the zone of influence of which 9 voltage waves have already passed, and 11-13 voltage waves have already affected neighboring wells. Accordingly, the area of the newly formed crack is already increased several times and gas emissions from wells without plugging significantly weaken, since the cross-sectional area of the well is already comparable to the surface of the newly formed crack in the previously destroyed zone [14].

In combination with a wedge cut in the depth of the block, which provides a mode of blasting "in the clamp", the quality indicators are characterized by a compact collapse of cohesive loose rocks with a calm surface relief, which helps to reduce losses and dilution of minerals, and the practical absence of large fractions of rock mass.

3. Results
To study the parameters of displacement of the blasted rock mass with the help of radio beacons, experimental explosions were conducted with the location of wells with a diameter of 170 mm on a 4x4 m grid and the use of various intervals of inter-well deceleration, which showed the following.

At decelerations up to 100 MS, the average displacement of the blasted rock mass is from 2.6 to 6.5 m, the collapse surface is uneven, with large differences in elevation. When using decelerations from 150 to 200 MS, the average displacement of the exploded rock mass is in the range of 2.0 to 4.0 m, and the collapse surface becomes more calm. With an increase in decelerations to 275-300 MS, the average displacement of the exploded rock mass decreased to 1.1–1.8 m, and the collapse surface is uniform, there are no sharp changes in elevation. Reducing the displacement of the blasted rock mass delays 275-300 MS to 1-2 m horizontally allows to make the surface collapse of rock mass boundary local area of mineralization with the increase of the con-tour size by 1-2 m.

In the practice of developing valuable ores, there are cases when episodic testing of explosive wells in overburden rocks on the flanks of the Deposit reveals local areas of mineralization of significant size, allowing them to be involved in mining. Therefore, for such cases, it is advisable to conduct a gross testing of all blast wells when drilling overburden blocks.

Identified local areas of mineralization of industrial character allocated to the plan of blasting block and conduct overburden blasting unit with deceleration intervals above 300 MS, with increasing size of the contour of the boundaries of local areas of mineralization on the surface of disorder of mountain weight by 1-2 m. When using non-electric waveguide initiation systems, borehole retarders of 3000-5000 MS are installed [20].

Experimental mass explosions were performed using a surface network with decelerations of 300×400 MS. The nature of the collapse of the exploded rock mass allows us to judge the minimum displacement, even in comparison with decelerations of 275×300 MS. The spread of the exploded rock mass is insignificant – the main mass of the exploded rocks is located within the contours of the exploding block. An experimental explosion with a 450×600 MS surface network deceleration and 5000 MS borehole decelerators, performed in November 2019, showed a practical flat surface of the collapse completely remaining within the block contour. The upper layer of permafrost with a capacity of up to half a meter is fragmented without the use of additional charges in the upper part of the blast wells. The USE of RIONEL LP-50 downhole detonators with a deceleration of 5000 MS allowed to increase the level of safety in the production of blasting operations – the activation of surface networks occurs with a significant gap from the downhole detonators. In addition, it is now possible to install the initiation circuit on a block with different-sized grids for the location of blast wells.
4. Conclusions
Thus, the method of working out local areas of mineralization in strong rocks using explosive loosening of rocks in the conditions of natural "clamping" by a natural array with decelerations between successive explosions of boreholes above 300 MS allows to achieve a minimum displacement of the exploded rock mass in both horizontal and vertical directions without any additional costs.

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