ORIGINAL PAPERS

DOI: 10.17073/2500-0632-2019-1-4-15

The Study of Parameters of Quarry Faces in Muruntau and Myutenbai Open Pits in Case of Applying Major Blasts

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Abstract: The paper presents process layouts for excavation of zones near pit envelope based on the analysis of findings of the ore loss study in case of open-pit mining, as well as the results of field measurements in the quarry faces in Muruntau and Myutenbai open pits. In the course of the field measurements, parameters of the quarry faces at Muruntau and Myutenbai open pits were determined under the following working conditions of an excavator: at full bench with shotpile height of 19–21 m; at full bench with shotpile height of 12–14 m at excavation of the "blast cap"; at heading face and taking ramp material. In all the above-listed quarry faces, the slope angles and the ore mass shotpile height when excavating were measured. Besides, the used excavator type (dragline or hydraulic) was taken into account. For each face, 2–3 measurements were performed, and the average slope angle at the ore mass excavation was determined for each type of excavator. At the next stage of the field measurements, the bench height in the rock mass and the shotpile parameters were measured before and after blasting operations under the following arrangements for preparing the rock mass for excavation: a) under normal conditions, when the ore mass blasting is performed for the selected face or relieving wall of the required thickness; b) in compression with a "blast cap" formation; c) in the marginal parts of the bench. Based on the results of the actual bench height and the blasted rock shotpile parameter field measurements, the following conclusions were drawn: a) the actual slope angles of the quarry faces were 49° when excavating the "blast cap" using dragline excavators, and 53° when excavating the ore mass at full bench regardless of the excavator type used; the slope angles of 49° for the dragline excavator and 53° for the hydraulic excavators were taken for further calculations; b) the width of the marginal (near-envelope) zone, where losses and dilution of balance ore are generated, increased from 7 to 13.0 m (at 49°) and from 7 to 11.3 m (at 53°); as a result, the areas of loss and dilution triangles have increased; c) when blasting in compression conditions, in the upper part of the shotpile, intense mixing of the involved rock and all ore grades occurs, therefore, when excavating the "blast cap", bulk ore mass mining is only possible. The lower part of the blasted bench preserves the geological structure of the rock mass to a greater degree and can be selectively excavated with separation of the ore mass by grade; d) when blasting the rock mass, to maintain the required pulse direction and the blasting sequence, barren boreholes are included in the breaking outline, which increase the balance ore dilution, and structural dilution arises, which should be taken into account when drawing up the "Methods for determining, limitation and accounting for ore losses and dilution in the course of the Muruntau and Myutenbai (the fifth stage) open-pit mining"; e) when compiling the "Methods ...", the option of dividing a bench of 15 m high into two sub-benches of 7.5 m should be considered.

Keywords: excavator, face, blast, open pit, measurement, bench, ore, dragline, hydraulic, slope.

For citation: Raimzhanov B. R., Khasanov A. R., Vakhitov R. R. The study of parameters of quarry faces in Muruntau and Myutenbai open pits in case of applying major blasts. *Mining Science and Technology*. 2019;4(1):4-15. (In Russ.). DOI: 10.17073/2500-0632-2019-1-4-15.

Исследование параметров экскаваторных забоев при массовых взрывах в карьерах Мурунтау и Мютенбай

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Аннотация: В статье приводятся технологические схемы отработки приконтурных зон на основе анализа результатов исследований по потерям руды при открытой разработке месторождений и результаты проведения натурных замеров в экскаваторных забоях карьеров Мурунтау и Мютенбай. В ходе проведения натурных замеров определены параметры экскаваторных забоев на карьерах Мурунтау и Мютенбай при следующих условиях работы экскаватора: полным уступом с высотой развала 19–21 м; полным уступом с высотой развала 12–14 м при отгрузке «шапки взрыва»; проходке и подборе съезда. Во всех вышеперечисленных экскаваторных забоях произведены замеры углов откоса и высоты развала при экскаваторной выемке рудной массы. Также учитывался применяемый тип экскаватора – канатный или гидравлический. По каждому забою производились 2–3 замера и определялся средний угол откоса при экскаваторной выемке рудной массы для данного типа экскаватора. На следующем этапе проведения натурных замеров измерялись высота уступа в массиве и параметры развала до и после производства взрывных работ при следующих схемах рудоподготовки массива к экскавации: а) в нормальных условиях, когда взрывание рудного массива производится на подобранный забой или подпорную стенку требуемой толщины; б) в зажатой среде с образованием «шапки взрыва»; в) в краевых частях уступа. По результатам проведения натурных замеров фактических углов откоса и параметров развала взорванных пород сделаны следующие выводы: а) фактические углы откосов экскаваторных забоев составили при отгрузке шапки взрыва 49° при применении канатных экскаваторов, а при выемке рудной массы полным уступом 53° независимо от типа применяемого экскаватора; углы откоса экскаваторного забоя 49° для канатного экскаватора и 53° для гидравлических экскаваторов приняты для производства дальнейших расчетов; б) увеличилась ширина приконтурной зоны с 7 до 13,0 м (49°) и с 7 до 11,3 м (53°), где образуются потери и разубоживание балансовой руды, вследствие этого увеличились площади треугольников потерь и разубоживания; в) при взрывании в зажатой среде в верхней части развала происходит интенсивное перемешивание прихватываемой породы и всех сортов руды, поэтому при отгрузке шапки взрыва возможна только валовая выемка рудной массы. Нижняя часть взорванного уступа больше сохранит геологическую структуру массива и может быть отработана селективно с разделением рудной массы по сортам; г) при взрывании массива для соблюдения требуемого направления импульса и очередности взрывания в контур отбойки включаются безрудные скважины, которые увеличивают разубоживание балансовой руды, возникает конструктивное разубоживание, которое необходимо учесть при составлении «Методики определения, нормирования и учета потерь и разубоживания руды при разработке карьеров Мурунтау и Мютенбай (V-очередь)»; д) при составлении «Методики…» следует рассмотреть возможность разделения уступа высотой 15 м на два подуступа по 7,5 м.

Ключевые слова: экскаватор, забой, взрыв, карьер, замер, уступ, руда, канатный, гидравлический, откос.

Для цитирования: Раимжанов Б. Р., Хасанов А. Р., Вахитов Р. Р. Исследование параметров экскаваторных забоев при массовых взрывах в карьерах Мурунтау и Мютенбай. *Горные науки и технологии.* 2019;4(1):4-15. DOI: 10.17073/2500-0632-2019-1-4-15.

For increasing effectiveness of gold ore deposit development by open-cut mining, the actual task of a mining enterprise in the gold ore extraction is to determine, control, standardize and account for the values of ore loss and dilution, as well as the parameters of quarry faces.

The previous studies on this topic performed by domestic and foreign scientists were devoted to excavators with small bucket capacity. Interesting production data are given in the work of B. P. Yumatov. The studies of changing ore losses and dilution depending on the number of rows of boreholes were carried out by a number of authors. Based on the measurements taken in the conditions of the Sorsky deposit, it was noted that at multi-row blasting the losses increased by 6 times, and dilution, by 3 times compared with single-row blasting. The authors explain these defects of multi-row blasting by the individual features of the geological and morphological structure of the Sorsky stockwork and the imperfection of the implemented drilling and blasting.

In fact, the defects are the result of the fact that the outliners of the ore bodies in the shotpile were not known, and therefore the excavation of the blasted rock mass was carried out "blindly". This work correctly indicates that the use of the method of tool surveying and designing commercial and non-commercial sections for a multi-row block shotpile is only possible with accurate taking into consideration the degree of transformation and mixing of the ore sections of the block during the blasting. At the same time, the possibility of implementing such an operation with modern drilling and blasting methods is being called into question.

An attempt to theoretically determine the positions of the individual layers of a bench in the shotpile was undertaken by G.G. Lomonosov. He proposed an algorithm for predicting shotpile parameters based on the laws of external ballistics. The essence of the algorithm is that based on the magnitude of the initial rock fragment velocity, using the laws of external ballistics, it is possible to determine the trajectories of points located on the outer contour of the blasted bench. This allows determining the nature of the bench rock distribution in the blasted rock mass.

In the process of drawing up the "Methods for determining, limitation and accounting for ore losses and dilution in the course of the Muruntau and Myutenbai (the fifth stage) open-pit mining"; for the "M" mine of the Central Mine Group of the Navoi Mining and Metallurgical Combine, the initial data were determined and refined.

Process layouts for mining in near-envelope (contact) pit zones

Based on the analysis of the findings of the studies on ore losses during open pit mining, it was found that the contact (or near-envelope) zone demonstrates a complex shape of the ore-rock contact surface and in some cases may not have a distinguished contact surface. It is possible to distinguish a certain volume of rock mass located in the transitional zone from balance ore to off-balance ore or from one ore grade to the next. Depending on an ore body dip angle and the height of a working bench, the contact zone may have different widths.

The size of the contact zone in plan view and in the cross-section depends on a number of factors:

– grades of valuable components in the contact zone;

– the ore body dip angle in the contact zone;

– the height of working bench;

– visual distinguishability of ore and rock.

Excavation of contact zones can be carried out by longitudinal or transverse cuts. The selection of cut type depends on the following factors:

– curvature of the contact zone line in plan view;

– the degree of visual distinguishability of ore and rock in the contact zone;

– the degree of curvature of the "ore-rock" contact plane in vertical sections;

– parameters of ore bodies – strike, thickness, dip angle.

The less curved the contact zone line in plan view and the greater its length, the more appropriate the selective excavation of the contact zone, since in this case the excavating cut does not practically change its direction. The selection of the longitudinal or transverse layouts for contact zone excavation is carried out on the basis of the requirements for the quality of the extracted minerals. The longitudinal mining pattern should be selected under conditions of a large length of the contact zone without changing direction, whereas the transverse one, in case of a strongly curved contact zone line with changeable direction in plan view.

Currently, when using the block model for reserve estimation in the contour of the mined bench, which is considered to be a mining unit, the following ore grades are distinguished:

– three grades of rich ore located in the central part of the ore deposit being developed (core of the deposit), namely:

a) balance ore with the metal grade in excess of 4.0 conditional units (CU);

b) balance ore with the metal grade of 2.0 to 4.0 CU;

c) balance ore with the metal grade of 1.50 to 2.0 CU;

– balance ore with the metal grade of 1.0 to 1.50 CU;

– balance ore with the metal grade of 0.50 to 1.0 CU;

– off-balance ore graded at from 0.40 to 0.50 CU;

– rock – mineral mass with the metal grade below 0.40 CU

To draw up grade plans for ore excavation (digging) within the mining bench, at the current planning, three balance ore grades (a, b, c), due to their small amount, are usually combined into one grade of balance ore with the metal grade exceeding 1.50 CU, which is selectively excavated, stockpiled in a separate sectional type ore stockpile, and serves to charge leaner ore grades supplied to GMZ-2 (processing plant) for processing. This allows stabilizing the metal grade in the commercial ore going to processing, and ensures stability of the final product output.

The analysis of the ore excavation parameters in the contact zones involved the following ore grades:

– balance ore with the metal grade in excess of 1.50 CU (denoted as R – "Rich");

– balance ore with the metal grade of 1.0 to 1.50 CU (denoted as M – "Medium");

– balance ore with the metal grade of 0.50 to 1.0 CU (denoted as LG – “Low-grade ore”);

– off-balance ore with the metal grade of 0.40 to 0.50 CU (denoted as OB – “Off-Balance”);

– rock with the metal grade of less than 0.40 CU (denoted a R "Rock").

The presented division of ore mass into grades corresponds to the approved conditions for the Muruntau and Mutenbai deposits development in the fifth stage envelope.

Analysis of the “ore - enclosing rocks” contact zones for the Muruntau and Mutenbai deposits made it possible to classify their manifestations.

The developed classification covers the features of the contact zone geological structure, the qualitative characteristics of the enclosing rocks, the ore grades, rock types, the valuable component content in relation to the mine engineering parameters of mining operations (concordant or discordant dipping of the contact zone, the bench slope line and front of acting benches, the contact dip angle) (Fig. 1).

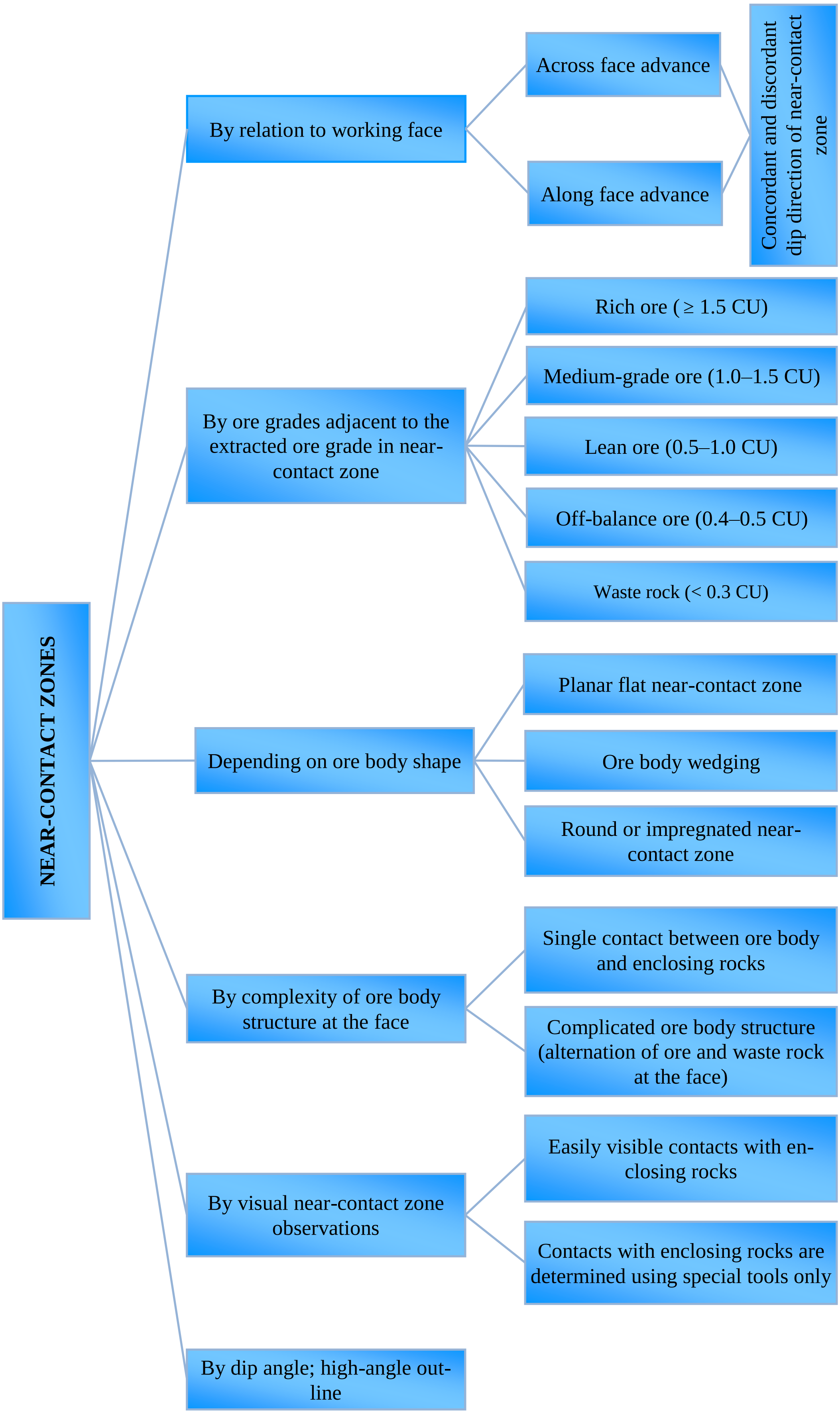

Fig. 1. Classification of contact zones

For the analysis, the main types of the contact zones were selected on the grade plans presented by the Navoi MMC specialists. The studied contact zones are the boundaries between the ore grades, the extraction of which is carried out selectively according to the surveyed reference points. Bulk mining of all grades of ore and rock with preservation of the rock mass structure is envisaged. The boundary between the grades of ore and rock is assumed to be vertical within the limits of the extracted bench.

In this case, the face in vertical section can be conditionally divided into right and left parts, respectively, with ore of one grade and ore of the next grade, ore of one grade and rock, or vice versa, depending on the direction of excavation. The metal grade in the rock mass of the near-contact zone is assumed to amount to the average value between the grade of excavated ore and the grade of the bordering ore (admixed to the excavated ore).

The boundary grade at the contact between the ore or rock grades is assumed to be equal to the cut-off grade for the division of the ore and rock grades. The width of the near-contact zone, where different ore types and rock are mixed, was determined by the graphical-analytic method depending on the slope angle during excavation of the blasted rock mass. The maximal slope angle is accepted for both transverse and longitudinal cuts: 49^{o} and 53^{o}, respectively. The contact zone width amounted to 13.0 m (Fig. 2).

The ratio of the different ore grades interval lengths in the extraction contour was determined based on the equation of $C_{вк}$, the metal grade at the boundary of the extraction contour; $C_{бс}$, the accepted grade for the separation of ores into the grades for the reserve estimate. The $C_{бс}$ value is taken according to the current separation of ore into the grades when planning production in an open pit.

In this case, the length of ore and rock intervals on the boundary between the ore grades in the course of excavation is determined from the following equation:

$$H \cdot C_{бс} = h_р \cdot C_р + h_п \cdot C_п,$$
$$h_р = \frac{H \cdot (C_{сб} - C_п)}{(C_р - C_п)}, \quad (1)$$
$$h_п = H - h_р,$$

where H is the height of the extracted layer at the boundary between the selectively extracted ore types; $h_р$ is the length of the extracted ore grade at the face or the length of the ore interval at the ore/rock boundary; $h_п$ is the length of the rock interval at the face at the boundary with the extracted ore grade type, or the length of the rock interval at the ore/rock boundary; $C_р$ is the gold grade in the ore in the extraction contour (the normalized average gold grade for the extracted ore grade type); Сп is the gold grade in the admixed rock mass (the normalized average gold grade for the ore grade type adjacent to the extracted ore grade type); $C_{бс}$ – cut-off grade of gold for the division into the ore grades, the ore/rock separation.

In Fig. 2: L – the length of an elementary ore block or the length of the scooping line at several scooping faces, m; S_p – the area of the ore loss triangle in the elementary ore block, m; $S_п$ – the area of the triangle of admixing of the adjacent ore grade or dilution of the elementary ore block by rock, m; α – the angle at which the upper contour of the blasted rock mass begins to be loaded when the excavator bucket scoops along the bench bottom (determined experimentally), degrees; $C_{бс}$ – boundary (cut-off) grade for separating the ore grades, ore and rock, conditional units; $C_п$ – gold grade in diluting rock mass, conditional units; C_p – gold grade in the elementary ore block, conditional units; $l\Delta$ – the width of the near-envelope (near-contour) zone, m; $\Delta_р$ – the distance to the point of positioning the flag, indicating the border of the rock mass loaded as ore, m.

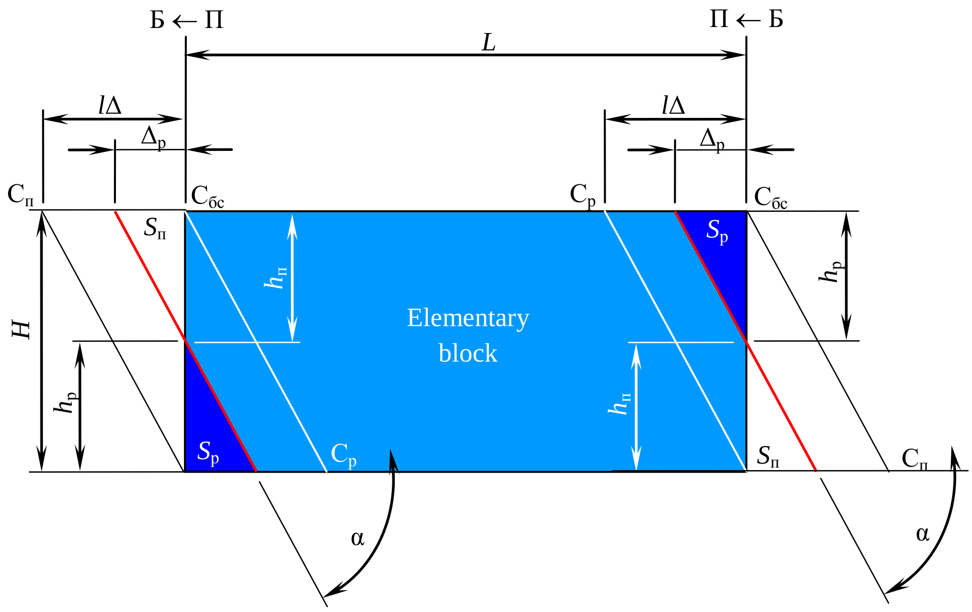

Fig. 2. Schematic of losses and dilution generation in bench slopes when scooping blasted ore mass:
L – the length of an elementary ore block or the length of the loading line at several sides of loading, m; $S_р$ – the area of an ore loss triangle in an elementary ore block, m^2; $S_п$ – the area of a triangle of admixing the neighboring ore grade or dilution by a rock for an elementary ore block, m^2; α – the angle at which the upper contour of the blasted rock mass begins to be undermined when scooping along the bench bottom (to be determined experimentally), degrees; $С_{бс}$ – cut-off grade of gold for the separation of grades of ore, ore and rock, conditional units; $С_п$ – gold grade in the diluting rock mass, conditional units; $С_р$ – gold grade in the elementary ore block, conditional units; *l*Δ – width of the border zone, m; $Δ_р$ – the distance to the flag-indicator to be installed for indicating the boundary of the rock mass loaded as ore, m)

As part of the analysis, various options for selective ore extraction in the contact zones between different ore grades, depending on the direction of excavation, are considered.

It is accepted that: when excavating ore from richer one towards leaner one, a shift from the contact by the size of the loss triangle should be taken, while when excavating in opposite direction, the shift from the contact by the size of the dilution triangle should be taken.

The slope angles of excavating cuts are taken on the basis of the field measurements at the Muruntau and Mutenbai open pits and amount to 49° for dragline excavators and 53° for hydraulic excavators.

Results of the field measurements in the quarry (excavating) faces of the quarries of the Muruntau and Mutenbai open pits

The parameters of the quarry faces were measured at the Muruntau and Mutenbai open pits under the following conditions of excavating:

– by full bench with the shotpile height of 19–21 m;

– by full bench with the shotpile height of 12–14 m when excavating the “blast cap”;

– by ramp cutting and scooping.

In all the above-listed quarry faces, the slope angles and the ore mass shotpile height at digging were measured. Besides, the used excavator type (dragline or hydraulic) was taken into account. For each face, 2-3 measurements were performed, and the average slope angle at the ore mass digging was determined for the type of excavator.

The results of determining the slope angles of the quarry faces are given in Table 1.

At the next stage of the field measurements, the bench height in the rock mass and the shotpile parameters were measured before and after blasting operations under the following arrangements for preparing the rock mass for excavation:

a) under normal conditions, when the of the ore mass blasting is performed for the swept face or relieving wall of the required thickness;

b) in compression with a “blast cap” formation;

c) in the marginal parts of the bench.

Table 1

Slope angles of quarry faces

Type of excavator	Type of work	Slope angle, degrees		
		from	to	average
Muruntau open pit				
EG-12	Full bench	52	55	53
Myutenbai open pit				
EKG-77	“Blast cap” loading	45	50	49
EKG-60	Full bench	52	55	53
EG-14	Ramp cutting	47	51	–

Table 2

The results of the field measurements of the blasted rock shotpile parameters

Level	Bench height, m	Blasting method	Blasted bench height, m		
			from	to	average
Muruntau open pit					
+330	15	With “blast cap” formation	17	+330	15
+135	15	With “blast cap” formation in marginal parts	16	+135	15
Myutenbai open pit					
+315	15	With “blast cap” formation	23	+315	15
+315 (Block 1)	10	Under compression conditions	15	+315 (Block 1)	10
+315 (Block 2)	10	Under compression conditions	16.5	+315 (Block 2)	10
+300	15	For excavated face	13.8	+300	15

At the “M” mine open pits, row-by-row arrangement of blast holes on a 5.6×5.6 m grid was adopted. The drilling within a working bench is based on the drilling project. The boreholes located within an ore body outline are exploratory-production, in which drill cuttings are sampled every 5 m. In the samples of drill cuttings in the laboratory, the metal grade is determined, and then the average metal grade in the block model cell tied to this borehole is calculated.

For each specific block, a Project for loading borehole charges is drawn up, which indicates the blast network installation layout, providing the required direction of the initiating pulse passage and the sequence of blasting of the borehole charges.

In accordance with the specific mining conditions and parameters of the excavation equipment used, the following types of the blasted block rock mass shotpile formation are distinguished:

– normal conditions when the shotpile height is compatible with the digging height of the excavator used;

– with "blast cap" formation along the shotpile axis;

– with "blast cap" formation near the bench face – to be applied in the edge parts of the bench.

In the course of the field measurements, the elevation of the rock mass was measured before and after blasting, and then the height of the formed shotpile was determined.

The results of the field measurements of the blasted rock shotpile parameters are given in Table 2.

Conclusion

Based on the results of the field measurements of the actual slope angles and the parameters of the blasted rock shotpile, the following conclusions can be drawn:

– the actual slope angles of the quarrying faces amounted to the following values:

– when excavating the "blast cap" and using excavators – 49°;

– when mining ore mass by full bench – 53°, regardless of the excavator type used;

– the slope angles of the quarry face, 49° for dragline excavators and 53° for hydraulic excavators, are accepted for further calculations;

– it should be noted that the actual slope angles of the slope angles are lower than the slope angles adopted in the calculation method used by the mine, where the slope angle is 70–75°;

– the width of the marginal (near-envelope) zone where losses and dilution of balance ore are generated increased from 7 to 13.0 m (at 49°) and from 7 to 11.3 m (at 53°); as a result, the areas of loss and dilution triangles have increased;

– the height of the blasted rock shotpile when blasting to a relieving wall or swept face does not exceed the digging height of the excavators used;

– when blasting in compression conditions with the formation of "blast cap", the height of the blasted rock shotpile exceeds the excavator digging height that restricts the scope of use of hydraulic excavators;

– when blasting in the edge parts of the bench, the direction of the rock mass breaking and the shotpile formation occur at the bench face;

– when blasting in compression conditions, in the upper part of the shotpile, intense mixing of the involved rock and all ore grades occurs, therefore, when excavating the “blast cap”, bulk ore mass extraction is only possible. The lower part of the blasted bench preserves the geological structure of the rock mass to a greater extent and can be selectively excavated with separation of the ore mass by grade;

– when compiling the "Methods ... ", the option of dividing a bench 15 m high into two sub-benches 7.5 m high should be considered.

– when blasting the rock mass, to maintain the required pulse direction and the blasting sequence, barren boreholes are included in the breaking outline, which increase the balance ore dilution, and structural dilution arises, which should be taken into account when drawing up the “Methods for determining, limitation and accounting for ore losses and dilution in the course of the Muruntau and Myutenbai (the fifth stage) open-pit mining".

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