

Study on the influence of the deformation zones of the quarry sides on the rock mass movement

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Abstract. The article presents a study and analysis of the causes of deformation of the slopes and sides of the quarry indicates that the magnitude and nature of the deformation processes depend on the height of the ledge, the angle of slope of the slopes, the physical and mechanical properties, the lithological and structural features of the instrument array and the geodynamic activity of the fault zones. The influence of the deformation zones of the sides of the quarry on the transport of rock masses is justified. The zone of deformed masses of the ore deposit, which affect the movement of the rock mass, is studied. Each process performed in open pit mining is linked to another workflow. Without ensuring the safety of mining operations and performing the tasks set is impossible. Transportation of rock masses in the lower horizons of a deep quarry is one of the main tasks of the industry. At the same time, the removal of deformation and landslides in the area where the transport berm is being constructed for draining and continuous transportation is the main goal of the quarry. The stability of the transport berm depends directly on the stability of the side of the quarry. It is determined that the choice of a single-lane or two-lane transport berm constructed for heavy-duty quarry dump trucks depends on the condition of the side of the quarry.

1 Introduction

Ensuring the stability of the sides of quarries is a very urgent problem [1, 2]. The issues of stability are solved in the conditions of the unique diversity of mining and geological conditions in a very strict economic framework when determining both the maximum depth of open-pit mining and the slope angles of the sides on the limit contour. The stability of the slopes is considered by most experts as a result of the manifestation of mountain pressure [3, 4]. Along with the commonality of a number of issues of ensuring the stability of slopes, there are also differences and this is primarily due to the peculiarities of the geological structure of deposits, development technologies and requirements for the extracted raw materials. For example, quarries for the extraction of non-ferrous metals and iron ores have much in common both in terms of the range of engineering and geological conditions, and in terms of development technology. High value of non-ferrous metal ores

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technologies for the development of metals and iron ores have much in common both in terms of the range of engineering and geological conditions, and in their development provides for the use of expensive landslide measures, while in the conditions of iron ore quarries they may be economically impractical, etc.

An increase in the volume of open-pit mining operations is associated with a number of features of ensuring the stability of slopes [5, 6]. Among them are the following:

- increase in economically feasible depths of open works;
- the interdependence of slope stability with the development system and the mining regime;
- the need to change the parameters and configuration of slopes during the operation of quarries;
- determining influence of technological factors;
- maintaining the slopes of the sides of the quarry in a stable state;
- creation of normal working conditions for mining and transport equipment.

This example shows that the transfer of research results is possible when taking into account not only geological features, but also all the factors that determine the stability of the sides of quarries. Depending on the purpose of the slope section of the quarry side and the time of its existence, there are five groups of slopes:

- slopes of the opening workings;
- permanent boards near protected objects;
- permanent boards that do not contain transport communications;
- temporary-permanent boards;
- slopes of working ledges.

2 Methods

The angles of the slopes of the ledges vary from 25-30° to 90° and they are determined structurally and are for working sides and berms and platforms for various purposes – 10-25°, for permanent sides and slopes of trenches, from 15° to 45-60°.

Taking into account the time, the state of the slope and its purpose, it is recommended to vary the stability margin coefficient from 1.1 for the ledges of the working sides of the quarries of the opening workings. The recommended coefficients of the stability margin of the slope quarries are given in the Table 1 [7].

A group of technological factors that determine the behavior of rocks in the sides is the method of opening, the development system.

The direction of development of mining operations in space should be chosen taking into account the engineering and geological structure of the massif and at the same time the stability of the slopes of the working ledges and the sides of the quarry should be evaluated by a complex technological parameter – the speed of movement of the front of the mining operations. For both working and non-working boards, it is important to take into account their design parameters, shape in the plan and profile.

Therefore, it seems effective to adopt a rational mining regime based on the results of engineering and geological zoning of quarry fields. However, as practice shows, the angles of inclination of the slopes of the sides when calculating the volumes of overburden and mining operations were taken without taking into account the variability of the engineering and geological conditions of the quarry fields. At the same time, the change in the strength characteristics of the rocks of the side array over time was not taken into account, which led to a decrease in the reliability of determining the reserve coefficient and the true determination of the volume of overburden work.

Table 1. Recommended coefficients of the slope stability margin of the quarry

Group	Slope characteristics	Service life	Anti-deformation measures	Recommended stability margin factor
I	Slopes of opening workings, areas containing stationary devices (conveyor and skip lifts, tunnels, inclined shafts, etc.)	Almost the entire service life of the quarry (40-50 years)	Any technical possible and economically feasible	1,3-1,5
II	Permanent boards, near which there are protected objects-safety pillars at reservoirs, settlements, highways, etc.	The same thing	Determined by technical and economic calculations	1,2-1,4
III	Permanent boards that do not contain transport communications	As the limit contours are drawn up	For the slope, filtration loading, upland ditches, drainage, in some cases, sowing of grasses, shotcrete	1,2-1,3
IV	Temporary-permanent boards	10-15 years	For the slope, filtration loading, drainage	1,15-1,2
IV	Working ledges	A few months	As a rule, it is regulated by the height and angle of inclination, as well as the parameters of the equipment used; drainage; in exceptional cases, loading with filtering material (Sarbaysky quarry)	1,1-1,2

Recently, quite a lot of research has been carried out, the purpose of which was the engineering and geological zoning of quarry fields according to the conditions of slope stability and the development of mining and technological solutions for the choice of field development systems and slope management using special methods. When assessing the stability of the slopes, conditional-instantaneous indicators of rock strength were used, taking into account the coefficients of structural weakening of the massif.

Of the technological processes, drilling and blasting operations have the greatest influence on the stability of the slopes of rock and semi-rock rocks and on the value of the angle of inclination of the sides [8].

The explosion, as it were, simulates in miniature an earthquake, the epicenter of which is located at the location of the explosive charge. On the surface of the charging chamber, a voltage pulse equal to (10 – 30) MPa occurs during the explosion. Under the influence of this pulse, a shock wave occurs in the rock, the voltage of which decreases sharply as it moves away from the center of the charge, reaching a value of 250 – 180 Mpa at a distance of five radii of the charge, and at a distance of 20 radii – 30 – 180 Mpa. The following

zones are formed near the charge: plastic deformations, where the stress exceeds the compressive strength of rocks; elastic-plastic deformations, in which the destruction occurs due to defects in the structure of the rock mass, and the stresses exceed the tensile strength of the structural defects; cracking and elastic vibrations. Near the last row of wells, sometimes a pinhole zone is isolated, where large cracks with displacement appear after the explosion.

In many quarries, the technology of forming a preliminary gap on the project contour of the ledge is currently used to protect the legal rocks from the crushing and seismic effects of explosions; a screening gap is created by simultaneously exploding hose charges in wells drilled along the contour with an interval of 2.0 -3.0 m. However, detonation in the contact area must be carried out under certain conditions. The main condition is to ensure the complete flow of water from the screening slot. For example, in the near-contour massif of the Murantau quarry, there are zones of intensely fractured rocks and areas of dehydrated rocks, so preliminary crevice formation does not give the desired effect in these areas. Taking into account the above, instrument arrays can be divided into two categories:

- 1) areas of the instrument array where pre-crevice formation is an effective means of protecting against mass explosions;
- 2) areas of the instrument array, where the use of the method of preliminary crevice formation does not give the desired effect.

Therefore, the choice of effective technological schemes of slope in the zone of residual deformations should be carried out taking into account the geological structure of the near-contour array and on the basis of a technical and economic calculation of the depth of the quarry, at which it is economically feasible to use preliminary crevice formation, which is determined by the formula:

$$H \geq \frac{2 \cdot C_3}{C_3 \cdot (\operatorname{ctg} \alpha - \operatorname{ctg} \alpha_3) \cdot \sin \alpha_3} \quad (1)$$

Where C_3 – is the cost of cutting 1 m² of the slope, taking into account the costs of drilling and blasting the contour row of wells, the amounts;

C_B – the cost of extracting 1 m³ of overburden, the amounts;

α – the angle of inclination of the side of the quarry without contour blasting, deg;

α_3 – angle of inclination with the use of contour blasting, deg.

Therefore, taking into account the above, the design depth of the quarry is an important factor that should be taken into account when zoning the instrument array.

With an increase in the depth of the quarry, the nature of the stress distribution in the rock mass changes, the greatest concentration of shear stresses occurs along the side of the quarry and at the bottom of the slope, which partially changes the overall field stress and forms dangerous deformations. It should be noted that the destruction, as a result of drilling and blasting operations, penetrates deep into the massif and affects the stable state of the sides of the quarry. For example, the drilling of wells of the order of 3 m significantly destroys the upper part of the slope of the future horizon and along it the safety and transport berms become unstable.

Mass explosions near the limit contour of the board create a zone of partial crushing of rocks, extending to 60-70 m from the explosion site, dramatically weakening their strength and accelerating the process of weathering. In addition, the stress state of the rock mass also changes noticeably, which reduces the strength of the rock bond over the weakest surface of the rock mass and, with a small margin of stability, leads to sudden collapses of significant sections of the quarry sides.

In most cases, flat models are used to study the mechanism of explosion action. The theoretical justification for the use of flat models is quite fully described. The specifics of modeling the effect of an explosion on low-modulus optically active materials require the study of the initial (before the action of the charge) voltage fields in the module, taking into account all the necessary conditions for modeling a gravitational array with a cavity whose parameters correspond to the simulated design of the charge [9,10,11].

As practice shows, the issues of applying special methods of conducting mining and drilling and blasting operations to ensure the stability of the sides of the quarry are solved depending on the mining and geological structure of the instrument array and the mining conditions of the quarry. It should be noted that the surfaces of structural weakening of rocks significantly affect the width of the fracture zone [12-15].

3 Results and Discussions

The analysis of the causes of deformations showed the following:

- almost all types of deformations have been recorded at the Muruntau quarry-collapses, landslides, chipping, subsidence and scree. Landslides and collapses are most developed;
- the areas of the sides that are confined to fault zones, tectonic disturbances, composed of layered carbonaceous and micaceous shales, and weathered siltstones are most susceptible to deformation;
- conditions for the formation of separation and slip cracks, structural and tectonic blocks occur at the junctions and intersections of violations of different orientations, for example: north-eastern with southern, sublatitudinal or submeridional.

To date, the depth of the Muruntau quarry is 630 m. the main mode of transport for the transportation of rock mass is automobile. The main transport berms are located on the North and South sides of the quarry. At the same time, it is necessary to take into account the degree and volume of deformation on the sides of the quarry where the transport berm passes. It is necessary to take into account the deformation zones that affect the transport berm. The condition of the side must meet all technical requirements, since the continuity of the transportation process depends on the stability of the transport berms developed on the sides. Therefore, the earthquake-safe methods used at the Muruntau quarry ensure the safety of structures in the quarry with sufficient reliability [16-20].

Fig. 1 and Fig. 2 show the lines of deformation and their influence on the mining workings of the ledge and transport berms.

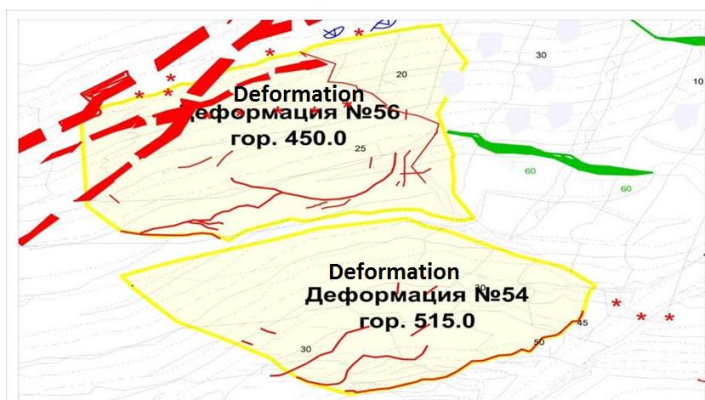


Fig.1. Zones of deformed arrays

The area of these zones subject to deformation will not remain unaffected when transporting rock mass.

The width of transport berms (highways) in quarries varies depending on the number of lanes and the intensity of oncoming traffic, the size of cars and their speeds. In this regard, for heavy-duty vehicles, the width of permanent roads abroad increases to 18-20 m, and in some cases, when they are installed at the exits from the quarry, up to 25-26 and even 30 m (Bingham quarry, USA). In the transverse profile, the width of the roadway increases on curved sections. The transverse slope of paved roads is assumed to be no more than 2%, and the slope of roadsides is up to 4%. But the most important thing is to ensure the stability of transport berms and increase their service life.



Fig.2. Deformations at the Muruntau quarry deformation contour

With the increase in the load capacity of dump trucks, the requirements for the strength, durability and operational reliability of quarry roads, which are mainly paved with crushed stone, increase. Modern quarry roads must ensure high productivity (traffic intensity) and complete safety of road transport operation in conditions of significant dynamic loads. The technology of construction of quarry roads includes the following operations: construction of the roadway; preparation of the roadbed for laying layers of building materials provided for by the road construction; distribution of building materials in the road layers; formation of a cross-section profile of roads; compaction of road layers; treatment of road pavement with binders. Preparation of the roadway involves: marking the route, cleaning oversized pieces of rock, hauling and evenly distributing the crushed material over the entire surface (to eliminate irregularities) and compacting the material by watering it with water (to facilitate the mutual movement of individual pieces). In quarries that develop rock formations, the necessary flatness of the road is achieved by laying and distributing crushed rock voids of the appropriate granulomeres composition on its surface [21].

Due to the fact that in reality, the geometry of the routes of mining dump trucks is characterized by a great variety, there is a need to apply a single design scheme of the route. Depending on the geometry, there are simple, loop, spiral, and combined routes, the sweep of which is a set of route segments. If we assume that the longitudinal slopes of the sections of the route change slightly, then we can imagine any route as a simple one, in which the transport length is inversely proportional to the longitudinal slope of the road [22].

One of the most urgent problems of the development of deep-lying mineral deposits in the open method is the problem of additional separation of the sides for the placement of opening workings. The volume of additional separation of boards for the placement of

opening workings in deep quarries is millions and tens of millions of cubic meters of opening rocks. This is due to the fact that the placement of opening workings leads to a flattening of the sides of the quarry in comparison with their stable values. The sides of quarries, according to the stability conditions, most often have a convex profile, and according to the design conditions, a concave one. The reason for the latter is an increase in the specific weight of the opening workings in the total mass of the platforms and berms on the sides as the depth of the quarry increases due to a decrease in the length of the lower ledges. This is especially true for quarries with a small bottom length, in which the reduction of the length of the ledges with depth is particularly intense [23].

The slope of quarry roads is associated with the volume of mining operations during the construction of transport berms. In deep quarries, the distance of transporting rock mass from the bottom to the surface of the quarry where the transshipment point is located is very large. Therefore, theoretically, in order to reduce the distance and volume of mining operations for the construction of quarry roads, it is necessary to increase the guiding slope [24].

$$V_{r.m} = \frac{0.5 \cdot H^2_k \cdot B_{т.б} \cdot k_{p.тп}}{i} (M^3). \quad (2)$$

Where H^2_k – the depth of the quarry m, $B_{т.б}$ – the width of the transport berm m., $k_{p.тп}$ – the coefficient of development of the route; i – the guiding slope.

According to the above formula, it can be seen that the amount of work performed for transport berms is inversely proportional to the guiding slope of the highway. If you increase the slope of quarry roads, then the volume of mining operations will significantly decrease. Reducing the volume of mining operations affects the reduction of work performed on the sides of the quarry.

4 Conclusions

Increased slopes are sometimes advisable to use when using vehicles at temporary exits, when driving to transshipment warehouses, and especially when refining deposits or their individual sections. The need for accelerated lowering of mining operations is also often the reason for the introduction of increased slopes. In quarries, the most common slopes are caused by the traction, dynamic and speed parameters of the two-axle dump trucks used. They usually amount to 7-8 % and only in some cases reach 9 %. The planned modernization of dump trucks provides for the installation of high-power engines on them, which will increase their power, and this will facilitate the movement of dump trucks with increased speed or overcome steeper slopes. Thanks to this, the guiding slopes that can be overcome will be 10-12 %.

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