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## STABILITY EVALUATION OF JSC "YuGOK" EASTERN PIT WALL TAKING INTO ACCOUNT SEISMIC MASS BLASTING EFFECT

**Purpose**. To determine safe DBO parameters and the numerical estimation of seismic influence on the stability of mass blasting the rock benches. A spiral deep trench for rail transport should have been built during the reconstruction of the transport system of the pit "YuGOK" in order to maintain its production capacity. The construction of the eastern wall is to be produced in limited working area and under unfavorable geological conditions.

**Problem of Research**.The seismic influence of mass blasting on the stability of the benches and bench groups is currently a poorly defined. In the above mentioned methodological instructions only the fact that the negative impact of seismic mass blasting on the stability of open mines is mentioned, but analytical expressions for the numerical determination of the influence are not given.

**Research methods**. Theoretical aspects of the geomechanical process in the open-pit mine slope. The calculation of the safety degree along the redesigned most dangerous sliding surface performed by means of the algebraic summation of the forces. The refraction point of the sliding surface determined by a gradual approximation using incremental calculations. The geotechnical schemes used to calculate the stability of the benches and bench groups. To determine the numerical value of the rock massif vibration acceleration in mass blasting, the results of seismic monitoring were used.

**Results**. Based on analysis of previous works, the analytical expressions for determining the degree of stability of open pit mining considering seismic impact of mass blasting were obtained. The parameters of the drilling and blasting operations providing the long-term sustainability for benches and bench groups in the pit were elaborated.

**Keywords**: mass blasting, stability factor, seism safe parameters of drilling and blasting operations.

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**Statement of the scientific problem.** The degree of stability of open pits is usually determined by either at the design of mining companies, or at their reconstruction [3]. So in the reconstruction of the transport system of pit "YuGOK" in order to maintain its production capacity it was necessary to build a spiral deep trench for rail transport. This construction, especially in the eastern wall, is to be produced in limited working area and under unfavorable geological conditions (presence of planes of weakness with a slide in the pit and a close residential village). Therefore, the numerical estimation of seismic influence on the stability of mass blasting on rock benches to determine safe DBO parameters during their construction is an important scientific task.

**Analysis of research and publications** Analysis of the literature shows when calculating stability of pit benches and slopes usually engineering methods are used, which are based on the fundamentals of the limit equilibrium theory and are recommended as regulations[1,2].

Basic reference data of these methods is based on the fact that the limit equilibrium is not ensured in all the points of the massif, but only on its inner boundary (most probable slide surface), for which the value is determined by retaining $\Sigma F_{\text{ud}}$ and shear forces $\Sigma F_{\text{sdv}}$. Their ratio determines the value of the safety factor on this $n_z$ surface subsidence

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$$n_Z = \frac{\sum F_{ud}}{\sum F_{sdv}} \, . \tag{1}$$

It is believed that if $n$>1, then rock slope is stable if $n_z$<1, then the slope is unstable. When $n$=1 breed slope is in limiting equilibrium.

The numerical value of the confining forces is determined by the adopted hypothesis of rock strength. When calculating the stability of open pit mines, usually Coulomb-Mohr hypothesis is used according to which the value of holding forces can be determined from the following relation [6]

$$\sum F_{ud} = \sum_{i=1}^{n} m_i \, g \cos \beta_i \cdot tg \varphi_i + \sum_{i=1}^{n} C_i \ell_i \ , \tag{2}$$

where $m_i$ - mass of elementary blocks into which a prism of probable displacement, H; $g$ - acceleration of gravity, m/s$^2$; $\ell_i$ - the area of elementary block foundations of the, m$^2$; $\beta_i$ – slope angle of elementary blocks foundations, deg.; $\varphi_i$ - angle of internal friction on the sliding surface, deg.; $C_i$ - the coefficient of molecular adhesion on the surface of elementary blocks, Pa.

Shearing forces are determined by the sum of the internal (gravity, seismic, hydraulic, etc.) and external forces (load of mining equipment, etc.).

The magnitude of the gravitational forces caused by the rock mass between the prism and the probable displacement determination has no substantial difficulties in accordance with the selected calculation scheme [2].

However, the definition of the seismic influence caused by holding mass blasting on the stability of the benches and bench groups is currently a poorly understood issue. In the above mentioned methodological instructions only the fact that the negative impact of seismic mass blasting on the stability of open mines is mentioned, but analytical expressions for the numerical determination of the influence are not given.

**Physical-mathematical model.** As it is marked blasting of explosive charges in benches does not only perform useful work of crushing rocks, but also has a significant impact on the adjacent, to the blasting unit, part of the rock mass. Thus seismic forces mean the force effect on the rock due to a significant amount of energy during a mass blasting, resulting in the rock mass through the spread seismic waves which cause oscillation of separate pieces of rock mass. These processes are characterized by vibration of velocity $V$ and acceleration of vibrating rock particles.

In accordance with Newton's second law acceleration, determines the magnitude of the of the inertial forces acting on the $F_i$ staggering unsteady rock particles

$$F_i = - m_i \, a_i, \tag{3}$$

where $m_i$ - mass of the oscillating part of the rock mass, kg.

The distribution of the velocity vectors and acceleration in the propagation of seismic waves in rock masses in analytic functions can hardly be described and can be characterized as close to chaotic. Therefore, when determining the direction of the vector of inertia force, we will choose one that most favorable from the view of stability of the rock slope, namely, tangentially to the surface displacement in worked out area (see Fig. 1).

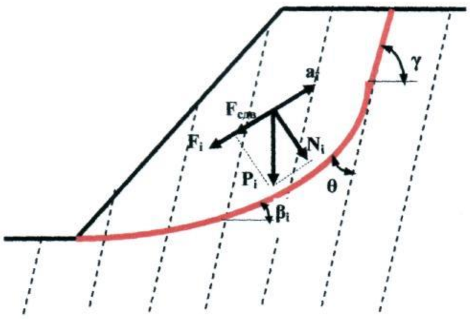


**Fig.1.** Scheme of slope stability calculation in case of steep weakness surfaces and inertia forces

All other possible directions of inertia forces will be directed more favorably in terms of sustainability, as lead to its reduction and the safety factor of rock slope increase.

Then the magnitude of shearing forces acting on the probable sliding surface, can be determined from the analytical expression (4), and the degree of resistance of rock slope based on a seismic impact of mass blasting, of the expression (5)

$$\sum F_{сдв} = \sum_{i=1}^{n} m_i \, g \sin \beta_i + \sum_{i=1}^{n} m_i a_i \ , \tag{4}$$

$$n_3 = \sum_{i=1}^{n} m_i \, g \cos \beta_i \cdot tg \varphi_i + \sum_{i=1}^{n} C_i \ell_i \Bigg/ \sum_{i=1}^{n} m_i g \sin \beta_i + \sum_{i=1}^{n} m_i a_i \ , \tag{5}$$

where $a_i$ - acceleration which elementary blocks vibrate, which prism of probable displacement in split, m/s$^2$; $n_z$ - the safety factor, the proportion of units.

To determine the numerical value of the rock massif vibration acceleration in mass blasting, let us use the results of seismic monitoring.

The analysis of the seismic monitoring results in mass blasting enabled us to determine and present the data [7-9] as to the actually observed velocities of seismic waves and their dependence on the explosive charge weight.

For mining and geological conditions in the eastern edge of the open pit of JSC "YuGOK" the above mentioned dependence is described by the following empirical regularity

$$V = k \cdot \left(\sqrt[3]{q}/r\right)^n, \tag{6}$$

where V is the seismic wave velocity, m/s; q is the explosive weight per delay, kg; r is the distance from the explosion area to the observation point, m; $k$, $n$ are the empirical coefficients characterizing the seismic properties of the rock massive which are equal to: $k$=21,1; $n$=1,86 in this case.

Considering the well-known relationship between the velocity and acceleration of the vibrating body, we obtain

$$a = V\omega = \frac{2\pi V}{T} = \frac{2\pi}{T} \cdot k \cdot \left(\frac{\sqrt[3]{q}}{r}\right)^n, \tag{7}$$

where $T$ is the vibration period, s.

In our research [7], the results of the experimental determination of the seismic vibration period of the rock massif in the eastern pit wall of "YuGOK" are presented. The statistical analysis of the results have revealed that this parameter is equal to $T$=33,5±6,8 ms. The relative error of this parameter determination makes 20,4 %. It should be noted that the seismic vibration period of the rock massif in this area has remained relatively stable over the past few years.

**Bench group stability calculation**. Considering the fact that in accordance with the results of the research [5], the eastern pit wall of "YuGOK" is characterized by steep rock seams directed towards the mined space at an angle of 70-75°, it is appropriate to use the scheme X shown in Table 7.1 to determine its stability degree following the guidelines [2].

When using the mentioned designed scheme (see fig. 1) we take into account that at the border with a loose connection the sliding surface acquires a fracture with an angle θ, which is defined by the formula (8). In the upper part of the movement prism the curved movement surface is designed considering the availability of natural or man-made weakness surfaces and in the middle and bottom parts the movement surface is taken a shape close to the circular and cylindrical one

$$\theta = \frac{\pi}{4} - \frac{1}{2} \cdot \left(\varphi - \varphi^1\right) - \frac{1}{2} \cdot \arcsin\left(\frac{\sin\varphi^1}{\sin\varphi}\right), \tag{8}$$

where $\varphi$ is the angle of internal friction along the country rock, rad.; $\varphi^1$ is the angle of internal friction along the fractures, rad.

The calculation of the safety degree along the redesigned most dangerous sliding surface is performed by means of the algebraic summation of the forces. The refraction point of the sliding surface is determined by a gradual approximation using incremental calculations.

The bench stability calculation in case of eastern pit wall bench groups of "YuGOK" is based on their designed position after the completion of the railway spiral V-shaped extended trench and the location of the vertical sections on the designed pit outline is shown in Fig. 2.

The geotechnical schemes used to calculate the stability of the benches and bench groups are shown in Fig. 3.

While taking into account the seismic impact of the mass blasting on the stability of bench groups in the area of the V-shaped trench construction it has been highlighted that the maximum explosive weight per delay in this case should not exceed 1075 kg. This is justified by the fact that the mass blasting operations at the open pit of "YuGOK" cannot cause seismic waves in the area of protected sites with the force of more than 2 points on the International Seismic Scale MKS- 64. The calculation results are presented in table 1. At the same time as the following standard parameters have been adopted: for a of bench group of the spoil-pile wall composed of fractured rocks with a lifetime of more than 5 years the stability degree should be at least 1.3, for benches of the spoil-pile wall composed of fractured rocks with a lifetime of more than 5 years the stability degree should be at least 2.0.

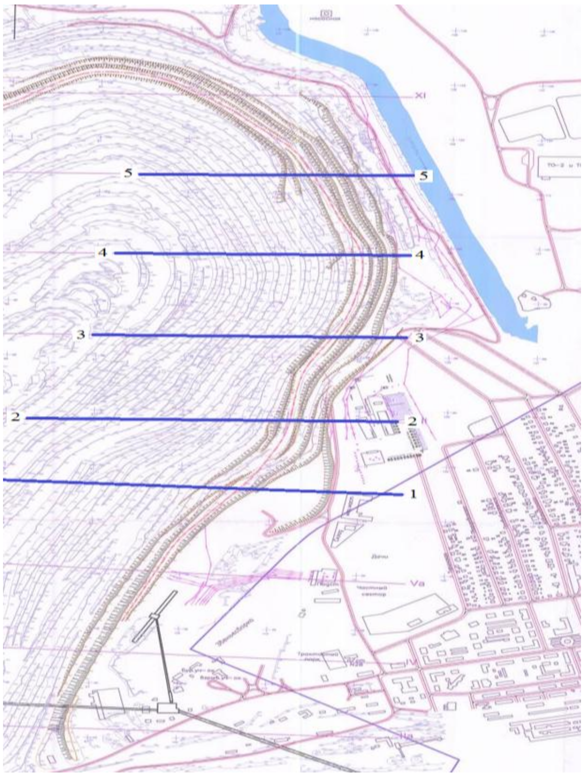
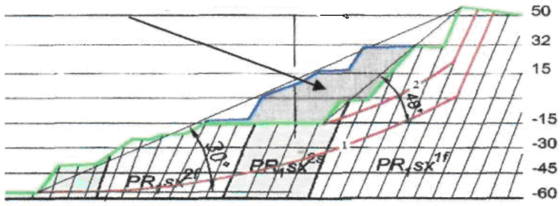


**Fig. 2.** Position of calculated sections in the eastern pit wall design of "YuGOK"




rock volume to be mined when constructing V-shaped trench

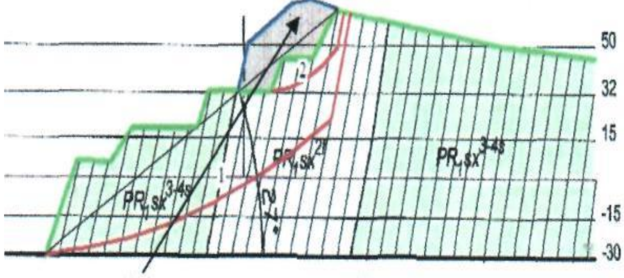



**Fig. 3.** Scheme to the calculation of the bench groups stability along the section 2-2 (*a*) and the section 4-4 (*b*)

**Analysis of the results.** The calculation results prove that the stability degree of benches and bench groups along the profile of the V-shaped trench line under construction and without the seismic impact of mass blasting meets standard indices (the calculated value of the stability factor is 1,33-2,49).

However, given the seismic impact of mass blasting (see table. 1, option 1) the stability degree of designed mine workings does not meet the standard indices (the calculated value of the stability factor is within 1,18-1,92).

Table 1

Results of stability calculations for bench groups of the eastern wall of "YuGOK" open pit in the area of the railway V-shaped trench construction

| Cross section | Line of sliding | Slope height, m | Slope angle, deg. | *SF* unit fractions | *SF*, with seismicity (Option 1) | *SF*, with seismicity (Option 2) |
|---|---|---|---|---|---|---|
| 1-1 | 1 – wall | 80 | 22 | 1.88 | 1,48 | 1,78 |
| | 2 - wall | 50 | 26 | 1.92 | 1,54 | 1,84 |
| | 3 - bench | 20 | 70 | 2.53 | 1,97 | 2,32 |
| 2-2 | 1 – wall | 90 | 27 | 1.62 | 1,34 | 1,48 |
| | 2 - bench | 28 | 62 | 2.49 | 1,92 | 2,34 |
| 3-3 | 1 - bench | 65 | 25 | 2.08 | 1,64 | 2,01 |
| | 2 - wall | 50 | 35 | 1.92 | 1,52 | 1,82 |
| 4-4 | 1 - wall | 65 | 48 | 1.33 | 1,18 | 1,31 |
| | 2 - wall | 110 | 30 | 1.37 | 1,22 | 1,33 |
| 5-5 | 1 - wall | 75 | 39 | 1.38 | 1,21 | 1,35 |
| | 2 - wall | 110 | 26 | 1.53 | 1,36 | 1,44 |

Therefore, when designing a mass blasting scheme along the V-shaped trench line under construction and on its limiting contour, it is recommended to apply down hole delay deck charges that reduce the weight of explosives per delay to 358 kg.

At that, the blasting block should be drilled around by an Atlas Copco ROC L-8 drilling rig (165 mm holes), and a contour holes should be drilled at an angle 65-70° toward the mined space.

These recommendations were taken into account when calculating the stability factor of benches and bench groups along the V-shaped trench line under construction considering the seismic impact of mass blasting (see table 1, option 2).

The obtained results showed the stability degree the mine workings correspond to standard indices (the calculated value of the stability factor (SF) is within 1,31-2,34).

**Conclusions**. Thus, the proposed method for calculating the stability of open pits, considering the seismic impact of mass blasting, allows to determine numerical values of drilling and blasting parameters, the use of which when designing the spiral extended V-shaped trench in the eastern wall area of the "YuGOK" open pit allowed the construction of the trench in conditions of the limited working area and secured long-term and safe operation.

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## МОДЕЛЬ ОПТИМИЗАЦИИ РЕЖИМОВ МЕХАНОХИМИЧЕСКОГО ВЫЩЕЛАЧИВАНИЯ


**Цель исследования.** Разработка универсальной математической модели комбинированной технологией с сочетанием методов химического обогащения и механической активации в дезинтеграторе.

**Методы.** Анализ концепции извлечения металлов из некондиционных отходов добычи и переработки металлосодержащего минерального сырья, обобщение и математическое осмысление экспериментального выщелачивания свинца и цинка из хвостов обогащения Садонских месторождений осуществлено в лабораторном дезинтеграторе.

**Научная новизна.** Эксперимент по химическому обогащению и механической активации в дезинтеграторе осуществлен впервые в мировой практике. Также впервые для эксперимента в качестве исходного сырья использовано некондиционное металлосодержащее минеральное сырье.

**Практическая значимость.** Возможность радикальной утилизации отходов добычи и переработки металлосодержащего минерального сырья с использованием накопленной техногенной базы и получением комплексного экономического, экологического и социального эффекта. Обоснована методическая основа механизации расчетов пара-



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