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Geomechanics substantiation of pillars development parameters in case of combined mining the contiguous steep ore bodies

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Abstract

Purpose. Determining the actual dimensions of the protecting and crown pillars of ore bodies by seismic survey and assessing the possibility of rock mass collapse and fracturing at the lower levels of the Zhairemskoye field.

Methods. An integrated approach is used, which involves the analysis of complete ore bodies development during the combined mining. To determine the geological strength index (GSI) and rock mass rating (RMR), the mass structure is studied, as well as the survey is executed of rock fracturing on the contours of mine workings at levels of +288, +240, +192, +144 m. In addition, the physical and mechanical properties of rocks are refined using the RocLab software. Using the numerical modelling of the self-caving process, when mining the protecting and crown pillars, the processed results of numerical modelling are analysed and the possible zones of the mass deformation are assessed based on the Phase2 software.

Findings. It has been determined that during the mining of ore bodies 4 and 6, protecting pillars between the quarry and the underground mine, crown pillars between the levels up to the level of +144 m, the rock displacements are possible along glide surfaces. It has been revealed that the haulage workings of levels +240 and +192 m fall into the zone of possible displacements influence, and the rock pillar between ore bodies 4 and 6 will be exposed to inelastic deformations during the mining of crown pillars to the level of +144 m. It has been found that after the crown pillar development between the levels of +240 and +192 m for ore body 6, the rock pillar destructions are possible between ore bodies 4 and 6, since during the modelling, displacements of more than 2 mm are observed. In this case, the destruction processes are possible in the rock pillar upper part.

Originality. A geomechanical assessment of the rocks tendency to caving is given and problem areas of stability during the mining of ore bodies 4 and 6 in the Zhairemskoye field are identified.

Practical implications. The stable parameters of protecting and crown pillars have been substantiated, which is an important aspect in the design/efficient technology of mining the contiguous ore bodies.

Keywords: *engineering seismic, ore body, pillar, level, iron, manganese*

1. Introduction

The Zhairemskoye field is mined by a combined method of mining. When mining the deposits by a combined method, natural and technogenic reserves (up to 15-20% of the peripheral reserves volume) usually remain in the bowels of the Earth, which are not included in the mining schedule. These are the pillars left at the border of the quarries to separate surface and underground mining operations and to maintain the walls in a stable state [1], [2]. Their mining is complicated by the high broken state of the masses, the presence of aerodynamic coupling between the stope area and the quarry atmosphere, the low stability of the undermined walls of the quarries that are in the limiting state and characterized by increased indices of losses and dilution [3], [4].

When mining the steep deposits at the border of surface and during underground mining by a combined method, the pillars are formed, which are part of the peripheral reserves [5]-[7]. Despite the broken state and complex mining conditions, they can be an object of development in terms of their vo-lumes and content of useful components [8].

The choice of technological schemes for mining the studied pillars is greatly influenced by the broken state of the mass, the shape, size, location of the pillars, the state of the quarry space at the time of surface and underground mining completion [9], [10]. To draw up technological schemes of mining operations, the pillars left at the border of the quarries are divided into barrier, protecting, supporting and isolating, based on the analysis of their functional purpose, ways of formation, as well as the experience of their mining (Table 1).

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Table 1. Characteristics of pillars for various functional purposes, formed at the border of surface and underground mining

Name	Functional purpose, parameters	Location relative to the wall and bottom of the quarry	Field of application
Barrier	Separation of surface and underground mining fronts. In the walls of the quarries up to 30 m thick, and in the bottom of the quarries up to 50 m thick	In the quarry walls In the quarry bottom	Steep deposits of valuable ores
Protecting	To ensure the objects safety: quarry cross-over tracks, adits, loading points. In the walls of the quarries up to 50 m thick	In the quarry walls	Steep deposits with difficult mining-and-geological conditions
Supporting	Improving the stability of the quarry walls. With a thickness up to 20 m, height up to 40 m, strike up to 50 m	In the quarry walls	Steep deposits of valuable ores with a great distribution depth
Isolating	Isolation of underground mine workings and stope areas. In the walls or in the bottom with a thickness of 3-5 m	In the quarry walls In the quarry bottom	Steep deposits of valuable ores with complex physiography

When drawing up technological schemes, it is taken into account that the wall of the quarry will be in an unstable or limiting state. Therefore, for the calculation period of mining operations, it is necessary to ensure the temporary stability of the undermined mass by creating a surcharge, strengthening the mass with cable bolts or using intensive mining extraction technologies, which makes it possible to reduce the mining period [11]-[13].

The assessment of various technological schemes shows that they are all characterized by different performance factors and completeness of subsoil use. For example, underground mining systems, such as chamber, bench, sublevel caving, are applicable for barrier pillars in the wall and bottom of the quarry. Open-pit and underground, as well as cutting-in systems of mining are applicable for protecting and supporting pillars. Isolating pillars are mined by the method of open-stope mining, mass extraction with bursting and by surface method.

To assess the stability of the undermined walls of the quarry when mining the barrier pillars and to develop the measures for their strengthening, the stress-strain state of the rock mass has been studied and the stability margin factor of the quarry walls has been calculated using the finite element method in a flat formulation of the problem on the example of Uchalinsky, Molodezhnoe and Sibai fields.

The stress state of the mass and the pillars adjacent to the quarry was assessed at the following stages of mining operations:

– setting a quarry in limiting state;

– mining the reserves adjacent to the walls by the method of hardening backfilling;

– creating the rock surcharge of the wall and mining the reserves of the barrier pillar by sublevel caving systems;

– mining the pillar reserves without a surcharge.

The geomechanics survey results analysis [1], calculations of the stability of the undermined walls of the quarries at the time of mining of all reserves, as well as the data obtained by other researchers, allow to draw the following conclusions:

– development of pillars formed at the border of surface and underground mining operations is accompanied by a decrease in the stability margin factor (K_s = 0.8-1.1). The lowest value of K_s refers to barrier and supporting pillars;

– development of pillars on the limiting contour of quarries does not lead to a loss of the overall walls stability, and the local zones of caving are formed along local glide surfaces;

– the presence of a sufficiently high residual stability margin of the undermined quarry walls during the pillars mining in combination with strengthening measures and an intensive mining regime make it possible to ensure the possibility of safe reserves extraction;

– with small volumes of reserves in pillars, short terms of development and the use of high-performance equipment with remote control, mining is possible with stability margin factors of the walls equal to 1.1-1.2, according to the recommendations of the Research Institute of Mining Geomechanics & Mine Surveying (VNIMI).

On the basis of research on the selection of underground mining systems of N.I. Trushkov, D.R. Kaplunov, G.N. Popov, M.I. Agoshkov, O.A. Baikonurov, Yu.V. Volkov et al. [3], a methodology has been developed for the comparative assessment and selection of effective technological schemes for mining by surface, open-pit-underground, underground methods, as well as for determining the area of their application. It is proposed to select the rational options, taking into account a set of measures to maintain the undermined masses of walls in a stable state according to the criterion of maximum profit when mining the filled reserves [14].

Purpose of the research. Using the ELLIS-3 seismograph during seismic survey, determine the actual dimensions of the protecting and crown pillars of ore bodies 4 and 6 up to the level of +144 m of the Ushkatyn-3 Mine in the Zhairemskoye field and assess the possibility of rock mass fall at the lower levels. For this purpose, it is necessary to perform seismic surveys at the levels +288 and +192 m, +144 and +96 m, as well as to survey the rock fractures.

2. Methods

2.1. Ore body description

Currently, the issues of reserves remediation on abandoned pillars as a result of the ore reserves depletion are being widely studied at a number of deposits in the country. In this regard, in the Zhairemskoye field, on the pillars of the depleted levels, the problem arises of repeated mining the remaining iron-manganese ores for ore bodies 4 and 6 (Table 2). In terms of occurrence, the ore bodies are steep (Fig. 1).

According to the project, the block is divided in height from the mined-out and backfilled block of the upper level by a continuous temporary pillar (crown pillar) with a thickness of 5-6 m, designed to support the weight of the backfilling mass. There is a need to determine the specific dimensions of these pillars left after extraction operations .

In order to determine the actual dimensions of the crown pillars, ground-penetrating radars and seismographs are provided.

Table 2. Parameters of ore bodies in the ferriferous manganese part of the Ushkatyn-3 deposit

Ore body seam No.	Western flank		Eastern flank	
	Length, m from-to	Thick-ness, m from-to average	Length, m from-to	Thick-ness, m from-to average
Seam 4, RT-4	50-1000	1.2-7.9 / 3.9	10-220	1.0-11.3 / 4.73
Seam 6, RT-6	70-780	1.2-6.8 / 4.3	60-220	1.5-5.6 / 2.8
Seam 6/7, RT-6/7	80-150	0.9-1.9 / 1.12	–	–

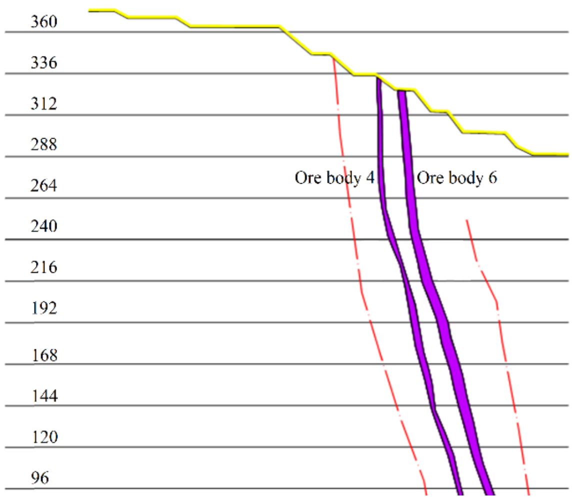

Figure 1. Occurrence of ore bodies 4 and 6 in the Zhairemskoye field

Since the ore is in an iron mass, a ground-penetrating radar, operating through a magnetic field, may not provide accurate information. For this purpose, it is necessary to use the ELLIS-3 seismograph, which determines the sound wave [15].

2.2. Determining the actual dimensions of protecting and crown pillars

Using the ELLIS-3 seismograph, actual dimensions of protecting and crown pillars of ore bodies 4 and 6 are determined. The level +288 m plan is shown in Figure 2.

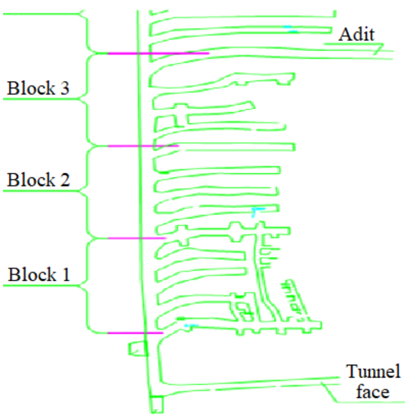

Figure 2. The level +288 m plan (1, 2, 3 blocks)

The survey is made at a level +288 m for ore bodies 4 and 6 in blocks 1, 3, 5. On the first incline of ore bodies 4 and 6, the seismic network is laid out in a parallel way, and between ore bodies – in a longitudinal way. The seismograph sensors are placed at a distance of 90 cm from the mine working wall. For ore body 4, the distance between sensors is 70 cm, and for ore body 6, it is 100 cm. The sensors are placed longitudinally between ore bodies, the distance between them is 200 cm.

On the subsequent (second, third, fourth) inclines, seismic survey is not carried out, because the presence on these inclines of piles and puddles does not allow research work [16], [17].

Next survey is conducted on the fifth incline. On this incline, the network is laid out in parallel only for ore body 4, and between ore bodies – in a longitudinal way. In both cases, the sensors are located 90 cm from the wall of mine working.

In the third block, the seismic survey is made only on the seventh and ninth inclines. On the seventh incline, the network is laid out only between ore bodies, since there are puddles and piles on ore bodies 4 and 6.

On the ninth incline of ore body 4, the sensors are located at a distance of 95 cm, and for ore body 6-75 cm. According to the longitudinal scheme, the distance between the sensors is 150 cm.

In block 5, seismic survey is performed only on the tenth incline. And the rest of the inclines are piled. On the tenth incline of ore body 4, the sensors are laid out at a distance of 150 cm, and for ore body 6-75 cm. According to the longitudinal scheme of ore bodies, the distance between the sensors is 150 cm.

The survey is also performed at a level +192 m of ore bodies 4 and 6 in the fourth and third seams. After survey of the level +288 m, when descending by the haulage roadway, the fourth and third seam of the level +192 m are also surveyed.

2.3. Work procedure

The total number of sensors is 8. The place of each sensor is thoroughly cleared. The sensors are located at equal distances from each other and strictly directed in one direction. They are firmly attached with gypsum to the pillar. The wires of the sensors with the coordinate points X, Y, Z are connected with the same coordinate points on the cable, respectively. The cable is connected to the main block and the computer [17].

To get signals, it is necessary to create a mechanical stroke (with a sledge hammer) between the placed sensors. To register signals, eight strokes with an interval of 2-5 seconds should be made.

When changing over to another scheme, the last two sensors are left, which are the base points for the next survey. The survey scheme for ore body 4 at a level +288 m is shown in Figure 3. The sensors are marked with round icons, and the place of stroke with a sledge hammer is marked with crosses in Figure 3.

The survey of ore body 6 is conducted in a parallel way. The distance between the sensors is 100 cm. The distance between the sensor and the place of the sledge hammer stroke is 50 cm. Number of the sledge hammer strokes is 15. The survey scheme for ore body 6 is shown in Figure 4.

2.4. Office processing of seismic data

Office processing of seismic data involves determining the wave field characteristics in the mass depth according to the data obtained at near-surface areas and restoring the configuration of reflecting and refracting boundaries interacting with this field. For office data processing, a professional RadExPro system (DECO Geophysical Software Company) and a package of office programs are used.

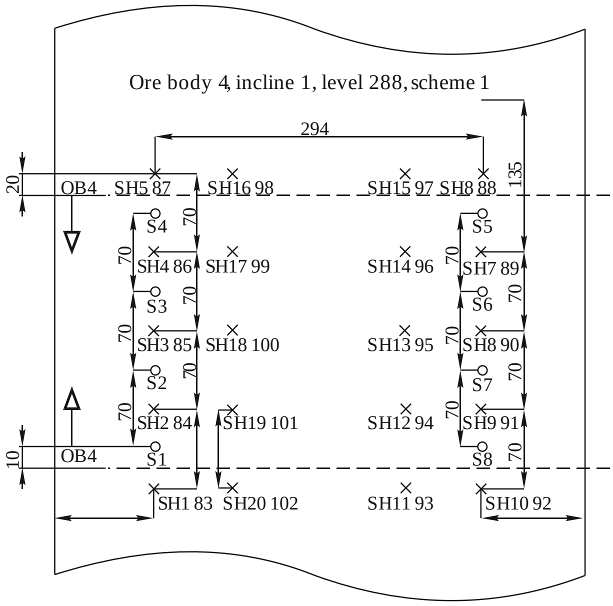

Figure 3. Survey scheme for ore body 4: OB – ore body; SH – place of the sledge hammer stroke; S – sensor

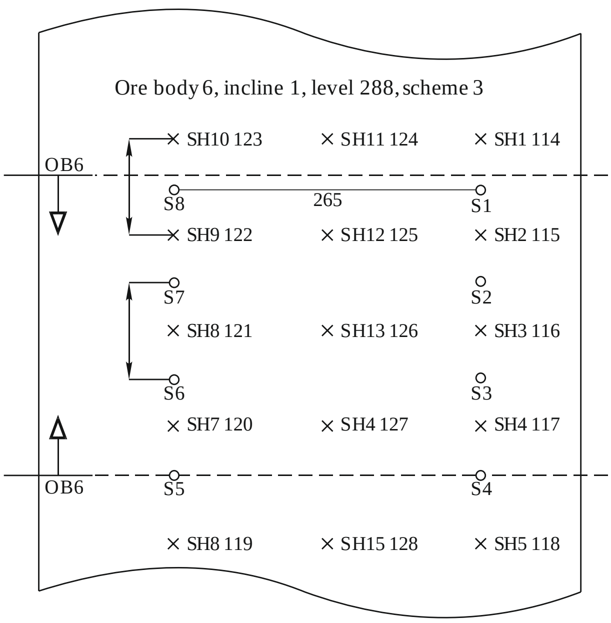

Figure 4. Survey scheme for ore body 6: OB – ore body; SH – place of the sledge hammer stroke; S – sensor

2.5. Numerical modelling of the self-caving process when mining the protecting pillars

Numerical modelling of the stress-strain state of the rock mass adjacent to steep ore bodies 4 and 6, provided that they are completely mined up to the level of +144 m, is performed using the Phase2 software. Phase2 is a program for two-dimensional finite element modelling of the stress-strain state of a rock mass in underground mining in an elastic and/or elastic-plastic formulation. The program is interactive and easy-to-use, ideal for performing quick parametric analysis, preliminary design, and as a training tool for numerical analysis of stresses in geotechnical problems.

Phase2 is designed as a quick and easy-to-use tool for parametric analysis in order to study the influence of geometry and in-situ stresses on the value of stresses in the rock mass during mining operations.

The finite element method is used to explain the contour failure mechanism of a particular mine working. This method considers a bounded area (flat or volumetric), which is divided into a finite number of elements (in a plane problem, triangular elements are usually accepted), while the elements are joined only at the vertices. The finite element software package allows solving linear and nonlinear, stationary and nonstationary spatial problems of deformable solid mechanics and structural mechanics (including nonstationary geometrically and physically nonlinear problems of structural elements contact interaction).

The calculated stresses in the analysed plane can be presented in the form of isolines around the driven mine working. To interpret the deviatoric stress values (the difference in principal stresses) around mine working, the isolines of strength factor are displayed, which are a quantitative measure of the strength/acting stresses ratio in accordance with the selected criterion of rock mass strength. If the strength factor value is less than unity, then this indicates that the mass is destroyed at the given stress state.

The advantage of the Phase2 software package is that it enables modelling of geomechanical processes occurring near by the technogenic outcrops of various cross-sectional shapes with a large number of stope spaces located at different levels (bottom and top).

Numerical modelling is conducted in conditions of complete mining of ore bodies 4 and 6 to a level of +144 m and mining of protecting pillars, without gobbing and backfilling the mined-out areas in order to create an internal dump. The plane problem of determining the stress-strain state of the rock mass adjacent to ore bodies 4 and 6 is solved.

Using the Phase2 program, a geological section is constructed with ore bodies 4 and 6, host rocks, conventionally divided into 5 sections according to the depth of occurrence from the surface.

The computational scheme for the numerical analysis of the stress-strain state of the rock mass by the finite element method is shown in Figure 5.

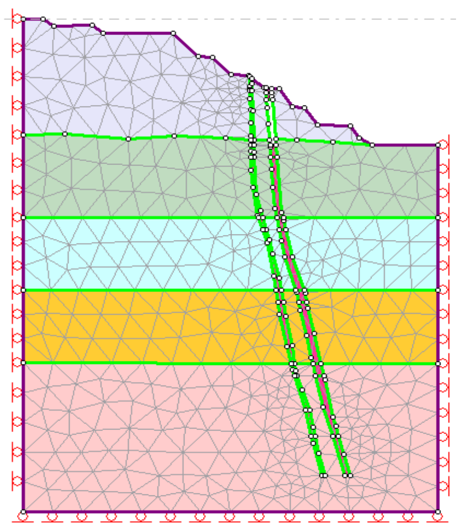

Figure 5. Computational scheme for the numerical analysis

At the first stage, the contour of the mine working cross-section is constructed, which is placed in a flat model with fixed boundaries. The boundaries must be discretized. Then, the rock mass is divided into a finite number of triangular elements, while the elements are joined only at the vertices (Fig. 5). After the finite element grid is created, interference is prohibited and the number of elements and nodes in the grid can be seen [18], [19].

At the second stage, the rock mass properties are specified. This program makes possible to take into account a wide variety of mining-and-geological conditions and strength criteria [20], [21].

The initial data for numerical modelling are determined using the RocLab software.

Hoek and Brown criterion can be accepted as failure criterion [11]:

$$\sigma_1 = \sigma_3 + \sigma_c \left(m_b \cdot \frac{\sigma_3}{\sigma_c} + s \right)^a, \quad (1)$$

where:

m_b – constant dependent on the type of rock and converted from m to a fractured mass by its GSI;

s and a – rock mass constants, and for undisturbed rock s = 1.

The modelling is performed under the condition that ore body 6 at a level of +288 m is mined first, then ore body 4 of the same level is mined. In this order, ore bodies are mined at the levels + 240, +192 and +144 m. These actions are divided into 8 stages of modelling. Mining of protecting pillars between the quarry and underground mine, crown pillars between the levels are also divided into 8 stages. Full modelling includes 16 stages of numerical analysis. At each stage, the stress-strain state of the rock mass can be observed, taking into account their state at the previous stages [22]-[24].

3. Results and discussion

The numerical modelling results of assessing the geomechanical rock mass state during the mining of ore bodies 4 and 6 up to the level of +144 m, as well as during the mining of protecting and crown pillars are shown in Figures 6-13.

Based on the numerical modelling results, the following conclusions have been made:

– when mining the ore bodies 4 and 6, protecting pillars between the quarry and the underground mine, and crown pillars between the levels up to the level of +144 m, the rock displacements along glide surfaces are possible (Figs. 11-13);

– haulage workings of the levels +240 and +192 m fall into the zone of possible displacements influence (Figs. 11-13);

– the rock pillar between ore bodies 4 and 6, when mining the crown pillars up to the level of +144 m, will be exposed to inelastic deformations;

– after mining the crown pillar between the levels of +240 and +192 m for ore body 6, the rock pillar destructions are possible between ore bodies 4 and 6, since during the modelling, displacements of more than 2 mm are observed. The destruction processes are possible in the upper part of the rock pillar (Fig. 8);

– when mining the protecting and crown pillars, drilling operations should be carried out after bringing the workplace into a safe state or after determining the safest place to perform operations.

Mining of the protecting pillar between the quarry and the underground mine for ore body 6 influences the stable state of the same pillar for ore body 4. The upper right part of the pillar for ore body 4 has a strength factor of less than 1 (Fig. 6). It is possible that self-destruction processes can occur in the pillar of ore body 4 in its certain areas [25], [26].

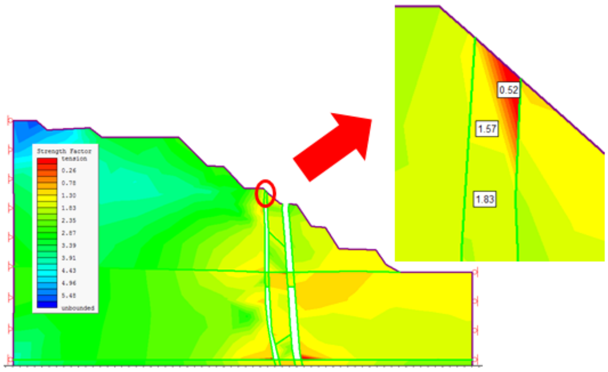

Figure 6. Mining of the protecting pillar between the quarry and the underground mine for ore body 6

After mining the protecting pillar for ore body 4, the lower part of the rock pillar between ore bodies 4 and 6 in the area of +288 m level is exposed to inelastic deformations and the strength factor is 0.52. The rock mass near the crown pillars between the levels of +288 and +240 m is in the limiting state (Fig. 7). When mining the crown pillars between the levels of +288 and +240 m, the probability of rock displacement from the side of the hanging wall of ore bodies is high. Mining operations during their development should be conducted from more stable and safe areas of mine workings.

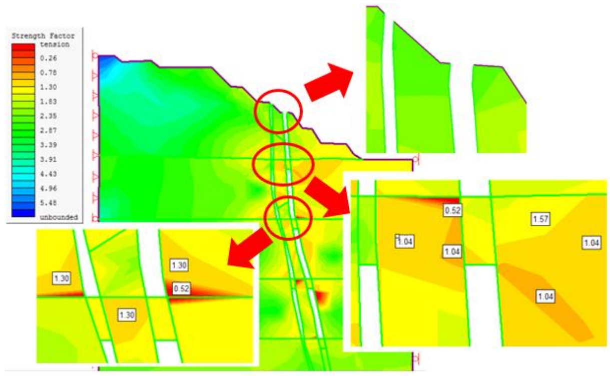

Figure 7. Mining of the protecting pillars between the quarry and the underground mine for ore bodies 4 and 6

Mining of the crown pillar between the levels of +288 and +240 m for ore body 6 influences the stable state of the crown pillar for ore body 4 at the same level. In this pillar, destruction processes can occur in the upper part of the pillar, where the strength factor is less than 1. The rock pillar between ore bodies 4 and 6 passes into this state in the area of +288 m level. According to the model, the rock pillar between ore bodies 4 and 6, as well as between the levels of +288 and +240 m is in the limiting state (Fig. 8). At this stage of the crown pillars mining, the displacements of the rock pillar upper part begin (in the area of +320 m level) between ore bodies. The displacement value is 2 mm.

Given the rock pillar displacements and predicting its destruction in the upper part, further modelling is carried out with account of the above-described deformations.

After mining the crown pillar for ore body 4 between the levels of +288 and +240 m, the rock mass below +288 m level has a strength factor of less than 1 (destruction). At this level, the mass is exposed to inelastic deformation. The rock mass between the levels of +288 and +240 m is in the limiting state (Fig. 9).

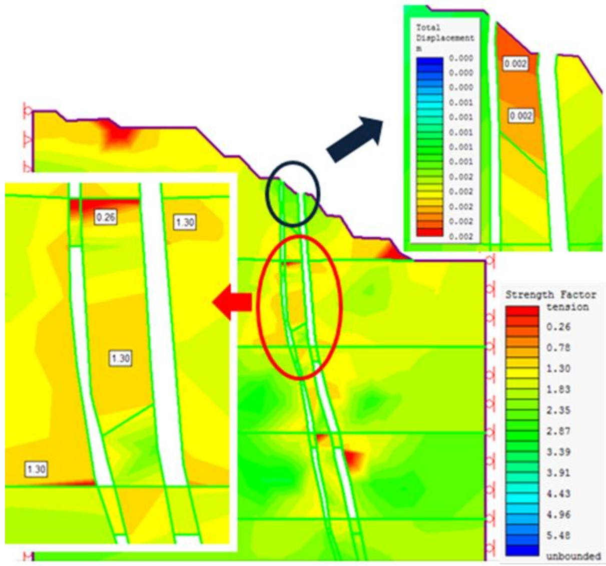

Figure 8. Mining of the crown pillar between the levels of +288 and +240 m for ore body 6

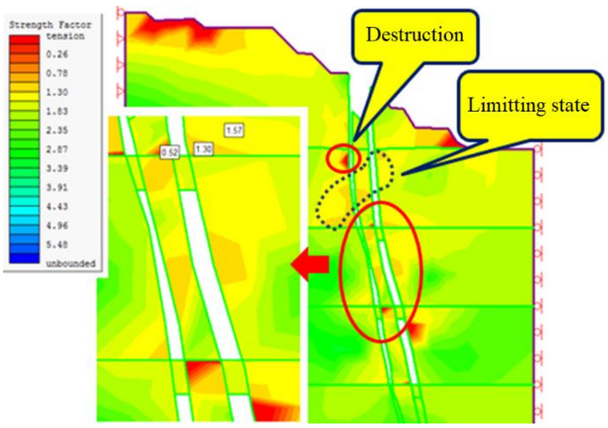

Figure 9. Mining of the crown pillars between the levels of +288 and +240 m for ore bodies 4 and 6

Part of the mass within the levels of +240 and +192 m is also in a state close to the limiting one. The areas of the rock pillar between ore bodies 4 and 6, and the hanging wall of ore bodies below the level of +192 m passes into an inelastic state, where the strength factor is less than 1.

As a result of mining the crown pillar for ore body 6 between the levels of +240 and +192 m, the adjacent pillar remains stable, but the strength factor is not high. In addition, the rock pillar between ore bodies 4 and 6 is in a limiting state. In the case of complicated hydrogeological and mining-geological conditions, the loss of the pillar stability for ore body 4 and the rock pillar is possible. At this stage of mining the crown pillars, a zone of possible rock displacements from the side of the footwall and hanging wall of ore bodies is formed (Fig. 10).

After mining the crown pillar for ore body 4 between the levels of +240 and 192 m, the curve of the possible rocks glide does not change direction, but the deformation zones are more activated and can be clearly observed in Figure 10. At this stage, the rock pillar upper part (in the area of +305 and +288 m levels) between ore bodies has a displacement value of 12-21 mm. The displacement vectors are directed from the quarry into the mass depth.

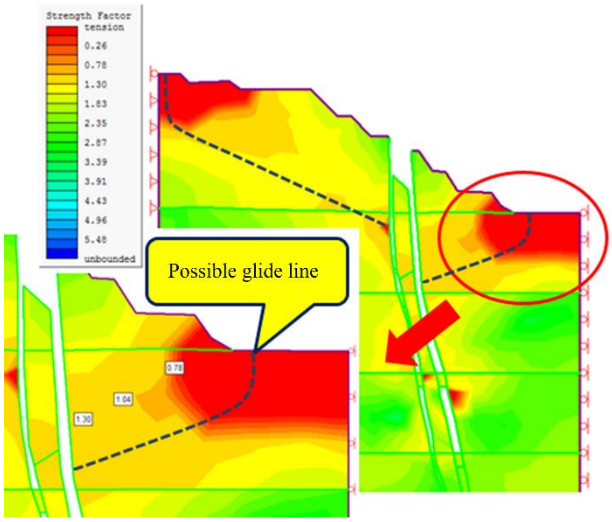

Figure 10. Mining of the crown pillar between the levels of +240 and +192 m for ore body 6

The middle part of the rock pillar between +240 and +192 m levels has a strength factor of less than 1, which indicates its destruction (Fig. 11). In the area of +180 m level, the rock mass from the side of ore bodies hanging wall is exposed to inelastic deformations. These areas are dangerous during the mining of crown pillars between the levels of +192 and +144 m. When mining the crown pillar for ore body 6 between the levels of +192 and +144 m, it is necessary to ensure the safety of mining operations.

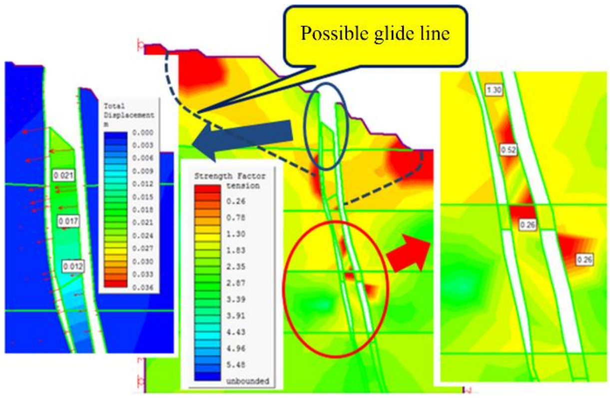

Figure 11. Mining of the crown pillars between the levels of +240 and +192 m for ore bodies 4 and 6

Figure 12 shows the geomechanical situation when mining the crown pillar for ore body 6 between the levels +192 and +144 m. In the area of +240 and +185 m levels, the rock pillar destruction is possible between ore bodies 4 and 6. The area of the rock pillar below +185 m level is in the limiting state. Certain rock pillar areas (in red) have a strength factor of less than 1. The zone of rocks deformation increases in the same direction as in the previous stages of mining the crown pillars [20], [27], [28].

The numerical modelling final stage is mining the crown pillar for ore body 4 between the levels +192 and +144 m.

At this stage, the rock pillar displacement between ore bodies reaches 52 mm, which makes it possible to speak of its destruction. Displacement vectors are directed from the quarry towards the rock mass.

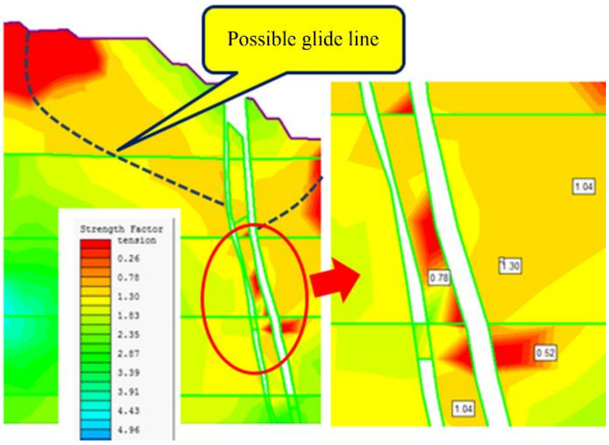

Figure 12. Mining of the crown pillar between the levels of +192 and +144 m for ore body 6

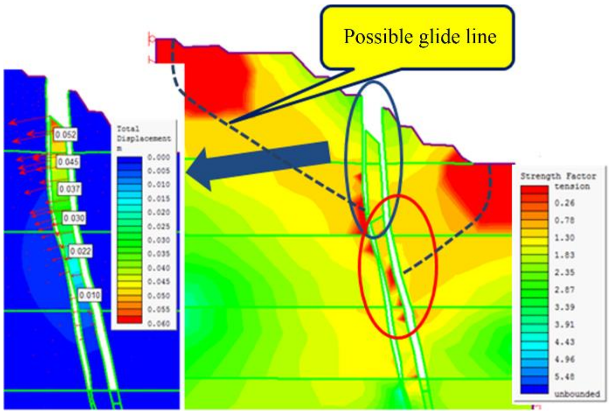

Figure 13. Mining of the crown pillars between the levels of +192 and +144 m for ore bodies 4 and 6

From the side of ore bodies footwall (from the level of +260 m) and from the side of ore bodies hanging wall (from the level of +215 m) to the earth's surface, the rock displacement zones are formed. The rock mass in the area of +192 m level is in the state close to the limiting one. The rock pillar between ore bodies 4 and 6, near the levels +240 and +185 m, is exposed to inelastic deformations. According to the rock mass model, with the complete mining of the crown pillars for ore bodies 4 and 6 from the surface to the level of +144 m, the rock pillar between them will collapse.

When analysing the seismic data, many sources of reflected waves have been found, which, being mutually overlapped, make it difficult to identify reflecting boundaries. Despite this, several deep-earth reflecting boundaries have been found on seismograms obtained under various conditions.

For example, for a line along the incline 1, the position of the reflecting boundary is within 7-10 meters, and for a line along the incline 5, it is within about 5-8 meters.

It should be noted that the studied rock mass has a relatively high acoustic density and the velocity of longitudinal waves in it reaches 6 km/s. Hence, the increased wavelength, when summing the common depth points, significantly reduces the survey detail and the error in depth can reach several meters.

The actual dimensions (thickness) of the pillars are shown in Tables 3 and 4.

Table 3. Actual size of protecting and crown pillars

Studied area	Pillar thickness, m		Note
	Ore body 4	Ore body 6	
level +288 m incline 1	7 and 10	5 and 8	two different values are obtained from one place
level +288 m incline 5	7	5	–
level +288 m incline 7	5	6	surveys are made only between ore bodies
level +288 m incline 9	5.5	6	–
level +288 m incline 10	5	6-7	–

Table 4. Actual size of protecting and crown pillars

Seam	Feature	Scheme	Depth to reflecting boundary, m
4	ore body 4	2	4-6
	ore body 6	1	3-6
	ore body 6	2	3-5
	ore body 6	3	4-5
	ore body 6	4	3-6
3	ore body 6	1	5-7
	ore body 6	2	6-7
	ore body 4	3	5-7
	ore body 4	4	4-6

4. Conclusions

The paper presents the results of research into the mass structure and survey of the rocks fracturing on the contours of mine workings at levels of +288, +240, +192 and +144 m, as well as the results of determining the geological strength index (GSI) and rock mass rating (RMR). The physical and mechanical rock properties have been confirmed using the RocLab program. Numerical modelling has been performed for assessing the geomechanical rock mass state during the mining of protecting pillars between the quarry and the underground mine, as well as when mining the crown pillars between the levels up to +144 m level.

The processing of the numerical modelling results has been analysed and possible zones of the rock mass deformation have been assessed. In addition, the analysis has been made of mining the pillars during the combined mining of contiguous steep ore bodies in the Zhairemskoye field. The actual dimensions of the protecting and crown pillars left over the ore bodies 4 and 6 of the deposit have been determined in the field environment using the ELLIS-3 seismograph.

Seismic surveys were performed at the levels of +288 and +192 m for ore bodies 4 and 6. For office data processing after seismic survey in the field environment, a professional system and a set of office programs RadExPro were used. As for the +288 m level, the average pillar thickness for ore body 4 is 6.5 m, and for ore body 6-6.2 m.

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Геомеханічне обґрунтування параметрів відпрацювання ціликів при комбінованій розробці зближених крутопадаючих рудних тіл

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Мета. Визначення фактичних розмірів охоронних і стельових ціликів рудних тіл за допомогою сейсмічної розвідки та оцінка можливості обвалення гірничої маси на нижніх горизонтах в умовах Жайремського родовища.

Методика. Застосовано комплексний підхід, що включає в себе аналіз повноти вилучення рудних тіл при комбінованому відпрацюванні; вивчення структури масиву та зйомки тріщинуватості гірських порід на контурах гірничих виробок на горизонтах +288, +240, +192 і +144 м для визначення індексу геологічної міцності (GSI) та рейтингу масиву гірських порід (RMR), а також уточнення фізико-механічних властивостей порід із застосуванням програми RocLab. Здійснено чисельне моделювання процесу самообвалення при відпрацюванні охоронних і стельових ціликів із використанням програми Phase2; аналіз обробки результатів чисельного моделювання та оцінка можливих зон деформування масиву.

Результати. Встановлено, що при відпрацюванні рудних тіл 4 і 6, охоронних ціликів між кар'єром і підземним рудником та стельових ціликів між горизонтами до позначки +144 м можливі зрушення гірських порід по поверхнях ковзання. Визначено, що в зону впливу можливих зрушень потрапляють транспортні виробки горизонтів +240 і +192 м. Породний цілик між рудними тілами 4 і 6, при відпрацюванні стельових ціликів до позначки +144 м, піддасться непружним деформаціям. Встановлено, що після відпрацювання стельового цілика між горизонтами +240 і +192 м по рудному тілу 6 можливі руйнування породного цілика між рудними тілами 4 і 6, оскільки при моделюванні спостерігаються зміщення більше 2 мм, при цьому процеси руйнування можливі у верхній частині породного цілика.

Наукова новизна. Надано геомеханічну оцінку схильності гірських порід до обвалення та виявлено проблемні області стійкості при відпрацюванні рудних тіл 4 і 6 в умовах Жайремського родовища.

Практична значимість. Обґрунтовано стійкі параметри охоронних і стельових ціликів, що є важливим аспектом при проектуванні ефективної технології відпрацювання зближених рудних тіл.

Ключові слова: *інженерна сейсміка, рудне тіло, цілик, горизонт, залізо, марганець*

Геомеханическое обоснование параметров отработки целиков при комбинированной разработке сближенных крутопадающих рудных тел

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Цель. Определение фактических размеров охранных и потолочных целиков рудных тел с помощью сейсмической разведки и оценка возможности обрушения горной массы на нижних горизонтах в условиях Жайремского месторождения.

Методика. Применен комплексный подход, состоящий из анализа полноты извлечения рудных тел при комбинированной отработке; изучения структуры массива и съемки трещиноватости горных пород на контурах горных выработок на горизонтах +288, +240, +192 и +144 м для определения индекса геологической прочности (GSI) и рейтинга массива горных пород (RMR), а также уточнения физико-механических свойств пород с применением программы RocLab. Проведено численное моделирование процесса самообрушения при отработке охранных и потолочных целиков с использованием программы Phase2; анализ обработки результатов численного моделирования и оценка возможных зон деформирования массива.

Результаты. Установлено, что при отработке рудных тел 4 и 6, охранных целиков между карьером и подземным рудником и потолочных целиков между горизонтами до отметки +144 м возможны сдвижения горных пород по поверхностям скольжения. Определено, что в зону влияния возможных сдвижений попадают транспортные выработки горизонтов +240 и +192 м. Породный целик между рудными телами 4 и 6, при отработке потолочных целиков до отметки +144 м, подвергнется неупругим деформациям. Установлено, что после отработки потолочного целика между горизонтами +240 и +192 м по рудному телу 6 возможны разрушения породного целика между рудными телами 4 и 6, поскольку при моделировании наблюдаются смещения более 2 мм, при этом процессы разрушения возможны в верхней части породного целика.

Научная новизна. Дана геомеханическая оценка склонности горных пород к обрушению и выявлены проблемные области устойчивости при отработке рудных тел 4 и 6 в условиях Жайремского месторождения.

Практическая значимость. Обоснованы устойчивые параметры охранных и потолочных целиков, что является важным аспектом при проектировании эффективной технологии отработки сближенных рудных тел.

Ключевые слова: *инженерная сейсмика, рудное тело, целик, горизонт, железо, марганец*