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Identifying rational locations for field mine workings in the zone influenced by mined-out space during repeated mining of pillars

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Abstract

Purpose. The research aims to study the influence of bearing pressure from the barrier pillar on the field drift in order to determine the rational locations for placing field mine workings in the zone influenced by repeated mining at the Zhomart Mine of the Zhaman-Aybat field.

Methods. Research includes an analysis of the results of mine studies conducted on the basis of instrumental measurements of actual parameters of the mining system structural elements, processing of multi-year statistical data on monitoring of the rock mass state, as well as modeling using Rocscience software to determine the stress-strain state of the rock mass. The actual physical-mechanical properties of the ores and host rocks of the Zhaman-Aybat field are used for modeling.

Findings. The research makes it possible to determine the parameters of the field conveyor drift rational location relative to the protective pillar and the mined-out space. It is substantiated that the field conveyor drift should be designed not less than -30 m deeper than the bottom of the mined-out deposit 4-1 and at a distance of -70 m from the protective pillar boundary. The maximum stresses σ_{max} acting on the contour of the field conveyor drift when it is located at different points are calculated.

Originality. The dependence of the change in maximum stresses acting on the contour of the field conveyor drift on its location relative to the protective pillar has been found, which makes it possible the rock mass geomechanical state to be assessed in the form of a model.

Practical implications. The mine surveys and numerical experimental studies have provided a new solution to an important scientific problem related to predicting the geomechanical state of the rock mass and ensuring the stability of mine workings adjacent to the mined-out space. The research results can be used in designing repeated mining operations and predicting the geo-mechanical state of the rock mass in order to ensure safe mining operations when driving preparatory workings.

Keywords: *ore, repeated mining, pillar, mining operations, mined-out space, modeling, field*

1. Introduction

The efficiency and safety of underground mining depends directly on the ability to control the state of the rock mass in the vicinity of the preparatory workings. This aspect is of key importance when substantiating the application of modern technologies, since disturbances in mass stability can lead to accidents, reduced productivity and increased costs [1]. Many geomechanical models have been developed to understand the behavior of the rock mass, each of which seeks to describe the processes occurring in the earth's crust during mining operations. These include both generally recognized concepts and new approaches that are in the development stage [2]-[5].

Kazakhstan is one of the leading countries in the world in terms of mineral resource mining, which makes the development of the mining industry strategically important for the country's economy. Large fields such as Zhaman-Aybat in Karaganda Coal Basin, as well as the mines in the Zhezkazgan Region provide Kazakhstan with significant reserves of ore and coal resources [6]-[8]. However, the development of mining in the country faces a number of challenges related to the increasing depth of mining operations, intense rock pressure and the need to reuse extraction workings [9]. This requires the development of innovative approaches to managing the rock mass state, taking into account the peculiarities of each field.

Mining operations are particularly challenging in the conditions of repeated field mining, where significant volumes of mined-out space create additional stress zones [10]. The Zhomart Mine of the Zhaman-Aybat Field, where the room-and-pillar mining system has been actively applied since 2008, has accumulated a unique experience in the repeated extraction of rib pillars. Over 18 million cubic

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meters of mined-out space were formed during the period of mine operation, which resulted in significant changes in the mass stress-strain state [11]. In such conditions, it is critical to understand the rock pressure redistribution mechanisms and their impact on the stability of field and capital drifts adjacent to caving zones and barrier pillars [12], [13].

For the mining industry of Kazakhstan, the issues of ensuring the stability of mine workings are not only of industrial, but also of strategic importance [14]. The reliability of mine operations is directly related to occupational safety, reduction of economic losses and efficient use of natural resources [15]. It is important to note that mining companies in Kazakhstan actively use modern approaches, including geomechanical modeling, monitoring systems and innovative fastening technologies, which help to improve the stability of mining structures and minimize risks in the conduct of mining operations [16]-[20].

The purpose of the present research is to study the influence of the bearing pressure from the barrier pillar on the field drift in order to determine the rational locations for placing field mine workings in the zone of influence of repeated mining at the Zhomart Mine of the Zhaman-Aybat Field. To achieve this purpose, a methodology has been developed that includes analysis of mine survey results, p rocessing of multi-year statistical data of rock mass state monitoring, and modeling using Rocscience software.

2. Study background

Between 2008 and 2023, the Zhaman-Aybat Field, where the Zhomart Mine is located, produced over 48 million tons of ore using the room-and-pillar system, resulting in more than 18 million cubic meters of cavities, supported by 12265 rib pillars. Since then, in 2009, experimental work began on extracting the rib pillars, up until 2014, when their full-scale repeated mining began. By the beginning of 2019, 2954 pillars had already been mined out. By caving the overlying stratum, 8.9 million m^3 of cavities have been filled (50% of the total volume of cavities formed).

Since the second half of 2017, the geomechanical situation at the mine has become extremely acute:

– seismic activity of the mass increased up to technogenic earthquakes, which were registered by all seismic stations of the Republic of Kazakhstan;

– the values and rates of the earth's surface subsidence have increased dramatically.

The deterioration of the geomechanical situation was caused by:

– the presence of a large number of localized pillar extraction sites with small filled spans, the areas between which turn out to be overloaded (Fig. 1);

– rock stratum overhangs on unmined barrier and massive pillars, creating a bearing pressure on them and the surrounding mass;

– violation of the repeated mining design procedure, in particular, premature cutting of barrier pillars ahead of the filling front by more than 3 rows of the rib pillar.

Based on the experience of the Zhezkazgan mines, it is clear that the geomechanical situation at the Zhomart Mine develops in the following sequence: repeated mining in many localized areas without settling of the overlying stratum → formation of bearing pressure zones between them → partial destruction of rib pillars over large areas → destruction of protective pillars of capital transportation and conveyor drifts → caving over a large area with complete settling of the overlying stratum up to the surface, with technogenic earthquake and air burst in the mine. At the Zhomart Mine, the geomechanical situation by 2018 has already passed the first stages.

Figure 1. State of mining operations at Zhomart Mine

The seismic control system plays a key role in monitoring and predicting critical deformations in a rock mass [21]. This process begins with a thorough analysis of seismic events that may indicate the beginning of critical deformation. One of the main indicators is the localization of seismic events in the weakened area. Localization of seismic events means that there is an increase in the number of seismic signals in a certain area. This may be due to the fact that microfractures or other changes in rock structure occur in this area, which can lead to critical deformation [22]. The seismic control system allows the location and depth of these events to be accurately determined, enabling risk assessment and prediction of possible consequences. Another important indicator is the compaction of seismic events in time. This means that the time intervals between signals decreases, which may indicate increased rock mass activity [23], [24].

Thus, according to the seismic monitoring data of Kazakhmys Corporation LLP of 09.03.2019, a seismic event (SE) with an energy class of 9.8 (6.3 billion J) occurred at the mine. After this event, the seismic regime of the mass changed: seismic energy release began to occur at a slower rate. Prior to the strongest seismic event of 09.03.2019, the breaking mass radiated seismic energy for a whole year at an average flow rate of 617 kJ/day. During this period, the earth's surface subsidence occurred at a very high rate of 4-5 mm/month. After 09.03.2019 (during half of the year), the average energy release rate from the mass has decreased by 2.2 times – to 280 kJ/day. The rate of subsidence also decreased sharply – to 1.0-1.5 mm/month.

These facts indicate a slowdown in the processes of mass destruction, which is most likely caused by the cessation of mining operations in the central part of the mine field [25]. When resuming operations on mining the remaining ore reserves in the pillars, the seismic activity of the mass, as well as the rock stratum and the earth's surface shear will be activated until the complete settling of the overlying stratum by caving to the surface occurs, as well as elimination of existing overhangs [26]-[28].

During the construction and initial operation of the mine, the main form of destruction during driving of capital and preparatory workings was the crushing of ore/rocks in the roof with high horizontal tectonic stresses that exceeded the vertical pressure of the rock stratum [29]. Therefore, roof bolts and shotcrete were used to fasten only the mine working roof. The mine working walls were not fastened.

During the period of mining of stope reserves on a large area, the level of horizontal pressure in the mass decreased according to the laws of mechanics. Problems with the mine working roof stability have become significantly fewer. There were problems only during driving mine workings on the mine field flanks [30].

After the transition to the second stage of reserve mining (pillar extracting), the vertical stresses of the bearing pressure in the mass became maximum [31]-[34]. Gradual (plastic) destruction of the rib pillars and the overlying rock stratum subsidence lead to the bearing pressure loading of the most rigid protective pillar of the 85 m wide capital drifts, located in the middle of the extensive mined-out space [35]-[37].

Numerous destructions of haulage drifts adjacent to the mined-out panel space began to occur in the walls, which were not fastened. Almost everywhere the same rockfall mechanism is observed: crushing and crumbling of numerous interlayers of weak rocks and subsequent cleavage of large blocks of strong gray sandstones along subvertical natural fractures or rupture cracks (Fig. 2).

Figure 2. Destruction of the haulage drift 1 wall from the side of panel 7

Often after cleavage and rockfall from the wall, a cantilever of a thick layer of gray sandstones is formed in the spring (Fig. 3a). In some places, destruction of the pillar between the haulage drift wall and the mined-out stopes in the panel is observed (Fig. 3b).

The first rock pressure manifestations began in April 2016 and continued through May and July in conveyor drift 1 in the area of panel 10 south (Fig. 4).

According to the results of surveying, the average cross-sectional area of the 22 m^2 conveyor drift after rockfall from the walls with a thickness of 0.3-1.5 m increased to 27 m^2. The reason for the increased vertical pressure on the pillar of the drifts and their destruction is the repeated mining of panels north (panels 7, 8, 9, 10) and south (panels 7 south, 8 south, 9 south, 10 south) of the protective pillar of the drifts. At two intervals of the conveyor drift 1destruction, a frame metal support made of special profile SCP-18 (27 and 17 frames) was installed with backfilling of the fastening cavities with timber. This required stopping the conveyor and cutting through its structure.

In September 2016, between two fastened intervals, destruction of the conveyor drift southern wall occurred with the fallout of large blocks of crushed ore.

(a) (b)

Figure 3. Characteristic forms of destruction: (a) walls of drifts with the formation of a cantilever; (b) the pillar crushing between the drift wall and the stope

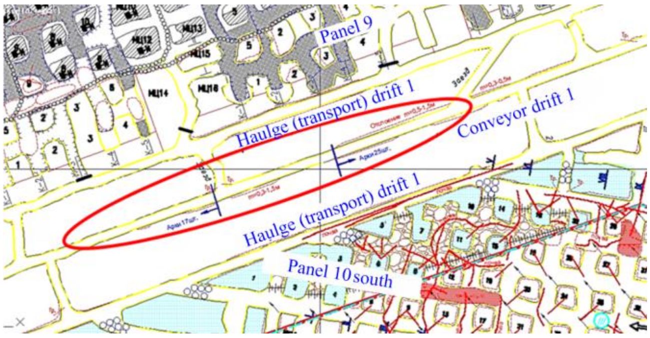


Figure 4. Area of conveyor drift 1 destruction in April-September 2016

Deformation of the conveyor structures was prevented by pre-installed prop stays and pipe spacers, which took the impact of the caved ore upon themselves. After rockfall from the lower ("unfastened") part of the southern conveyor drift wall, a cantilever overhang of rocks was formed in the upper part of the drift. The cantilever stratified on the horizontal contact. The cantilever cutter break was eliminated by blasting.

In order to determine the rational locations for placing field mine workings (haulage and conveyor drifts) in the zone of influence of the mined-out space during the repeated mining of pillars, it is necessary to conduct a set of geotechnical studies, including both field and theoretical aspects [38]. This approach provides a complete insight into the state of the field mine workings and their interaction with the mined-out space.

In November 2018, specialists of the Limited Liability Partnership "Nauchno-Tehnicheskij Tsentr Promyshlennoj Bezopasnosti" together with the surveying service of Zhomart Mine performed mass measurements (with a step of 1 m) of the dimensions of haulage and conveyor drifts (Table 1). The histograms in Figures 5, 6 show both the most frequently occurring (modal) values and the existing deviations from the mean. In local areas, the maximum overshoots in height/width of drifts can be quite significant (up to 2-3 m).

The problem of mining the remaining 18.8 million tons of ore from the rib pillars in the Zhomart-1 Mine field includes a set of scientific-technical tasks aimed at safe and economically feasible implementation of operations. One of the key tasks is to identify areas where it is possible to extract rib pillars. This requires conducting geologic and geomechanical studies to assess the current state of the stope roofs and pillars.

Table 1. Dimensions of capital drifts

Drifts	Number of measurements	Cross-sectional area		Average overshoot, m	
		Actual average, m²	Actual/ Projected	Heights	Widths
Haulage 1, 2, 3, 4	5181	33.0	140%	0.5	1.1
Conveyor 1, 2	684	37.3	160%	1.6	0.7

(a) (b)

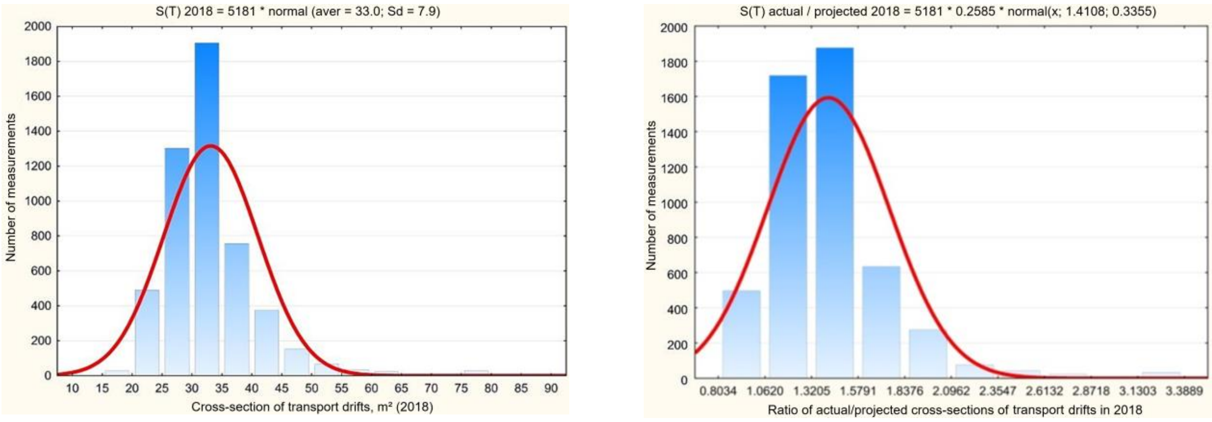


Figure 5. Dimensions of haulage drifts: (a) actual cross-section; (b) ratio of actual and projected cross-sections

(a) (b)

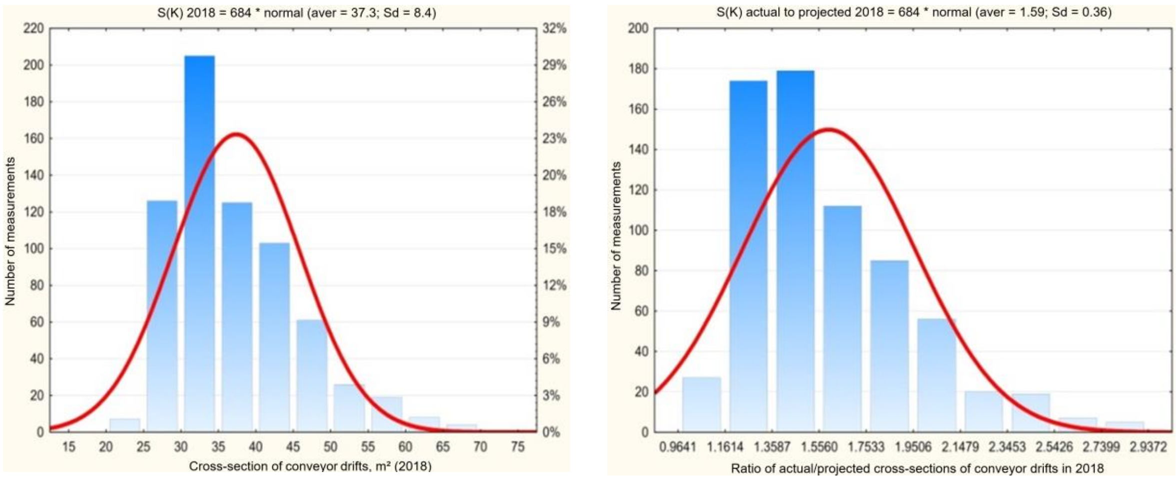


Figure 6. Dimensions of conveyor drifts: (a) actual cross-section; (b) ratio of actual and projected cross-sections

Advanced technologies such as scanning and 3D modeling provide a more accurate analysis of the structural rock mass peculiarities and identify potential zones for mining [39]-[41]. Such approaches minimize the risks of caving and improve the accuracy of identifying areas for extracting.

The next stage is to develop the technology and sequence of mining the barrier pillars and the remaining rib pillars. Based on the results of previous studies [42]-[44], it is necessary to consider the geological and geomechanical characteristics of the sites to develop a safe mining strategy. Optimizing the extracting sequence ensures maximum ore mining while minimizing costs. At the same time, the use of numerical modeling methods makes it possible to predict the rock mass behavior during the mining process and make timely adjustments to the plan [45], [46].

Special attention should be paid to predicting the state of capital drifts and the prospects for extracting their protective pillars [47]. The state of the drifts is monitored using GPR systems and acoustic methods, which allows for a detailed assessment of the state of the structures and the surrounding mass. Based on these data, predictions and strategies are developed for drift maintenance, including repair work aimed at ensuring safe operation under intense rock pressure conditions.

Numerical models demonstrate important patterns of rock pressure redistribution during repeated mining of pillars [48]-[50]. After extracting of rib pillar group, the maximum bearing pressure is transferred to the outer pillars located on the border of the caving zone when making cut cavities in underground mine workings [51]. As the roof caves, the pressure on the outer pillars decreases. The caving zone height is directly dependent on the equivalent span width: the larger it is, the higher the caving zone and the lower the pressure on the pillars [52]. Complete settling of the rock stratum to the surface, accompanied by a reduction of the bearing pressure to a minimum, occurs when an equivalent span of the caving zone is formed, exceeding one-third of the depth. The identified patterns should be taken into account when designing repeated mining to reduce risks and ensure the stability of mine workings.

After the possibilities for extracting the pillars from the open mined-out space have been exhausted, the optimal procedure for repeated mining is to first cave the entire rock stratum to the surface in the center of the mine field. This requires the extraction of at least two barrier pillars between the filled panels and further development of the repeated mining front in all directions from the formed caving zone. The whole settling of the stratum, as experience shows will be accompanied by strong seismic events [53]-[55]. For the initial settling of the overlying stratum to the surface, it is recommended to mine two barrier pillars between panels 42-43-44. The surrounding mass will then be de-stressed from bearing pressure and the repeated mining of the adjacent panels will be conducted under much more favorable geomechanical conditions. When further developing the repeated mining from the area of complete settlement of the overlying stratum, it is necessary not to leave rigid bearings such as barrier pillars, rib pillars in the mined-out space in order not to create conditions for new overhangs.

3. Methodology

The research methodology is based on a comprehensive geotechnical approach, including several interrelated stages aimed at analyzing and predicting the state of field mine workings in the context of repeated mining of pillars. The main stages include conducting mine measurements, analyzing the nature of rock mass destruction, selecting destruction criteria for modeling, numerical modeling of mining methods and determining the optimal locations for placing field mine workings.

The first stage involves detailed measurements of the actual state of field mine workings, including geometric measurements, rock state analysis, identification of fractures and other defects, as well as an assessment of the dynamics of their development. The data obtained provide an idea of the current stability of the mine workings and possible changes in the pillar mining conditions. Particular attention is paid to identifying patterns of destruction of pillars and walls, which allows predicting their behavior under stress.

The next stage is to select the destruction criteria for numerical modeling. Criteria are developed based on data on mechanical properties of the rocks, such as strength, plasticity and strain modulus, as well as the geometric characteristics of the mine workings, including their dimensions and spatial location.

Numerical modeling is used to analyze different methods of pillar mining and assess their impact on the state of field mine workings. Modern software packages are used, which make it possible to calculate in detail the stress-strain state of the mass, to identify the zones of increased risk of destruction and to assess the impact of caving on the stability of adjacent mine workings. Particular attention is paid to the influence of caving parameters, such as the width of the caving zone and the height of the overlying stratum settlement.

The modeling results make it possible to determine the most rational locations for placing new field mine workings. The locations for placement are chosen to minimize the risk of destruction, ensure operational safety and maximize mining efficiency. This approach enables to adapt design solutions to real conditions and prevent emergency situations.

The comprehensive nature of the methodology ensures that all key factors influencing the rock mass stability are taken into account. This allows not only to predict the consequences of repeated mining, but also to develop recommendations for safe and efficient conduct of mining operations, which is particularly important for the difficult conditions of the Zhomart Mine.

3.1. Designing of barrier pillar extraction technology

The following methodology is used to determine the optimal technology for extracting barrier pillars. At the initial stage, numerical modeling is conducted based on the data on physical-mechanical properties of the mass rocks and the mined-out space parameters. Modeling is performed using software that allows assessing the stress-strain state of the rock mass influenced by repeated mining.

To analyze the influence of the depth of placing the field drifts on the mass stability, scenarios with different placement depths are searched. To assess the rock stability when planning drifts, the Strength Factor parameter is used to identify zones of increased vulnerability in the mined-out space. This parameter is also used to select locations with minimum stress levels, which helps to determine the optimal locations for drifting. The further research stage includes the analysis of the nature of destruction of roof and drift walls under the influence of volumetric stresses.

3.2. Determining the required rock parting thickness for the extraction of rib pillars

As part of the research, the required rock parting thickness is determined using numerical modeling in Examine (Rocscience) software. To analyze the stability of field drifts under rib pillars and mined-out stopes, three scenarios with different "bridge" thicknesses – 8, 7 and 6 m – are examined. Each modeling option uses mass properties specified by the Hoek-Brown criterion taking into account the Geological Strength Index (GSI) and other mass parameters [56]-[58]. Mass properties used in modeling are presented in Table 2.

Table 2. Mass properties used in modeling

Parameters	Ore	Rocks
Sample strength under uniaxial compression, MPa	120	60
Sample Young's modulus, MPa	27	20
Poisson's ratio	0.2	0.2
Core disturbance RQD, %	88	88
Fracture roughness index J_r	1	1
Index of weathering and fracture filling J_a	1	1
Geological strength index GSI	67	67
Coefficient m_i	13	13
Mass strength at uniaxial compression, MPa	35	17
Mass tensile strength, MPa	1	1
Deformation modulus, MPa 8 8 lus, MPa	8	8

The first stage is to determine the physical properties of the ore and rocks, including their strength at uniaxial compression, elasticity modulus, Poisson's ratio, as well as fracturing indices (RQD, J_r, J_a). These data are used to accurately reproduce the stress-strain state of the mass for different options of drift placement.

3.3. Predicting the state of capital drifts during mining of barrier pillars

A comprehensive approach, including numerical modeling, current data analysis and prediction, is used to assess the impact of mining of barrier pillars and rib pillars on the state of capital haulage and conveyor drifts. The research is based on the use of Phase 2 (Rocscience) software package with the inclusion of Discrete Fracture Network (DFN) modulus to account for the thin-layer rock mass structure. The physical-mechanical properties of the mass rocks, including parameters of strength, elasticity, fracturing and geological strength index are the basis for modeling (Table 2). The current data on roof and wall destruction are supplemented by calculations of the rockfall and cleavage volumes, which make it possible to correlate the modeled scenarios with the real situation. In particular, the predicted values of roof (1.7 m) and wall (1.5 m) destruction are compared with the actual data.

The optimal location of the duplicate field conveyor drift is calculated to minimize the risk of destruction. Its position is determined relative to the protective pillar taking into account the data on stress distribution and the mass destruction zones. This approach ensures the stability and safety of operations during barrier pillar mining and minimizes the probability of caving in capital drifts.

Comprehensive analysis, including numerical modeling and consideration of real data, allows not only to predict possible risks, but also to develop effective measures to prevent destruction and ensure safe operation of capital drifts.

3.4. Determining the depth of field conveyor drift placement

As part of the research, to determine the optimal depth of the field conveyor drift placement, a numerical analysis of the rock mass stress-strain state is conducted, taking into account various options of the drift location relative to the protective pillar and the mined-out space. The main objective is to reduce the risk of drift destruction while maintaining its maximum stability and functionality in high pressure conditions in the rock mass.

Thus, 3 options for the depth of the field conveyor drift placement are considered: -20, -30, -40 m below the bottom of the ore deposit and 12 options of location relative to the protective pillar (Fig. 7). Under the pillar with a distance of 0, +10, +20, +30, +40 m from its boundary and under the mined-out panel space with a distance of -10, -20, -30, -40, -50, -60, -70 m from the pillar boundary. A total of 36 options of field drift location are examined.

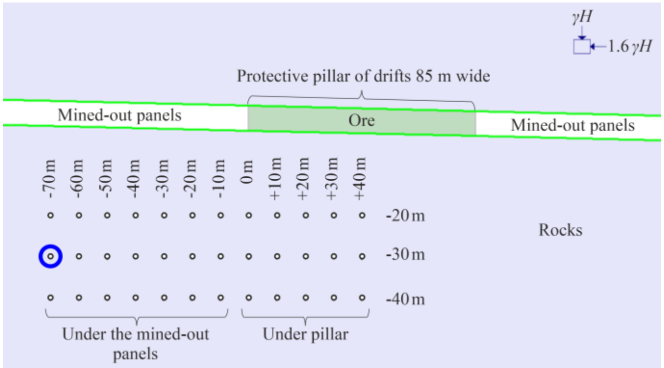


Figure 7. Options for placing a field conveyor drift

Mining operations are modeled in a section across the axis of the haulage and conveyor drifts at the depth of $H = 600$ m. The mass properties used in the modeling of fractured ore and rock masses are given in Table 2. Natural stress state of masses: rock stratum gravitational pressure – γH, horizontal tectonic stresses – 1.6 γH. To the left and right of the drift pillar, mined-out spaces of 600 m long panels are modeled assuming that both the rib pillars and barrier pillars are extracted. That is, for the situation when the load on the protective pillar is maximized.

Maximum stresses σ_{max} acting on the field conveyor drift contour are calculated by B. Kirsch formula [59]:

$$\sigma_{max} = 3\sigma_1 - \sigma_3 . \quad (1)$$

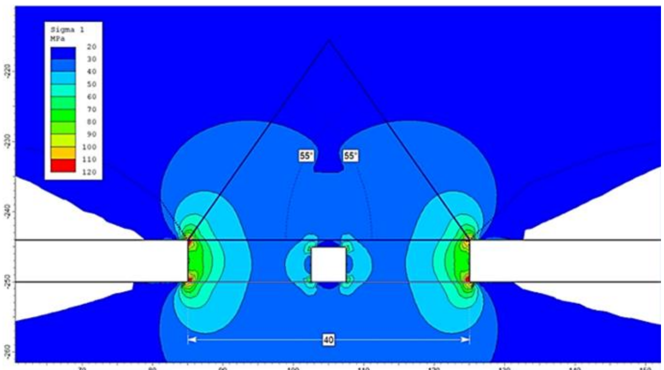
This approach makes it possible to take into account the complex stress state of the mass caused by repeated mining and to develop solutions for improving safety in the conduct of mining operations.

4. Results and discussion

4.1. Technology recommended for extraction of barrier pillars

Based on the numerical modeling results, in the barrier pillars between the filled panels, the distribution of maximum acting stresses has the form of a parabola, as in an elastic medium under a rigid stamp. The edge parts of the pillar are particularly heavily loaded (Fig. 8). In order to extract the ore reserves in the barrier pillar, two field drifts are required for trench drawing of the broken ore. They should be driven in places with minimal acting stresses (Fig. 8). Under the barrier pillar boundaries, the level of acting stresses is maximal. Analysis of causes of the ventilation cut drift caving of panel 41 bottom (in the 3-VI deposit) shows that the caving of the walls and roof of the drift occurs under the barrier pillar boundaries between panels 41-42, that is, in the areas with the maximum stress level. The thickness of the bridge composed of water-flooded red-colored siltstones is 9 m.

(a)



(b)

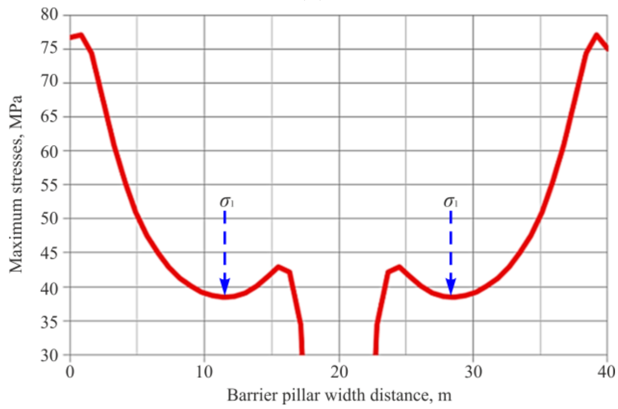


Figure 8. Distribution of maximum stresses (σ_1), acting in the barrier pillar between filled panels: (a) numerical modeling result; (b) graphical interpretation

The optimum 8 m depth for placing field drifts with a cross-section of 14.6 m^2 (the minimum cross-section for Solo drilling rigs) is found by searching through the options for their placement. Figure 9 shows a layout of placing field drifts under the barrier pillar for design purposes.

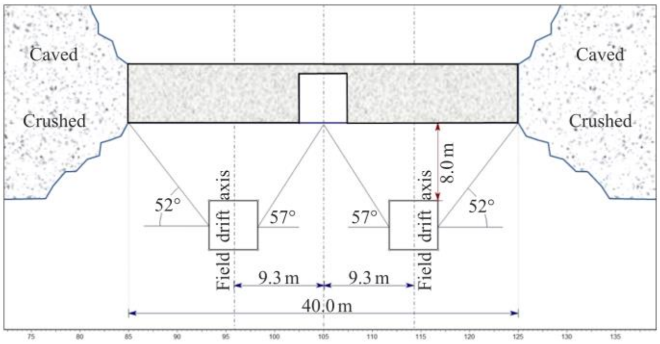


Figure 9. Layout of placing field trench drifts under the barrier pillar

Figure 10 shows the mass strength factor distribution at the optimal rock parting thickness of 8 m. The figure shows that in the panel drift on the ore bottom in the center of barrier pillar, the destruction of walls, roof and bottom develops to a depth of 0.9-1.3 m from the contour. Also, the edge areas of barrier pillar are crushed to a depth of 1.6-2.0 m (in Figure 10, the crushed parts of the mass are highlighted in white).

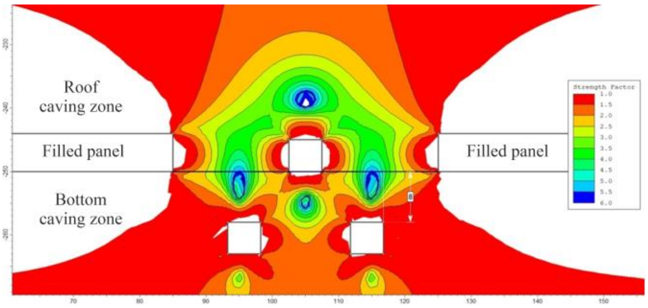


Figure 10. Rock stability during field preparation of barrier pillar between filled panels

Figure 10 clearly shows the roof caving zone above the filled panel and the symmetrical zone of rock crushing in the bottom of the panel. Therefore, field drift driving under the filled mined-out space will be conducted in a crushed mass. Under barrier pillar, the mass is in a volumetric stressed state and therefore is not yet destroyed.

Field drifting under barrier pillar is also accompanied by crushing of rocks in the roof and walls to a depth of up to 1.2 m. In order to support them, it is necessary to fasten both the roof and the walls of the field drifts with combined support:

– roof bolts SPAK ∅ 22 mm, length 2.2 m with screw nut with spacing 1×1 m;

– welded metal mesh made of ∅ 5 mm wire with cell # 100×100 mm;

– shotcrete concrete structure at least 5 cm thick.

Roof bolts without a screw nut and shotcrete concrete structure are used and do not prevent crushed rocks from falling out. Shotcrete concrete structure without mesh bursts and crumbles. Therefore, only the combination of roof-bolt + mesh + shotcrete can support field drifts in highly stressed weak rock masses. The driving of field drifts, and even more so the breaking and shipping of ore from them without a strengthened combined support is doomed to failure.

The experience of mines in Eastern Kazakhstan has shown that the combined support is superior to metal frame support in terms of load-bearing capacity, serviceability, mechanization levels and operational safety. The Kazminerles company management has set a task for its mines to replace frame metal support with combined support in the near future.

4.2. Required rock parting thickness for extracting rib pillars

The calculation results show that when the field drift is placed 6 and 7 m below the bottom of the mined-out panels, the rib pillar is pressed into the drift in a similar way to a rigid punch (stamp) presses through the curtain wall and is pressed into the cavity. At a bridge thickness of 8 m, there is no more pressing of the rib pillar, although the field drift is destroyed in the roof and walls (Fig. 11). Depth of destruction: in the roof – 1.6 m, in the walls – 1.1 m. This volume of destruction can be avoided by using a strengthened combined support (roof-bolts + mesh + shotcrete concrete structure). The areas of destruction with strength factor less than 1 and with strength factor greater than 2 are highlighted in white in Figure 11.

(a)

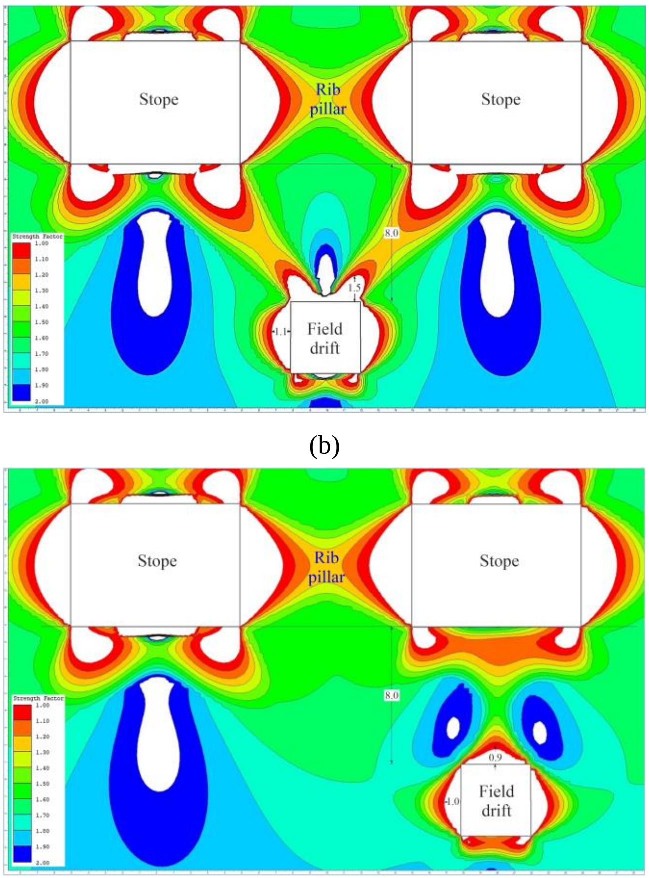


Figure 11. Distribution of strength factors of masses: (a) when driving the field drift under the rib pillar; (b) when driving the field drift under the stope

In order to support field drifts, in addition to compliance with the required thickness of the ceiling and strengthened combined fastening of the roof and walls (from skirting to skirting), it is extremely important to maintain the minimum dimensions of the drift, to conduct driving of the drift with contour blasting and to strengthen the fastening of joints with horizontal metallic strips to prevent "iron" from breaking down.

Based on the experience of Shatyrkul Mine for Solo drilling rig operation, the minimum sufficient cross-section (width × height) = 3.8×3.9 m, that is14.6 m^2. At the Nurkazgan Mine, good quality of contouring of drifts with the minimal overshoots was achieved, when not GVV A-6 granulite, but ammonium nitrate (of all industrial types of explosives, nitrate has the lowest brisance) was used for blasting of contour drifts. Tishinsky mine (Kazzinc, RGOK) uses strips to support mine workings in weak rock at depths greater than 1 km.

Given that the prospects for completed mining of the pillars at Zhomart-1 Mine are related to field preparation, two issues need to be addressed:

– calculate the feasibility of switching to a smaller size of equipment in order to reduce the driving volume of mine workings in the rock;

– identify locations for stockpiling of rock from driving of field mine workings or a separate haulage route for rock delivery to the surface.

4.3. Predicting further state of capital drifts

Mining of barrier and rib pillars with field preparation will be accompanied by an increase in pressure on the protective pillar of capital drifts, at least until full settlement of the overlying stratum. According to rough estimates, the increase in the load on the drift pillar may reach 50% of the current state. Naturally, damage to the haulage and conveyor drifts will continue, and primarily in the walls.

For haulage drifts located close to the mined-out space, the main risk of their loss as a result of caving is the destruction of the pillar between the drift and the panel (Fig. 3b). The calculation results are shown in Figure 12.

The destruction zones in Figure 12 are highlighted in white. The current scale of the calculated roof rockfall to a height of 1.7 m is almost identical to the average value of actual cleavage of 1.6 m. The calculated thickness of wall cleavage of 1.5 m is 2 times higher than the average value of actual rockfall. But the histogram in Figure 6 shows that cleavage from the conveyor drift walls often reaches 2-3 m. Thus, it can be considered that the calculated assessment of the current state of the conveyor drifts in general corresponds to the observed in practice scale of rock pressure manifestation.

To predict the state of the conveyor drifts after barrier pillar mining, the load on the protective pillar increases by 50%. The destruction zones in the walls increase insignificantly – up to 1.8 m. But the state of the roof deteriorates dramatically: the height of roof caving exceeds 3 m. This means that in the areas of fastening the drifts with roof bolts, the roof-bolt support will cave together with the crushed rock, and in the areas of fastening the drifts with SCP frames, the load on them may exceed the limit, and the support may be destroyed, because one arch made of SVP-22 special profile, designed for a cross-section of 10-12 m^2, in the mine working with a cross-section of 30-35 m^2 (Table 1 and Fig. 6) can withstand no more than 10-15 tons. This prediction means that the risk of caving of capital haulage and conveyor drifts during mining of barrier pillars is very significant.

Numerous destructions in haulage and conveyor drifts and prediction of their loss during barrier pillar mining require consideration of the issue of driving a duplicate field conveyor drift. Numerical modeling is used to determine its optimal location relative to the protective pillar of haulage and conveyor drifts.

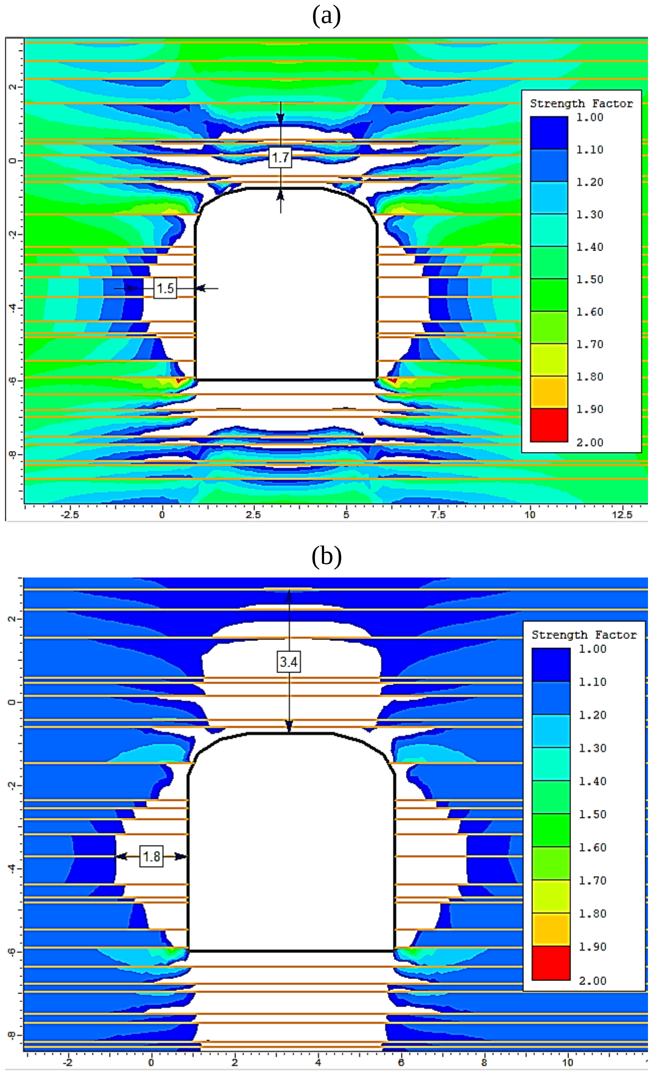


Figure 12. Extent of destruction of conveyor drifts after mining of barrier pillar: (a) current; (b) predictive

4.4. Determining the depth of the field conveyor drift placement

The protective pillar is located in the center of the mined-out space under high pressure, which will only increase during further repeated mining. This makes it problematic to locate the field conveyor drift under the pillar coaxially with the existing conveyor drift. The distribution of the values and directions of action of the maximum stresses σ_1 (or example) is shown in Figure 13.

The maximum stresses σmax that will act on the field conveyor drift contour are summarized in Table 3 and in Figure 14. The values of maximum σ_1 1 and minimal σ_3 stresses acting in the mass are taken from the calculation model at the points of possible field conveyor drift location (Table 4).

Based on the calculation results, it is seen that placing the field drift under the pillar is inexpedient, because the values of maximum stresses σmax arising on its contour significantly exceed the strength of the mass, ore (gray sandstones) and rocks. The lowest values σmax on the field drift contour are observed when it is placed -30 m deeper than the bottom of the mined-out deposit 4-1 and at a distance of -70 m from the protective pillar boundary. Even in this case, the acting stresses in the drift roof will be greater than the rock strength.

Table 3. Maximum stresses on the field drift contour, MPa

σ_{max}		Distance from the pillar boundary under the panels (-) or under the pillar (+), m											
		Under mined-out panels							Under pillar				
		-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40
Deepening, m	-20	71	80	92	109	135	178	228	257	239	205	186	179
	-30	82	94	108	125	148	178	205	221	218	205	195	190
	-40	93	105	116	133	149	173	190	199	203	198	195	194

Table 4. Stresses acting in the mass, MPa

σ_1, σ_3			Distance from the pillar boundary under the panels (-) or under the pillar (+), m											
			Under mined-out panels							Under pillar				
			-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40
Deepening, m	-20	σ_1	24	27	31	37	46	61	80	94	93	85	80	78
		σ_3	1	1	1	2	3	5	12	25	40	50	54	55
	-30	σ_1	28	32	37	43	51	62	73	81	83	81	79	78
		σ_3	2	2	3	4	5	8	14	22	31	38	42	44
	-40	σ_1	32	36	40	46	52	61	68	73	76	76	76	76
		σ_3	3	3	4	5	7	10	14	20	25	30	33	34

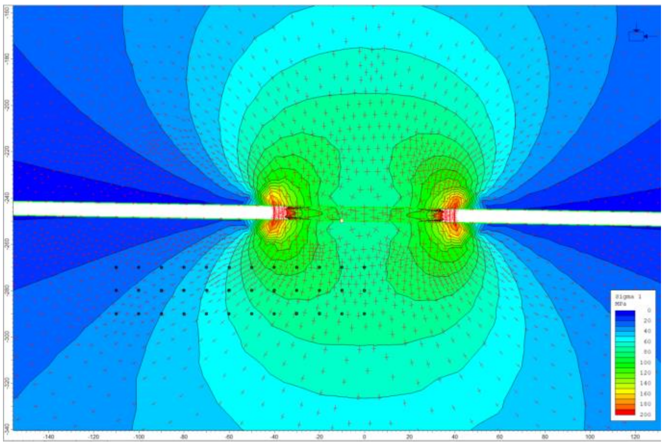


Figure 13. Maximum stresses acting in the vicinity of the protective pillar of haulage and conveyor drifts

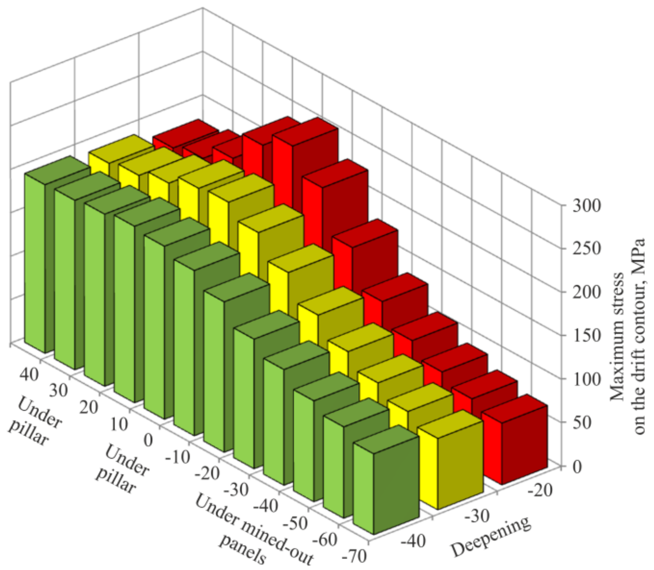


Figure 14. Values of maximum stresses σmax acting on the field drift contour while it is placed at different points

The point of recommended field drift placement (at a distance of -70 m from the pillar boundary and -30m below the bottom of the mined-out space) is highlighted in blue in Table 3, and in Figure 7 it is marked with a blue circle.

When placing a field conveyor drift under the mined-out space, it will intersect unmined barrier pillars. To assess the state of the field drift under the barrier pillar, similar numerical modeling is performed in a section along the conveyor drift axis (across the barrier pillar axes). The distribution of values and directions of maximum stresses σ_1 acting in the mass are shown in Figure 15.

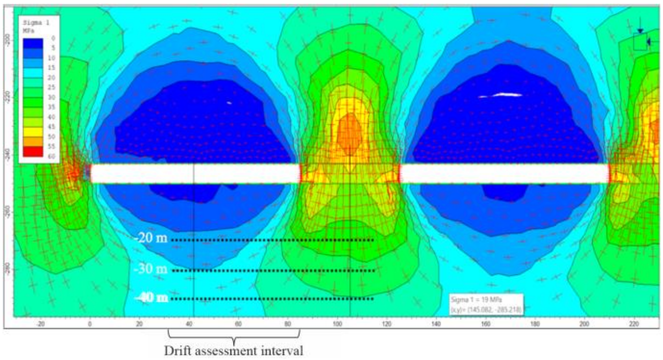


Figure 15. Maximum stresses acting in the vicinity of filled panels separated by barrier pillars

The 85 m wide panels and the 40 m wide barrier pillars are periodically repeated. Therefore, to assess the state of the field drift (dashed lines with different depth of placement), the interval from the middle of the panel to the middle of the barrier pillar is selected (Fig. 15). The curves of calculated values σ_1, σ_3, σ_{max} along the field drift axis at different depths of its placement are shown in Figure 16.

Figure 16 analysis shows that when the field drift is placed at a depth of -20 m below the bottom of the filled panels, the maximum stresses on its contour become quite large. Therefore, a depth of -30 m may be chosen as the optimum depth to place a field conveyor drift.

The research results show that to ensure the stability of mine workings near the mined-out space, it is necessary to design a field conveyor drift not less than -30 m deeper than the bottom of the mined-out deposit 4-1 and at a distance of -70 m from the protective pillar boundary. The maximum stresses max σ that will act on the field conveyor drift contour, when it is placed at different points, have also been calculated.

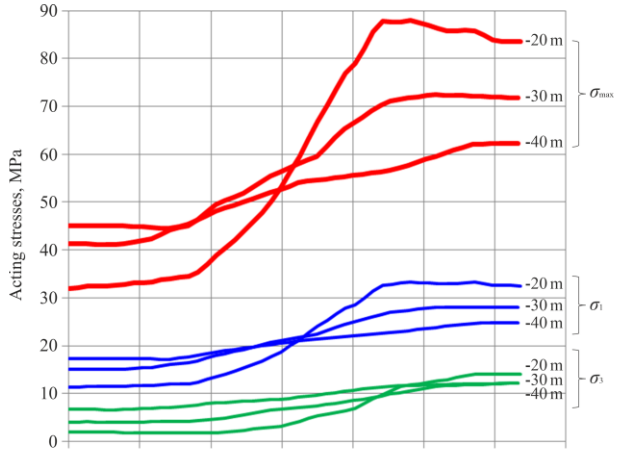


Figure 16. Values of stresses acting in the mass σ_1, σ_3 and on the field drift contour σ_{max} at different depth of its placement

The scientific novelty of the research is in proposing a new solution to an important scientific problem related to predicting the geomechanical state of the rock mass and ensuring the stability of mine workings near the mined-out space. The dependence of the change in maximum stresses acting on the field conveyor drift contour on its location relative to the protective pillar has been numerically determined, which makes it possible the rock mass geomechanical state to be assessed in the form of a model. This solution can be used in designing repeated mining operations and predicting the geomechanical state of the rock mass to ensure safe conduct of mining operations when driving preparatory workings.

5. Conclusions

The research results and conclusions presented in the paper underline the importance of a comprehensive approach to the design of field mine workings in the context of repeated mining of pillars. The main purpose of the research was to determine rational locations for placing field mine workings, which was achieved through analysis of bearing pressure from the barrier pillar and its influence on the design of field conveyor drifts. A research conducted at the Zhomart Mine of the Zhaman-Aybat field demonstrates how the use of instrumental measurements and multi-year statistical data can lead to more accurate prediction of the geomechanical state of a rock mass. This, in turn, makes it possible to determine the optimal parameters for placing field conveyor drifts, which is critically important for ensuring the stability of mine workings.

One of the key aspects identified in the research is the need to design field conveyor drifts at a depth of at least 30 m below the mined-out deposit and at a distance of 70 m from the boundary of the protective pillar. These parameters minimize the risks associated with caving and other geomechanical problems that may arise during repeated field mining. The use of numerical modeling based on Rocscience software allows not only to assess the stress-strain state of the mass, but also to adapt design solutions depending on changing conditions during the mining process.

Prospects for further research in this area may include a more detailed study of the influence of various factors, such as rock type, water content and dynamics of mining operations, on the stability of mine workings. For example, integrating data on geologic conditions and dynamic loads can lead to more complex models that take into account not only static but also dynamic aspects of mining operations. This will improve the prediction of possible caving and other negative consequences, which, in turn, will increase the safety of miners and the efficiency of mining operations.

In addition, it is worth noting that the results of this research can be used to develop new standards and recommendations for the design of mine workings in the context of repeated mining. This may include the development of guidelines for mining engineers that will take into account the specific conditions of each particular field. Thus, research in the field of geomechanics not only contributes to improved design, but can also be a basis for the formation of new approaches to risk management in the mining industry.

Author contributions

Conceptualization: DT; Data curation: MZ, DI; Formal analysis: AZ, BR; Funding acquisition: DT; Methodology: DT, AK; Project administration: DT; Resources: AZ, MZ; Software: MZ; Supervision: DT; Validation: AZ, DI; Visualization: MZ, BR; Writing – original draft: DT, MZ; Writing – review & editing: AZ, DT, DI. All authors have read and agreed to the published version of the manuscript.

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Conflicts of interests

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

References

[1] Zhienbayev, A.B., Zhunusbekova, G.J., Zharaspaev, M.A., & Balpanova, M.J. (2023). Investigation of the stability of mine workers in the zone of influence of excavation work during the development of deposits. *Mining Magazine of Kazakhstan*, *5*, 41-46. https://doi.org/10.48498/minmag.2023.2017.5.004

[2] Zhiyenbayev, A. (2023). *Geomekhanicheskoe obosnovanie povtornoy razrabotkitselikov na osnove dannykh kompleksnogo monitoringa sostoyaniya massiva gornykh porod*. PhD Thesis. Karaganda, Kazakhstan: Abylkas Sagynov Karaganda Technical University.

[3] Guo, Y., & Miao, Y. (2022). Study on stope stability in continuous mining of long-dip, thin orebody by room – pillar method. *Sustainability*, *14*(15), 9601. https://doi.org/10.3390/su14159601

[4] Adamaev, M., Kuttybaev, A., & Auezova, A. (2015). Dynamics of dry grinding in two-compartment separator mills. *New Developments in Mining Engineering 2015: Theoretical and Practical Solutions of Mineral Resources Mining*, 435-439. https://doi.org/10.1201/b19901-76

[5] Boguslavskiy, E.I., & Andreev, M.N. (2014). Tekhnologiya chastichnoy otrabotki mezhdukamernykh tselikov pri etazhno-kamernoy sisteme razrabotki korobkovskogo mestorozhdeniya kurskoy magnitnoy anomalii. *Zapiski Gornogo Instituta*, *207*, 12-16.

[6] Sirazhev, A., Istekova, S., Tolybaeva, D., Togizov, K., & Temirkhanova, R. (2025). Methodology and results of detailed 3d seismic exploration in the zhezkazgan ore district. *Applied Sciences*, *15*(2), 567. https://doi.org/10.3390/app15020567

[7] Zhaimina, V., Mustapayeva, S., & Omarova, G. (2024). New data on the study of Serpukhov deposits of the Beleuti section. *Engineering Journal of Satbayev University*, *146*(6), 39-46. https://doi.org/10.51301/ejsu.2024.i6.06

[8] Aidarbekov, Zh.K., Istekova, S.A., & Glass, H. (2021). Complex of geophysical research for studying geological structure of Zhezkazgan ore region in Kazakhstan. *Proccedings of the 17th Conference and Exhibition Engineering and Mining Geophysics 2021*, 1-9. https://doi.org/10.3997/2214-4609.202152070

[9] Rakishev, B.R., Rakisheva, Z.B., & Kuttybayev, A.Y. (2025). *Method for the complete extraction of conditioned ores from complex-structured blocks of ledges*. Patent for the invention of the Republic of Kazakhstan, IPC: E21C 41/00 (2006.01). Application number: 2023/0880.1. Number and date of Bulletin # 6, 07/02/2025, #37180.

[10] Sarybayev, O., Nurpeisova, M., Kyrgizbayeva, G., & Toleyov, B. (2015). Rock mass assessment for man-made disaster risk management. *New Developments in Mining Engineering 2015: Theoretical and Practical Solutions of Mineral Resources Mining*, 403-409. https://doi.org/10.1201/b19901-70

[11] Istekova, S., Makarov, A., Tolybaeva, D., Sirazhev, A., & Togizov, K. (2024). Determining the boundaries of overlying strata collapse above mined-out panels of Zhomart Mine using seismic data. *Geosciences*, *14*(11), 310. https://doi.org/10.3390/geosciences14110310

[12] Dzimunya, N., & Fujii, Y. (2024). A proposed framework to estimate pillar strength in room-and-pillar hard rock mines. *Proceedings of the 58th U.S. Rock Mechanics / Geomechanics Symposium*, ARMA-2024-0116. https://doi.org/10.56952/ARMA-2024-0116

[13] Ren, Q., & Cao, J. (2024). Characteristics of coal crack development and gas desorption in the stress affected zone of rock pillar. *Scientific Reports*, *14*(1), 24551. https://doi.org/10.1038/s41598-024-76612-6

[14] Rysbekov, K.B., Toktarov, A.A., & Kalybekov, T. (2021). Technique for justifying the amount of the redundant developed reserves considering the content of metal in the mining ore. *IOP Conference Series: Earth and Environmental Science*, *666*(3), 032076. https://doi.org/10.1088/1755-1315/666/3/032076

[15] Portnov, V.S., Yurov, V.M., & Mausymbaeva, A.D. (2018). Influence of surface properties of minerals on rebellious ore disintegration. *Journal of Mining Science*, *54*, 681-689. https://doi.org/10.1134/S106273911804460

[16] Stupnik, M., Kalinichenko, V., & Pismennyi, S. (2013). Pillars sizing at magnetite quartzites room-work. *Annual Scientific-Technical Collection – Mining of Mineral Deposits*, 11-15. https://doi.org/10.1201/b16354-3

[17] Portnov, V.S., Yurov, V.M., & Maussymbayeva, A.D. (2016). Applied problems of thermodynamic approach to the analysis of geophysical information. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, *1*, 5-11.

[18] Kassymkanova, K.K., Rysbekov, K.B., Nurpeissova, M.B., Kyrgizbayeva, G.M., Amralinova, B.B., Soltabaeva, S.T., Salkynov, A., & Jangulova, G. (2023). Geophysical studies of rock distortion in mining operations in complex geological conditions. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *48*, 57-62. https://doi.org/10.5194/isprs-archives-XLVIII-5-W2-2023-57-2023

[19] Istekova, S.A., Tolybayeva, D.N., Issayeva, L.D., Ablessenova, Z.N., & Talassovm, M.A. (2024). The effectiveness of the use of geophysical research in the underground development of ore deposits. *Engineering Journal of Satbayev University*, *146*(4), 24-33. https://doi.org/10.51301/ejsu.2024.i4.04

[20] Matayev, A., Kainazarova, A., Arystan, I., Abeuov, Y., Kainazarov, A., Baizbayev, M., Demin, V., & Sultanov, M. (2021). Research into rock mass geomechanical situation in the zone of stope operations influence at the 10th Anniversary of Kazakhstan's Independence mine. *Mining of Mineral Deposits*, *15*(1), 103-111. https://doi.org/10.33271/mining15.01.103

[21] Krupnik, L.A., Bitimbaev, M.Z., Shaposhnik, S.N., Shaposhnik, Y.N., & Demin, V.F. (2015). Validation of rational backfill technology for Sekisovskoe deposit. *Journal of Mining Science*, *51*, 522-528. https://doi.org/10.1134/S1062739115030138

[22] Liu, B., Wang, W., Liu, Z., Ouyang, N., Mao, K., & Zhou, F. (2024). Study on large deformation of soil-rock mixed slope based on GPU accelerated material point method. *Scientific Reports*, *14*(1), 6983. https://doi.org/10.1038/s41598-024-57362-x

[23] Kostyuko, V.V., Makarov, A.B., Myakshev, V.S, & Ushkov, S.G. (1980). Geomekhanicheskiy analiz konstruktsii dnishcha dlya sistem s zakladkoy. *Gornyy Zhurnal*, *10*, 44-46.

[24] Fan, S., Chen, Y., Wang, L., Liu, X., & Chen, J. (2023). Application of seismic channel wave technology on small structure exploration in coal mine. *International Journal of Energy*, *3*(3), 14-18. https://doi.org/10.54097/ije.v3i3.004

[25] Protopopov, I.I., Paliy, V.D., Piskarev, V.K., & Afanasyev, Yu.S. (1985). Prognoz geomekhanicheskikh protsessov i upravlenie gornym davleniem na shakhtakh. *VNIMI*, 84-93.

[26] Ivadilinova, D.T., Issabek, T.K., Takhanov, D.K., & Yeskenova, G.B. (2023). Predicting underground mining impact on the earth's surface. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, *1*, 32-37. https://doi.org/10.33271/nvngu/2023-1/032

[27] Feng, G.R., Bai, J.W., Shi, X.D., Qi, T.Y., Wang, P.F., Guo, J., & Kang, L.X. (2021). Key pillar theory in the chain failure of residual coal pillars and its application prospect. *Journal of China Coal Society*, *46*(1), 164-179. https://doi.org/10.13225/j.cnki.jccs.2020.0927

[28] Bron, K.B., Gardner, L.J. & Zyl, J. (2024). Beyond the empirical pillar design method: The strain criterion and the pillar load inversion concepts. *Journal of the Southern African Institute of Mining and Metallurgy*, *124*, 293-302. https://doi.org/10.17159/2411-9717/3125/2024

[29] Zhanibekov, B., Kamalovich, M., Toshmukhamdov, B., Abdunabieva, M., & Abdusamatova, D. (2024). Geodynamic issues of ore deposits in Central Asia. *E3S Web of Conferences*, *497*, 02032. https://doi.org/10.1051/e3sconf/202449702032

[30] Sevastyanov, B.N., Udalov, A.E., Bitimbaev, M.Zh., & Bekbaev, S.M. (1990). Upravlenie gornym davleniem pri vyemke tselikov. Upravlenie gornym davleniem i prognoz bezopasnykh usloviy osvoeniya ugolnykh mestorozhdeniy. *VNIMI*, 137-143.

[31] Hao, J., Chen, A., Li, X., Bian, H., Shi, Y., Wang, X., Zhao, J., & Liu, H. (2022). A case study of pillar extraction techniques based on strip-filling and second-mining method. *Frontiers in Earth Science*, *10*, 1051245. https://doi.org/10.3389/feart.2022.1051245

[32] Jiang, P.F., Kang, H.P., Zhang, J., Lin, J., & Si, L. (2011). Mechanism of load-transfer between coal pillars with different widths in mining the short-range seams. *Journal of Mining and Safety Engineering*, *28*, 345-349.

[33] Slashchova, O., Kohtieva, O., Rahimov, S., & Kharchenko, V. (2024). Forecasting the risks of underground roadway stability loss based on mine research data. *IOP Conference Series: Earth and Environmental Science*, *1348*, 012057. https://doi.org/10.1088/1755-1315/1348/1/012057

[34] Wu, Y., Hu, J., Xie, C., & Shi, D. (2021). Case study on the stability control of broken surrounding rock in roadway excavation on the edge of a collapsed stope area. *Advances in Civil Engineering*, *1*, 1-14. https://doi.org/10.1155/2021/8658847

[35] Kozhogulov, K.C., Takhanov, D.K., Kozhas, A.K., Imashev, A.Z., & Balpanova, M.Z. (2020). Methods of forward calculation of ground subsidence above mines. *Journal of Mining Science*, *56*, 184-195. https://doi.org/10.1134/S1062739120026637

[36] Sadykov, B.B., Baygurin, Zh.D., Altayeva, A.A., Kozhaev, Zh.T., & Stelling, W. (2019). New approach to zone division of surface of the deposit by the degree of sinkhole risk. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, *6*, 31-35. https://doi.org/10.29202/nvngu/2019-6/5

[37] Dai, Z., Tang, J., Wang, Y., Jiang, Z., Zhang, L., & Liu, S. (2017). A model for predicting mining subsidence in bedding rock slopes. *Chinese Journal of Rock Mechanics and Engineering*, *36*, 3012-3020. https://doi.org/10.13722/j.cnki.jrme.2017.0415

[38] Xia, K., Chen, C., Liu, X., Zheng, X., Zhou, Y., Song, X., & Yuan, J. (2024). Ground collapse and caving mechanisms in strata overlying sublevel caving mines: A case study. *Bulletin of Engineering Geology and the Environment*, *83*(1), 21. https://doi.org/10.1007/s10064-023-03529-1

[39] Baibatsha, A.B., Shaiyakhmet, T.K., Bashilova, E.S., & Fedotenko, N.A. (2024). Geomechanical assessment of mineral deposits based on 3D modeling. *Eurasian Mining*, *41*(1), 28-32. https://doi.org/10.17580/em.2024.01.07

[40] Kakimzhanov, Y., Kozhaev, Z., & Bektemirova, S. (2015). Technique of creation interactive visualization of 3D maps. *International Multidisciplinary Scientific Geoconference*, 845-850. https://doi.org/10.5593/sgem2015/b21/s8.108

[41] Shults, R., Seitkazina, G., & Soltabayeva, S. (2023). The features of sports complex "Sunkar" monitoring by terrestrial laser scanning. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *48*, 105-110. https://doi.org/10.5194/isprs-archives-XLVIII-5-W2-2023-105-2023

[42] Takhanov, D., Balpanova, M., Kenetayeva, A., Rabatuly, M., Shaikhova, G., & Usupayev, S. (2024). Evaluation of weakened areas to determine actual rock properties. *AIP Conference Proceedings*, *3243*, 020081. https://doi.org/10.1063/5.0248142

[43] Nemova, N.A., Tahanov, D., Hussan, B., & Zhumabekova, A. (2020). Technological solutions development for mining adjacent rock mass and pit reserves taking into account geomechanical assessment of the deposit. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, *2*, 17-23. https://doi.org/10.33271/nvngu/2020-2/017

[44] Imashev, A., Suimbayeva, A., Zholmagambetov, N., Takhanov, D., & Abdimutalip, N. (2018). Research of possible zones of inelastic deformation of rock mass. *News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences*, *2*, 177-184.

[45] Nurpeisova, M.B., & Kurmanbaev, O.S. (2016). Laws of development of geomechanical processes in the rock mass Maykain mine. *News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences*, *6*(420), 109-115.

[46] Yensepbayev, T.A., Cathelineau, M., Baymaganbetov, B., & Nurmaganbetova, L.A. (2022). Thermobaric characteristics of fluid inclusions in subsalt rocks of the East of Precaspian syneclise and the Pre-Ural of Aktobe. *Engineering Journal of Satbayev University*, *144*(2), 28-33. https://doi.org/10.51301/ejsu.2022.i2.05

[47] Zhang, Z., Li, Z., Xu, G., Gao, X., Liu, Q., Li, Z., & Liu, J. (2023). Lateral abutment pressure distribution and evolution in wide pillars under the first mining effect. *International Journal of Mining Science and Technology*, *33*(3), 309-322. https://doi.org/10.1016/j.ijmst.2022.11.006

[48] Takhanov, D., Zhienbayev, A., & Zharaspaev, M. (2024). Determining the parameters for the overlying stratum caving zones during re-peated mining of pillars. *Mining of Mineral Deposits*, *18*(2), 93-103. https://doi.org/10.33271/mining18.02.093

[49] Qiu, S., Zhang, S., Jiang, Q., Li, S., Zhang, H., & Wang, Q. (2024). Investigation of stress-induced progressive failure of mine pillars using a Voronoi grain-based breakable block model. *International Journal of Mining Science and Technology*, *34*(5), 713-729. https://doi.org/10.1016/j.ijmst.2024.05.001

[50] Bazaluk, O., Petlovanyi, M., Zubko, S., Lozynskyi, V., & Sai, K. (2021). Instability assessment of hanging wall rocks during underground mining of iron ores. *Minerals*, *11*(8), 858. https://doi.org/10.3390/min11080858

[51] Lozynskyi, V., Yussupov, K., Rysbekov, K., Rustemov, S., & Bazaluk, O. (2024). Using sectional blasting to improve the efficiency of making cut cavities in underground mine workings. *Frontiers in Earth Science*, *12*, 1366901. https://doi.org/10.3389/feart.2024.1366901

[52] Nurpeisova, M.B., Sarybaiev, O.A., & Kurmanbaiev, O.S. (2016). Study of regularity of geomechanical processes development while developing deposits by the combined way. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, *4*, 30-36.

[53] Tripathy, D.P., & Ala, C.K. (2018). Identification of safety hazards in Indian underground coal mines. *Journal of Sustainable Mining*, *17*(4), 175-183. https://doi.org/10.46873/2300-3960.1138

[54] *Opredelenie granits zon obrusheniy nalegayushchey tolshchi nad pogashennymi panelyami rudnika Zhomart*. (2021). Otchet NIR. Almaty, Kazakhstan: TOO "Kazgipro-tsvetmet", 72 s.

[55] Takhanov, D., Balpanova, M., Kenetayeva, A., Rabatuly, M., Zholdybayeva, G., & Usupayev, S. (2023) Risk assessments for rockfalls taking into account the structure of the rock mass. *E3S Web of Conferences*, *443*, 04012. https://doi.org/10.1051/e3sconf/202344304012

[56] Hoek, E., & Diederichs, M.S. (2006). Empirical estimation of rock mass modulus. *International Journal of Rock Mechanics and Mining Sciences*, *43*(2), 203-215. https://doi.org/10.1016/j.ijrmms.2005.06.005

[57] Brady, B.H.G., & Brown, E. (2006). *Rock mechanics for underground mining*. New York, United States: Chapman and Hall, 645 p.

[58] Hoek, E., Carter, T.G., & Diederichs, M.S. (2013). Quantification of the geological strength index chart. *ARMA US Rock Mechanics / Geomechanics Symposium*, ARMA-2013.

[59] Kirsch, G. (1898). Die theorie der elastizität und die bedürfnisse der festigkeitslehre. *Zeitschrift des Vereines Deutscher Ingenieure*, *42*, 797-807.

Визначення раціональних місць закладання польових виробок у зоні впливу виробленого простору при повторній розробці ціликів

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Мета. Дослідження впливу опорного тиску від бар'єрного цілика на польовий штрек з метою визначення раціональних місць закладання польових виробок у зоні впливу повторної розробки на руднику Жомарт родовища Жаман-Айбат.

Методика. Дослідження включає аналіз результатів шахтних випробувань, проведених на основі інструментальних вимірів фактичних параметрів конструктивних елементів системи розробки, обробку багаторічних статистичних даних моніторингу стану масиву гірських порід, а також моделювання з використанням програмного забезпечення Rocscience для визначення напружено-деформованого стану масиву гірських порід. Для моделювання використовувалися фактичні фізико-механічні властивості руд та вміщуючих порід родовища Жаман-Айбат.

Результати. Дослідження дозволило визначити параметри раціонального розташування польового конвеєрного штреку відносно охоронного цілика та виробленого простору. Обґрунтовано, що польовий конвеєрний штрек необхідно проєктувати не менше, ніж на -30 м глибше підошви відпрацьованого покладу 4-1 і на віддаленні -70 м від межі охоронного цілика. Розраховані максимальні напруження $\sigma_{\max}$, які діятимуть на контурі польового конвеєрного штреку при його закладанні в різних точках.

Наукова новизна. Встановлено залежність зміни максимальних напружень, що діють на контурі польового конвеєрного штреку, від його розташування відносно охоронного цілика, що дозволяє в модельному вигляді оцінювати геомеханічний стан масиву гірських порід.

Практична значимість. В результаті проведених шахтних випробувань та чисельних експериментальних досліджень запропоновано нове вирішення важливої наукової проблеми, пов'язаної з прогнозуванням геомеханічного стану масиву гірських порід та забезпеченням стійкості гірничих виробок поблизу виробленого простору. Результати досліджень можуть бути використані при проєктуванні повторних розробок і прогнозуванні геомеханічного стану гірського масиву, щоб забезпечити безпечне ведення гірничих робіт при проходженні підготовчих виробок.

Ключові слова: *руда, повторна розробка, цілик, гірничі роботи, вироблений простір, моделювання, родовище*

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