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Determining the parameters for the overlying stratum caving zones during re-peated mining of pillars

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Abstract

Purpose. The research aims to determine the parameters for the overlying stratum caving zones above the mined-out space during repeated mining of pillars at the Zhomart Mine of the Zhaman-Aybat field for the purpose of predicting hazardous zones of influence of mining operations.

Methods. Research includes an analysis of the results of previous in-situ studies conducted using seismic surveys, as well as modeling with the Examine2D software to determine the stress-strain state of the overlying stratum mass. The elastic and strength characteristics of an anisotropic mass are used for modeling, taking into account the generalized Hoek-Brown criterion with the Geological Strength Index (GSI) based on a geomechanical description of the mass quality. Comparative analysis of modeling results with seismic survey results is conducted to confirm the effectiveness of the developed methodology.

Findings. The research provides an opportunity to determine the overlying stratum caving parameters, such as the caving arch height and the condition for complete undermining of the overlying stratum at the Zhaman-Aybat field at different spans of the mined-out space (from 50 to 350 with a step of 50 m, reaching the maximum span of 370 m).

Originality. It has been determined that the caving arch height depends on the outcrop span and increases exponentially (h_{cav} = 16.473 $e^{0.008Le}$). In addition, the condition of the earth's surface complete undermining has been identified depending on the depth of the site to be gotten.

Practical implications. The research results can be used to develop a normative document for calculating the earth's surface shear during the repeated mining of pillars at the Zhomart Mine of the Zhaman-Aybat field. The data obtained will also be useful in planning repeated mining and predicting the earth's surface shear to avoid negative impacts of mining operations on surface structures.

Keywords: *repeated mining, undermining, pillar, caving arch, mining operations, seismic survey, modeling, field*

1. Introduction

The world experience of repeated mining of mineral deposits shows that it is often applied at ore deposits in the form of full or partial extraction of reserves left in support (rib pillars, barrier pillars, panel pillars, etc.) pillars after mining of stope reserves (primary mining) using the room-and-pillar mining system [1]-[4].

Repeated mining at fields in Central Kazakhstan carried out by Kazakhmys Corporation LLP involves extraction of previously abandoned pillars for various purposes in panel-and-pillar or room-and-pillar mining systems to ensure the most complete mining of reserves from the subsurface [2].

The room-and-pillar mining system is one of the optimal technologies for mining the horizontal and flat-lying ore deposits, providing high productivity and intensity of mining operations with high technical and economic indicators. The conditions for using this mining system are flat-lying low-thickness and medium-thickness deposits with stable or moderately stable ores and host rocks. The use of self-propelled equipment to create a room-and-pillar mining system makes it possible to obtain sufficiently high indicators in terms of economic performance [5]-[7]. There are other disadvantages: constant exposure of people to the open stope operations, high ore losses in the support pillars, and increasing cavity volume, which is supported by an increasing number of rib pillars and barrier pillars [8], [9]. This mining method's impact on ore processing has been examined in various studies, including the study of gravity-flotation concentration of lead-zinc ore at the deposit, the examination of the preliminary gravity dressing influence on the deposit complex ore, and the application of hydrolytic precipitation for separation of rare-earth and impurity [10]-[15].

To date, it is common knowledge that it is impossible to support the overlying rock stratum with rib pillars for long periods of time [3]. A number of cases of premature failure of pillars and the roof caving with outcrop to the earth's surface were recorded at Sayak, Zhezkazgan, Mirgalimsay, Shatyrkul and other mines. The main structural elements of the room-

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and-pillar mining system are the stope roof and the rib pillar. In turn, the stability of the stope roof and pillars, at the first stage of mining the stope reserves and repeated mining of pillars with the mined-out space to be gotten [16], are the main indicators for effective and safe conduct of mining operations.

At the Mirgalimsay Mine, an extensive set of studies using laboratory and in-situ testing was performed to assess the rock pressure manifestation and rock mass shear using a roof caving mining system. After conducting research, the parameters for this system have been determined and recommendations have been developed that are aimed at controlling rock pressure and rock shear [17], [18].

Research aimed at developing methods for repeated mining of reserves in the pillars of previously mined-out sites was completed at the end of the last century. Thus, as a result, the feasibility of similar operations has been confirmed with the provision of appropriate recommendations in the form of R&D reports and technological instructions [19].

Over time and under the influence of mining operations, brittle fracture accumulates in the rib pillars. The brittle behavior of high thin pillars means that after failure they quickly lose their load-bearing capacity, which means that they no longer support the overlying stratum and the stratum caving occurs [20]-[24]. Failures at the field began to occur in the period from the mid-1990s. During this period, they occurred in the form of technogenic earthquakes and were accompanied by mining and air bursts in mines.

In the absence of a room-and-pillar system alternative that can ensure efficient use of the balance reserves, ore pillars should be repeatedly mined in previously mined-out panels, while reducing the volume of mined-out areas and eliminating the consequences of caving [25], [26]. At the plant, it is recommended that cavities in weakened areas with partially destroyed rib pillars should be gobed using controlled self-caving, as well as in areas with important structures on the surface – by means of backfilling using beneficiation tailings [26]. As a result of this decision, a fundamental decision was made to move to the liquidation of open stope spaces that had been depleted over a long period of time.

There are two technologies that are used to repeatedly mine pillars. They are used in equal shares:

– in panels with minable thickness of up to 12 m (depending on the capabilities of the roofing machinery) and stable rib pillars – from the open space;

– in unstable areas with destroyed pillars – with release to field mine workings through end ore passes;

– in areas where there are objects on the earth's surface, the mined-out space is backfilled.

Repeated mining of reserves in pillars was chosen as the primary method for cavities to be gotten. However, the planning and implementation of repeated undermining can be difficult for a number of reasons, and these include [28]-[31]:

– additional allocation of funds to relocate facilities outside the shift trough zone, as well as increased time for repeated mining when developing built-up areas, where there are often engineering facilities;

– reduction of primary stability from the occurrence of rheological processes associated with long-term use of rib pillars;

– consideration of multilevel mining when developing overlapping deposits and rock thickness variability between partings.

The chain reaction of rib pillar failure during the redistribution of loads from the mined-out to the remaining pillars makes the repeated mining very difficult. It should also be noted that there is a possibility of overloading and failure of rib pillars on a domino principle when the bearing pressure is concentrated on rib pillars that are located within the caving zone.

The lack of stability that exists in rib pillars is a deterrent to repeated mining of large deposits from open space. Repeated mining of pillars becomes more complicated and dangerous when performing operations in large mined-out areas and with a large undermined span compared to mining individual panels with small widths [32], [33].

This fact is also proved by the results of repeated mining of reserves at the Zhezkazgan field. Most often, the repeated mining of rib pillars is successful in separate isolated mining blocks (panels). The chain reaction of rib pillar failure began with the repeated mining of thick deposits that had large spans of mined-out space without rigid bearings (barrier pillars) inside them [34], [35].

Rib pillar extraction rates in the panels were analyzed to confirm this fact. A total of 1524 rib pillars were left, of which only 174 pillar (12%) were extracted. And 705 pillars (48%) were crushed by rock pressure in the zones where caving occurred. That is, within this area, the volume of cavities gotten by uncontrolled caving of the adjacent stratum after successive rib pillar failure is 4.4 times greater than the volume of that gotten by controlled self-caving during repeated mining. Due to the impossibility of protecting the roof and the risk of chain failure, rib pillars are not suitable for repeated mining from the open stope space of panel with a maximum height of more than 12 m.

Dynamics of accumulation of rib pillars, destroyed by rock pressure at the Zhezkazgan field, testify that already in the early 2000^s, more than 5000 rib pillars were completely destroyed and more than 4000 were partially destroyed. Current roof control methods to prevent rib pillar failures at the Zhezkazgan field are not sufficiently effective.

Although repeated mining with field preparation is a rather expensive method to gob roof due to the fact that it requires high costs for driving field workings under mined-out deposits in a volume of 60-90 m^3/1000 tons, it is safer and has shown good results in caved areas when recovering ore from losses from destroyed rib pillars [2].

Complete mining of useful minerals from the earth's subsurface is fundamental to the rational mining of deposits [36]-[38]. However, field mining practice has shown that technological difficulties and the need to ensure safe mining conditions often prevent the process of complete mining of all existing reserves [39]-[43].

In 2006, the Zhaman-Aybat copper ore field, mined by the Zhomart Mine of Kazakhmys Corporation LLP, located near Zhezkazgan in the Ulytau Region in Central Kazakhstan, was commissioned. At present, over 41.6 million tons of ore have been extracted from the subsurface during the mine's operation, and about 15.4 million m^3 of cavities have been formed in the mined-out space, which is supported by about 5000 rib pillars and 60 barrier pillars.

Repeated mining requires an integrated approach, using monitoring results and identifying potential negative impacts on underground mine workings and surface infrastructure. Due to the fact that today new deposits are being discovered and modern monitoring technologies such as space radar interferometry [44], automated seismic control systems [45], [46] and others are being introduced, as well as advanced methods for determining the actual state of the mined-out space, overlying stratum and earth's surface [47], [48] are being applied, the issue of geomechanical substantiation of repeated mining of pillars based on integrated monitoring is topical.

In 2021, the Zhomart Mine conducted research and development work to identify the boundaries of the overlying stratum caving zones above the gotten panels of the Zhomart Mine using modern seismic technologies, which provide the opportunity to obtain information from hard-to-reach rock mass areas. These studies were conducted by specialists of Kazgiprotsvetmet LLP under the guidance of Professor S.A. Istekova (Fig. 1) [49].

Figure 1. Profile lines of seismic surveys

The SCOUT recording system was used when organizing the work. To ensure the required survey parameters and productivity, 480 geophone groups were involved in the work. In addition, a full set of floor equipment and all the necessary equipment for the work was used [49].

According to the results of the research conducted using seismic profile data, it is possible to conclude that certain structural elements, which are associated with the change in the rock-mechanical properties of rock masses, are clearly observed in the seismic wave zone. According to seismic survey data, profiles II and III clearly show the zones in which sediments above the gotten panels are displaced (Fig. 1).

Subsidence zones are identified above the mined-out areas of the deposit. Profile III is located at a distance from the initial profile lines (mining-geological sections). Correlation of seismic horizons, as well as the delineation of target zones for profile III, was performed identically to profile II. Table 1 summarizes the results of determining the caving zone based on seismic survey data [49]. Based on this information, geological sections have been constructed (Figs. 2, 3).

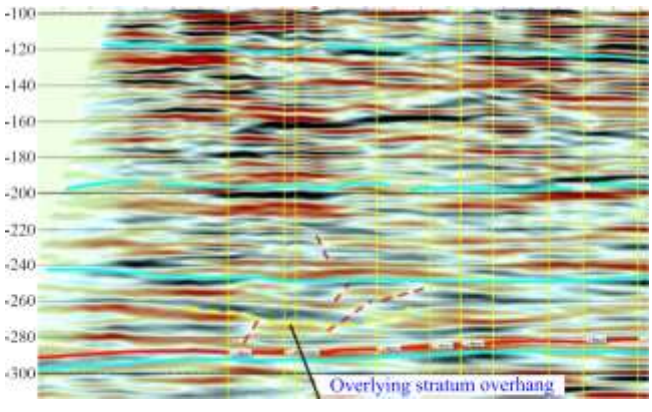

Figure 2. Seismic profile II fragment (panels 52 and 51)

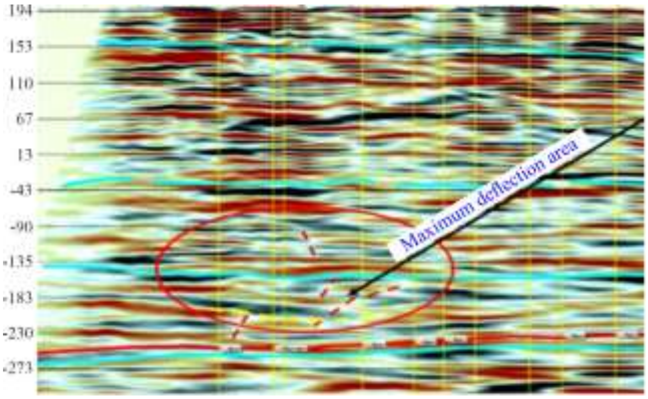

Figure 3. Seismic profile II fragment (panels 48 and 52)

Table 1. Caving zones identified from seismic data

No.	Panel name	Profile pickets	Absolute height mark of the caving zone, m	Subsidence amplitude, m
Profile II				
1	Panels 49-51	1050-1120	-195	9
2	Panels 47-48	1154-1203	-119	9
3	Panels 47-48	1178-1217	40	10
4	Panels 44-46	1215-1280	-124	8
5	Panels 43-45	1252-1338	-58	14
6	Panels 42-44	1297-1370	-158	7
7	Panels 42-44	1300-1365	41	9
8	Panels 42-43	1376-1450	-250	10
9	Panels 39-40	1376-1452	-249	9
10	Panels 39-41	1400-1470	-122	7
11	Panels 2-39	1480-1532	-123	5
Profile III				
12	Panels 61-64	986-1200	-40	14
13	Panels 64	1150-1237	-113	6
14	Panels 61	1151-1215	108	4

In the process of determining the deformation (shear) zones in which the rock mass caving occurs above the gotten mine workings using seismic survey technologies and geophysical methods, materials have been obtained that allow to get an idea of the study area structure and identify possible tectonic objects [50]. Presumed disintegration zones are qualitatively identified through seismic observation data. This can be seen on the time and depth sections. According to the performed research results, roof caving is associated with the rock mass facial variability [49].

Determining the overlying stratum caving zone boundaries and the condition of complete undermining with the outcrop of caving to the earth's surface are the main parameters for the safe conduct of mining operations and the protection of surface facilities and infrastructure. In the absence of data on these parameters, the results are taken from deposits with similar mining-geological conditions [51]. For the Zhaman-Aybat field, the mining-geological conditions are similar to that of the Zhezkazgan field [52], but the physical-mechanical rock properties are two times weaker and mining depth is 15 times deeper, which has led to complications during the primary room-and-pillar mining system and secondary repeated mining [53].

In [49], using seismic survey method, the results on the boundaries of formation of overlying stratum caving zones above the areas of repeated mining at the Zhaman-Aybat field on five profiles have been obtained. For profile II, the maximum roof subsidence above the gotten panels has been identified (Fig. 4). The caving arch above the gotten and caved panels ranges from 42 to 264 m.

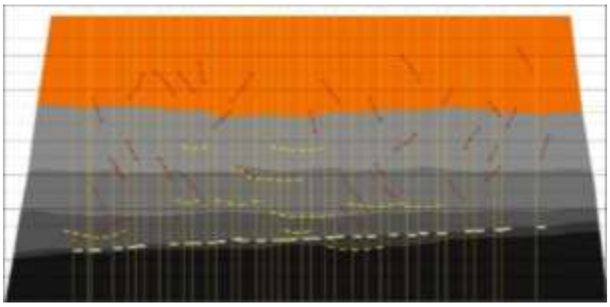

Figure 4. Failure zones for profile II (yellow dotted lines)

To summarize, it can be said that as a result of analysis of MOGT-2D seismic materials, used within the Zhomart Mine area, structural data for the studied depth interval have been obtained (400-800 m). The information provided in dynamic interpretation made it possible to reveal tectonic deviations and structural levels that were identified from the seismic survey data. Examination of the seismic data provided qualitatively distinctive information about the zones of caving.

The purpose of this research is to model the process of the overlying stratum caving above the gotten panels as a result of repeated mining, based on the data obtained from seismic survey technologies, and to determine the dependence of the overlying stratum caving thickness on the gotten span. The results of complex geomechanical monitoring for the mined-out space state, the overlying stratum and the earth's surface can be used to determine safe conditions for repeated mining of pillars and to develop methods for predicting negative consequences.

2. Methodology

To compare in-situ measurement results of caving arch determined by seismic survey technologies, numerical modeling by the finite element method using Examine2D software has been performed for the mining-geological conditions of the Zhomart Mine, due which it is possible to obtain not only the elastic but also the superlimiting state of the mass.

For the mining-geological conditions of the Zhaman-Aybat field, Examine2D simulated the repeated mining of all rib pillars with leaving 40 m wide barrier pillars in 19 panels, which is identical work to the profile II [49]. The natural stress state of rocks, according to mine testing data, is specified by vertical lithostatic pressure γH [54], [55]. Horizontal normal stress along the strike of the ore body from west to east is 0.9 γH, perpendicular to the considered section from north to south 1.6 γH, where the unit specific gravity of overlying rocks is γ = 2.6 t/m^3.

On the basis of the actual positions of mining operations according to Micromine software data, a section for the profile II can be constructed (Fig. 5). Profile section of 19 panels is taken into the calculation model (Fig. 6). Table 2 presents the elastic and strength characteristics of anisotropic masses. The data are calculated using the generalized Hoek-Brown criterion with the Geological Strength Index (GSI) based on a geomechanical description of the quality of the masses, based on the results of studying the mass fracturing and laboratory testing of rock properties, conducted using the RocLab program [56]-[58].

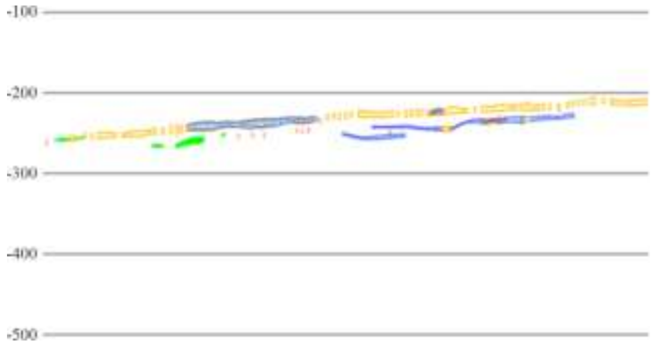

Figure 5. Geological section for profile II in Micromine software

Figure 6. Section for profile II in Examine2D software

Table 2. Elastic and strength characteristics of anisotropic mass taken for modeling in Examine2D software

Parameters	Value
Earth's surface elevation, m	354
Overburden unit weight, MN/m^3	0.026
Horizontal stress ratio	0.9
Out of plane stress ratio	1.6
Elastic modulus, MPa	4000
Poisson ratio (v)	0.25
Intact compressive strength	120
Geological Strength Index (GSI)	50
Intact rock constant (m_i)	17
Disturbance factor (D)	0.8

Historical data on complete earth's surface undermining after complete failure [59] or extraction of pillars at the Zhezkazgan field provided the basis for the development of criteria for complete overlying stratum caving to the earth's surface, which is shown in Figure 7.

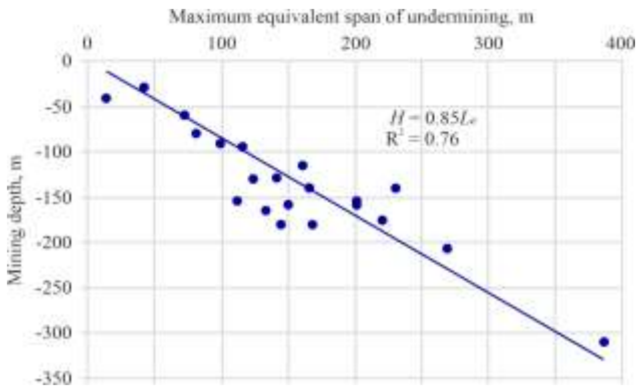

Figure 7. Pattern for complete overlying stratum caving to the earth's surface at the Zhezkazgan field: H – mining depth; L_e – maximum equivalent span of undermining

It follows from this that at the Zhezkazgan field, if all the pillars in the panels are extracted, a complete caving of overlying mass to surface will occur, provided that the following Condition is met (1):

$$H < 3L_e \text{ or } L_e > \frac{H}{3}, \quad (1)$$

where:

L_e – cumulative equivalent span of all mined-out panels along the strike of the deposit.

After comparing the actual data obtained at the Zhezkazgan field with the data of the Temporary Rules for the Protection of Structures [60], it is possible to obtain the condition of the overlying stratum caving with the outcrop to the surface when mining medium-thickness deposits using caving mining systems:

$$H < k_1 \cdot L_e, \quad (2)$$

where:

k_1 – the coefficient taking into account rock hardness f according to Protodyakonov's scale.

The weaker the rocks composing the mass, the higher is the coefficient k_1, and vice versa (Fig. 8). According to Formula (1), at the Zhezkazgan field, the k_1 coefficient is 0.85. Data from Zhezkazgan agree well with the general dependence, if, as a basis, the average rock hardness coefficient value is 18 (considering horizontal stress due to high tectonic stresses).

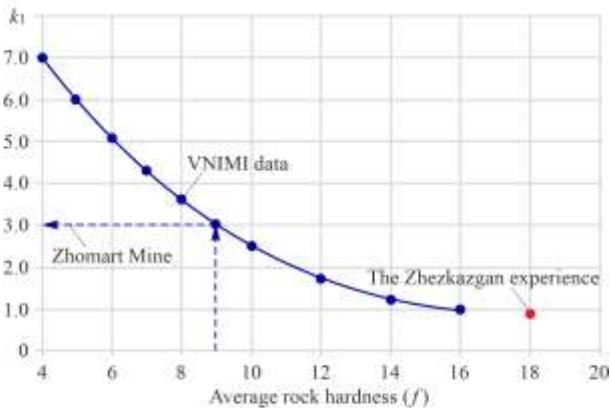

Figure 8. Graph of dependence of k_1 coefficient values on average rock hardness f

The study [53] makes the conclusion that at the Zhomart Mine, the mining plan developed by the Main Design Institute uses a value of f = 8.9, which corresponds to the average rock hardness. The level of horizontal tectonic stresses is twice as low, which contributes to the maintenance of the undermined stratum within its lateral clamping. In this case, the coefficient k_1 is 3 (Fig. 8). In addition, due to the greater depth (2 times) and lower rock hardness, the conditions at the Zhomart Mine are 4 times more severe than those at the Zhezkazgan Mine. This means that after completion of the second stage of mining the reserves (repeated mining of all pillars in the panel), complete overlying stratum caving to the surface will occur, provided that the Condition (1) is met.

The results described have been obtained using a hypothesis based on rock properties as determined by the Temporary Rules [60]. However, confirmation of actual earth's surface caving results for the geological conditions of the Zhomart Mine is required.

3. Results and discussion

Modeling the extraction of all rib pillars along the width of panel 19 without extraction of barrier pillars ensures a stable state of the overlying stratum along the strike of the deposit (Fig. 9a). Barrier pillars with a strength factor of 3, in turn, support the entire overlying rock stratum without the outcrop of caving to the earth's surface (Fig. 9b).

(a)

(b)

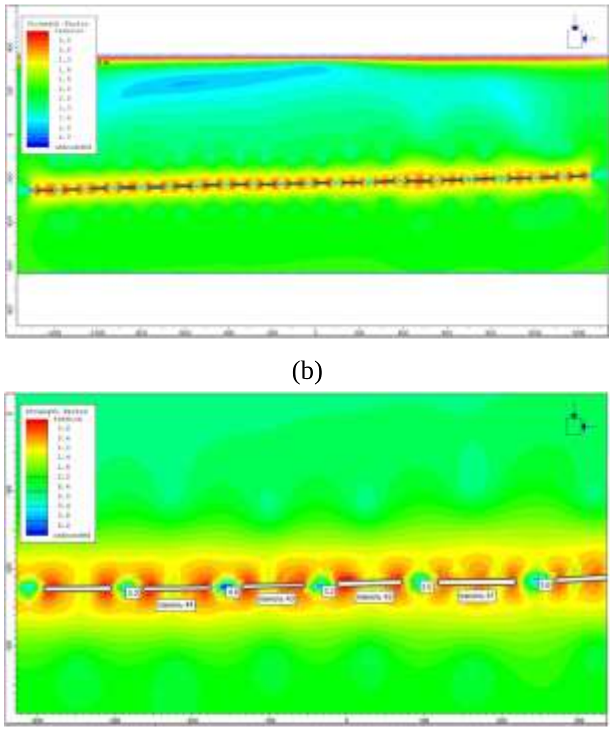

Figure 9. Results of modeling the extraction of all rib pillars from 19 panels without extraction of barrier pillars: (a) the overlying stratum stable state; (b) strength factors for barrier pillars

To determine the caving arch above the mined-out panels, a strength factor of less than 1 is assumed for the caving boundary. This means that in zones where the hardness coefficient decreases below 1, there is a loss of the rock mass stability, leading to its caving. According to the results of modeling performed for all mined-out rib pillars for the studied panels, the caving arch depth ranges within 27-41 m (Fig. 10). This range indicates the variability of conditions in different zones of the panel, which may be due to differences in geological conditions, rock properties and mining specifics. Modeling takes into account a complex of factors influencing the rock mass stability, such as the stress-strain state of rocks, their strength characteristics and tectonic stresses. Thus, the depth of caving is defined as the critical value at which the rock mass structure is destroyed, which requires careful monitoring and analysis to ensure the safety of mining operations.

After repeated mining of rib pillars in several panels, it has been found that none of the barrier pillars is completely mined-out, but only brought to the massive pillar due to their premature cutting (profile II). In fact, this caused them to be destroyed and to form deformation zones in the form of a caving arch above them. In order to obtain the calculated height for the so-called caving arch formation above the mined-out panels, numerical modeling of the failure (crushing) of barrier (massive) pillars is performed.

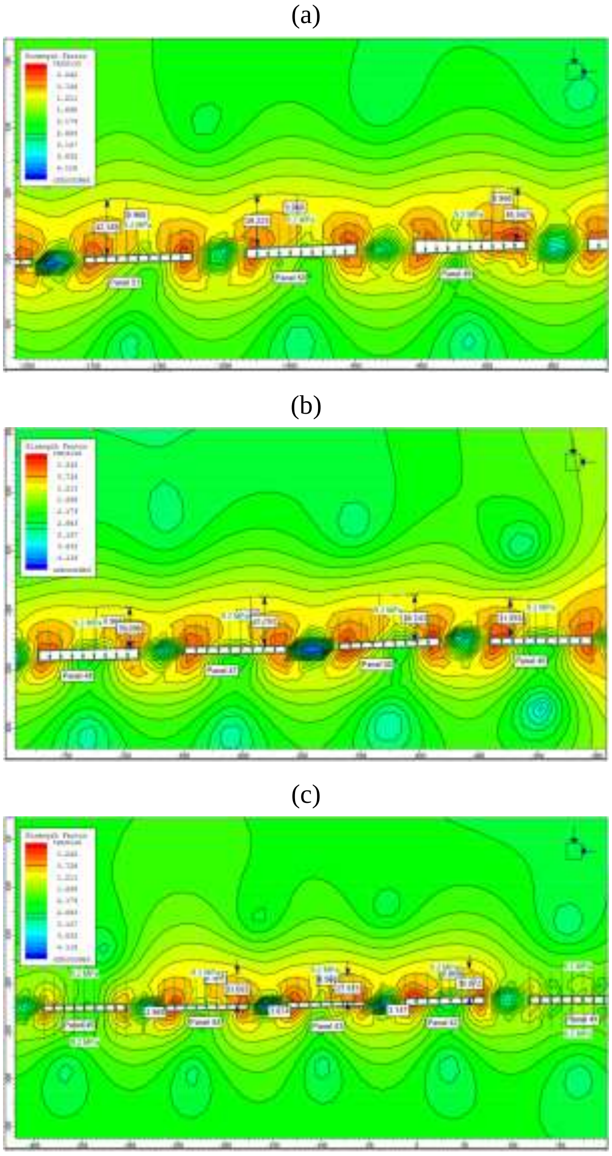

Figure 10. Caving arch when mining rib pillars: (a) above the panels 49, 50, 51; (b) above the panels 45, 46, 47, 48; (c) above the panels 42, 43, 44

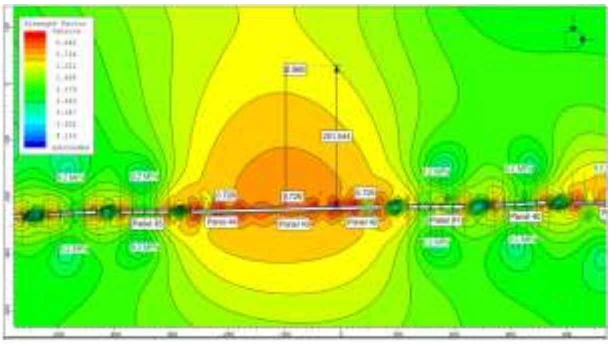

Figure 11. Caving arch during mining of rib pillars and crushing of massive pillars above panels 42, 43, 44

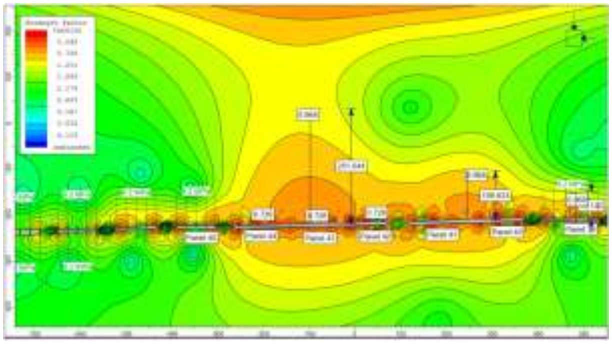

Figure 12. Caving arch during crushing of massive pillars between panels 40, 41

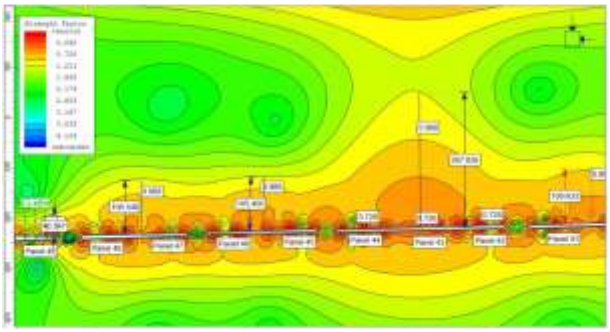

Figure 13. Caving arch over the crushed massive pillars between the panels 45-46 and 47-48

Based on the modeling results, it has been determined that in the area of panels 42, 44 and 45, the maximum earth's surface subsidence along the profile lines is recorded. The caving arch has reached a height of 251 m when modeling the crushing of the barrier pillar between them (Fig. 11). In the case of crushing the massive pillars between panels 40 and 41, the inelastic deformation zone height (caving arch) is 106 m (Fig. 12). For the western flank from the panels 42, 43, 44, a model has been created in which the barrier pillar between the panels 45-46 and 47-48 is destroyed. The height of the deformation zone above these sites is 105-106 m. The obtained modeling results are shown in Figure 13. The obtained results of mathematical modeling of the process of overlying rock stratum caving above the mined-out spaces and crushed massive pillars between them using Examine2D software are compared with the results of seismic surveys to determine the overlying rock stratum caving zones above the gotten panels, and are given in Table 3.

Based on the modeling results, it can be concluded that the seismic survey results and the numerical modeling results of rock mass caving above the mined-out areas that have undergone repeated mining are practically close.

To further study, this model can be used as a starting material for modeling to determine the conditions for complete earth's surface undermining, as well as to identify the pattern of caving arch formation from the equivalent mine working span.

In order to determine the caving zones above the repeatedly mined gotten panels, using seismic technologies, mathematical modeling is performed, the result of which is the dependence of the height (thickness) of overlying stratum caving on the mined-out space width.

In order to perform calculations in the mining-geological conditions of the Zhomart Mine, the modeling by Examine2D software is conducted. To model the caving arch, the span width of the mined-out space is taken in 50 m increments, that is, 50, 100, 150, 200, 250, 300, and 350 m (Fig. 14a-g) until the maximum span (370 m) is reached, at which the overlying stratum will be completely undermined (Fig. 14h). The results obtained are given in Figure 15.

As a result of Figure 15 data analysis, it has been found that as the outcrop span increases, the caving arch coefficient increases, reaching complete overlying stratum undermining.

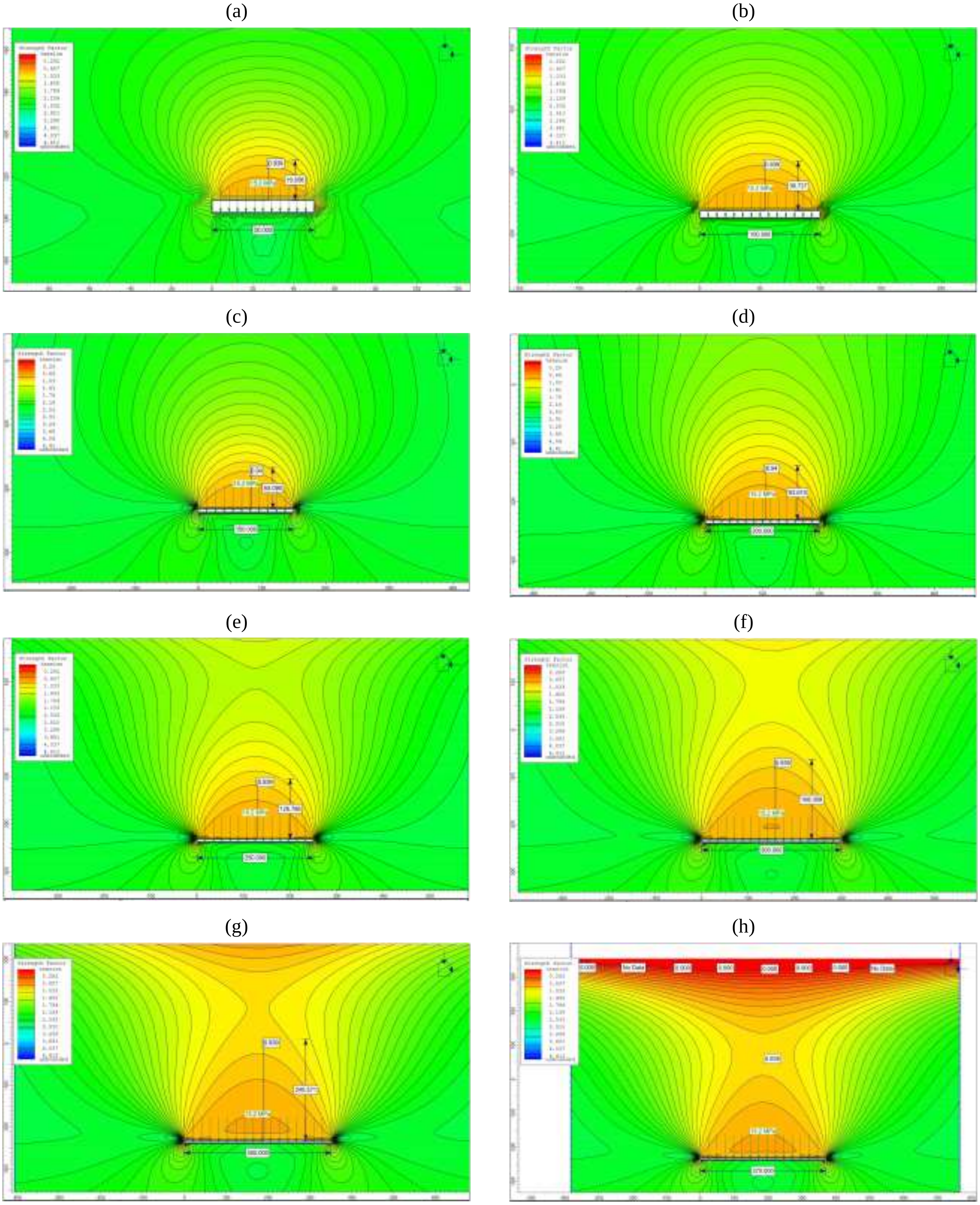

Figure 14.* *Caving arch formation at different spans of the mined-out space: (a) 50 m; (b) 100 m; (c) 150 m; (d) 200 m; (e) 250 m; (f) 300 m; (g) 350 m; (h) 370 m

In this case it can be represented as follows:

$$H_{cav} = 16.473e^{0.008L_e}, \text{ m.} \tag{3}$$

Thus, the condition under which a complete overlying stratum caving to the surface occurs at the Zhomart Mine, as a result of repeated mining, is as follows:

$$L_e > \frac{H}{1.6} \text{ or } H < 16L_e, \tag{4}$$

where:

L_e – the equivalent span of unsupported mined-out space.

Table 3. Comparison of seismic and modeling results of the overlying stratum caving above the mined-out space

Panel	51	50	49	48	47	46	45	44	43	42	41	40	39	1	2
Earth's surface elevation, m	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350
Bottom elevation, m	-252	-248	-244	-242	-237	-232	-229	-228	-225	-222	-221	-216	-214	-209	-204
Depth, m	606	602	598	596	591	586	583	582	579	576	575	570	568	563	558
Deposit thickness, m	6	8	9	9	6	6	7	6	5	7	8	7	6	6	6
Arch height based on seismic survey, m	-195	-195	-195	-119	-119	-124	-124	-158	-250	-250	-249	-249	-249	-123	-123
	–	–	–	40	40	–	-58	-124	-158	-249	-122	-122	-123	–	–
	–	–	–	–	–	–	–	-58	-58	-158	–	–	-122	–	–
	–	–	–	–	–	–	–	41	41	41	–	–	–	–	–
Caving arch thickness based on seismic survey, m	52	45	41	114	112	102	99	65	-26	-28	-36	-40	-41	80	75
	–	43		273	271	–	165	99	62	-34	92	87	85	–	–
	–	–	–	–	–	–	–	165	162	57	–	–	–	–	–
	–	–	–	–	–	–	–	264	261	256	–	–	–	–	–
Caving arch thickness based on modeling, m	42	39	41	107		105			268		106		108		40

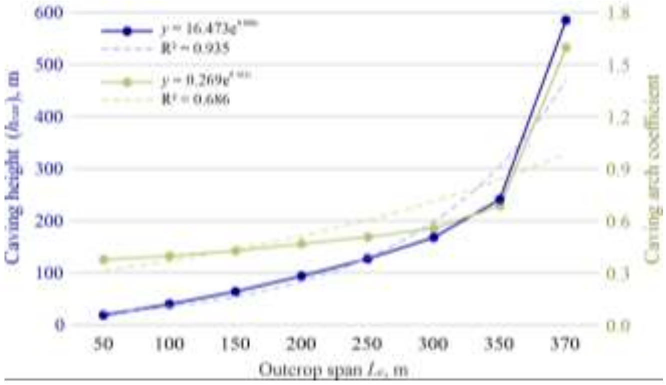

Figure 15. Modeling results of caving arch formation depending on the outcrop span

Thus, the coefficient k_1 value, which takes into account rock hardness for the Zhomart Mine, is 1.6. This is about 2 times lower than the value of 3, determined by earlier hypothesis.

The research performed to identify the overlying stratum caving zones using seismic technologies helped to gain an idea of the level of change in the rock mass deep structure at the Zhomart Mine as a result of technogenic impact. The conducted research has provided information on the actual conditions of caving zone formation above the mined-out spaces, which will make it possible to study in more detail the process of the adjacent stratum failure.

Shear and deformation patterns have been identified in the zone of influence of stope operations. In turn, they depend on the size of the mined-out space and the location of the barrier pillars relative to the mined-out space.

Analysis of comparing the in-situ measurement results (seismic technologies) with the numerical modeling results has shown that the shear and deformation parameters of rocks and earth's surface in the conditions of the Zhaman-Aybat field can be determined by means of modeling.

Based on the properly developed model, the conditions (parameters) for the complete earth's surface undermining at the Zhomart Mine of the Zhaman-Aybat field have been determined and the dependence of the caving zone parameters on the mined-out space span has been obtained.

To plan the order of repeated mining of pillars, as the main geomechanical parameter of the room-and-pillar mining system, the condition for complete earth's surface undermining (L_e > H/1.6) has been set for the mining-geological conditions of the Zhaman-Aybat field.

Prospects for further research include the development of the earth's surface shear methodology specifically adapted to the conditions of the Zhilandy Mine. This will make it possible to more accurately predict changes in the earth's surface structure and improve the safety of mining operations. In the future, it is planned to extend the application of the proposed methodology to other mines with similar geological conditions, which contribute to the improvement of the overall methodology for managing the earth's surface shear in the mining industry.

4. Conclusions

Having summarized information on the current norms and rules for the protection of buildings, structures and their elements from harmful impact of underground mining operations for the Zhomart Mine of the Zhaman-Aybat field, it has been revealed that the results of previously conducted studies are inconsistent with the existing facts of the earth's surface subsidence.

The variety of forms of the shear process implementation at the Zhaman-Aybat field is determined by the dependence of the overlying stratum stability on the span of the mined-out space, which is not supported by ore pillars, and horizontal tectonic stresses, creating lateral undermined stratum clamping. The combination of these factors determines whether the overlying stratum overhangs, caves with the formation of a caving arch, or completely caves to the surface.

Based on the results of determining the overlying stratum caving zones using seismic survey technologies, a reliable mathematical model has been obtained, resulted in the dependence of the caving arch formation on the equivalent span of the site to be gotten after repeated mining of the pillars (h_{cav} = 16.473$e^{0.008L_e}$).

Using mathematical modeling method for the Zhomart Mine conditions based on the seismic survey results, the condition for complete earth's surface undermining has been determined (L_e > H/1.6 or $H < 1.6L_e$).

Based on the experience of caving at the Zhezkazgan field, it has been found that the condition for caving the whole rock stratum to the surface is that the equivalent span of the unsupported mined-out space exceeds the depth of its occurrence. In these cases, the lateral clamping is no longer able to prevent lateral shear of the rock stratum into the mined-out space.

To achieve the best results in solving geomechanical problems when mining ore deposits with open space, it is necessary to conduct research different from those previously performed. In addition to theoretical research, there is a need to analyze mine statistics and seismic survey results.

Using the research results, it may be possible to plan and implement repeated mining of reserves in pillars, as well as to predict the earth's surface shear in order to eliminate the negative impact of underground mining operations on engineering structures located on the surface.

Author contributions

Data curation: MZ; Formal analysis: AZ; Funding acquisition: DT; Methodology: DT; Project administration: DT; Resources: AZ, MZ; Software: MZ; Supervision: DT; Validation: AZ; Visualization: MZ; Writing – original draft: DT, MZ; Writing – review & editing: DT, AZ. 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.

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Визначення параметрів зон обвалення налягаючої товщі при повторній розробці цiликiв

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Мета. Визначення параметрів зон обвалення налягаючої товщі над виробленим простором при повторній розробці цiликiв на руднику Жомарт родовища Жаман-Айбат з метою прогнозування небезпечних зон впливу гірничих робіт.

Методика. Дослідження включає аналіз результатів попередніх натурних досліджень, проведених із використанням сейсморозвідувальних робіт, а також моделювання із застосуванням програмного забезпечення Examine2D для визначення напружено-деформованого стану масиву налягаючої товщі. Для моделювання використовувалися пружні та міцнісні характеристики анізотропного масиву, з урахуванням узагальненого критерію Хоека-Брауна з геологічним індексом міцності GSI, заснованим на геомеханічному описі якості масивів. Порівняльний аналіз результатів моделювання з результатами сейсморозвідки проведено для підтвердження ефективності розробленої методики.

Результати. Дослідження дозволило визначити параметри обвалення налягаючої товщі, такі як висота склепіння обвалення і умова повної підробки налягаючої товщі на родовищі Жаман-Айба при різних прольотах виробленого простору (від 50 до 350 з кроком 50 м) із досягненням максимального.

Наукова новизна. Встановлено, що висота склепіння обвалення залежить від прольоту відслонення та збільшується за експоненційною залежністю ($h_{обв} = 16.473e^{0.008Le}$). Крім того, була виявлена умова повної підробки земної поверхні залежно від глибини ділянки, що погашається.

Практична значимість. Результати дослідження можуть бути використані для розробки нормативного документа з розрахунку зрушення земної поверхні при повторній розробці цiликів на руднику Жомарт родовища Жаман-Айбат. Отримані дані також будуть корисні при проєктуванні повторних розробок та прогнозуванні зрушення земної поверхні, щоб виключити негативний вплив гірничих робіт на поверхневі споруди.

Ключові слова: *повторна розробка, підробка, цілик, склепіння, гірничі роботи, сейсморозвідка, моделювання, родовище*

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