Mining of Mineral Deposits
Volume 17 (2023), Issue 1, 129-137

https://doi.org/10.33271/mining17.01.129

Analysis of the roof span stability in terms of room-and-pillar system of ore deposit mining

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Abstract

Purpose. To ensure the roof span stability in terms of room-and-pillar system of mining taking into consideration the calculations, modelling, and statistic analysis of factual rock falls from the roof.

Methods. Analysis of inelastic deformations to define overall displacement of a thin-layer roof of the chamber being 9 m wide was performed with the help of software complex RS2. To estimate the effect of chamber spans on the roof stability, a problem was considered in two variants where chamber width was 8 and then 7 m. The results were analyzed in terms of strength factor of the interchamber pillars. Statistic analysis of the roof stability loss for the chambers was carried out according to the results of monitoring of a state of the worked-out space in the context of the Zhaman-Aibat deposit. The obtained data were compared in terms of chamber roof spans being 9-7 m.

Findings. The performed studies make it possible to state that the reduction of chamber spans down to 7 m decreases the roof deflection up to 2 cm and ensures stability of both chamber roof and worked-out space by 13 times; in its turn, that results in safe conditions while stoping. Optimal parameters of the roof span stability for chambers and safe mining conditions were substantiated basing on computer modelling and statistic analysis of the results of geotechnical monitoring of a state of worked-out space at the Zhaman-Aibat deposit.

Originality. The regularity of changes in the safety factor of the peripheral part of a chamber was substantiated depending on the chamber width (7, 8, and 9 m) and considering the distance from the contoured chamber (m). Reduction of the chamber span by 1 m (from 9 to 8 m) reduces roof deflection by 2 times (up to 5 cm); moreover, breaking depth in the roof experiences considerable reduction – up to 1.75 m. Reduction of the chamber span by 1 m more (from 8 to 7 m) reduces the roof deflection up to 2 cm; breaking depth in the roof decreases considerably as well – up to 1.33 m.

Practical implications. The proposed variant of chamber span reduction can decrease significantly the total area of rock falls and ensure stability of the worked-out space of the Zhomart mine where roof stability is the weakest element on the mining system. The obtained results can be the basis for the development of methodological recommendations to calculate mining parameters at the Zhaman-Aibat deposit as well as at other deposits with medium roof stability.

Keywords: *room-and-pillar mining, remining, chamber span, roof stability, formation of rock falls, interchamber pillar*

1. Introduction

In recent years, the difficulties of mining operations while developing ore deposits are associated mainly with various geotechnological problems. They are associated, for example, with the widespread trend of transition from open-pit to underground mining [1], [2], where the issues of predicting the earth's surface subsidence to ensure safety of both surface structures and underground operations are being studied more and more often due to necessity to analyze a stress-strain state of rocks in terms of both open pit space and underground mining factors [3]-[6]; these are the studies aimed at solving the geomechanical problems to assess stability of mine workings [7]-[10].

Along with the abovementioned major geomechanical problems of mining operations at ore deposits, there are many seemingly insignificant problems but the ones which can affect to a large extent not only the efficiency of mining operations but also their safety [11]-[13].

Proper selection of the systems for ore deposit mining is of great importance and determines mainly the effectiveness of their development. According to specific mining conditions, several different development systems can be used at most ore deposits. However, for each field, the most rational system must be selected that meets different technical and economic requirements. These are the most important ones [14], [15]:

Received: 30 January 2023. Accepted: 16 March 2023. Available online: 30 March 2023

Mining of Mineral Deposits. ISSN 2415-3443 (Online) | ISSN 2415-3435 (Print)

– ensuring safe and healthy working conditions for employees;

– achievement of the minimum prime cost of production;

– compliance with the specified ore productivity of a mine in compliance with the accepted standards for ore quality;

– rational use of subsoil, economically substantiated minimum losses and ore dilution as well as integrated development of useful components and deposits.

The Zhaman-Aibat deposit has been developed since 2006 by the Zhomart mine of Kazakhmys Corporation LLP, located southeast of Zhezkazgan. Due to both flat dip of ore bodies and similar mining and geological conditions with the Zhezkazgan deposit, which by that time had been mined for more than 100 years, a room-and-pillar mining system was adopted with the division of mining units (deposit reserves) into panels.

Structural elements affecting a stable state of the mined-out space in terms of room-and-pillar system of development are the roof span of chambers and the parameters of support pillars. Ensuring their stability by adopting optimal geometric parameters for safe conditions for mining operations and completeness of mineral extraction (economic efficiency) is the main goal of geomechanical support of mining operations when using a room-and-pillar mining system.

For more than a decade, the Zhomart mine has been working to optimize the parameters of a panel-and-pillar mining system for more efficient and safe mining [14]. Since 2009, the first experimental-industrial remining of the reserves in pillars has begun at the Zhomart mine [15] both from the open worked-out space and with in-stone development (beginning from 2022). According to the mining plan for developing the Zhaman-Aibat deposit reserves, two stages are envisaged (Table 1): stage I – development of chamber reserves with a panel-and-pillar mining system protected by barrier pillars; stage II – goaf filling and pillar recovery on retreat [14], [15].

Table 1. Ore losses and dilution according to the development systems of the Zhomart mine

Development stage	Losses, %	Dilution, %	Share of the extracted reserves, %
Stage I – development of chamber reserves	2	4	40
Stage II – goaf filling and pillar recovery from the open worked-out space	42	10	35
Stage II – pillar recovery with in-stone development	10	50	25
In terms of development systems	18	18	100

As Table 1 shows, the losses during transition to stage II of pillar recovery from the open worked-out space account for 40%. The figure is obtained from the results of previously conducted experimental-industrial mining except the pillars not included in the remining due to complicated geomechanical situation (rock falls from the roof, pillar breaking, geological disturbances etc.). This makes the remaining reserves to be mined with in-stone development, which in turn leads to an increase in the prime cost of mining.

Studies on optimizing the parameters of the panel-pillar mining system for more efficient and safe mining operations were carried out in paper [15], where, basing on a reverse calculation method, the strength characteristics of the rock mass were determined by the fact of breaking of interchamber pillars, and an approach was given to determine strength of rocks in the massif [16]-[18].

The essence of the applied reverse calculation technique is that the passive experiment on strength testing is carried out by the natural forces of rock pressure, not by us. While mining, we only create conditions for loading the pillars, working out the chamber reserves, and arranging the supporting pillars.

A passive full-scale experiment differs significantly from the laboratory tests of rock samples on presses in following way [19], [20]:

– dimensions of the pillars broken by rock pressure are hundred times larger than the ones of the samples tested in the laboratory on presses. This takes into account a scale factor;

– in natural conditions, the nature tests a structure – a pillar with a real geological structure (fracturing, interlayers, weakening surfaces, contacts); in laboratories, samples are tested without visible disturbances. Thus, passive experiment takes into account all factors weakening the pillar strength;

– pillars are under load for decades; laboratory testing of samples lasts for minutes. Thus, during the passive experiment, the time factor is taken into account.

By considering all the main factors, reliability of the obtained data concerning the interchamber pillar (ICP) strength is ensured. If a group of pillars collapses, then the loads on the broken interchamber pillars turned out to be maximum. That makes it possible to find the ICP and ore mass strength (taking into account a coefficient of pillar shape). The obtained data on the ore mass strength are used to assess the stability of the remaining pillars within the area. Thus, the pillar strength is determined not traditionally (by multiplying the rock strength in the sample by a number of attenuating coefficients) but by the reverse calculation, i.e. by determining the load at which pillar collapsed and accepting this load as the limiting one for the ICP.

Paper [21] demonstrates that the reverse calculation based on the fact of partial ICP breaking gives the same values of the ore mass strength as in tests up to complete breaking of the pillars. It means that partial collapse of 127 ICPs at the Zhomart mine can be used for reverse calculation of the ore mass strength in the interchamber pillars.

According to the results of reverse calculations, the average value of the ICP areas is 100 m^2 with a variation coefficient of 19%, i.e. the area of partially collapsed ICPs corresponds to the project. The average ratio of the pillar diameter and height is $d/h = 1.7$ (a variation coefficient is 17%), i.e. the width of pillars is always greater than their height. The average strength value of the ore mass in pillars is 32.6 MPa with a standard deviation of 6.2 MPa (a variation coefficient is 19%). The strength distribution is close to the normal law (Fig. 1). Within the depth range from 530 to 625 m, the changes in the ore mass strength along with depth are within the range of variability being not statistically significant.

Experimental data on the ore mass strength can be obtained by measuring maximum actual stresses in the pillars. The actual stress values in the pillars of the Zhomart mine were determined in 2013 by recording acoustic emission using the Kaiser Memory effect [22]. Maximum stresses at the boundaries between the zones of an out-of-limit and elastic state of the ore mass in pillars, corresponding to the mass strength, are 29 MPa in ICP and 44 MPa in BP (barrier pillar). Depth of the zone of an out-of-limit mass state reaches 2.2-2.5 m.

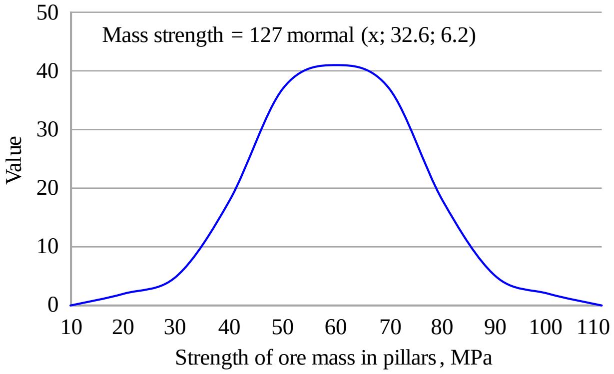

Figure 1. Distribution of the ore mass strength in pillars according to the reverse calculation data

The second measurement cycle was carried out in panel 47 in ICP #120 (in 3 wells) and in BP (in 3 wells). The maximum stresses in the pillars turned out to be 28, 29, and 30 MPa in ICP and 36 MPa in BP. The average value of the maximum stresses in pillars, corresponding to the mass strength, is 32.7 MPa with a coefficient of variation being 19%. The experimental data obtained in mine conditions confirm fully the results of reverse calculations of the ore mass strength in pillars. This indicates the reliability of the assessment of ore mass strength obtained by two different methods [22].

If we compare the strengths in the ore mass σ_m = 32.6 MPa and in the samples σ_o = 120 MPa, we can find the integral attenuation coefficient by their ratio σ_m / σ_o. In terms of the Zhomart mine, it is 0.27. This coefficient takes into account structural mass weakening by fractures, presence of weak rock interlayers, contact conditions, a drilling and blasting method of the ICP formation, a scale factor, and the duration of pillar loading.

According to the previous analysis of the roof stability in stopes at stage I and the problems while transiting to stage II, in 2019 paper [15] considered a new approach in calculating the chamber span stability for layered intermittent rocks. By comparing the calculated results, the approach assumed a relative increase or decrease in the chamber span stability to the accepted (the reference is 9 meter) chamber width. Its main principle was as follows:

– for the entire period of the Zhaman-Aibat field development, no complete breaking of an interchamber pillar was recorded. It has already been determined and is being applied in practice how to control the pillar parameters for different parameters of the room-and-pillar mining system (panel spans, mining thickness) at the field. However, the problem of chamber span stability control is complicated by unwillingness of the company's management to reduce their parameters due to a decrease in breaking per cycle and an increase in preparatory, loading, drilling and blasting, and other operations;

– in 2018, a geomechanical department of Kazakhmys Corporation LLP proposed the parameters for development systems for the Zhomart mine; in 2020, the technology to develop the block 56-C_2 reserves at the Zhomart mine was recommended. Since September 2022, a pilot operation has been carried out to develop chamber reserves of block 56-C_2 with new parameters of the room-and-pillar mining system.

As of 11 September 2022, the area of the chamber roof outcrop in the panels under consideration is 35509 m^2; the total number of recorded rock falls is 6 with the total area of 298 m^2 and thickness of 0.3-1.9 m, being about 1% of the total roof area outcrop.

To compare the efficiency and safety of the pilot parameters of the mining system involving massive pillars, a stable state of the roof outcrop with the total area of more than 2 mln m^2 in 104 panels was analyzed (Table 2). That shows the percentage of rock falls from the roof to the total outcrop area depending on the adopted parameters of the room-and-pillar development system. Thus, to date, ensuring a stable state of roof outcrop as well as reducing the number of rock falls is relevant.

Table 2. Percentage ratio of the total area of rock falls from the roof to the total area of roof outcrop according to the previously accepted parameters of the panel-pillar mining system at the Zhomart mine

Parameters of the interchamber pillar with the height up to 12 m, m	Grid of the interchamber pillar arrangement	Width of the barrier (massive) pillar, m	Number of panels/blocks, pcs	Total area of roof outcrop, m^2	Total area of rock falls from the roof, m^2	Ratio of rock falls to outcrop area, %
9 by 30	18 by 18	40	1	23867	3603	15
9 by 9	18 by 18	55	9	259390	4774	2
10 by 10	19 by 19	40	91	1723571	226390	13
7 by 7	14 by 14	35 by 35	3	35509	298	1

The research purpose is to substantiate the allowable span of chambers by the calculation method. To achieve the goal, the selection of a physical model of a roof caving process, corresponding to the mining and geological conditions of the Zhomart mine, should be substantiated. It can be based on practical observations of the regularities of rock pressure manifestation in mine workings, depending on mining and geological factors as well as mine engineering conditions.

2. Materials and methods

Analysis of both chamber roof stability at stage I and problems of pillar recovery at stage II has shown that the designed 9 m roof span does not correspond to the mining and geological conditions of the Zhaman-Aibat deposit. In addition, its support with the accepted parameters does not remedy the situation. To substantiate the allowable span of the chambers by calculation, it is necessary to select a physical model of the roof caving process that corresponds to the mining and geological conditions of the deposit. It is based on the analysis of geomechanical conditions of the deposit and regularities of roof caving observed in practice. The study is based on the previously specified regularities of roof caving, indicated in paper [12], i.e.:

– in terms of chamber slashing and formation of the first interchamber pillars, the anchored roof flakes away from the overlying rocks and hangs on the anchors. Numerous ruptu-ral fractures appear. There is a need for their forced caving. One can often observe rock delamination between anchors with a thickness of 0.1-0.3 m. Within the roof sections that are not fixed with shotcrete, one can see ruptural fractures up to 1.5-2.0 m long with an opening width being up to 0.5 cm;

– within the first hours after its outcrop, the lower layer of roof rocks is broken and anchors are exposed up to 0.5 m in most chambers in the face zone after ore breaking;

– ruptural fractures as well as crushing and breakage of the bearing plates of anchor support are often observed in the centres of stopes coupling within the areas of maximum roof deflection; the observations made using the TAIS video probe showed the fracture openings along the interlayer horizontal contacts at a depth of 1.9 m to 2.4 m from the roof contour;

– after formation of 2-3 ICP rows, the roof condition usually improves: the number of exposed anchors and the amount of timber replacement are reduced. However, as with first workings, perches (delaminations) appear on the anchors. Ruptural fractures are observed (however, to a lesser extent) passing mainly along the axis of chambers;

– after roof caving with a thickness greater than the anchor lengths, the contour of the caving zone acquires a characteristic shape of a trapezoid with a flat upper base (Fig. 2).

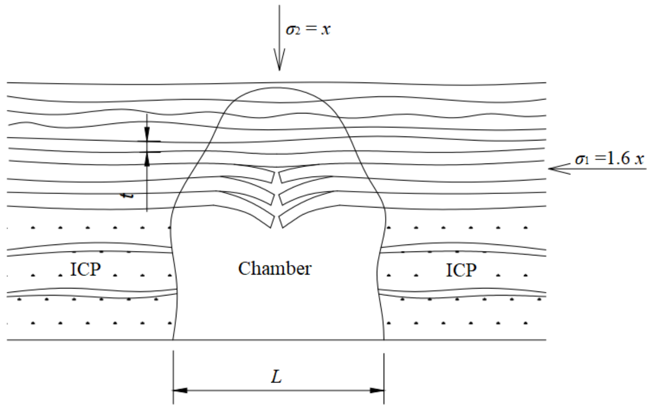

Figure 2. Characteristic shape of chamber roof caving at the Zhomart mine: σ₁ is the effective natural stress field being 1.6 times greater than the vertical stresses from the total weight of the overlying rocks, γH

Stresses in the Zhaman-Aibat deposit massif were determined:

– in 2004 – by geotechnical engineers of Kazakhmys Corporation LLP at the stage of deposit opening by core disking;

– in 2013 – by the Mining Institute using the method of gapping relief within the area of shaft "Ventiliatsionnyi 1" in drifts between panels 64-65 at a depth of $H = 650$ m. At $\gamma = 2.6$ t/m^3, gravitational pressure of the overburden is $\gamma H = 17.5$ MPa.

According to the results of measurements of the maximum tectonic stresses σ_1, they act across the length of the deposit side with the azimuth of 156-336°. A lateral pressure coefficient is $\lambda_1 = \sigma_1 / \gamma H = 1.6$. Minimum principal stresses σ_3 act along the long side of the deposit with the azimuth of 66-246°. A lateral pressure coefficient is $\lambda_3 = \sigma_3 / \gamma H = 0.9$. In its value, the vertical gravitational pressure of the overlying stratum is the intermediate principal stress $\sigma_2 = \gamma H$. In connection with the represented data, it is necessary to carry out mathematical modelling with the decreased width of the stopes and find the acceptable dimensions ensuring safety of the interchamber pillars.

Nowadays, when solving problems of geomechanics, i.e. when assessing stability of the near-contour massif of mine workings, numerical methods are widely used [23]-[28]. They include a finite element method, a boundary element method, a finite difference method etc. Of the above mathematical methods, the FEM has found its widest application in mining practice while solving geomechanical problems, which makes it possible to introduce averaged deformation and strength properties of the rock mass into the calculation scheme. In this method, filling the geomechanical model with the appropriate input data requires strict adherence to the procedure for collecting input data in mine conditions from the first day of the deposit development.

The paper uses statistical analysis of the results of geomechanical monitoring of the state of chamber roof span stability and computer modelling using the RS2 software (Rocscience, Canada) to substantiate the need for transition to safer and more cost-effective development conditions. To solve this problem, a set of research methods was applied, including the following: scientific analysis, full-scale research, generalization of the field observation results to establish the criteria for thin-layer roof mass breaking, and a modelling method.

If we represent the stope roof as a package of thin layers of intermittent rocks, being 0.1-0.3 m thick and compressed by tectonic stresses, then these regularities of chamber roof caving (delamination) correspond to the loss of stability from longitudinal compression by horizontal stresses according to L. Euler. It is according to this scheme that it is necessary to calculate the permissible chamber roof spans. To confirm the selection of the calculation scheme, numerical modelling of the behaviour of thin-slabby stope roof, fixed with anchors being 2.4 m long within a grid of 1×1 m, was carried out in the presence of tectonic stresses in the rock mass.

To ensure the chamber roof stability and interchamber pillar safety, a numerical analysis of the rock mass was performed by the finite element method and according to the conditions of the Mohr-Coulomb strength factor. The Mohr-Coulomb strength factor is widely used to analyze the bearing capacity of pillars and ceilings. When loaded, the pillars work mainly in shear along the surface with the lowest bearing capacity. Therefore, shear strength is the defining strength characteristic for the pillar. Breaking occurs at the moment when the shear stress value reaches the ultimate strength of bearing capacity of a pillar. Therefore, the relationship between normal and shear stresses is a strength factor for the rock mass.

The Discrete Fracture Network (DFN) tool with a random arrangement of extended horizontal fractures was used to specify thin layering of the roof massif in the RS2 software. According to the block model, the fracture frequency (FF) in the deposit roof 4-1 varies in the range of FF = 2-10. Within a large part of the Zhomart 2 mine field, the fracture frequency is FF = 4-5. That corresponds to the distance between fractures (layer thickness) $t = 1/\text{FF} = 0.20\text{-}0.25$ m. Higher fracture frequency is expected only within the tectonic fault zones. For further calculations, assume that the distribution of distances between fractures (spacing) follows an inverse exponential law with an average value of 0.2 m and a range of variation from 0.1 m to 0.3 m. It corresponds to thickness t of the modelled rock layers in the roof.

The Zhaman-Aibat deposit rocks are overlaid by red clayey rocks of Zhiland formation. Ore bodies are the areas of ore-bearing medium- and coarse-grained sandstones; the main ore-forming minerals are copper and lead sulfides (chalcocite, galena, chalcopyrite, bornite). The initial data for computer modelling is shown in Table 3.

Table 3. Averaged initial data of the rocks for numerical modelling

Material name	Rock
Unit weight, MN/m^3	0.027
Poisson's Ratio	0.2
Young's modulus, MPa	4700
Failure criterion	Mohr-Coulomb
Peak friction angle, degrees	35
Peak cohesion, MPa	8.7

A characteristic feature of the Zhomart and Zhaman-Aibat deposits is that the immediate roof of stoping area is represented only by siltstones. Therefore, only one rock is modelled. Mine workings (i.e. chambers) are driven through the ore.

The modelling was carried out for a mining depth of 430 m. The natural stress state of the massif was assumed to be gravitational (vertical stresses are equal to γH) with a lateral pressure coefficient $\lambda = 1.6$. The elastic properties of the thin-slabby roof area are given by the deformation modulus $E = 4.7$ hecto Pascal and Poisson's ratio $\nu = 0.2$; strength properties – by cohesion in the rock mass $C = 8.7$ MPa and internal friction angle $\varphi = 35°$.

3. Results and discussion

The section represents the results of computer modelling performed using the RS2 software. The results can be useful for understanding various processes and phenomena associated with the system under study. The RS2 software is designed for 2D analysis of a rock mass by finite element methods. The software allows you to model and analyze complex geotechnical problems. Numerical modelling of a rock mass using finite element methods makes it possible to determine the zones of stress relief and concentration, rock displacement, safety factor, magnitude of the main stresses acting within the massif, and zones of elastic and inelastic deformations around the worked-out space.

Figure 3 shows the zone of inelastic deformation (ZID) around the chamber with a width of 9.0 m. According to the results of numerical analysis, it can be seen that ZID along the roof reaches 2.36-2.55 m. Figure 4, represented in this section, shows the results of computer modelling performed to determine the total displacement of a thin-layer roof of a chamber being 9 m wide.

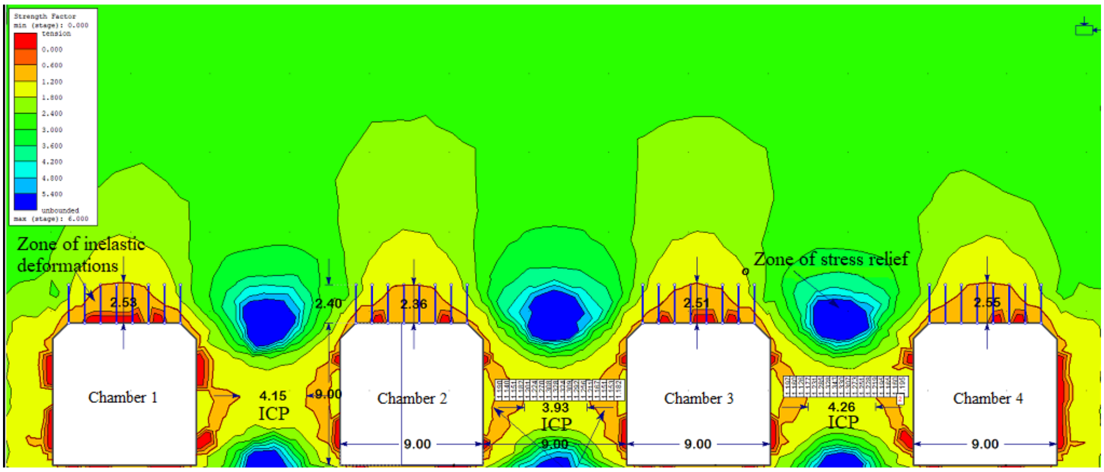

Figure 3. Zone of inelastic deformation of a chamber being 9.0 m wide; the chamber is anchored at a pitch of 1×1 m to a depth of 2.4 m

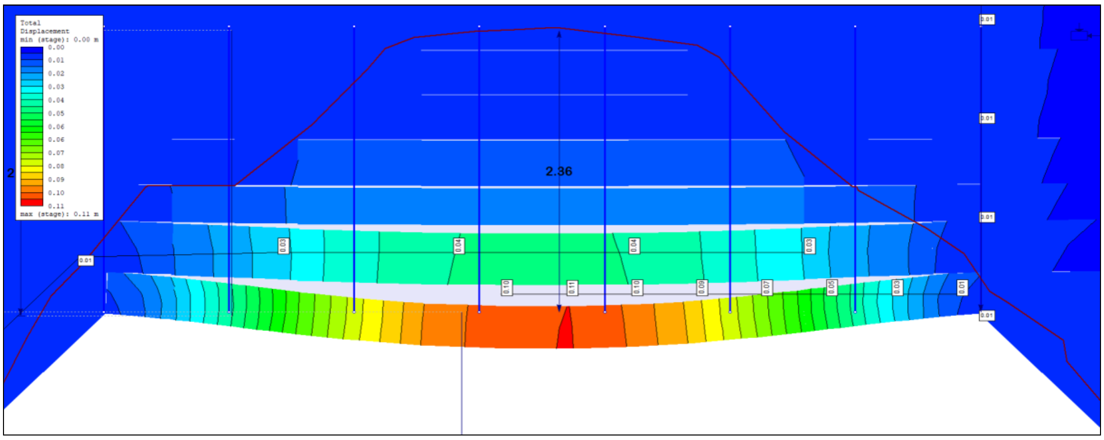

Figure 4. Deflection of a thin-layer roof of a chamber being 9 m wide; the chamber is anchored at a pitch of 1×1 m to a depth of 2.4 m

As the graph demonstrates, the displacement in the middle of the span is about 10 cm. The calculated deflection of the roof of chambers in the middle of the span reaches 10 cm. In the order of magnitude, it corresponds to the results of field observations using displacement sensors. The modelling also shows roof lamination due to difference in displacements of different layers. Roof laminations were also recorded in the wells drilled into the roof using the TAIS video probe. These facts testify to the convergence of the calculation results with rock pressure manifestations observed in practice. That indicates the reliability of the calculation model.

Figure 5 shows distribution of the strength factor in the chamber roof. For clarity, the breaking zones (with a safety factor being less than 1.2) are highlighted in orange. It can be seen that when developing chambers with a design span of

9 m, the load on ICP is large, which leads to pillar breaking. With a pillar width of 9 m, the broken part on both ICP sides reaches up to 5.0 meters in total.

Figure 6 shows maximum stress distribution (Sigma 1) around the chamber. It can be seen that at 1.6 γH chamber mining, a zone of stress concentration in the roof of mine working can reach up to 34 MPa, while within the stress relief zone (chamber walls) Sigma 1 is about 10 MPa.

Next, a numerical analysis was performed with certain changes in the parameters to assess the effect of chamber span on the roof stability. To achieve this goal, numerical modelling was carried out using different chamber widths: 8.0 and 7.0 m. The studies were carried out to determine the optimal chamber size and ensure roof stability under different operating conditions. Figure 7 shows distribution of a safety factor in the roof of a chamber being 8 m wide.

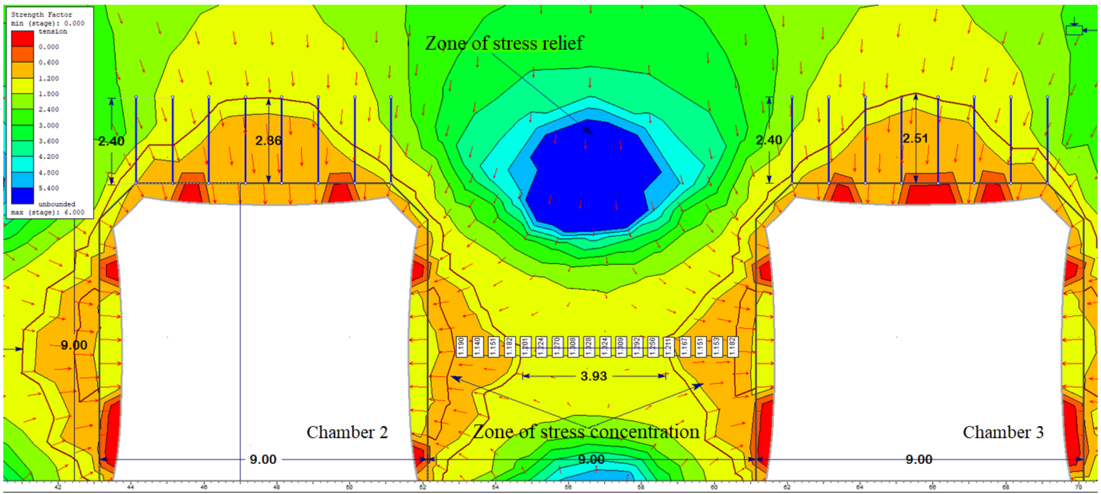

Figure 5. ICP breaking (in orange) in terms of 9 m width of the chamber anchored at a pitch of 1×1 m to a depth of 2.4 m

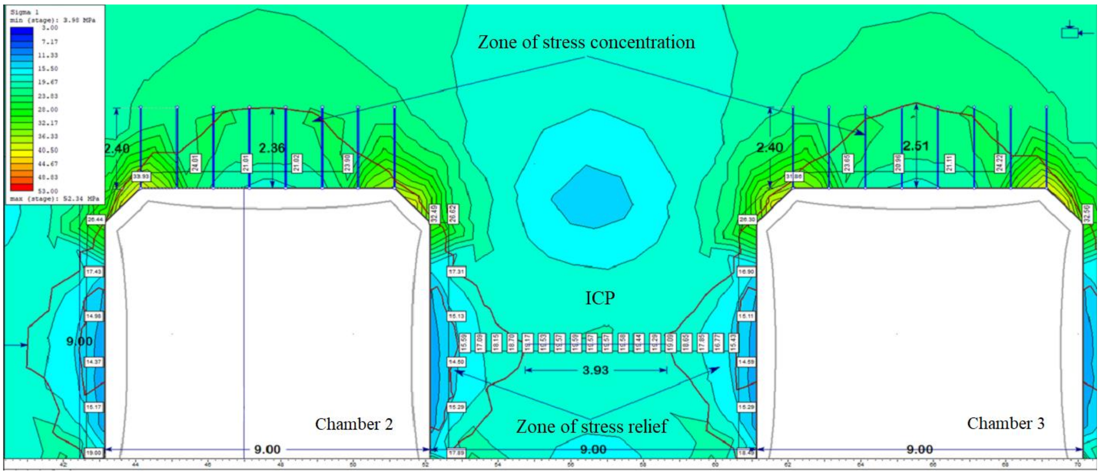

Figure 6. Zone of Sigma 1 concentration at 9 m width of the chamber anchored at a pitch of 1×1 m to a depth of 2.4 m

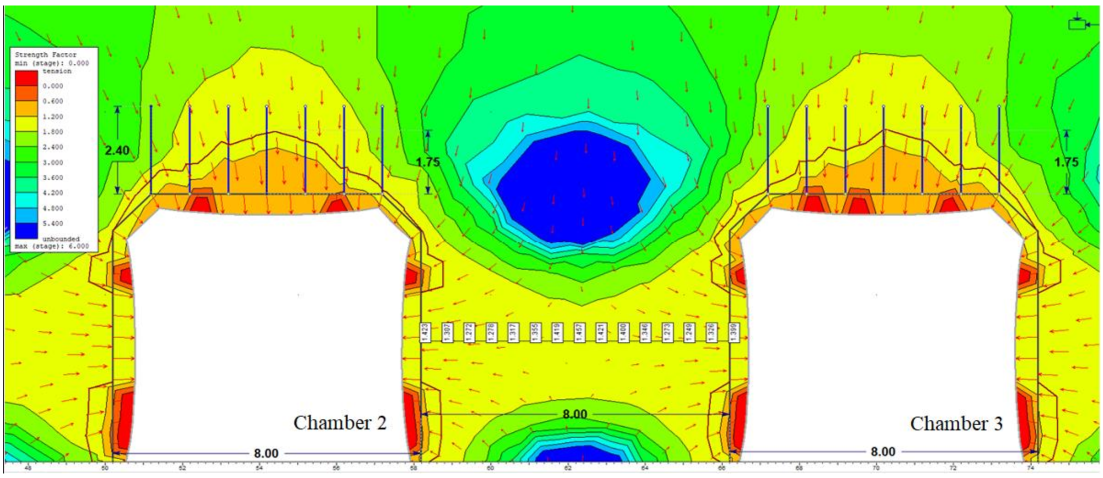

Figure 7. Breaking (in orange) of a thin-layer roof of the chamber being 8 m wide; the chamber is anchored at a pitch of 1×1 m to a depth of 2.4 m

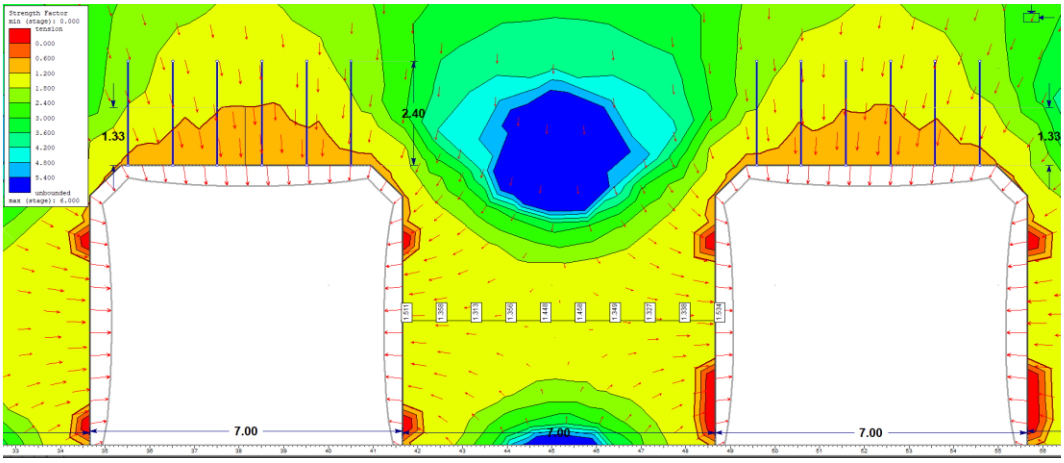

Figure 8. Breaking (in orange) of a thin-layer roof of a chamber being 7 m wide; the chamber is anchored at a pitch of 1×1 m to a depth of 2.4 m

Figure 8 shows a chamber width of 7 m. A decrease in the chamber span by 1 m (from 9 to 8 m) reduces the roof deflection by 2 times (up to 5 cm). The depth of roof breaking is also reduced significantly – up to 1.75 m. Anchor support being 2.4 m long is still not able to hold a thin-layer roof within such a span. However, the load on ICP has decreased, i.e. with a chamber width of 8.0 m, ICP is not broken.

A decrease of the span chamber by another 1 m (from 8 to 7 m) reduces the roof deflection up to 2 cm. The depth of roof breaking is also reduced significantly – up to 1.33 m. On average, the ICP strength factor is 1.35, ensuring the pillar safety.

Figure 9 shows changes in the safety factor of the peripheral part of the chamber depending on the chamber width.

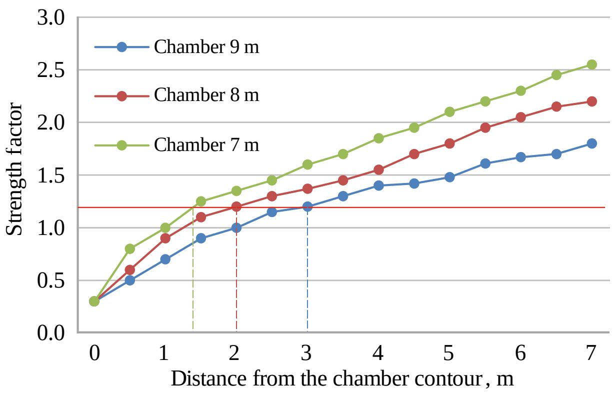

Figure 9. Graph of changes in the strength factor depending on the chamber width

Relying on the graph, we can conclude that, on average, the ICP strength factor for a chamber being 7 m wide at 1.5 m distance from the chamber contour is equal to a chamber being 9 m wide at 3 m distance from the contour. This suggests that a decreasing chamber span reduces the deflection of the roof; moreover, the breaking depth in the roof decreases, and the anchor is exposed. Thus, the number of rock falls is reduced considerably.

According to the results of monitoring the panels with a chamber width of 7 m, it was noted that for the period from June to September 2022, 6 massive and 109 interchamber pillars were formed in the panels 21 of deposit Zh-A 5-III, 22 of deposit Zh-A 4-III, and 23 of deposit Zh-A 5-IV (block 56-C_2). As for geomechanical observations and geomechanical plans in panel 23 of deposit Zh-A 5-IV, breaking of the lateral surfaces was identified while stoping before the formation of the first massive pillar on 10 interchamber pillars, associated with horizontal rock pressure. Such collapse of the pillars was also identified while forming first chambers of panels 39 yug, 1, 2, 3 of deposit Zh-A 4-I. In panels 21 of deposit Zh-A 5-III and 22 of deposit Zh-A 4-III, there were no signs of pillar failure.

A method of statistical analysis in terms of rock fall amounts for the period of 2019-22 within the driving and stope workings did not lead to any results without taking into account the areal nature. If we consider the areal nature of the loss of roof span stability involving the ratio of outcrop areas to the area of stability loss, that will make it possible to prove the obtained modelling results.

According to the results and taking into account the technological parameters of mineral mining along with evaluation of a geomechanical state of the overlying rock mass, a new technological scheme for mining ore bodies will be developed to ensure the chamber span stability at the stage of remining. Therefore, the next stage of research involves monitoring of the state of stability of structural elements of the development system while transiting to the next stage – remining.

4. Conclusions

Numerical modelling has shown that span reduction is an effective way to ensure the roof stability of the chambers, which, according to the 12-year experience of the Zhomart mine, is the weakest element of the development system.

The conducted studies give grounds to believe that the proposed option for increasing the chamber span stability can improve significantly the condition of mine workings owing to a reduced roof deflections and rock falls. The proposed solution increases the chamber span stability by more than 10 times, which is an obvious positive effect making it possible to accelerate a driving rate and achieve a significant economic effect. The proposed method for increasing chamber span stability can be applied not only in the Zhomart mine but also in other thin-slabby mines hazardous in rock falls, i.e. the ones peculiar for unstable rocks. This method can be useful for those involved in design and operation of mines and underground structures as it reduces accident risks and improves the overall reliability and safety of the facilities.

The research can become the basis for the development of a new principle for determining technological parameters of the room-and-pillar system of primary deposit mining (to prepare safe conditions for secondary mining) – the principle that means determining a stable roof span, remaining unchanged at numerous variations in sizes of pillars (both interchamber and barrier ones).

Acknowledgements

This research has is funded by the Science Committee of the Ministries of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP14972873). Project manager – M.Zh. Balpanova The team of authors also expresses its gratitude to colleagues who helped to perform mathematical modeling. Special thanks should be expressed to the editors and reviewers of the journal for their valuable advice taken into account to improve the quality of the publication.

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Аналіз стійкості прольоту покрівлі при камерно-стовповій системі розробки рудних родовищ

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Мета. Забезпечення стійкості прольоту камер при камерно-стовповій системі розробки з урахуванням розрахунків, моделювання та статистичного аналізу фактичних вивалів порід з покрівлі.

Методика. Аналіз зон непружних деформації щодо визначення загального зміщення тонкошарової покрівлі камери шириною 9 м здійснювався за допомогою програмного комплексу RS2. Для оцінки впливу прольоту камер на стійкість покрівлі задача розглядалося у двох варіантах, де ширина камер спочатку задавалась 8 м, потім 7 м. Результати аналізувалися за запасом міцності (Strength Factor) міжкамерних ціликів. Статистичний аналіз втрати стійкості покрівлі камер був виконаний за результатами моніторингу за станом виробленого простору родовища Жаман-Айбат. Отримані дані зіставлялися при прольоті покрівлі камер 9-7 м.

Результати. Проведені дослідження дають підстави вважати, що зниження прольотів камер до 7 м знижує прогин покрівлі до 2 см і забезпечує стійкість покрівлі камер та виробленого простору в 13 разів, що, у свою чергу, призводить до безпечних умов при веденні гірничих робіт з очисної виїмки. Обґрунтовано оптимальні параметри стійкості прольоту покрівлі камер та безпечні умови розробки на основі комп'ютерного моделювання і статистичного аналізу результатів геомеханічного моніторингу за станом виробленого простору родовища Жаман-Айбат.

Наукова новизна. Встановлено закономірність зміни запасу міцності законтурної частини камери залежно від ширини камери (7, 8 і 9 м) з урахуванням відстані від контурної камери (м). Зменшення прольоту камери на 1 м (з 9 до 8 м) знижує прогин покрівлі в 2 рази (до 5 см), значно знижується глибина руйнувань у покрівлі – до 1,75 м. Зменшення прольоту камери ще на 1 м (з 8 до 7 м) знижує прогин покрівлі до 2 см, значно знижується і глибина руйнувань у покрівлі – до 1,33 м.

Практична значимість. Запропонований варіант зменшеного прольоту камери може суттєво зменшити сумарну площу вивалів та забезпечити стійкість виробленого простору рудника Жомарт, де стійкість покрівлі є найслабшим елементом системи розробки. Отримані результати можуть стати основою для розробки методичних вказівок щодо розрахунку параметрів систем розробки на родовищі Жаман-Айбат, а також на інших родовищах із середньою стійкістю покрівлі.

Ключові слова: *камерно-стовпова система розробки, повторне відпрацювання, проліт камер, стійкість покрівлі, вивалоутворення, міжкамерний цілик, стійкість покрівлі*