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Research into deformation processes in the rock mass surrounding the stoping face when mining sloping ore deposits

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Abstract

Purpose. Determining the patterns for geomechanical state changes in the rock mass, depending on the stoping face technological parameters for sloping ore deposits.

Methods. The state-of-the-art CAE Fidesys strength analysis system has been adopted to conduct the research on geomechanical processes around the stoping face, which is effective in a flat formulation. The system used provides a complete engineering process cycle from the preparation of the calculation model to the visualization of the calculation results. The real physical-mechanical properties of ores and host rocks of the Zhezkazgan field (Kazakhstan) are the initial data.

Findings. As a research result, the patterns of change in the stress-strain state around the stoping face have been obtained, namely, the maximum tensile and compressive deformations in the room fenders and rocks of a parting, depending on its thickness (from 0 to 10 m). Based on the data obtained, it has been revealed that in the studied mining-geological conditions, elastic deformations predominate around the stoping face.

Originality. As a result of conducted numerical experimental studies, a new solution is proposed for an important scientific problem related to predicting the natural and technogenic geomechanical state of the rock mass.

Practical implications. The results obtained make it possible to develop technical solutions for the modernization of the room-and-pillar (panel-and-pillar) mining system under conditions of sloping fall of ore bodies in the conditions of the Zhezkazgan field.

Keywords: *Zhezkazgan field, stress-strain state, stability, pillar, room*

1. Introduction

At present, due to the constant increase in the depth of mining worldwide and the complexity of mining-geological conditions, the issues of safety and efficiency of underground mining are becoming more relevant [1], [2]. One of the key aspects when planning and exploiting underground mine workings is the study of deformation processes in the rock mass [3]-[5].

It is important to note that increasing the ore mining efficiency is of great importance for the economic development of the country, since ore deposits are one of the key revenue sources for many countries [6]-[8]. One of the leading mining systems in the underground mining of ores and other solid minerals is the room-and-pillar system. For this system, as for all mining systems with an open stope area, the process of deformation and destruction of its structural elements is characteristic, depending on one or another degree of influence and a combination of unfavorable mining-geological factors in each specific case [9], [10]. An important aspect using a room-and-pillar mining system is also the choice of optimal parameters, including room dimensions, pillar spacing and depth of mining, as well as the correct combination with other mining technologies and methods [11], [12]. Effective use of the room-and-pillar system requires an integrated approach and highly qualified specialists, as well as continuous improvement of technologies and working methods [13].

The room-and-pillar mining system can be used for mining flat and sloping (with a dip angle of up to 20°) ore deposits up to 18 m thick with stable and very stable ores and host rocks of medium and lower ore value [14], [15].

At the mines of TOO Kazakhmys Smelting (Kazakhstan), in connection with the transition to the use of diesel self-propelled equipment, the type of room-and-pillar mining system, namely the panel-and-pillar mining system, is widely used. The design peculiarity of the panel-and-pillar mining system is that the panels are limited in width by barrier pillars and the room fenders are left in a regular pattern.

From the condition of the possibility of providing an inspection of the roof state and bringing it to a safe state using the available technological equipment, the height of mining with a panel-and-pillar mining system is limited to 12 m. Thick ore deposits are mined using a panel-and-pillar mining system up to 12 m high, leaving ore on the deposit bottom, which is involved in mining by borehole breaking from mine workings driven below the deposit bottom, without equipment and people entering the stope area [16], [17].

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In accordance with the design peculiarities of the panel-and-pillar mining system, the overlying rock stratum is supported by room fenders and barrier pillars.

It is mandatory to leave barrier pillars in the following cases:

– on vast deposits, when their width is greater than the maximum span, with a built-up surface and the presence of unmined reserves in the overlying stratum;

– when mining the lower tiers in a suite of overlying deposits, above which there is a previously mined-out space, leaving barrier pillars with a parting thickness of less than 35 m;

– at the centers of mass collapses to localize destructive processes within the panel or block;

– in order to use the effect of de-stressing room fenders.

The use of room-and-pillar mining system for involving in the mining of ore deposits under protected objects of the Zhezkazgan field is regulated by the current methodological recommendations [18], [19]. However, despite this, when using this mining system in the conditions of a rock mass, various deformation and destruction processes of structural elements are possible, which may lead to the need for additional measures to ensure mining safety and prevent accidents [20]. In this regard, the study of deformation processes in a rock mass associated with the use of a room-and-pillar mining system, and the development of methods for optimizing this system, taking into account the mining-geological and mining-engineering conditions of a specific deposit, is of particular importance.

Accordingly, the study of geomechanical processes and the identification of the causes and patterns of destruction of the room-and-pillar mining system structural elements in order to strengthen them in a timely manner is a very topical issue that has both theoretical and practical importance.

By considering the geomechanical aspects of the mining system, including understanding destructive processes and implementing appropriate measures, the overall control over dilution can be enhanced [21], [22]. This, in turn, can positively impact the economic viability and efficiency of the mining operation. By minimizing ore dilution through effective geomechanical studies and timely reinforcement of structural elements, mining operations can maximize ore recovery and profitability while minimizing waste [23]-[25].

Thus, the purpose of this research is to study the patterns of changes in the stress-strain state of the rock mass surrounding the stoping face when mining sloping ore deposits, depending on the stoping face technological parameters. To achieve this purpose, it is necessary to perform modeling of deformation distribution and determine its effect on the stoping face, which enables development of an effective technology for mining sloping deposits using a room-and-pillar system in the conditions of the Zhezkazgan field.

2. Study area

The Zhezkazgan field belongs to the type of copper-bearing sandstones and is represented by deposits of disseminated ores in gray-colored seams of partly conglomerate-like sandstones, rhythmically alternating with red-colored terrigenous rocks (sandstones, siltstones, argillites). The total ore-bearing stratum thickness is about 600 m, in which 10 ore horizons, 27 layers, more than 360 ore bodies are distinguished. The immediate roof and underlying bottom rocks of the deposits are composed of red-colored, mainly fine-grained rocks – gray-colored sandstones, siltstones, argillites [26], [27].

The main ore minerals are chalcosine and bornite; galenite, sphalerite and chalcopyrite have a subordinate distribution. Malachite, azurite, chrysocolla predominate in the oxidation zone, cuprite and native copper are found. According to the composition of ore components, ores of the deposit are divided into copper (sulphide, mixed, oxidized), complex (copper-lead, copper-lead-zinc), lead (lead-zinc, zinc). Copper sulphide ores dominate (83% of the total industrial reserves of the deposit).

The natural stress field in the Zhezkazgan field mass has a geodynamic character. The horizontal tectonic stresses σ_1, acting in the submeridian direction along the strike of the flexure zones, are maximum in value. They exceed the vertical gravitational pressure of the overlying rock stratum γH by 2-5 times. Horizontal stresses, intermediate in value, act across the strike of flexures in the natural mass. Their value also exceeds the vertical pressure γH and varies within (2-3) γH. In different areas of the deposit, the values of tectonic stresses can differ by several times. In flexure zones, the natural stress state due to the strong mass disturbance caused by fractures approaches the hydrostatic state (natural stresses are equal to γH in all directions). The heterogeneity of the natural stress state of the mass is associated with the inhomogeneity of the mass fracturing. The higher the fracturing intensity, the lower the mass elasticity modulus and the lower the level of natural tectonic stresses acting in the mass.

The Zhezkazgan field hydrogeological conditions are characterized by heterogeneous water saturation of rocks of different compositions, increased water content of tectonic fault zones [28]. The filtration coefficient of water-bearing rocks ranges from 0.01 to 0.4 m/day; the water yield factor is 0.017. Grey-colored sandstones have high water content. Red-colored rocks, such as argillites and siltstones, are waterproof.

The flow rates of numerous water points confined to gray sandstone seams are tenths of liters per second and only in some cases reach 15-20 l/s. Mine water is drained directly by mine workings during mining. The type of groundwater regime is desert, pressure-drainless with the allocation of azonal areas with the influence of artificial factors. The annual decline in groundwater levels reaches 3-5, sometimes 10-15 m. The increase in water inflows into mine workings occurs in proportion to the deposit mining intensity, both in depth and in area. The total water inflows into the mine workings of the ore field are 1800 m^3/hour. Mine waters have a predominantly chloride-sulfate sodium composition with a total mineralization of 2.4-4.5 g/l and hardness of 10-30 mg-eq.

The rock mass fracturing of the Zhezkazgan field in flat-dipping areas, not complicated with tectonic disturbances, is represented by three main fracture systems (Table 1).

The Central ore field reserves, occurring closer to the surface and at medium depths (up to 300 m), are practically mined-out and decommissioned. At present, mining operations have mainly moved to peripheral areas (Annensky and Akchiy-Spassky mining regions) to deep horizons (depth of 500 m and below). They are represented by difficult mining-geological conditions (sloping occurrence of ore deposits, increased fracturing of ores and host rocks, complex lithology of the undermined stratum, dominated by a red-colored rock complex, etc.).

For 70 years, until 2014, the Zhezkazgan sloping ores were successfully mined using the room-and-pillar mining system. At the same time, 32.4% of the approved reserves with dip angles of 15-35° are concentrated in the Zhezkazgan field.

Table 1. Characteristics of the Zhezkazgan field fracture system

System No.	Characteristic	Strike azimuth, deg.	Dip angle, deg.	Distance between fractures, m	The most frequently occurring joining material
1	Flat-dipping bedding joint and shear fractures, often with slickensides and large openings filled with vein minerals	0-360	0-15	0.5-1.0	G
2	Steep-dipping dominating clevage fractures along the strike of flexures	10-30 (190-210)	75-90	0.2-0.8	clay gouge, iron and sulphide oxides
3	Steep-dipping shear fractures across the flexure strike	80-110 (260-290)	75-90	0.8-1.5	iron and sulphide oxides

The technological instruction on the application of a room-and-pillar mining system with the leaving of columnar pillars in the Zhezkazgan field underground mines takes into account the transition to the implementation of all technological processes for the mining of ore using diesel self-propelled equipment. This one provides high performance and is characterized by reliability, safety in operation at the global level of mining production.

3. Materials and methods

3.1. Choice of the research method

The solution of geomechanical problems in the analytical formulation involves the use of fairly simple calculation schemes. Their complication aimed to take into account the influence of stoping operations, other technological or mining-geological factors, the existing area of destroyed rocks around the stoping faces, the rock mass structural peculiarities significantly complicates the solution [29]-[31]. Consequently, the use of simple analytical dependences becomes impossible even when considering the rock medium elastic deformation.

A more accurate solution of the problem can be obtained if the calculation scheme or method immediately takes into account the studied factors [32]. At the present stage of development of research methods, numerous methods of solution, borrowed from the mechanics of a deformable solid body, open wide possibilities. The most effective of them are the Finite Element Method (FEM) [33] and the Boundary Element Method (BEM) [34]. Somewhat more complicated than the above is the Discrete Element Method (DEM) [35], which is currently being actively developed and used to solve problems related to the study of the rock and mass destruction processes.

In the above mentioned methods, the elasticity theory equations are first reduced to the body boundary and then the boundary integral equations (BIE) are solved. The BIE method advantages are in reducing the dimension of the problem and the amount of source information, as well as achieving high accuracy of solutions in areas with large stress gradients when solving areal problems [36]. The FEM advantage is in the low sensitivity of the method to the complexity of geometry and mechanical properties of rocks, which makes it indispensable in the analysis of local zones of destructions around the stoping face [37].

These methods are massive computing tools that have gained extraordinary value in recent years with the development of computer technology and software. They are versatile enough to handle a wide variety of problems for multiply connected areas with different types of inhomogeneity. Each of these methods has its advantages and disadvantages, depending on the specific conditions of this model and the objectives set [38]-[41].

To solve various problems in the field of geotechnics and geomechanics, the finite element method is more often used, which has more opportunities for modeling various inhomogeneities of the medium and the nonlinearity of physical relationships. Given this, the FEM is advantageous for the possibility of obtaining solutions in a nonlinear formulation, which is, under the assumption that the environment is deformed inelastically and allows plastic deformation or brittle destruction. Thus, this makes it a convenient and powerful tool for solving various nonlinear problems. Approximation of the research object to a certain number of elements, adopted in the FEM, has a well-defined physical nature, which makes it convenient to present the calculation results. The FEM is characterized by the ease of calculating the elastic state of bodies made of several materials with irregular boundaries, and the simplicity of taking into account different boundary conditions. The FEM apparatus is applicable not only to solving plane problems, the spatial domain of the mass can also be approximated by solid finite elements [42], [43]. Thus, taking into account the FEM advantages in solving nonlinear problems, good development of its mathematical apparatus, convenience in its algorithmization for computers, and its widespread use in solving geomechanical problems, it is accepted in this research as a numerical research method.

To assess the zones of the stress-strain state of the rock mass surrounding the stoping face, the state-of-the-art CAE Fidesys strength analysis system is adopted, which is effective in a flat formulation, capable of competing with world leaders in the software segment for engineering analysis. The system provides a complete cycle of the engineering process from the preparation of the calculation model to the visualization of the calculation results. CAE Fidesys allows solving complex static and dynamic strength problems, modeling thermal processes, has a built-in algorithm for optimizing the shape of a part and supports integration with CAD systems and third-party calculation packages for connected multi-physical tasks [44]. The high accuracy of the calculation results has been confirmed both analytically and in comparison with other calculation packages. The algorithm for setting boundary conditions is traditional for packages implementing FEM. It should be noted that in the spatial formulation, the use of the FEM is associated with significant difficulties caused by the formation of a computational volumetric model and problems with the solution convergence.

3.2. Initial characteristics of rocks and ores, the natural stress field horizontal component and mining data

The initial data of the studied deformation processes in the rock mass surrounding the stoping face when mining sloping ore deposits should include such parameters as: dimensions, service life, depth from the surface, layout, as well as the physical-mechanical properties of ores and rocks.

The main physical-mechanical rock properties that determine their stability in outcrops and pillars, used in mining-engineering calculations when planning the parameters for mining systems and assessing the stability of mined-out spaces, are specific weight, compressive and tensile strength, rock cohesion, internal friction angle, elasticity modulus, Poisson's ratio. The main strength and elastic properties of ores and host rocks of the Zhezkazgan Central ore field in samples in an average form are presented in Table 2.

The specific weight of host rocks ranges within 2.5-2.6 t/m^3, ores (depending on the useful component content) – within 2.55-2.8 t/m^3.

Table 2. Physical-mechanical properties of the Zhezkazgan field ores and host rocks

Rock type	Ultimate strength, MPa		Cohesion, MPa (c)	Internal friction angle, deg. (φ)	Elasticity modulus, GPa (E)	Poisson's ratio, unit fraction
	compression (σ_c)	tension (σ_p)				
Copper ore	140-230	10-18	25-30	35	32-45	0.2-0.22
Copper-zinc ore	160-240	10-18	30-34	35	50-65	0.18-0.21
Ore-free gray sandstone	160-245	8-11	25-34	35	45-65	0.18-0.22
Red sandstone	80-120	2-4	20-25	30	39-42	0.2-0.22
Red siltstone	30-60	2-4	18-20	30	32-40	0.22-0.25

Fracturing significantly influences the formation of the rock mass strength state, reducing the strength and deformation properties of rocks. The value of the structural weakening coefficient, which is the ratio of the mass strength to the sample strength, depends on the structural block size, the height of the pillar outcropping (h) and the pillar diameter (d). Knowing the fracture intensity, it is possible to determine the rock structural weakening coefficient. The structural weakening coefficient of the mass is recommended to be taken, according to the requirements, SNiP, and based on the methodological provisions of the "Guidelines for the design of underground mine workings and the support calculation", 1983. For the calculation, structural weakening coefficient K_{str} = 0.1 is taken.

The elasticity modulus of a stratified fractured overlying stratum on large bases is calculated from the velocity of a longitudinal elastic wave passing through the rock stratum, determined using vertical seismic profiling. For medium field conditions, the longitudinal wave velocity in the rock stratum from the surface to the depth of 300 m is 2500 m/s, which corresponds to the elasticity modulus of the fractured stratified stratum of $0.5 \cdot 10^4$ MPa.

The volumetric weight of the overlying host rocks (γ) is taken for calculation equal to 2.6 t/m^3; Poisson's ratio of rocks (μ) is 0.22; Young's modulus for rocks (E_r) is 44000 MPa; Young's modulus for ores (E_o) is 44000 MPa. The ultimate compressive strength (σ_c) is taken equal to 120 MPa, ultimate tensile strength (σ_t) is taken equal to 8.8 MPa.

The depth of the stoping face location is taken in the range of 500-600 m. The calculation coefficient, which takes into account the influence of the horizontal rock pressure component of the natural stress field (λ_h), is selected on the basis of experimental data for depths of 500-600 m and is equal to 0.7. The deposit dip angle is 25°.

4. Results and discussion

4.1. Distributions of deformations around the stoping face

Deformations that can occur when mining ore around a stoping face can have a significant impact on its stability:

Firstly, deformations can lead to collapses in the face. When mining ore, the rock mass is exposed to a large number of forces that can cause rock deformation. If the deformations become too significant, this can lead to collapses in the face. Collapses can be hazardous to workers and can cause significant delays in production.

Secondly, deformations can lead to a change in the stoping face geometry. If the rocks are deformed, this can lead to a change in the stoping face shape. This may affect the efficiency of ore stoping and require additional efforts to ensure the stoping face stability.

Thirdly, deformations can lead to the formation of fractures and cavities in rocks. This can lead to the penetration of water and gases into the face. This can increase the risk of accidents, as well as worsen working conditions for miners.

In general, deformations can seriously affect the stability of a stoping face during ore mining. To ensure the safety and efficiency of mining operations, it is necessary to take into account possible deformations and take measures to prevent and eliminate them.

This section presents the modeling results of the stress-strain state of the rock mass surrounding the stoping face for three options for the occurrence of coal seams at an angle of 25°, namely, for a single seam, contiguous seams with parting thickness of 5 m, and contiguous seams with parting thickness of 10 m. In all cases, the seam thickness is 12 m.

Figure 1 shows the distribution curves of the principal deformations (maximum compressive and maximum tensile) when modeling a single seam with a thickness of 12 m.

Figure 1 analysis shows that a single sloping seam is exposed to various forms of deformation. Here the rock mass can be compressed and tensioned, bent and broken. All these processes affect the mechanical properties of rocks and minerals, as well as the stoping face stability. Understanding the deformations in a single seam is essential for the safe and efficient mining of minerals and the construction of underground structures. Based on the data obtained, decisions can be made on the choice of mining methods, mining parameters, risk assessment and the stability of mine workings, etc.

Deformations in contiguous seams are studied to determine its effect on the stability of stopes and room fenders. Studying the deformations resulting from the mining of contiguous seams at different distances between seams is important for understanding the processes occurring in the rock mass during mining. This data can be used to make decisions about the safety and efficiency of mining operations, the choice of mining methods, the selection of mining parameters, and the stability of mine workings.

Figures 2 and 3 show the distribution curves of the principal deformations (maximum compressive and maximum tensile) when modeling contiguous seams with a thickness of 12 with parting thickness of 5 and 10 m, respectively.

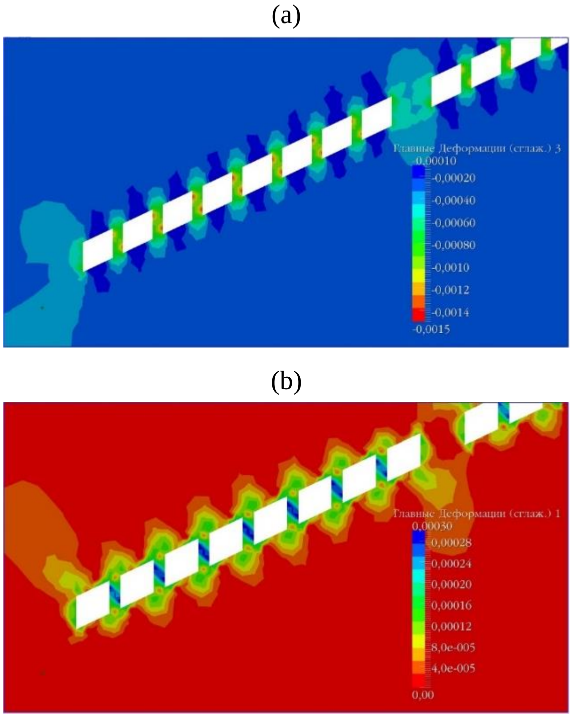


Figure 1. ***Distribution curves of the principal deformations at the seam thickness 12 m and dip angle (α) 25°: (a) maximum compressive deformations; (b) maximum tensile deformations***

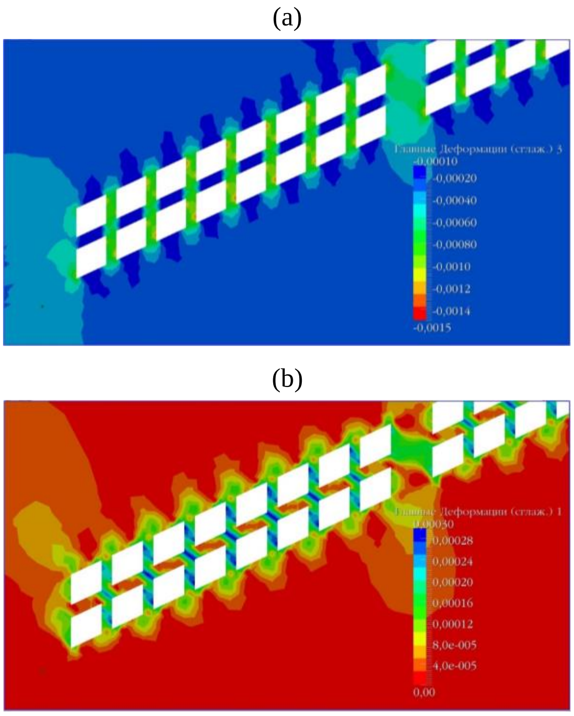


Figure 2. ***Distribution curves of the principal deformations at the seam thickness 12 m and dip angle (α) 25° with a parting thickness (L) 5 m: (a) maximum compressive deformations; (b) maximum tensile deformations***

Based on the analysis of the principal stress curves shown in Figures 2 and 3, it can be argued that the resulting deformations in the upper seam affect the deformations in the lower seam, which may affect the stoping face stability. The distribution of deformations in contiguous seams at a distance of 5 and at 10 m has its own peculiarities.

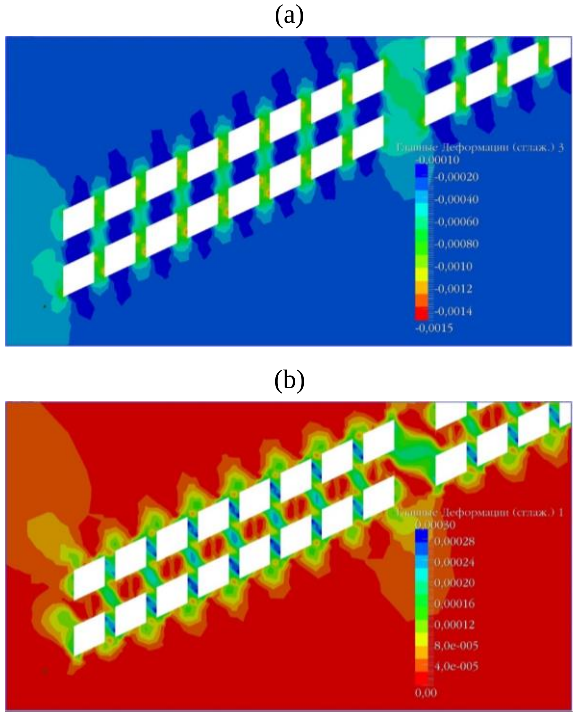


Figure 3. ***Distribution curves of the principal deformations at the seam thickness 12 m and dip angle (α) 25° with a parting thickness (L) 10 m: (a) maximum compressive deformations; (b) maximum tensile deformations***

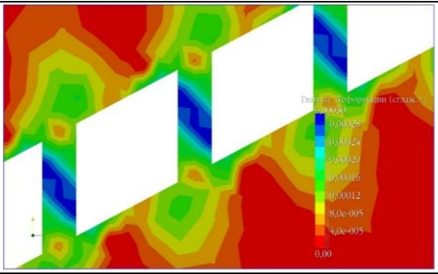
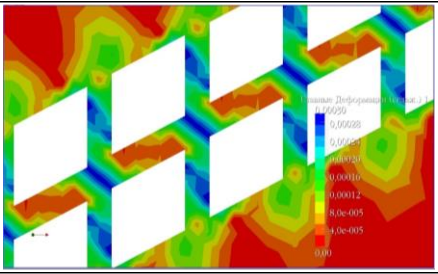
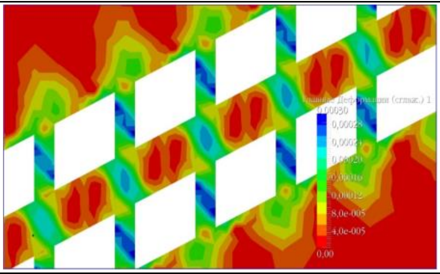
Studies show that in the case of contiguous seams at a distance of 5 m and a dip angle of 25°, deformations in one seam lead to changes in the deformations of the adjacent seam. Specific values of deformations depend on a number of factors, including the direction of loading, rock properties, their structure and environmental conditions. At a distance of 5 m, deformations in adjacent seams have a stronger effect on each other, since the distance between them is smaller. At a distance of 10 m, the effect of deformations of adjacent seams becomes less significant. In particular, studies show that at a distance of 5 m between adjacent seams and a dip angle of 25°, significant deformations are possible, including deflections and twisting. At the same time, deformations in both seams can have an increased effect on the deformations of the undermined rock stratum, leading to the occurrence of more complex deformation forms. In the case of a distance between seams of 10 m, the effect of the adjacent seam deformations may be less significant. However, deformations can also occur, including deflection and twisting, which can affect the room stability.

Thus, the deformations that occur when mining contiguous seams located at a distance of 5 and 10 m at a seam dip angle of 25° lead to complex deformation forms compared to the mining of a single seam, which have a non-critical effect on the stoping face stability. The study of these deformations is important for understanding the processes occurring in the rock mass, as well as for decision-making on the safety and efficiency of mining operations.

4.2. Generalization of calculation results

The distribution patterns of the first principal deformations (maximum tensile deformations) in the room fenders and parting rocks, depending on the parting thickness at a dip angle of 25° are given in Table 3.

Table 3. Distribution patterns of the first principal deformations (maximum tensile deformations) in the room fenders and parting rocks, depending on the parting thickness

Parting thickness, m		
0	5	10
		

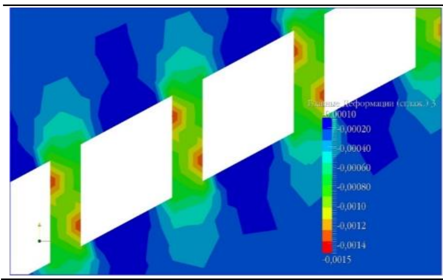
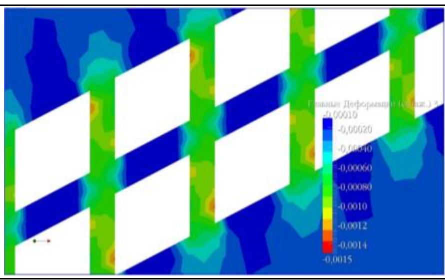
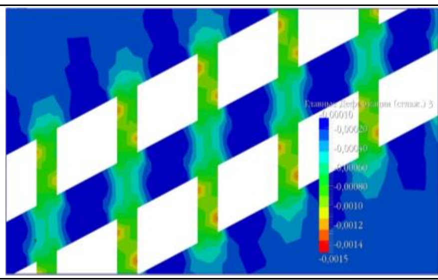
The analysis of the obtained results shows that at the considered depths of 500-600 m, the maximum tensile relative horizontal deformations in the room fenders (ε^{rf}) do not exceed $0.3\cdot10^{-3}$, in the parting rocks (ε_p^{pr}) do not exceed $0.5\cdot10^{-4}$, and in the crossing of room fender and parting rocks (ε_p^{p}) do not exceed $0.3\cdot10^{-3}$. Here, the maximum manifestation of tensile stresses is observed, which reach values up to 7.5 MPa in the parting space containing coaxially located room fenders, regardless of the thickness and dip angle of adjacent deposits. In this case, the parting thickness is 5 m. It should be noted that tensile stresses are an important factor influencing the processes occurring in mine workings.

As the distance between contiguous ore deposits increases, the tensile stress values decrease, indicating possible increased stability of mine workings. Despite this, it must be taken into account that the deformation processes in rocks caused by tensile stresses are dynamic and can change over time. Therefore, when planning mine workings, it is necessary to take into account this peculiarity and conduct a regular monitoring study of deformation parameters to ensure the safety and efficiency of mining ore minerals [45]-[47].

Taking into account the recommendations given in [48], it can be concluded that elastic deformations predominate in the above-mentioned elements of mining structures.

The distribution patterns of the third principal deformations (maximum compressive deformations) in the room fenders and parting rocks, depending on the parting thickness, are shown in Table 4.

Table 4. Distribution patterns of the third principal deformations (maximum compressive deformations) in the room fenders and parting rocks, depending on the parting thickness

Parting thickness, m		
0	5	10
		

The analysis of the obtained results shows that at the considered depths of 500-600 m, the maximum compressive relative horizontal deformations in the room fenders at the junction of the room fender with the roof and bottom (ε_c^{rf}) do not exceed $-1.4\cdot10^{-3}$, in the parting rocks (ε_c^{pr}) do not exceed $-1.0\cdot10^{-4}$, and in the crossing of room fender and parting rocks (ε_c^{p}) do not exceed $-0.8\cdot10^{-4}$.

At the edges of the room fenders and in the places of their junction with the roof, located from the side of the rise on the upper deposits, as well as on the lower deposits, at the edges of the room fenders and at their junction with the bottom from the side of the dip, the maximum values of compressive stresses are observed, which can reach up to 65-70 MPa. In this case, the dip angle of the deposit does not have a significant effect on the manifestation of compressive stresses. Their value is mainly affected by the deposit thickness, which can be considered as the room fender height.

Compressive stresses are an important factor affecting the deformation of rocks and the stability of mine workings during mining operations. Stresses arise as a result of various factors, such as the geometry of the deposits, the mechanical properties of the rocks, and the peculiarities of the mining technology. Based on the analysis of the effect of compressive stresses on mine workings, it is possible to take measures to optimize mining technology, increase their stability and ensure labor safety.

As a result of the conducted research, it has been determined that the expected room fender settlement will be:

– w = 5.6 mm at room fender height of h = 4 m;

– w = 11.2 mm at room fender height of h = 8 m;

– w = 16.8 mm at room fender height of h = 12 m.

Thus, it can be stated that the expected room fender settlement will not exceed 0.2%, which is true for the elastic mode of the room fender deformation.

Further, it is necessary to conduct studies of the stress-strain state of the room fender of various configurations when the seam thickness changes from 4 to 12 m with dip angles of 20-35°. The obtained results can be used to optimize the technologies for mining ore minerals, increase the efficiency and safety of mining operations. These studies can increase the efficiency of ore mining, which is important for the country's economic development.

In addition, further studies of the stress-strain state of the room fender and other mining system elements for underground mining of ores can be directed towards a more detailed study of various mining-geological and mining-engineering factors, affecting the stability and efficiency of mines. Particular attention will be paid to studying the interaction between the mining system elements, as well as to the application of new technologies and materials that can reduce the likelihood of accidents and improve the working conditions of miners.

Also, given the importance of preserving the environment and reducing the negative impact of mining activities on the environment, our research is focused on developing more efficient and environmentally friendly methods of mining ore minerals. In general, the development of research in this direction can help improve the efficiency and safety of underground mining of ores and other minerals, as well as reduce the negative impact of mining operations on the environment.

5. Conclusions

Taking into account the performed complex assessment of the rock mass stress state, a new solution is proposed for an important scientific problem related to predicting the natural and technogenic geomechanical state of this mass.

At the considered depths of 500-600 m, the maximum tensile stresses reach 7.5 MPa in the parting of coaxially located room fenders, regardless of the thickness and dip angle of contiguous deposits, with a parting thickness of 5 m. As the distance between contiguous ore deposits increases, tensile stresses decrease.

The maximum compressive stresses reach 65-70 MPa at the edges of the room fenders and at their junction with the roof from the side of the rise in the room fenders located on the upper deposit, as well as at the edges of the room fenders and at their junction with the bottom from the side of the dip in the room fenders located on the lower deposit. In this case, the dip angle of the deposit does not have a primary influence. The main influence is performed by the deposit thickness (the room fender height).

With a parting thickness of 5.0 m, the rock coverage between the rooms is under conditions of significant tensile stresses of 7.5 MPa, which reaches a permissible tensile strength of 5-10 MPa on average, and indicates an insufficient load-bearing capacity of the coverage. When the parting thickness is equal to or more than 10.0 m, the tensile stresses in the rock coverage decrease to 2.5 MPa or less, which does not exceed the permissible tensile strength of 5-10 MPa on average and provides more than a twofold safety margin. Thus, the conduct of mining operations on contiguous ore deposits with a parting thickness of more than 10 m may be considered as separate.

It has been determined that at the considered depths of 500-600 m, the maximum tensile relative horizontal deformations do not exceed: in the room fender – $0.3 \cdot 10^{-3}$; in the parting rocks – $0.5 \cdot 10^{-4}$; in the crossing of room fender and parting rocks – $0.3 \cdot 10^{-3}$. At the same time, the maximum compressive relative horizontal deformations do not exceed: in the room fender (at the junction of the room fender with the roof and bottom) – $-1.4 \cdot 10^{-3}$; in the parting rocks – $-1.0 \cdot 10^{-4}$; in the crossing of room fender and parting rocks – $-8.0 \cdot 10^{-4}$. The expected room fender settlement is 5.6 mm at a room fender height of 4 m; 11.2 mm at a room fender height of 8 m and 16.8 mm at a room fender height of 12 m. Thus, in the studied conditions, elastic deformations predominate in the rocks around the stoping face.

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Дослідження деформаційних процесів у гірському масиві навколо очисного вибою під час розробки похилих рудних покладів

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Мета. Визначення закономірностей зміни геомеханічного стану масиву гірських порід залежно від технологічних параметрів очисного вибою для похилих рудних покладів.

Методика. Для проведення досліджень геомеханічних процесів навколо очисного вибою прийнято сучасну систему аналізу міцності CAE Fidesys, ефективну в плоскій постановці. Використовувана система забезпечує повний цикл інженерного процесу від підготовки розрахункової моделі до візуалізації результатів розрахунку. Вихідними даними послужили реальні фізико-механічні властивості руд і порід Жезказганського родовища (Казахстан).

Результати. В результаті досліджень були отримані закономірності зміни напружено-деформованого стану навколо очисного вибою, а саме максимальних розтягуючих і стискаючих деформацій, в міжкамерних ціликах і породах міжпластя залежно від його потужності (від 0 до 10 м). На основі отриманих даних встановлено, що в гірничо-геологічних умовах навколо очисного вибою переважають пружні деформації.

Наукова новизна. В результаті проведення чисельних експериментальних досліджень було запропоновано нове рішення важливого наукового завдання, пов’язаного із прогнозуванням природного та техногенного геомеханічного стану гірського масиву.

Практична значимість. Отримані результати дозволяють розробити технічні рішення щодо модернізації камерно-стовпової системи розробки в умовах похилого падіння рудних тіл в умовах Жезказганського родовища.

Ключові слова: *Жезказганське родовище, напружено-деформований стан, стійкість, цілісність, камера*