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STUDY OF THE PRODUCTION MINE WORKINGS STABILITY SUPPORTED AT THE BOUNDARY WITH THE MINED-OUT SPACE OF THE WORKING FACES

Abstract. Study was conducted on the stability of the reused development workings by managing the geomechanics of the marginal massif from increased stresses using anchor support, including production workings supported at the boundary with the mined-out space of the working faces. The geomechanical state of the massif of underground mine workings on coal seams was studied for their efficient and safe operation in the mines of the Karaganda basin, ensuring stability with minimal consumption of supporting materials and labor intensity during subsequent maintenance at the boundary with the mined-out space of the working faces during mining development work. Deformation zones in the host rock were identified for intervention to ensure their stable support under challenging mining conditions and to determine support schemes for the cutting workings and adjacent coal-rock massif.

Key words: *mining works, technology, strength parameters, lining, workings, rock pressure, massif geomechanics, mining-geological and mining-technical conditions, deformed state.*

Жұмыс беттерінің өндірілген кеңістігімен шекарада бекітілген өндірістік шахта қазбаларының тұрақтылығын зерттеу

Аңдатпа. Қайта пайдаланылған игеру жұмыстарының тұрақтылығы туралы зерттеу шекті массивтің геомеханикасын зәкірлік тіреуішті қолдана отырып, кернеулердің жоғарылауынан, оның ішінде жұмыс беттерінің қазылған кеңістігімен шекарада бекітілген өндірістік қазбаларды басқару арқылы жүргізілді. Көмір қабаттарындағы жерасты шахталары массивінің геомеханикалық жағдайы Олардың Қарағанды бассейнінің шахталарында тиімді және қауіпсіз жұмыс істеуі үшін зерттелді, бұл тау-кен жұмыстарын жүргізу кезінде жұмыс беттерінің өндірілген кеңістігімен шекарада кейінгі техникалық қызмет көрсету кезінде тірек материалдарды минималды тұтынумен және еңбек сыйымдылығымен тұрақтылықты қамтамасыз етті. Тау жыныстарындағы деформация аймақтары күрделі тау-кен жағдайларында олардың тұрақты қолдауын қамтамасыз ету және кесу жұмыстары мен іргелес көмір-тау массивін қолдау схемаларын анықтау үшін араласу үшін анықталды.

Түйінді сөздер: *тау-кен жұмыстары, технологиясы, беріктік параметрлері, төсемі, қазбалары, тау жыныстарының қысымы, массив геомеханикасы, тау-кен-геологиялық және тау-кен-техникалық жағдайлары, деформацияланған күйі.*

Исследование устойчивости эксплуатационных выработок, поддерживаемых на границе с выработанным пространством очистных забоев

Аннотация. Произведено исследование устойчивости повторно используемых подготовительных выработок за счет управления геомеханикой приконтурного массива от повышенных напряжений с применением анкерной крепи, в т. ч. эксплуатационных выработок, поддерживаемых на границе с выработанным пространством очистных забоев. Исследовано геомеханическое состояние массива подземных горных выработок на угольных пластах для их эффективной и безопасной эксплуатации на шахтах Карагандинского бассейна с обеспечением устойчивости при минимальном расходе крепежных материалов и трудоемкости при последующем поддержании на границе с выработанным пространством очистных забоев при горно-подготовительных работах. Определены области деформаций во вмещающих породах для воздействия, для обеспечения стабильного поддержания их в сложных условиях разработки и для определения схем крепления присечных эксплуатационных выработок и прилегающего углепородного массива.

Ключевые слова: *горные работы, технология, прочностные параметры, крепление, выработка, горное давление, геомеханика массива, горно-геологические и горнотехнические условия, деформированное состояние.*

Introduction

The efficiency of coal seam development depends significantly on the development plan and mining system. When developing gently sloping seams, the non-core technology is widely used. Its use at deep horizons is accompanied by deterioration of the development workings. The costs of protection and maintenance often exceed the costs of excavation by 2.0 to 2.5 times. This is due to the increased and uneven distribution of rock pressure, significantly more complex conditions for maintaining the workings, insufficient bearing capacity, and the high labor intensity of supporting maintenance works. Increasing the efficiency of existing mines while maintaining the existing volume of coal production is possible by increasing the load on the working faces, by advancing them by 8–12 m/day, and to recreate prepared reserves, the rate of development of development workings should be at least 15–25 m/day.

In modern mines, three pillarless mining schemes are used: with the preservation of workings for reuse; with the construction of new workings adjacent to the mined-out space; with the construction of paired workings with the extraction of a pillar between them by an adjacent longwall.

The most progressive design of the non-pillar technology is the technology of preparing and developing seams by preserving the workings on the border with the working space during the development of the adjacent longwall.

The transition of mining operations to deeper levels is accompanied by a change in the manifestation of rock pressure. Unlike at shallow depths, where a collapse arch forms at the roof of the working, at greater depths, noticeable deformation occurs along the entire perimeter of the working. Development workings deform under the influence of stresses, both during excavation and during operation. Furthermore, workings reused fall within the zone of influence of stoping operations, leading to increased deformation of the rock and support structures, necessitating their re-support.

In this regard, the development of new and improvement of existing methods for maintaining workings during their service life with minimal costs is relevant.

Research materials and methods

In accordance with the recommendations [1], permanent artificial barriers should be used to protect workings at the border with mined-out spaces: organ rows, row of pillars, fires made of sleeper beams filled with rock, fires with an organ row, organ rows with a rubble strip, high-strength supports with limited flexibility, etc., and portable protective supports made of metal friction pillars, hydraulic pillars, etc.

When maintaining a working face for reuse, reinforcement support – two hydraulic props (HP or F friction props) – was installed ahead of the working face. Behind the working face, the support was reinforced with a third prop, and in the spaces between the main support props on the mined-out side, a series of two props was installed between the main support frames. After the active stage of rock movement had passed, the hydraulic props or friction props were removed and moved forward to the longwall, while the wooden props remained until the working face was abandoned. This method ensured the working surface remained operational until its abandonment.

At the Vorkutinskaya mine (Russia), a method of protecting workings using strips of lightweight gold-cement blocks was successfully tested during development of the «Chetverty» seam [2]. The seam thickness is 1.48 m. Roof displacements in the experimental section of the workings were reduced by 1.5–2.0 times compared to the original.

At the «Zyryanovskaya» mine of the «Yuzhkuzbassugol» Production Association [3], portable hydraulic pillar support was used as reinforcement. The main support for the workings consisted of three bolts with metal caps under a metal mesh. At the junction of the roadway with the longwall, on the mined-out side, a row of wooden hydraulic pillar support was installed at a rate of 3 frames per meter. A row of hydraulic pillars was used as reinforcing cut-off support at a distance of 5–6 m behind the longwall face. At a distance of 100 m behind the longwall face, the hydraulic pillar was removed and moved forward to the longwall face, and a leg of the standard support was installed in its place. The condition of the workings was satisfactory. This method is recommended for use in seams up to 3.5 m thick.

At the «Glubokaya» mine of the «Donetskugol» Production Association, the 35th eastern passage was protected by an 8-meter wide rubble strip. The working support was an AP-3 arched metal one.

Hydraulic prop reinforcement was installed under the support frames, with a total bearing capacity of 500 kN/m. The roof rock is 13 m thick clay shale. Roof and soil displacements were reduced by a factor of 1.5. At the «Krasnoarmeyskaya – Kapitalnaya» mine, at depths of 850–950 m, the use of reinforcement with a bearing capacity of 700 kN/m reduces heaving of sandy shale in the soil by 20–35%.

There is also experience in protecting reused workings with artificial fencing [5, 6, 7], for example, single or double rubble strips, reinforced concrete blocks, rolling fires, wooden organ 1–3-row supports, bollards made of expanded clay concrete, sawdust concrete, and reinforced concrete blocks enclosed in wooden fires (PA «Donbassanthracite», PA «Rostovugol»). These types of structures are often destroyed at some distance behind the longwall by thick sandstones lying in the roof or are pressed into weak soil rocks, failing to ensure a satisfactory state of the workings. Research Institute of Mining has developed П-shaped structures of reinforced concrete blocks filled with sand or rock intended for seams up to 2.5 m thick.

Cast strips constructed from hardening materials are considered highly rigid artificial protective structures [8]. Strips at least 0.7 times the seam thickness wide are mechanized behind the working face and, due to the high rate of material hardening, begin to quickly absorb loads. This is a typical support-cut artificial barrier, performing both cutoff functions due to its high rigidity and support functions due to its high load-bearing capacity.

In some cases, it is advisable to carry out workings towards the existing working face, adjacent to the mined-out space [9], or to carry out (design) them in it.

In the most challenging mining and geological conditions, development workings were typically constructed and maintained using arched supports. Currently, bollards made of reinforced concrete blocks, reinforced concrete blocks, and fire supports combined with organ supports are widely used.

However, despite scientific and technological progress, the problem of maintaining workings using pillarless technology with the reuse of mining workings has not been fully resolved. This is primarily due to the fact that the currently used method of supporting workings using framed metal arched and trapezoidal supports with reinforcing props is highly labor-intensive and metal-intensive. However, in conditions where the coal seam roofs contain layered fractured rocks over 3–4 meters thick, and the main roof contains difficult-to-break rock, maintenance-free workings cannot be ensured for the entire service life of the working.

Statement of the research problem. The change in the length of the consoles on the side of the mined-out space directly affects the stress-strain state of the near-edge massif, the size of the displacement zones in the edge zones of the longwall face and the load on the support that outlines the workings.

The conduct of cleaning operations leads to a periodic change in the length of the hanging consoles, which entails a periodic change in stresses, under the influence of which complex geomechanical processes occur in the marginal zones of the longwall, as well as in the rocks enclosing the workings, the result of which is a decrease in the stability of the workings in question.

Changes in the velocities and magnitudes of displacements in the contour of the workings depend on their protection methods, the physical and mechanical properties of the host rock, the shape and size of the workings' cross-section, and the technological features of the mining operations. During non-core mining, workings for reuse must be sufficiently stable and meet safety regulations regarding the cross-sectional area. This can be achieved if the deformations and stresses in the marginal zone of the workings in question do not exceed permissible values. To reduce the costs of protecting and maintaining the workings, it is necessary to reduce the stresses in the marginal zone of the workings, thereby reducing the load on the protective structures.

A promising approach to reducing the labor and metal consumption of supporting workings and increasing their stability is the use of roof bolts. However, experience has shown that using conventional rigid roof bolts 1.8–2 meters long is effective only for roofs with low thicknesses and small displacements during development outside the working zone. Large rock movements in the bearing pressure zone of the first face, and especially during periods of supporting workings at the boundary with the mined-out space, have led to the breakout of locks or failure of rods, necessitating the installation of frame supports in these workings as well. Therefore, the urgent problem of reliably supporting reusable, non-bolted workings using cost-effective roof bolts remains unresolved.

To determine the stability of the workings supported behind the production face, a selection of technical documentation from various mines in the Karaganda basin was made for the development of thin and complex seams. The parameters and design features of the lining reinforcement and workings protection against the effects of mining operations were identified. Analysis showed that the selection of these means for specific mining and geological conditions is often made in an unsystematic manner, ignoring such an important factor as the extracted seam thickness, and failing to achieve the required workings stability. Analysis of the measurement results [10] made it possible to determine the stress-strain state of the coal and rock mass around the workings for specific mining and geological conditions, depending on the lining reinforcement and protection methods. In terms of magnitude and distribution of stress concentration at a seam thickness of 1 to 2 m and protection of the workings with wooden fires and block walls: the maximum values on the coal massif side and on the mined-out space side are approximately the same and amount to 150–170 kN/m^2, and with organ support they decrease to 130–150 kN/m^2 (Table 1). At a coal seam thickness of 2.0–2.5 m and protection with organ support: on the massif side, the stress concentration is 160–170 kN/m^2, and on the mined-out space side – 230–250 kN/m^2, above the working head – 50–70 kN/m^2 (Figures 1, 2). Moreover, an increase in the number of organ rows reduces the rigidity of the support and the use of more than one organ row is irrational.

Table 1

Maximum stresses in a rock mass, surrounding the workings

Кесте 1

Қазбаларды қоршап тұрған тау жыныстарының массасындағы максималды кернеулер

Таблица 1

Максимальные напряжения в горном массиве, окружающем горные выработки

Seam thickness, m	Security equipment	Maximum stress values, kN/m^2	
		from the side of the massif	from the side of the mined-out space
2.0–2.5	Double-row organ support	170–250	150–240
	Three-row organ support with rubble strip	150	230
	Three-row organ support with rubble strip	170	300
1.0–1.9	Wooden fires	170	180
	Wooden wall	170	180
	Single-row organ support	145	130
	Double-row organ support	150	140

The nature of the pressure distribution depends on the extracted thickness of the seam; for example, the displacement and convergence of roof and soil rocks with an increase in the thickness of the seam from 1.0 to 2.0 m increases by an average of 10–20%.

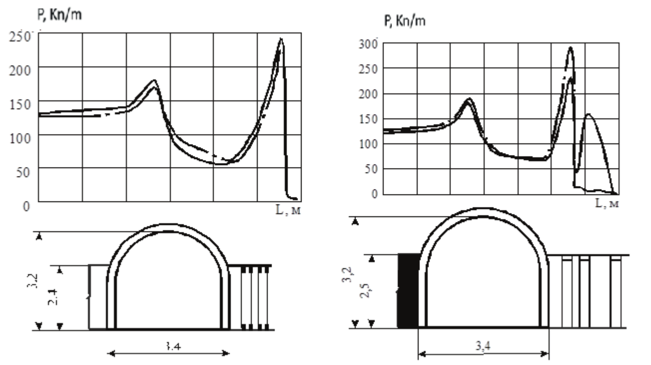

Figure 1. Distribution of rock pressure stresses P at protection of mine workings with organ rows.
Сурет 1. Тау-кен қазбаларын органикалық қатарлармен қорғау кезінде тау-кен қысымының P кернеуін бөлу.
Рис. 1. Распределение напряжений P горного давления при защите горных выработок органными рядами.

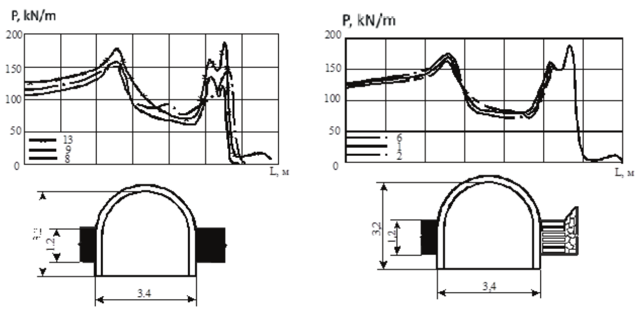

Figure 2. Distribution of rock pressure stresses P for different methods of protecting mine workings.
Сурет 2. Тау-кен қазбаларын қорғаудың әртүрлі әдістері үшін P жынысындағы қысым кернеуін бөлу.
Рис. 2. Распределение напряжений давления в породе P для различных методов защиты горных выработок.

Reduction of vertical displacements is ensured by increasing the bearing capacity of the workings support and increasing the rigidity of the reinforcement and protection means. Comparing the obtained data with the values of the load on the workings support in relation to the VNIMI classification, according to which loads from the roof for workings up to 60 kN/m^2 are classified as favorable support conditions; 60–120 kN/m^2 – as average; 120–350 kN/m^2 – as severe, it can be concluded that the conditions for supporting the workings behind the longwall in the Karaganda basin are relatively difficult.

To establish patterns of influence of mining and geological factors on the operational characteristics of mine workings, conditions and costs of maintenance, possible ranges of their variation were considered based on the physical and mechanical properties of roof and soil rocks, water inflow, etc., using the example of the conveyor intermediate roadway 43K2-3 of the K2 seam of the Kostenko mine of the Karaganda coal basin. Statistical data were established on the nature of heaving of the mine working soil, displacement of roof rocks, and deformation of the working support elements. With soft soil rocks made of siltstones and argillites with a strength of up to 2 MPa, soil heaving was up to 2.5–2.9 m along the entire cross-section of the working, and with strong soil rocks, its fractures in the internal cross-section of the working occurred with a displacement from the axis of the working by 0.5 m towards the intact coal massif. Flattening (squeezing out) of the upper logs into the cavity of the working was observed from the side of the mined-out space (10% of the length of the working – E1); ruptures of lock joints (stirrups and strips) on the elements of the support reinforcement of the UKR: from the side of the pillar (0.2% – E6), from the side of the mined-out space (2.5%), upper UKR (33% – E5). Along the length of the working, the extrusion of the lateral legs was observed: on the pillar side at 8.8% (E2) of the working length, which led to the loss of the bearing capacity of the working support and required its re-supporting over 6.7% of its length or at least replacement of the lateral arched legs; on the mined-out side, the extrusion of the lateral legs of the arched metal support occurred at 2.1% (E3) of the working length. The extrusion of both lateral legs of the arched support occurred at 1.6% (E4) of the working length, necessitating re-supporting in this area. In a number of sections – 1.2% of the working length, due to secondary roof settlements, the lateral posts of the arched support and, in part, the frame as a whole are inclined in the direction opposite to the direction of movement of the working face.

The following factors are accepted as influencing factors: the presence of zones of increased rock pressure; the strength characteristics of the roof and soil rocks of the formation and their thickness; the structure and water saturation of the rocks; the step of the main roof settlement; the presence of geological disturbances of a disjunctive nature; the speed of movement of the longwall face; the power characteristics of the lining of the workings.

The dependence of the costs (***T3***) for maintaining the observed conveyor intermediate drift $43K_{2\text{-}3}$ on the influence of the HMP zones ($\boldsymbol{P_{HMP}}$) is exponential, the formation disturbances ($\boldsymbol{P_D}$) and the characteristics of the soil rocks ($\boldsymbol{P_{SR}}$) are inversely proportional, and the roof rocks ($\boldsymbol{P_R}$) are parabolic. The general form of the dependence is as follows (with a correlation coefficient of 0.97):

$$T_3 = \mathbf{0,153}e^{0.264P_{HMP}} + \mathbf{0,234} - \frac{\mathbf{0,152}}{P_D} + \mathbf{0,0008}P_R^2 -$$
$$- \mathbf{0,0042}P_R - \frac{\mathbf{0,468}}{P_{SR}}.$$

Of the above factors, the maximum stress increases (up to 70% of the total values) are caused by the PGD zones.

The calculations made allowed us to establish that the cost of maintaining a conveyor intermediate drift in the conditions of the K2 seam of the Kostenko mine amounts to 10 to 15% of the initial cost of the working, taking into account the costs of installing reinforcement in the working.

To compare the expected displacements of roof and ground rocks under various technological schemes for mining thin, flat seams in the Karaganda basin, geomechanical studies were conducted (Table 2) using averaged actual data for the technological parameters of the extraction. The length of the extraction pillar is 1800 m, the rate of advance of the working faces is 60–70 m/month, the speed of development of the workings is 250–300 m/month, with a downtime between the end of the excavation and the start of extraction pillar development of 5–7 months.

The results of the analysis indicate that the conditions for maintaining workings formed behind the longwall face are 1.3–2.5 times more severe and are reused 1.7–3.5 times compared to the cuttings and workings driven in the coal massif.

Note – $\boldsymbol{V_{ozimo}}$ and $\boldsymbol{V_{zerp}}$ are the rates of rock displacement, respectively, outside the zone of influence of mining operations and in the zone of established rock pressure; $\boldsymbol{U_{01}}$, $\boldsymbol{U_{02}}$, $\boldsymbol{U_a}$, $\boldsymbol{U_o}$ are rock displacements in the zone of, respectively, temporary support pressure in front of the first and second longwall faces; active roof displacements behind the first longwall face; the total value of expected convergence.

Table 2

Expected roof and soil displacements in mine workings

Кесте 2

Қазбаларды қоршап тұрған тау жыныстарының массасындағы максималды кернеулер

Таблица 2

Максимальные напряжения в горном массиве, окружающем горные выработки

Nature of the event extraction workings	Calculated values					
	V_{ozimo}, mm/day	V_{zerp}, mm/day	U_{01}, mm	U_{02}, mm	U_a, mm	U_o, mm
Passed in the massif	0.5	-	60	-	-	250
Cutting mine workings	1.1	-	110	-	-	500
Designed behind the lava	-	1.5	-	110	160	680
Supported by lava:						
− organ ranks	0.5	1.5	60	110	160	850
− rock support	0.9	0.9	60	110	140	850
− rubble fires	0.6	0.7	60	110	150	850

Results and discussion

Strengthening the roof support with cable anchors increases the strength of the marginal rock mass at the junction of the longwall and the drift, in areas subject to supporting pressure from the working face and the impact of the mined space, and redistributes the load on the roadway support. Binding the rock mass with deep-set anchors delays its displacement, and after the roof settles, the reinforced rock mass is supported by the broken rock behind the mechanized system.

In this case, the anchor support is calculated in such a way as to ensure safe working conditions at the junction of the working face with the drift, and subsequently to preserve the workings for reuse and its maintenance without repairs for the entire period of operation.

A mine support system for low- and medium-thickness seams, preserved for reuse at the boundary with the mined-out space, can be used. Reinforcement of the mine support with cable anchors is used to preserve the workings, for gas control, drainage, emergency exits, and reuse.

When developing the support of workings for their preservation for the purpose of reuse by the adjacent longwall, the geomechanical basis for the calculation is the following provisions: the formation of a supporting beam by first-level anchors (Figure 3); the roof rocks of the working outside the natural pressure dome have smaller displacements and greater resistance to loads than the rocks in the dome; displacements of the roof rocks behind the longwall lead to an increase in the span of the pressure dome by the amount of possible destruction of the sides of the working and, accordingly, a significant increase in the dimensions of the natural pressure dome; the connection of the marginal rock mass in the natural pressure dome with the overlying rocks by means of deep-laid anchors leads to the suspension of the formed supporting beam of rocks to a stable massif and balancing the load on the working support.

Conclusion

Strengthening the roof support with cable anchors increases the strength of the marginal rock mass at the junction of the longwall and the roadway, in areas subject to supporting pressure from the working face and the impact of the mined space, and redistributes the load on the roadway support. Binding the rock mass with deep-set anchors delays its displacement, and after the roof settles, the reinforced rock mass is supported by the broken rock behind the mechanized system.

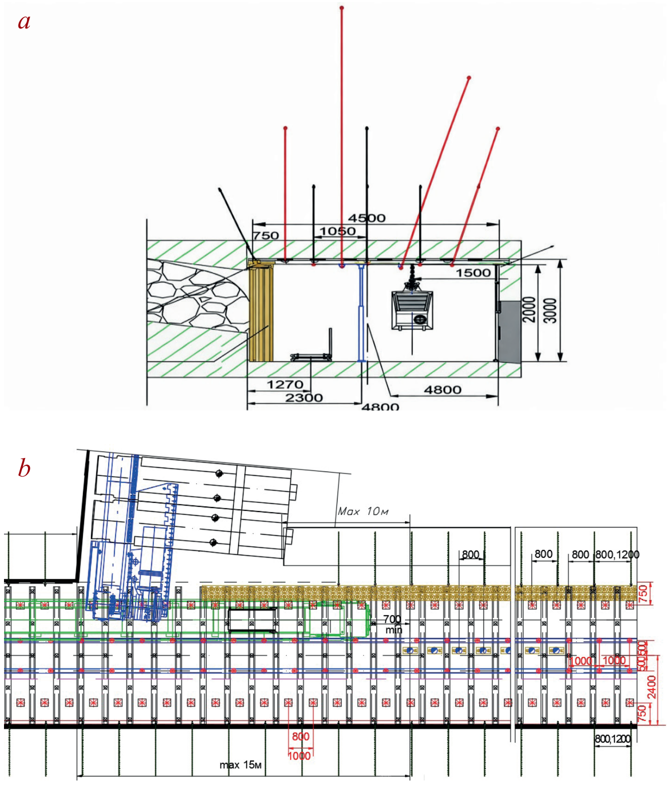

Figure 3. Preservation of workings at the boundary with mined-out space for reuse: *a – section; b – production profile.*

Сурет 3. Қайта пайдалану үшін өндірілген кеңістігі бар шекарадағы қазбаларды консервациялау: *a – қима; b – өндіріс профилі.*

Рис. 3. Консервация выработок на границе с выработанным пространством для повторного использования: *a – разрез; b – профиль производства.*

In this case, the anchor support is calculated in such a way as to ensure safe working conditions at the junction of the working face with the drift, and subsequently to preserve the workings for reuse and its maintenance without repairs for the entire period of operation.

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