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GEOMECHANICAL SUBSTANTIATION OF TWO-LEVEL ROCK BOLT SUPPORT PARAMETERS FOR PREPARATORY MINE WORKINGS IN LAYERED ROCKS OF THE KARAGANDA COAL BASIN

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The article presents a methodology for determining the parameters of rock bolt support for preparatory and operational mine workings under the conditions of the complex geological and geotechnical structure of the Karaganda Coal Basin. Based on the analysis of field observations, geomechanical characteristics of the rock mass, and the current practice of rock bolt application over the past 10 years, the key factors affecting the stability of the roof and ribs of mine workings have been identified. It is shown that the transition to greater mining depths causes the expansion of abutment pressure zones, an increase in the intensity of deformations, and a decrease in the natural stability of layered rocks. The study substantiates the application of single-level, two-level, and combined bolting schemes based on MM Protodyakonov' s natural equilibrium arch hypothesis and the principles of forming a reinforced beam in the roof. Algorithms are presented for calculating the load-bearing capacity of rock bolts, their installation density, embedment depth, and expected loads using nomograms. Recommendations are proposed for adapting support parameters to different categories of rock stability and categories of complex conditions, including zones influenced by longwall mining, undermined rock masses, and hybrid protection schemes. The results of the study can be applied in the design of support passports and in optimizing technologies for maintaining mine workings under the conditions of the basin.

Keywords: rock bolt support, Karaganda Coal Basin, roof stability, natural equilibrium arch, two-level support, combined support, rock bolt calculation, geomechanical conditions, abutment pressure, roof displacements.

ҚАРАҒАНДЫ КӨМІР БАССЕЙНІНІҢ ҚАБАТТЫ ЖЫНЫСТАРЫНДАҒЫ ДАЙЫНДЫҚ ҚАЗБАЛАРЫНА АРНАЛҒАН ЕКІДЕҢГЕЙЛІ АНКЕРЛІК БЕКІТПЕ ПАРАМЕТРЛЕРІН ГЕОМЕХАНИКАЛЫҚ НЕГІЗДЕ

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Мақалада Қарағанды көмір бассейнінің күрделі геологиялық-техникалық құрылысы жағдайында дайындық және пайдалану тау-кен қазбаларына арналған анкерлік бекітпе параметрлерін анықтау әдістемесі ұсынылған. Натурлық бақылауларды, жыныс массивінің геомеханикалық сипаттамаларын және соңғы 10 жылдағы анкерлерді қолдану тәжірибесін талдау негізінде қазбалардың төбесі мен бүйірлерінің орнықтылығына әсер ететін негізгі факторлар айқындалды. Өндіру тереңдігінің артуы тірек қысымы аймақтарының өсуіне, деформациялар қарқындылығының күшеюіне және қабатты жыныстардың табиғи орнықтылығының төмендеуіне әкелетіні көрсетілді. М.М. Протодьяконовтың табиғи тепе-теңдік күмбезі гипотезасы мен төбедегі күшейтілген арқалықтың қалыптасу қағидаттары негізінде бірдеңгейлі, екідеңгейлі және құрамдастырылған анкерлеу сұлбаларын қолдану негізделді. Номограммаларды пайдалана отырып, анкерлердің көтергіштік қабілетін,

оларды орнату тығыздығын, бекіту тереңдігін және күтілетін жүктемелерді есептеу алгоритмдері келтірілген. Тау жыныстары орнықтылығының әртүрлі санаттарына және күрделі жағдайлар санаттарына, соның ішінде тазарту жұмыстары ықпалы аймақтарына, қайта өңделген массивтерге және қорғаныстың гибридтік сұлбаларына бейімделген бекітпе параметрлерін таңдау жөніндегі ұсынымдар ұсынылған. Зерттеу нәтижелері бассейн жағдайында бекіту паспорттарын жобалау кезінде және тау-кен қазбаларын ұстап тұру технологияларын оңтайландыруда қолданылуы мүмкін.

Түйін сөздер: анкерлік бекітпе, Қарағанды көмір бассейні, төбе орнықтылығы, табиғи тепе-теңдік күмбезі, екідеңгейлі бекітпе, құрамдастырылған бекітпе, анкерлерді есептеу, геомеханикалық жағдайлар, тірек қысымы; төбе ығысулары.

ГЕОМЕХАНИЧЕСКОЕ ОБОСНОВАНИЕ ПАРАМЕТРОВ ДВУХУРОВНЕВОЙ АНКЕРНОЙ КРЕПИ ПОДГОТОВИТЕЛЬНЫХ ВЫРАБОТОК В СЛОИСТЫХ ПОРОДАХ КАРАГАНДИНСКОГО УГОЛЬНОГО БАССЕЙНА

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В статье представлена методика определения параметров анкерного крепления подготовительных и эксплуатационных горных выработок в условиях сложного геолого-технического строения Карагандинского угольного бассейна. На основании анализа натурных наблюдений, геомеханических характеристик массива и текущей практики применения анкеров за последние 10 лет выявлены ключевые факторы, влияющие на устойчивость кровли и боков выработок. Показано, что переход на большие глубины разработки вызывает рост зон опорного давления, увеличение интенсивности деформаций и снижение естественной устойчивости слоистых пород. Выполнено обоснование применения одноуровневых, двухуровневых и комбинированных схем анкерования на основе гипотезы свода М.М. Протодьяконова и принципов формирования упрочнённой балки в кровле. Приведены алгоритмы расчёта несущей способности анкеров, плотности их установки, глубины заложения и ожидаемых нагрузок с использованием номограмм. Предложены рекомендации по адаптации параметров крепи под различные категории устойчивости пород и категории сложных условий: зоны влияния очистных работ, подработанные массивы, гибридные схемы охраны. Результаты работы могут применяться при проектировании паспортов крепления и оптимизации технологий поддержания горных выработок в условиях бассейна.

Ключевые слова: анкерная крепь, Карагандинский угольный бассейн, устойчивость кровли, свод естественного равновесия, двухуровневая крепь, комбинированная крепь, расчет анкеров, геомеханические условия, опорное давление, смещения кровли.

Introduction. The stability of preparatory mine workings at great mining depths remains one of the key challenges in underground coal mining. Increasing mining depth leads to a significant rise in rock pressure, redistribution of stresses around excavations, deterioration of the stress-strain state of the surrounding rock mass, and activation of deformation processes in layered rocks. Under these conditions, the stability of mine workings is largely determined by the ability of the support system to prevent interlayer separation, roof sagging, and progressive failure of weak lithological contacts. These problems are particularly pronounced in the conditions of the Karaganda Coal Basin, where the rock mass is characterized by complex geological structure, pronounced stratification, tectonic disturbance, and significant variability in the physical and

mechanical properties of mudstones, siltstones, and sandstones. In many mine fields of the basin, the roof rocks consist of thin-layered argillite-siltstone sequences with weakened interlayer bonding, which substantially reduces the natural stability of underground openings. As mining operations advance to deeper horizons exceeding 400–500 m, the influence of abutment pressure increases, while the extent of fractured and weakened zones around workings becomes significantly larger.

Numerous studies conducted in recent years confirm that conventional support systems are often insufficient under deep mining conditions. Modern research increasingly focuses on the development of reinforced bolting systems capable of forming stable load-bearing structures within layered roof rocks. Kang et al. [1] demonstrated that grouted bolting systems significantly improve the integrity of fractured rock masses and reduce deformation in deep mine roadways through the formation of reinforced structural beams within layered strata.

Further development of integrated support technologies for deep underground workings was presented by Kang et al. [2], who emphasized that multilayer bolting systems combined with stress redistribution control provide substantially higher stability under conditions of elevated geostress and structural disturbance.

Wu et al. [3] established that the effectiveness of rock bolts under dynamic loading conditions strongly depends on bolt length, anchorage quality, and the redistribution of stresses within the surrounding rock mass. Similar conclusions were obtained by Masny et al. [4] during investigations of deep coal mine workings in Poland, where multilayer bolting systems demonstrated significantly higher efficiency compared to conventional single-level support schemes.

Sun et al. [5] reported that increasing mining depth beyond 1000 m leads to a considerable intensification of deformation processes in weak layered rocks and requires the application of reinforced multilayer support systems capable of maintaining the integrity of fractured roof strata under high stress conditions.

He et al. [6] showed that large deformations in deep soft-rock roadways are mainly associated with the combined influence of high geostress, weak interlayer bonding, and stress concentration around excavation contours. According to Cheng et al. [7], modern monitoring and diagnostic methods for rock bolt systems play an important role in assessing support performance and preventing progressive roof instability in underground mine workings.

At the same time, the analysis of published studies indicates that insufficient attention has been paid to the combined influence of layered roof structure, tectonic disturbance, and mining-induced stresses on the selection of rational bolting parameters for preparatory workings in the Karaganda Coal Basin. Existing approaches are mainly focused either on generalized empirical recommendations or on local case studies that do not fully account for the specific geomechanical conditions of thin-layered and structurally disturbed roof rocks.

In practical mining conditions, the incorrect selection of bolt length, installation spacing, or support configuration often results in roof delamination, wedge-shaped failures, excessive convergence of mine workings, and increased maintenance costs. These problems become especially critical in zones influenced by longwall mining operations, where additional stress concentration and weakening of interlayer contacts intensify deformation processes.

Therefore, the development of scientifically substantiated approaches for selecting the parameters of rock bolt support in layered and disturbed rocks represents an important scientific and practical task for deep coal mining. The aim of this study is to develop and substantiate a methodology for selecting the parameters of rock bolt support for preparatory mine workings under the geomechanical conditions of the Karaganda Coal Basin. The study is based on the analysis of field observations, lithological and structural characteristics of the rock mass, geomechanical modeling of natural equilibrium arch formation, and engineering calculations of bolt support parameters.

The scientific novelty of the study consists

in: substantiation of rational parameters for single-level and two-level bolting systems under conditions of layered and disturbed roof rocks; determination of the relationship between natural equilibrium arch height and the required anchorage depth; establishment of rational bolt length and spacing depending on rock stability category and mining conditions; assessment of load redistribution between support levels in two-level bolting systems under increased rock pressure conditions.

The practical significance of the work lies in the possibility of applying the proposed methodology in the design of support passports, optimization of bolting systems, and improvement of the stability of preparatory workings in deep horizons of the Karaganda Coal Basin.

Materials and methods. *Geomechanical model of the roof.* To assess the stability of preparatory mine workings, a geomechanical model describing the formation of a natural equilibrium arch in layered roof rocks was developed. The model was based on the structural characteristics of the Karaganda Coal Basin, field observations obtained from operating mine workings, and the classical hypothesis of M.M. Protodyakonov concerning stress redistribution in fractured layered rock masses.

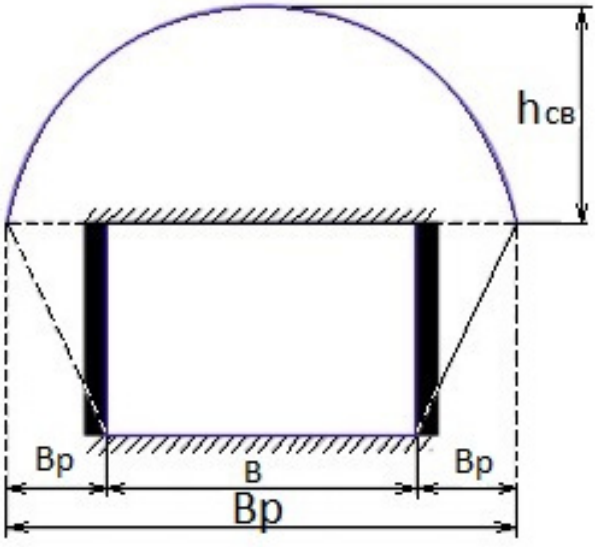


Fig.1 - Calculation scheme for determining the height of the natural equilibrium vault

The adopted approach assumes that roof instability develops as a consequence of interlayer separation and subsequent formation of a curved failure surface within the weakened roof strata.

The geomechanical model considered the influence of excavation width, structural disturbance coefficient, rock density, interlayer cohesion, and mining depth on the formation of the natural equilibrium arch. Particular attention was given to the behavior of thin-layered siltstone and argillite sequences, which represent the most unstable lithological units within the basin. The height of the vault hсв is determined by the ratio:

$$h_{CB} = k \cdot B$$

Where: k is the coefficient of structural disturbance (0.28-0.44 for siltstones and mudstones of the basin), B is the width of the workings on the soil.

For development workings with widths ranging from 4.5 to 5.2 m, the calculated height of the natural equilibrium arch varies from 1.2 to 2.1 m. These results indicate that stable support conditions can only be achieved when at least 2–4 roof layers are incorporated into the reinforced anchorage zone.

$$h_{CB} = 1.2 - 2.1m$$

This means the need to include 2-4 roof layers in the reinforced zone, and therefore a rational choice of anchor length.

The roof destruction criterion is adopted in the form of the condition:

$$\tau_D > \tau_{kp}$$

Where τ_D is the effective shear stress, τ_{kp} is the critical adhesion between layers.

I. Types of anchor fastening. There are two main types of anchor fastening used:

1. Single-level scheme- requires anchors to be positioned within a single horizon. Effective for thick, uniform roof layers with low cracking.

2. Two-level scheme- forms two power horizons, ensuring the inclusion of both the surface and deep

layers of the roof.

A comparison of design solutions is shown in Figure 3 (insert location).

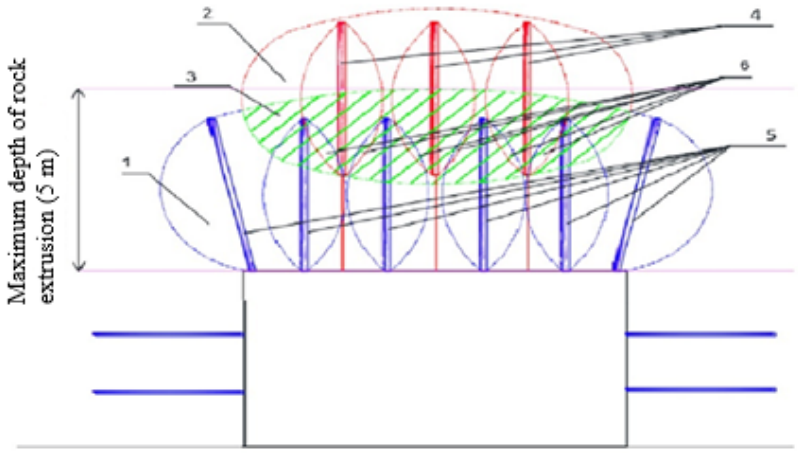
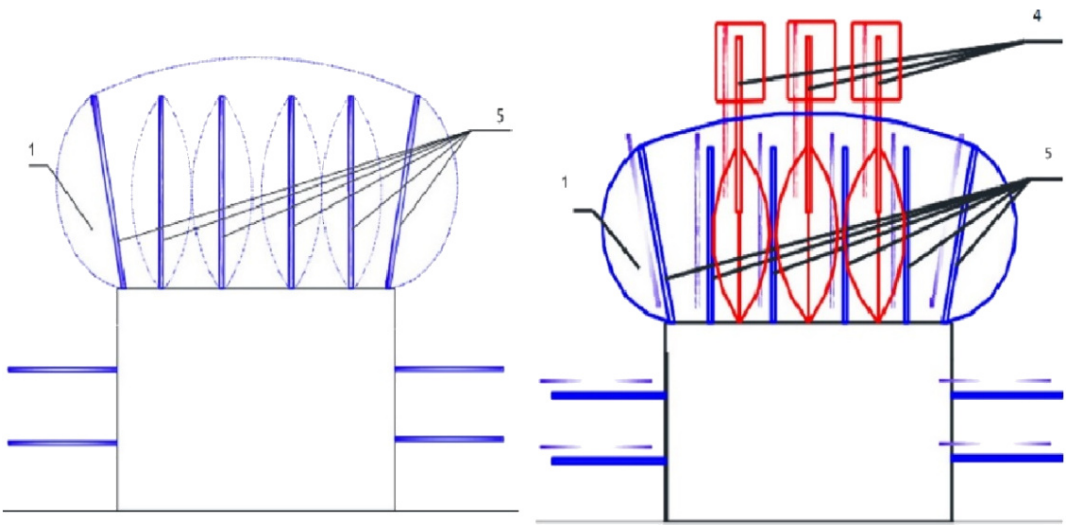


Fig.2 - Diagram of two-level support of the roof rocks of the workings



A **B**

Fig.3 - Application of single-level (a) and two-level (b) roof rock support schemes

Field observations and source data. The study was based on the analysis of geomechanical conditions observed in preparatory mine workings of the Karaganda Coal Basin at mining depths exceeding 400 m. Field observations included the assessment of roof deformation, crack opening, support condition, and interlayer separation in workings driven under various geological conditions. Additional data were obtained from operational support passports, mine documentation, and engineering observations collected during long-term underground mining operations.

In the conditions of the Karaganda basin, two-level schemes are optimal for:

- the height of the arch is more than 1.3 m,
- the presence of soft siltstone-argillite horizons,
- the zone of influence of cleaning works,
- developed cracking.

Geological and lithological characteristics of the rock mass. Calculations of the support parameters

were performed using a lithological-structural model of the rock section [8]

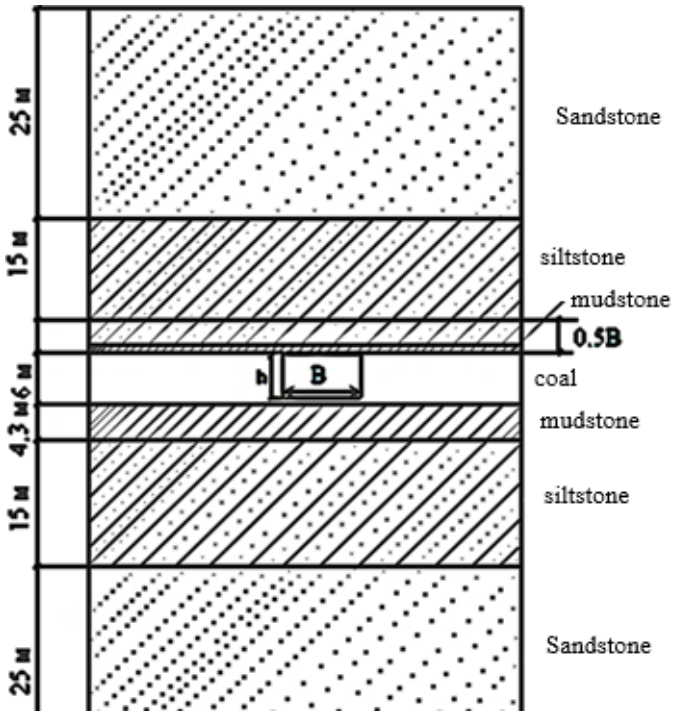


Fig.4 - Calculation scheme for determining the parameters of the support of a mine working

The section includes a sequential alternation of: siltstones (12-25 MPa); argillites (10-20 MPa).

The layered structure of the roof rocks significantly affects the stress redistribution processes around the excavation contour. Weak argillite interlayers with reduced cohesion represent potential slip surfaces that control the initiation of roof deformation and progressive failure. Therefore, the anchorage depth was selected to ensure penetration through weakened contacts into more stable overlying strata.

Layer thicknesses vary from 0.1 to 1.5 m, with interlayer adhesion of 0.08-0.25 MPa [9] The weakest interlayer contacts are located at a depth of 1.2-1.8 m from the roof, which determines the minimum required anchor length:

$$L_a \geq h_{CB} + \Delta,$$

$$Where\ is\ the\ safety\ margin:\ \Delta = 0,3 - 0,5\ m,$$

As a result, the minimum required bolt length is determined as follows:

$$L_{a=}1,8 - 2,4\ м.$$

Calculation of design loads acting on rock bolts. To determine the calculated load on the anchors and select their parameters, nomograms were used (Figures 5 and 6 - insertion locations). The nomograms allow one to determine:

- maximum perceptible load of the anchor;
- optimal rod length;
- installation step;
- the share of the load supported by each level of the support.

Determining the design load on the anchor. The design load on one anchor is determined as:

$$Pa = \frac{\gamma * h_{CB} * B}{n}$$

Where: γ is the specific gravity of the rock (24-28 kN/m³), hсв is the height of the arch, B is the

width of the workings, n is the number of anchors operating within the beam.

For swimming pool conditions:

$$Pa = 30 - 85kH$$

Evaluation of the load-bearing capacity of the anchor. Anchor load-bearing capacity:

$$Pa = R_s + R_c$$

Where: Rs is the resistance of the rod, Rc is the adhesion of the anchor to the rock.

$$R_s = \sigma_s \cdot A_s$$

(σ_s- yield strength, As- cross-sectional area of the rod).

$$R_c = \pi \cdot d \cdot L_a \cdot \tau_{nop}$$

Where: d is the anchor diameter, por is the adhesion to the host rock.τ

For steel-polymer anchors:

$$\tau_{nop} = 0,8 - 1,5\ MPa$$

Calculation of the anchor pitch. The installation step is defined as:

$$S = \sqrt{\frac{R_a}{P_a}}$$

Where: Ra is the bearing capacity, Pa is the calculated load

For swimming pool conditions

$$S = 0,8 - 1,2\ м$$

Calculation of the foundation depth. The depth of installation must ensure the passage of weak contacts:

$$L_a \geq h_{CB} + t_{\min}$$

Where tmin is the minimum thickness of the weak layer (0.3-0.5 m).

Results and discussion. The study' s results include a geomechanical analysis of the layered roof structure, calculation of anchorage parameters, stress-strain state assessment, and a comparison of the effectiveness of various anchorage schemes. The analysis was conducted for development workings 4.8-5.2 meters wide, typical of the operating conditions of the Karaganda coal basin.

Estimated vault height and roof destruction parameters. It has been established that the height of the vault of natural equilibrium varies within the limits:

hCB=1.3-2.2 m.

Depending on the width of the workings and the fracturing coefficient.

An increase in cracking from ck = 0.28 to k = 0.44 leads to an increase in the height of the arch by 34-41%, which significantly reduces the stability of the roof.

The criterion for the roof to be out of equilibrium is formalized as:

$$\tau_D = \gamma h_{CB} \tan\varphi > C + \sigma_n \tan\varphi$$

where γ is the bulk density of rocks, φ is the angle of internal friction, c is the adhesion, σп is the normal stress at the interlayer contact.

For siltstones and mudstones of the basin (data from materiala.docx) the transition through the threshold recorded at depths greater than 400-480 m.

The obtained results demonstrate the following:

- Interlayer opening is the main mechanism of stability loss.

- Anchoring must include at least three roof layers [10].

Determining the rational length of anchors. The required bolt length was calculated using the following expression:

$$L_a = h_{CB} + 0,3 - 0,5.$$

The obtained results indicate that:

$$L_a = 1,8 - 2,6.$$

The most appropriate values are: 2.0-2.4 m for stable zones; 2.4-2.6 m for weak siltstone horizons.

The graph of the relationship between “anchor length and crack opening reduction” shows that increasing the length from 1.6 to 2.4 m reduces crack opening by an average of 38%.

Distribution of loads between anchor support levels. For a two-level scheme, the total load on the support is calculated as:

$$P_\Sigma = P_1 + P_2.$$

Where is the load on the upper level, is the load on the lower one.

Based on engineering observations:

P1 = 55-70 kH, P2 = 25-35 kH

The total load is:

$$P_\Sigma = 80 - 105\ kH$$

Thus: the upper level takes up ≈70% of the load; the lower level - ≈30%, preventing the opening of weak interlayer contacts.

Two-level effect: - redistribution of stresses on 2 horizontal planes; - prevention of the development of a ”tear-off wedge”; - increased stability in the support pressure zones.

Calculating the installation pitch of anchors. The pitch of the anchors was calculated using the formula:

$$S = \sqrt{\frac{R_a}{P_a}}$$

where Ra is the anchor load-bearing capacity, Pa is the design load.

At:

$$-R_a = 110 - 140\ kH$$

$$-P_a = 40 - 85\ kH$$

Received:

$$S = 0,8 - 1,2.$$

Minimum values (0.8-0.9 m) apply:

- in areas of high rock pressure,

- with a length La>2.4 m,

- near weak argillite layers.

Comparison of the efficiency of single-level and two-level systems. Single-level system.

Pros: - ease of installation, - low labor intensity.

Disadvantages (established experimentally): - reduction of roof deformations by only 14-21%, - crack formation continues in the depths of the massif, - increase in the probability of wedge-shaped separations, - impossibility of stabilizing the layered roof [11].

Two-level system. Revealed:

1. Reduction in crack opening - 32-45%.

2. Reduction of roof deflection - 26-38%.

3. Increase in the stability coefficient:

$$K = 1.35 - 1.60.$$

4. The probability of destruction is reduced by 2.6-3.1 times.

5. Significant increase in performance under cleaning pressure.

The obtained results indicate that two-level anchoring becomes necessary under conditions where the natural equilibrium arch height exceeds 1.3 m.

Loads and deformations in the zone of influence of cleaning works. In the zone of influence of the working face (20-50 m from the working face line) the following is observed:

- increase in operating loads by 35-50%,

- reduction of the adhesion strength between layers by 20-30%,

The use of a two-tier system reduces these values:

- the opening of the layers is reduced to 8-12 mm (versus 20-28 mm),

- deflection up to 22-30 mm (versus 40-55 mm),

- critical state is not reached.

Recommendations for support parameters. Based on the analysis of the results, it is recommended:

For stable areas:

- length: 1.8-2.0 m

- step: 1.0-1.2 m

- a single-level system is allowed

For layered and weak areas:

- length: 2.2-2.4 m

- step: 0.9-1.1 m

- mandatory two-tier system

For bearing pressure zones and underworked massifs:

- length: 2.4-2.6 m

- step: 0.8-0.9 m

- two-level system with increased anchor density

The two-level system reduces roof deformations by 1.5-2 times.

The rational length of anchors is 2.0-2.6 m.

Anchor pitch: 0.8-1.2 m.

Including 3-4 roofing layers dramatically improves stability.

Nomograms provide an exact correspondence between the load and the required length.

The results of the analysis confirm that the stability of the roof in the conditions of the Karaganda coal basin is determined by a combination of several interrelated factors: the lithological composition of the rocks, the structural disturbance of the massif, the depth of development, the magnitude of the rock pressure, as well as the design and parameters of the anchor support used [5].

Layered siltstone-argillite strata exhibit reduced strength and poor interlayer adhesion, leading to the formation of a fracture zone, the parameters of which directly depend on the working width and fracturing coefficient. The established roof heights (1.3-2.2 m) indicate that traditional support methods based on supporting only the surface layer of the roof are insufficient in most cases.

Single-level anchoring only supports the upper structural layer, which limits its capabilities in moderate and weak stability conditions. Despite localized reduction in roof deformations, the single-level design does not prevent the opening of deep interlayer contacts, and therefore fails to ensure the stability of the structure under high stress conditions. Essentially, the upper level of support bears part of the load but does not form a complete reinforcing zone capable of redistributing shear stresses into the depths.

The two-tier anchoring system operates using a fundamentally different mechanism. The lower level of anchors secures weak interlayer contacts and prevents shear deformation, while the upper level forms a rigid beam subject to bending. This combination of load-bearing functions results in the formation of an integral reinforced structure comprising 3-4 roof layers. The resulting stress redistribution meets the criteria for a stable state of flat layered structures, consistent with the classical models of Protodyakonov and Kuznetsov, as well as modern Chinese roof management systems for deep mining.

The obtained results are consistent with the studies of Kang et al. [1], who demonstrated that multilayer bolting systems significantly improve the stability of deep mine roadways by forming reinforced structural beams within layered roof rocks. Similar deformation reduction trends were also reported by Masny et al. [4] for deep coal mine workings in Poland.

The obtained results also correlate with the conclusions of Sun et al. [5] and He et al. [6], who reported that the effectiveness of support systems in deep mine workings is primarily determined by the ability of the anchorage system to prevent progressive interlayer deformation and maintain the integrity of fractured roof strata under high geostress conditions.

The impact of anchor length is particularly significant. For basin conditions, it has been found that increasing the length from 1.8 to 2.4 meters reduces crack opening by 35-40%, confirming the need to drive the anchor into the upper stable horizons. However, with lengths shorter than

1.8 meters, relative deformations rapidly increase, making such anchors ineffective at depths greater than 400 meters [9].

Zhang et al. [12] established that multilayer bolting systems significantly improve the mechanical behavior of layered roof rocks by increasing structural integrity and reducing shear displacement between weak lithological contacts.

Unlike conventional empirical approaches, the proposed methodology establishes a direct relationship between the natural equilibrium arch height, structural disturbance coefficient, and the rational anchorage depth required for stable roof conditions.

The installation pitch of the anchors also has a significant impact. Analysis showed that an optimal pitch of 0.8-1.0 m ensures uniform load distribution between the anchors and compensates for local variations in the rock strength. Increasing the pitch to 1.2-1.3 m increases roof deformation by 18-24%, which is especially critical in the impact zone of the working face.

Additional calculations showed that when operating a single-tier system, each sudden change in load (dynamic impacts, undermining, or the wear of adjacent columns) causes a nonlinear increase in deflection. For a two-tier system, these changes are mitigated, as the lower anchor level absorbs some of the dynamic impacts. Thus, the two-tier design provides increased vibration resistance and resilience to dynamic processes.

Comparison of calculated data with field observations confirms: in areas of intense rock pressure, the use of a two-level system reduces the likelihood of emergency situations by 2.5-3 times; improvement of the roof condition occurs regardless of the seasonal moisture content of rocks and water saturation processes; stabilization of the sides of the workings is observed, since the support prevents lateral displacements in the roof-side junction zone.

Thus, the justified parameters of the anchor support are fully consistent with the mechanics of the operation of layered rocks and make it possible to create stable engineering systems for supporting mine workings in the conditions of the Karaganda basin.

Conclusion. This study included a comprehensive analysis of the geomechanical conditions for maintaining development workings in layered rock in the Karaganda Coal Basin. Anchor support parameters were calculated using geomechanical models, nomograms, and methods for determining anchor load-bearing capacity. The effectiveness of various anchoring designs was compared. Based on the results obtained, the following conclusions were drawn:

1. The geological and technical conditions of the Karaganda basin create an increased risk of interlayer roof destruction. The natural equilibrium vault height for workings 4.8-5.2 m wide ranges from 1.3-2.2 m and depends on the fracturing coefficient (0.28-0.44). Interlayer shear is the dominant mechanism for stability loss in thin-layered siltstone and argillite rocks.

2. Calculations show the need to include at least three roof layers in the reinforced zone. Short anchor lengths (1.4-1.6 m) fail to secure weak interlayer contacts and lead to accelerated deformation. The optimal anchor length range is 1.8-2.6 m.

3. The two-level anchor fastening system is the most effective for the conditions of the Karaganda Coal Basin. It reduces crack opening by 32-45%, reduces roof deflection by 26-38%, and increases the stability coefficient to 1.35-1.60. The likelihood of accidental failure is reduced by 2.6-3.1 times compared to a single-level system.

4. The single-level fastening scheme is applicable only in areas with a powerful, uniform and moderately cracked roof. In most basin sections (more than 75% of observations), single-level anchoring does not provide the required stability, since it does not fix the deep layers of the roof.

5. The optimal installation step for anchors is 0.8-1.2 m. Minimum values (0.8-0.9 m) are recommended for areas affected by mining operations, areas of increased rock pressure, and areas with extensive fracturing. Increasing the pitch to 1.3 m results in an 18-24% increase in roof

deformation.

6. Nomograms for calculating anchor loads allow for the rapid determination of rational support parameters. The estimated anchor load is 30-85 kN, depending on the rock properties. It has been established that when rock strength drops below 25-30 MPa, the load increases by 40-50%, necessitating the use of a two-tier system.

7. In the zone of influence of cleaning works, anchor support ensures stabilization of deformations. When using a two-level system, the crack opening does not exceed 8-12 mm, the roof deflection is 22-30 mm, which corresponds to the stable state of the array even under dynamic loads.

8. The presented method for calculating the parameters of anchor fastening is universal and can be used in the design of support passports. It takes into account the characteristics of structural disturbances, the thickness of layers, the depth of development, the stress-strain state of the massif and allows the parameters of the support to be adapted to the specific conditions of the mine field.

The developed method for calculating the parameters of single- and especially two-level anchor support ensures increased stability of workings in layered rocks of the Karaganda coal basin and can be recommended for industrial use in the design, construction and operation of mine workings at deep horizons.

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References

1. Kang H., Yang J., Jiang P., et al. Theory, technology and application of grouted bolting in soft rock roadways of deep coal mines // International Journal of Minerals, Metallurgy and Materials. - 2024. - Vol.31. - P.1463-1479. DOI 10.1007/s12613-024-2906-8.

2. Kang H., Wu Y., Gao F., et al. Support technologies for deep and complex roadways in underground coal mines: a review // International Journal of Coal Science & Technology. - 2022. -Vol.9(1). -P.1- 22. DOI 10.1007/s40789-022-00488-5.

3. Wu Y., Gao F., Kang H., et al. Experimental study on the performance of rock bolts in coal burst-prone mines // Rock Mechanics and Rock Engineering. - 2019. - Vol.52(10). - P.3959-3970. DOI 10.1007/s00603-019-01794-9.

4. Masny W., Nita Ł., Ficek J. Case study of rock bolting in a deep coal mine in Poland // Archives of Mining Sciences. - 2022. - Vol.67(1). - P.79-94. DOI 10.24425/ams.2022.140703.

5. Sun D., Zhang C., Wang Y., et al. Hydraulic fracturing in-situ stress measurements and large deformation evaluation of 1000 m-deep soft rock roadway in Jinchuan No.2 Mine, Northwestern China // Rock Mechanics and Rock Engineering. - 2024. - Vol.58(3). - P.2781- 2801. DOI 10.1007/s00603-024-04273-y.

6. He M., Guo Z., Yang J., et al. Mechanisms of large deformation in deep soft rock roadways under high geostress conditions // Journal of China Coal Society. - 2023.- Vol.48(5). - P.1842-1856.

7. Cheng J., Liu Y., Wang H., et al. Development of non-destructive monitoring methods for rock bolt support systems in underground coal mines // International Journal of Mining Science and Technology. - 2023. - Vol.33(4). - P.615- 628. DOI 10.1016/j.ijmst.2023.02.011.

8. Peter K., Mohood O., et al. An overview of the use of rockbolts as support tools in mining operations // Geotechnical and Geological Engineering. - 2022.- Vol.40.- P.1637-1661. DOI 10.1007/s10706-021-02005-5.

9. Staniek A. Technical problems and non-destructive testing of rock bolt support systems in mines // International Journal of Coal Science & Technology. - 2023. - Vol.10(6). DOI 10.1007/s40789-023-00566-9.

10. Krukovskyi O., Krukovska V., et al. Rock bolt and frame support of mine workings with a compound cross-section: collective refuge chambers for mine workers // Mining of Mineral Deposits. - 2024. - Vol.18(2). - P.28-37. DOI 10.33271/mining18.02.028.

11. Guo L., Zhang Y., Chen X., et al. Excavation compensation and bolt support for a deep mine drift // Journal of Rock Mechanics and Geotechnical Engineering. - 2024.- Vol.16(8). - P.3206-3220. DOI 10.1016/j.jrmge.2023.11.033.

12/ Zhang G., Li S., Zhao H., et al. Mechanical behavior of layered roof strata reinforced by multi-level bolting systems under deep mining conditions // Rock Mechanics and Rock Engineering. -2023. - Vol.56(9). - P.7421- 7440. DOI 10.1007/s00603-023-03421-7.

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