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Assessment of the Effective Application Area of Anchoring Technology in Mine Workings

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Abstract. *Assesses the effectiveness of anchoring technology in mine workings, with a specific focus on the Karaganda coal basin. Explores various factors that impact the effectiveness of anchoring in preparatory workings and assesses the specific geological and mining features of the Karaganda coal basin that may impact anchoring technology. Describes a study conducted to determine the area of effective application of anchoring technology. The results of the study were used to develop an expert computer information system that outputs information about features that have a predominant negative impact on mining operations and need to be influenced to increase efficiency. The findings of this study may be helpful in expanding the scope of effective application of anchor fastening technology in mining workings.*

Keywords: *anchoring, underground mining, factors, mining-geological and mining-technical conditions of development, efficiency, research, technological schemes, conduct of mine workings, level of technical characteristics, types of anchoring.*

Introduction. The main geological factors influencing the stability of workings with anchored supports include: geological structure, lithological types of rocks, their conditions of occurrence and influence of moisture on them, fracture and discontinuous disturbance of the rock mass, physical and mechanical and strength properties, thickness of the mined layer and its strength characteristics and other parameters of the surrounding rocks that define the complexity of engineering and geological conditions of mine workings and their maintenance in the zones of high rock pressure during mining excavation. The main mining and technical factors that influence the performance of anchor supports are: the size, shape, type of support and location of capital, preparatory and stope workings, their depth and penetration method, development systems, technological schemes of stope work, parameters of undermining or overworking, distribution of support and increased rock pressure zones, maintenance duration, compliance with technological certificates of support and maintenance, and so on.

Factors affecting the effectiveness of anchoring in preparatory workings. Factors affecting the effectiveness of anchoring in preparatory workings are: the strength of anchoring in the host rock, the size of the area of dangerous deformations around the workings, the amount of displacement of the roof and sides during the life of the mine, and the maximum amount of safe displacement (lowering) of the anchored roof rocks in the workings during its life.

The process of maintaining excavations is influenced by geomechanical, technological factors, as well as intermediate factors resulting from the influence of mining operations on the geomechanical state of the rock massif. The geomechanical factors include natural parameters of the massif: strength, volume weight, fracturing, depth of occurrence, dip angle, etc.; the technological factors include the shape and cross-section of the excavation, compliance and load-bearing capacity of the support. In the group of factors of intermediate nature, the most important should be considered the support pressure around the face and artificially caused by excavation fracturing of the surrounding rocks and coal seams.

The strength of rocks in the Karaganda Basin with increasing depth of their occurrence naturally increases. Volumetric weight of rocks (γ) in the Karaganda basin to a depth of 1000-1200 m varies from 2.3 to 2.7 g/cm^3 and on average to calculate the weight of the covering layer can be taken as 2.5 g/cm^3. With increasing depth, the vertical component of rock pressure γH increases, but at the same time the strength of the rocks containing the mining also changes. At the same depth, the strength, even for the same type of rock, can vary considerably.

It would be reasonable to use a complex dimensionless criterion that takes into account depth, rock strength and density [1, 2]

$$k = \frac{\gamma H}{\sigma_{cr}}, \qquad (1)$$

where γ – coal density, kN/m^3; H – depth of mining, m; σ_{cr} – rock strength, kN/m^2.

The natural fracturing of rocks of different types at different depths does not remain a constant value. Weak breeds tend to be weakened to a greater degree.

Endogenous and exogenous cleavage fractures are widely developed in the rocks of the Karaganda Basin. The density of endoclivation cracks is determined by the composition of rocks and the thickness of their interlayers. The degree of intensity of fracturing decreases from mudstones to siltstones and sandstones and as the thickness of the layers increases, regardless of the lithological differences in the rocks. The distance between exogenous fractures varies from a few centimeters to 10 meters and depends on the tectonic structure of the site, the lithological composition of rocks and their degree of metamorphism. In soft rocks, they are more common than in strong rocks. The value of K_{str} take for rocks: slightly fractured – 0,9-1,0; medium fractured – 0,7-0,89; strongly fractured – 0,5-0,69 [1, 2].

The factor of fracturing of the massif can be accounted for by the coefficient of structural weakening K_{str} [3, 4]:

$$k = \frac{\gamma H}{K_{str}\sigma_{cr}}. \qquad (2)$$

The nature of the support pressure around the working face depends significantly on the depth of the formation, its thickness, the length of the working face. The increase in rock pressure in the support zone of the mine drift is accounted for by the concentration coefficient, the value of which at depths up to 700 m reaches K_{con} = 2.0. Along the axis of the working face, the concentration coefficient of rock pressure at this depth reaches 3.5-4.0. Taking into account the reference pressure, the index of the difficulty of maintaining conditions is

$$k = \frac{K_{con}\gamma H}{K_{str}\sigma_{cr}}. \qquad (3)$$

At $K < 0.3$, the maintenance conditions are considered to be easy, at $K = 0.3\text{-}0.5$ – medium difficulty, at $K = 0.5\text{-}1.0$ – difficult, at $K > 1.0$ – very difficult (Table 1) [5, 6].

According to the cumulative effect of negative factors, the following layers can be referred to complex conditions of mine workings in the basin: $k_{18}, k_{14}, k_{13}, k_4, k_3, k_2$ in the Industrial area; k_{10}, k_7, d_7 – in Saransk and Shakhansk areas; k_{13}, d_2, d_1 – in Sherubay-Nurinsk area.

Assessment of factors caused by mining and geological and technological features of coal seam development. Table 2 shows the factors caused by mining and geological features of development, the use of anchoring technology in preparatory workings

Table 1 – Indicators characterizing the tectonic disturbance of coal-bearing areas and sections of the Karaganda Basin

Coal-bearing basin area	Neighborhood area	Angle of dip of strata a1, degree		Average length of discontinuities, a_2, km	Relative number of discontinuities, a_3, 1/km^2	Relative extent of discontinuities, a_4, km/km^2	Disjunctiveness coefficient KD, 1/km
		From-to	Average				
Karaganda	Industrial (center)	5-25	15	1,0	0,2	0,2	0,35
	Saran	10-30	20	1,6	0,8	1,8	0,58
Sherubay-Nurinsk	Southern	15-60	37	1,9	1,8	3,4	1,52
	Central	10-30	20	2,4	1,2	2,9	1,04
	Karadjaro-Shakhan and Dolinsk	0-40	20	2	0,7	1,4	1,1
Tentek	Tentek	5-30	17	1,2	0,8	1	0,5

Table 2 – Factors caused by mining and geological and technological features of coal deposits exploitation

Parameters	Germany		United Kingdom	Australia	USA	Karaganda basin
Mining and geological peculiarities of development						
Depth of development, m	1000		600	260	360	450-820
Vertical component of rock pressure p_n, MPa	25		15	6,5	9	15
Horizontal component of rock pressure p_r, MPa	p_r=1×p_n=25		p_r=1,5×p_n=22,5	p_r=2×p_n=13	p_r=2×p_n=18	p_r=1×p_n=15
Coal seam thickness, m	2,0		2,5	3,1	2,2	1,0-8,5/ average 2,28
Angle of bedding, deg.	5-10, no more than 15		no more than 5	no more than 5	no more than 5	7-25
Roofing breeds	from thin-layered mudstones to sandstones y_{cm}=35-80		from mudstones to sandstones y_{cm}=35-70	from mudstones to sandstones, partly coal y_{cm}=5-80	from mudstones to sandstones and limestones y_{cm}=10-80	from mudstones to sandstones y_{cm}=10-80
Soil rocks y_{cm} uniaxial compressive strength in MPa	thin-layered mudstones, vegetative interlayers and carbonaceous interlayers y_{cm}=45		claystones, partially intersected by partially crossed rooted y_{cm}=45	claystones, partially intersected by partially crossed rooted y_{cm}=40	claystones, partly sandstones y_{cm}=40	claystones
Load criteria						
Vertical component $p_v/\sqrt{\sigma_{cr}}$	$25/\sqrt{45}=3{,}7$		$15/\sqrt{45}=2{,}2$	$6{,}5/\sqrt{40}=1$	$9/\sqrt{40}=1{,}4$	$15/\sqrt{45}=2{,}2$
Horizontal component $p_h/\sqrt{\sigma_{cr}}$	$25/\sqrt{45}=3{,}7$		$22{,}5/\sqrt{45}=3{,}4$	$13/\sqrt{40}=2{,}1$	$18/\sqrt{40}=2{,}8$	$15/\sqrt{45}=2{,}2$
Application of anchoring technology in preparatory mine workings						
Scheme of preparation of excavation areas	EV	ZR	ER	ER	ER	ER
Leaving pillars	no		yes, tough	yes, malleable	yes, malleable	no
Aim width	0		80-130	10-20	10-30	0
Shape of the drift section	arched	rectangular	rectangular	rectangular		rectangular
Track height	4-4,8	2,5-4	2,5-5	2-4	2-3,5	3,5-3,7
Track width	6-7,5	5-5,8	4,5-6	5-6	4,7-6,1	5,5-6,5
Cutting rocks: roofing soils	 yes yes	 yes yes	 occasionally occasionally	 no no	 no no	 occasionally occasionally
Technological factors						
Anchor length, m	25,0-30,5		22	19-21	16-19	22
Anchor length by rock, m	2,1-2,4		2,1-2,4	1,5-2,4	2,1-2,4	2,3(2,9)
Design load capacity, kN (depending on material)	360-540		310	220-320	150-220	250
Anchor density, anchor/m^2: roof sides	 1-2 0,6-1,9	 1,4-2,2 0,5-1,2	 1,1-3,0 0,3-0,9	 0,5-0,7 0,11-0,23	 0,4-0,7 0.09-0,15	 1,0-1,5 0,6-0,7

(Figure 1), vertical and horizontal components of the criterion of loading of rock mass, technological conditions for the use of anchoring in countries with a developed coal industry in comparison with the conditions of occurrence of coal seams in the Karaganda basin [7-10].

The complex mining of several layers at great depths in Germany requires in most cases the maintenance of the longwall faces after the first longwall face (direct face mining – scheme «EV»). In some cases, the longwall faces have to be used for the second longwall face (forward mining of the first longwall face and backward mining of the second longwall face – scheme «ZR»). This is necessary for the following reasons: the high temperature of the host rocks and the gassiness of the seams require sublighting of the outgoing jet behind the face; the desire to avoid leaving rigid pillars, as the support pressure when mining several seams leads to significant damage to mine workings and, in addition, to uneven subsidence of the earth surface with significant damage.

In German (as well as Karaganda) mines the mine drifts have both arched and rectangular cross-sections. According to the conditions of placement of equipment in the drift its residual width near the face should not be less than 5.0-5.5 m, and when using arch support, it is necessary that the drift in the sinking had a width of up to 7.5 m.

For comparison: the mines of the Anglo-Saxon countries use tunnels 4.5-6.0 m wide of rectangular shape, secured by anchors, which are passed exclusively by the combine method through the bed with the leaving of rigid or compliant pillars. The drifts are extinguished after a longwall face is passed (working out of sections by the reverse course «ER»).

Research to determine the area of effective application of anchoring technology. In order to assess the complexity of different mining and geological conditions of mine reservoirs in the Karaganda coal basin ranking by formal criterial attributes in accordance with the technological consequences of mining operations has been made. Below is a list of formal geotechnological criterion attributes, which were evaluated and the final algorithm was formed.

K_A. Controllability of the roof: thickness of rocks of the immediate roof (M_C)/ reservoir thickness (m_n): ranges: $Y \geq 6$ – manageable; $3 \leq Y < 6$ – medium handling; $0 \leq Y < 3$ – administratively difficult to control. Expert coefficient by roofing classes: for 1 – $k_n = 1,0$; 2 – $k_n = 0,7$-$0,8$; 3 – $k_n = 0,5$.

K_B. Rock strength of the immediate roof: Q_{cp}, N/m^2: ranges: Q_{cp} up to 13,5 – composed

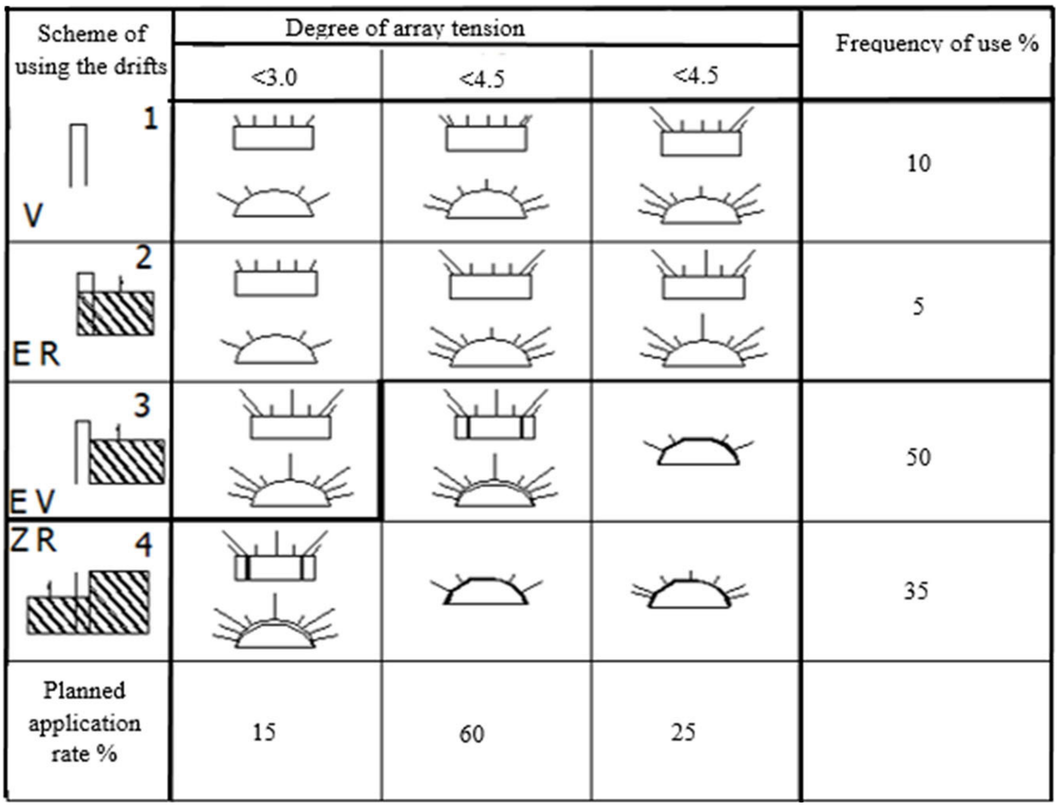


Figure 1 – Anchoring systems in mines, depending on the degree of strain of the rock mass and the scheme of using drifts

of carbonaceous claystone, $k_n = 0{,}5$; 13,5 – 400 – claystone, $k_n = 0{,}75$; 400-500, claystone with siltstone, $k_n = 0{,}85$; 500-600, siltstone, $k_n = 1{,}0$.

K_C. Compressive strength of host rocks, Q_{cp}, MPa: ranges: $Q_{cp} \leq 12$, $k_n = 0{,}5$; $Q_{cp} \leq 15$, $k_n = 0{,}6$; $Q_{cp} \leq 20$, $k_n = 0{,}7$; $Q_{cp} \leq 25$, $k_n = 0{,}85$; $Q_{cp} \leq 30$, $k_n = 0{,}9$; $Q_{cp} \geq 30$, $k_n = 1{,}0$.

K_D. Disjunctive bed disturbance (number of disturbances per kilometer of the excavation field), k_d, pcs/km^2: ranges: k_d up to 3 – $k_n = 1{,}0$; 3-5 – $k_n = 0{,}9$; 6-10 – $k_n = 0{,}75$; 11-15 – $k_n = 0{,}6$; 16-20 – $k_n = 0{,}55$; 21-25 – $k_n = 0{,}5$; 26-30 – $k_n = 0{,}45$; 31-40 – $k_n = 0{,}4$; 41-50 – $k_n = 0{,}35$; 51-60 – $k_n = 0{,}3$.

K_E. Power of the immediate roof rocks at tensile strength q_p, N/m^2 in table 3.

K_F. Length of violations per kilometer of excavation field, k_l: ranges: k_l up to 0,5 – $k_n = 1{,}0$; 2, $k_n = 0{,}9$; 4 – $k_n = 0{,}8$; 6, $k_n = 0{,}7$; 8, $k_n = 0{,}6$; 10; $k_n = 0{,}5$; 12, $k_n = 0{,}4$; 14, $k_n = 0{,}3$.

K_G. Cracking of rocks of the immediate roof at the angle of their spreading a_s: ranges: a_s up to 40°, $k_n = 1{,}0$; 50° – 0,85; 60° – 0,75; 70° – 0,5; 80° – 0,4; 90° – 0,3.

K_H. Distance between cracks b: ranges: $b > 5$ m – $k_n = 1{,}0$; 4 – 0,85; 2 – 0,7; 1,0 – 0,5; 0,5 – 0,3; < 0,2 – 0,2.

K_I. The presence of a false roof P_{fr}: ranges: P_{fr} up to 100% – $k_n = 0{,}5$; 90% – 0,7; 80% – 0,8; 70% – 0,9; 5. 50% – 1,0.

K_J. False roof capacity C_{fr}: ranges $C_{fr} = 0{,}1$-0,2, $k_n = 0{,}8$; 0,2-0,4, 0,7; 0,4-0,6, 0,5; 0,6-0,8, 0,4.

K_K. Water encroachment of mine workings M_w: ranges: M_w up to ≤ 5 m^3/hour, $k_n = 1{,}0$; 15 – 0,85; 25 – 0,75; 35 – 0,6; 50 – 0,5; 70 – 0,3; 100 – 0,1.

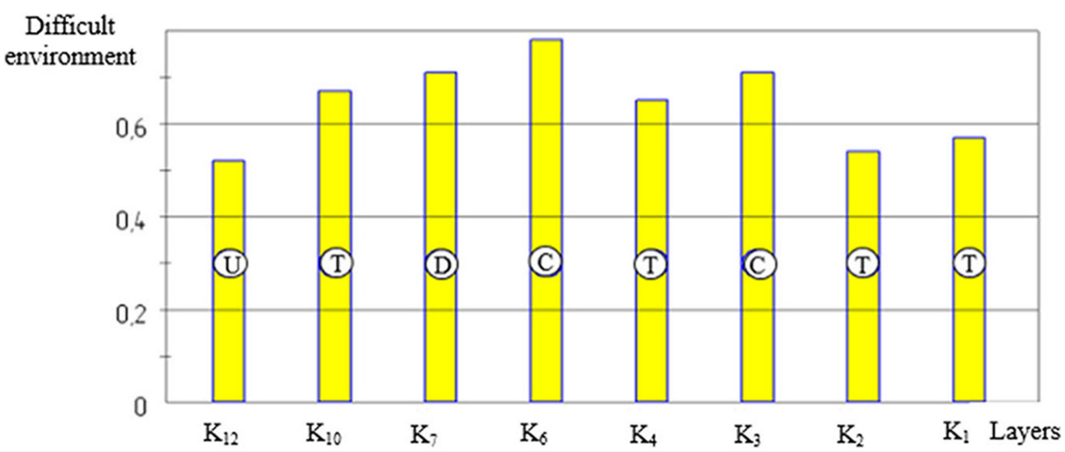
The total score K_t is determined by the sum of formal criterion attributes

$$K_t = K_A + K_B + K_C + K_D + K_E + \\ + K_F + K_G + K_H + K_I + K_K + K_L. \quad (4)$$

Conditions that are more complex have a sum of formal criteria signs, which is equal to eleven, the possibility and feasibility of using the fastener in other conditions is evaluated in relation to the maximum value (Figure 2). For example, an assessment of the complexity of

Table 3 – Power of the immediate roof rocks at tensile strength

Direct roofing	q_p^{dr}/q_p^{mr}	Main roof
k_n = 0,7 – carbonaceous claystone	M_C < 2 m	11/65, siltstone
k_n = 0,75 – laystone	M_C ≤ 2	45/65, siltstone
k_n = 0,8 – claystone	M_C > 2	45/65, siltstone
k_n = 0,9 – siltstone-argillite	M_C > 2	50/65, siltstone
k_n = 0,95 – siltstone	M_C > 2	55/60, siltstone
k_n = 1,0 – siltstone	M_C > 2	55/60, sandstone



U – controllability of the roof; T – thickness of the immediate roof rocks; C – distance between cracks; D – disjunctive disturbance of the reservoir.

Figure 2 – Complexity of development conditions by strata and mines

mining conditions for the mining and geological and mining conditions of exploitation of the Kostenko mine in the Karaganda coal basin.

Conclusions. To assess the complexity of various mining and geological conditions of the mine layers of the Karaganda coal basin, a ranking was made according to formal criteria in accordance with the technological consequences of mining operations. The developed version of the expert computer information system of the program, according to a given algorithm, also outputs information about the feature (R) that has a predominant negative impact and which needs to be influenced to increase the efficiency of mining operations to expand the scope of effective application of anchor fastening technology in mining workings.

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Тау-кен қазбаларында анкерлік бекіту технологиясын тиімді қолдану саласын бағалау

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Аңдатпа. *Мақалада Қарағанды көмір бассейніне ерекше назар аудара отырып, кен орындарындағы анкерлік технологияның тиімділігі бағаланады. Зерттеу дайындық жұмыстары кезінде толтыру тиімділігіне әсер ететін әртүрлі факторларды зерттейді және тіреу технологиясына әсер етуі мүмкін Қарағанды көмір бассейнінің нақты тау-кен-геологиялық және тау-кен ерекшеліктерін бағалайды. Анкерлік технологияны тиімді қолдану саласын анықтау үшін жүргізілген зерттеу де сипатталған. Зерттеу нәтижелері бойынша тау-кен жұмыстарына теріс әсер ететін және тиімділікті арттыру үшін әсер етуді қажет ететін ерекшеліктер туралы ақпарат беретін сараптамалық компьютерлік ақпараттық жүйе әзірленді. Зерттеу нәтижелері кен қазбаларында анкермен бекіту технологиясын тиімді қолдану аймағын кеңейту үшін пайдалы болуы мүмкін.*

Кілт сөздер: *анкерлік бекіткіші, жерасты игеруі, факторлар, тау-кен геологиялық және тау-кен техникалық игеру шарттары, тиімділік, зерттеулер, технологиялық схемалары, тау-кен қазбаларын жүргізу, техникалық сипаттамалар деңгейі, анкерлік бекіткішінің түрлері.*

Оценка области эффективного применения технологии анкерного крепления в горных выработках

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Аннотация. *Оценивается эффективность технологии анкерного крепления в горных выработках с особым вниманием к Карагандинскому угольному бассейну. Исследуются различные факторы, влияющие на эффективность крепления при подготовительных работах, и оцениваются специфические горногеологические и горнотехнические особенности Карагандинского угольного бассейна, которые могут повлиять на технологию крепления. Описано исследование, проведенное для определения области эффективного применения технологии анкерного крепления. По результатам исследования разработана экспертная компьютерная информационная система, выдающая информацию об особенностях, оказывающих преимущественное негативное влияние на горные работы и требующих воздействия для повышения эффективности. Результаты исследования могут быть полезны для расширения области эффективного применения технологии анкерного крепления в горных выработках.*

Ключевые слова: *анкерная крепь, подземная разработка, факторы, горно-геологические и горно-технические условия разработки, эффективность, исследования, технологические схемы, проведение горных выработок, уровень технических характеристик, виды анкерной крепи.*

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