Evaluating the Efficiency of the Mine Workings Supporting Technology Application to Increase Contour Stability

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Abstract. Maintaining the mine workings will also require significant costs to repair them both before and after they are introduced into production, especially in the zone of influence of the mining operations. Maintaining and increasing the volume of underground coal mining is only possible with a highly efficient technology for conducting and maintaining preparatory workings. The purpose of the study was to assess the parameters for controlling the stability of the contours of mine workings secured by anchor support to create a technology for intensive and safe conduct of mine workings based on the identified patterns of behavior of the adjacent rock masses. The idea of the approach is to use the anthropogenic stress-strain state to develop an effective technology for securing the contour rock massif. The mechanism of rock deformation, shear and collapse in a structurally disturbed heterogeneous rock massif is studied to assess the state of the rock massif around mine workings. Technological prerequisites for anchoring the marginal soil rocks, taking into account the state of the rock mass around the excavation, are developed and the parameters of anchor support operation in mines to secure the rods in excavations to ensure the safety of mining operations are determined.

Keywords: mining, study of deformation processes, strengthening parameters, geomechanical processes, rock pressure manifestation, technological schemes, stability of mine workings, mining factors, stress-strain state, massif.

Introduction
The roof of the seams in the driven mine workings of the Karaganda coal basin have low stability and when exposed more than one meter, they collapse. They are also prone to soaking and heaving. In tectonic terms, the developed coal seams are complex. Widespread introduction of technological schemes of non-pillar excavation of seams has led to high costs of supporting the roof, the need to drive mine workings near the goaf. The behavior of the mine roof of the coal seams of the Karaganda basin is determined by their composition, physical and chemical properties, stratification and fracturing. The immediate roof of coal seams is most often represented by mudstones, less often by siltstones and in isolated cases, by sandstones; the main roof is usually composed of sandstones. Mudstones also predominate in the soil of coal seams [1-4].

Research methods
Analyzing the latest studies and publications
The paper provides a brief analysis of studying domestic and foreign practice of schemes used for preparing and developing excavation fields that affect the formation of zones of increased and reference rock pressure, intense deformations of the roof, sides and soil of a mine working located within the areas of their impact.

In the coal mines of Western Europe, with increasing the depth of development, there are driven workings of a large section. Their sup-
port is carried out using a complex combination of sprayed concrete, anchor system and metal frame support with locating the excavation workings parallel to the direction of the main horizontal stresses [5-9].

An English high-strength anchoring system with mounting anchors is designed to provide increased bond strength and high rock shear resistance.

The traditional production experience in Western Europe involves locating longwalls next to each other to reuse the working of the previous longwall or driving an additional one, usually at the distance of 0 to 5.0 m from it. This technological scheme of preparation is not conducive to high-performance backwall mining.

In Great Britain, there has been developed a coal mining technology with increasing the depth of mining of coal seams with preparing single-mouth drifts with a pillar (coal column) of a considerable size between the longwalls, which allows high-speed penetration using roof bolting, regardless of the adjacent face.

In contrast to coal mining in the countries of Western Europe, in the United States of America and Australia, practically with the same mining and geological conditions, positive results are achieved when using multi-drift technological schemes for coal mining with rectangular excavation drifts and fixing them with anchors. In the United States of America and Australia, multi-drift technological schemes are mainly used in pillar mining with longwall lengths from 200.0 to 250.0 m. Excavation drifts of rectangular section are carried out in groups of two and four parallel ventilation and conveyor workings (width from 5.0 up to 6.0 m). The drifts directly adjacent to the longwall are extinguished after its passage, the rest are in most cases reused.

In the coal mines of the United States of America, the three-drift preparation (52%) is the most widely used, followed by the four-drift (46%) and sometimes two-drift (2%) scheme.

In the coal-mining countries of the CIS, non-pillar mining systems are predominantly used [10-14].

To date, the predominant share of coal mines are driven using the roof bolting system. At the same time, the technological capabilities of underground coal mining are expanding.

In the Karaganda basin, the following technological schemes of developing excavation pillars along the strike and to the dip of the coal seam are used.

Modifications of development schemes, together with mining and technological factors, have a significant impact on the methods and means of supporting mine workings.

Table 1 shows the factors determined by the mining and geological features of development in the countries with the developed coal industry.

Table 2 shows the following factors related to technological schemes of mine workings and mining operations in countries with a de-

<table>
<thead>
<tr>
<th>Options</th>
<th>Germany</th>
<th>Great Britain</th>
<th>Australia</th>
<th>USA</th>
<th>The Karaganda basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth of development, m</td>
<td>1000-1200</td>
<td>600-800</td>
<td>200-260</td>
<td>200-360</td>
<td>550-820</td>
</tr>
<tr>
<td>Vertical rock pressure, MPa</td>
<td>20-23</td>
<td>10-13</td>
<td>5,5-6,0</td>
<td>7-9</td>
<td>10-15</td>
</tr>
<tr>
<td>Horizontal rock pressure, MPa</td>
<td>20-23</td>
<td>20,0-21,5</td>
<td>10-13</td>
<td>13-17</td>
<td>10-14</td>
</tr>
<tr>
<td>Average mined thickness of coal seams, m</td>
<td>1,12</td>
<td>2,5</td>
<td>3,1</td>
<td>1,5</td>
<td>1,0-8,5/mean 2,28</td>
</tr>
<tr>
<td>Average inclination of the developed coal seams, deg.</td>
<td>5-10</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>7-20</td>
</tr>
<tr>
<td>Properties of rock formations of the seam roof</td>
<td>argillites, siltstones, sandstones with a compressive resistance of 40-80 MPa</td>
<td>argillites, siltstones, sandstones with a compressive resistance of 25-65 MPa</td>
<td>argillites, siltstones, sandstones with a compressive resistance of 5-80 MPa</td>
<td>argillites, siltstones, sandstones with a compressive resistance of 10-80 MPa</td>
<td>argillites, siltstones, sandstones with a compressive resistance of 10-80 MPa</td>
</tr>
<tr>
<td>Properties of soil rocks, uniaxial compressive strength in MPa</td>
<td>argillites, 45</td>
<td>argillites, 45</td>
<td>argillites, 40</td>
<td>argillites, partly sandstones, 40</td>
<td>argillites, 20</td>
</tr>
</tbody>
</table>
veloped coal industry.

Mines in the Karaganda Basin have both arch and rectangular cross-sections. Estimation of technological factors of anchoring systems operation shows that effective and reliable anchoring of preparatory mine workings in conditions of occurrence in the roof of weak fractured rocks, with increase of development depth and in various zones of influence of workings can be provided with application of steel-polymer anchors fixed along the whole length of borehole by quick-hardening resins with bearing capacity 250.0-300.0 kN and length from 2.0 to 3.0 m; for use in complex geological conditions special (rope) anchors up to 95.0 (6.0-7.0) m long may be used.

The main task of the anchoring system is to mobilize and save the inherent strength of the given massif so that it becomes self-supporting. The anchoring system supports the rock, keeping the restriction on roof movement and allowing horizontal tension to hold the roof in place, preventing it from falling out. To maintain the roof in the preparatory excavation requires sufficient horizontal tension to limit the movement of the roof and its effective fixation. Mountain roofing is prone to collapse, peeling along the strata. Blasting contributes to the deposition of weakened formation rocks, which creates unsafe working conditions. To work safely under such a mountain roof, it is necessary to create an anchoring beam in the roof. The primary task of anchoring in the formation of the beam is to resist the shear of rock layers along the horizontal strata.

The impact of anchoring is most pronounced where high shear stresses occur in the curved beam, i.e., at the ends of the beam. Installation of anchoring near the mine workings ensures that rock movement is relatively insignificant and that the individual parts have maximum adhesion. Maintaining this adhesion is a prerequisite for the self-maintenance of a rock mass, and any loss of adhesion leads to a significant loss of strength. Anchoring support system consisting of anchors to be installed and fixed in holes drilled into the roof and sides of the workings, supporting elements for anchors and anchor bolting on the contour, unlike metal frame and other powered supports, immediately after installation it binds and strengthens the massif in the roof and sides and actively resists shifts and fracture of rocks. This advantage allows for increased stability and reliability of mine support at the lowest metal consumption. Another advantage of the anchoring system is the possibility of complete mechanization of anchoring, which significantly reduces the labor intensity of tunneling operations and increases the performance of mine workings.

Anchor bolts are designed for use in the construction of anchoring system in the mines during the lifetime of mine workings in various mining and geological and mining conditions, including areas of intense high rock pressure, in workings through the coal seam, in weak fractured rocks, on rock-bump hazardous and outburst-prone coal seams, in underworked and overworked areas of mine fields. The choice of the type and parameters of anchoring depends on many factors, including: the structure and physical and mechanical characteristics of rocks, the degree of disturbance and water content of deposits, depth of development, distance between layers, configuration, purpose and service life of the mine workings, operating conditions, consumption, cost, scarcity and strength properties of anchoring materials, manufacturability of production and

### Table 2 – Factors related to the technological schemes of mine workings and coal face operations

<table>
<thead>
<tr>
<th>Technological parameters</th>
<th>Germany</th>
<th>Great Britain</th>
<th>Australia</th>
<th>USA</th>
<th>The Karaganda basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scheme of preparation of excavation faces</td>
<td>single-flow</td>
<td>return-flow</td>
<td>single-flow</td>
<td>single-flow</td>
<td>single-flow, return-flow</td>
</tr>
<tr>
<td>Leaving pillars</td>
<td>-</td>
<td>rigid, 80-120 m</td>
<td>yield, 10-20 m</td>
<td>yield, 10-30 m</td>
<td>- (according to special project)</td>
</tr>
<tr>
<td>Sectional shape of capital, auxiliary and mine workings</td>
<td>arched</td>
<td>rectangular</td>
<td>rectangular</td>
<td>rectangular</td>
<td>rectangular, arched, rectangular</td>
</tr>
<tr>
<td>Working dimensions, m:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>height:</td>
<td>4,1-4,8, 6,1-7,5</td>
<td>2,5-4,1, 5,1-5,8</td>
<td>2,5-5,1, 4,5-6,1</td>
<td>2,1-4,2, 5,1-6,2</td>
<td>2,1-3,5, 4,7-6,1</td>
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<tr>
<td>width:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3,5-3,7</td>
<td>5,5-6,5</td>
<td>187</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
construction of the anchoring system.

Table 3 shows the mining and technological factors caused by mining and geological features of development, the use of anchoring technology in preparatory workings, 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.

**Purpose of the study**

The purpose of the research is to justify the technology of controlling the stability of the contours of mine workings, taking into account the manifestations of rock pressure of the adjacent massif and changes in its geomechanical state.

The assessment of mining conditions of application of technological schemes of anchoring of mine workings in preparatory workings and establish effective technological schemes of conducting and anchoring the contours of preparatory mine workings in coal mines to improve the stability of their contours.

The results of the work were carried out as part of the research work on «Development of effective technology of preparatory workings with anchoring, taking into account the stress – strain state of the rock massif».

The practical value of the work lies in the establishment of technological principles for controlling the stability of the contours of mine workings, considering the manifestations of rock pressure of the adjacent massif and changes in its geomechanical state.

Proposed methodology for solving these problems based on the analysis of domestic and foreign practice to develop technological schemes for mining excavations, technological evaluation of the effectiveness of solutions in coal mining. In this article the methodical approach to the choice of effective types and means of anchoring mining works during the mining excavation is presented (Figure 1).

The choice of methods and means of rock anchoring is influenced by mining-geological and mining-technical conditions of coal mining, complicating factors of mining excavations (Figure 2). Also affected by the parameters of attachment and maintenance of mine workings have the scheme of development of mining and ventilation, their quantitative parameters and the ratio of mining and preparatory mining operations, the front of underworking and overworking of the coal seams [16–20].

**Scientific results**

Technological schemes of non-pillar mining of coal seams when conducting mine workings in the cut-off area ensures the necessity to guarantee the above-mentioned gaps in time between the caving of rocks and conducting cut-off workings. But at the same time, it creates certain difficulties for coal mines in the preparation and commissioning of the new front of coal face operations. The problems on preparation of coal face operations can be solved by implementing the following tasks: Leaving of temporary coal pillars for the whole length or part of the excavation field length with their subsequent extinguishing; group preparation of layers and carrying out of bottom-hole openings by separate sections between intermediate crossings (winze) outside the zone of influence of the mining pressure of the working face; mining of pillars in staggered order; alternate mining of pillars in wings of bilateral excavation fields, panels; carrying out the undercut mine after the longwall of the adjacent pillar with an auxiliary flank mine, brake incline [21–23].

Considered and evaluated the technological schemes of mining and fastening of mine workings on the example of the mine named after Kuzembaev. When carrying out mine workings in the Karaganda coal basin, depending

<table>
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<th>Table 3 – Mining and technological parameters of anchor support application</th>
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<tbody>
<tr>
<td><strong>Options</strong></td>
</tr>
<tr>
<td>----------------------------------</td>
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<tr>
<td>Anchoring length, m</td>
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<tr>
<td>Anchor length of the rock, m</td>
</tr>
<tr>
<td>Rated load capacity, kN (depending on the material)</td>
</tr>
<tr>
<td>Anchor support density / m²: roof flanks:</td>
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</table>
Figure 1 – Methodological approach to the selection of effective methods and means of supporting mine workings

Figure 2 – A set of factors affecting the efficiency and stability of mine workings supported by anchoring
on the development schemes and operational purpose of mine workings, the following technological schemes of fastening of near-surface rocks along the contours of mine workings are applied (Figures 3-7).

Figure 3 shows the technology of fixing the coal seam K_{12} windway 42K_{12}-z Kuzembaev mine on the roof and the sides (from the face – fiberglass anchors) with steel-polymer and rope mining anchors (three-tiered system of fastening).

The technological scheme makes it possible to steadily maintain the mine workings in the zone of influence of mining operations in the area before the front of the longwall motion. Wire rope anchors are installed ahead of the face support pressure zone at a distance of 100.0 to 120.0 m. In the windway 42K_{12}-z of mine named after Kuzembaev with steel-polymer anchors outside the zone of in-

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**Figure 3** – The windway 42K_{12}-z Kuzembaev mine with rope anchors and strengthen the anchorages junction between longwall face 45K_{12}-z by means of rope anchors

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**Figure 4** – Kuzembaev mine windway 42K_{12}-z of (b) with steel-polymer anchors outside the influence of mining operations

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**Figure 3** – Cross section of the anchoring scheme; b – rope anchor diagram; c – reinforcement with rope mountain anchors.

**Figure 4** – Rock section; b – section during operation of the excavation.
fluence of mining works are fixed in one-level and two-level technological schemes and in the zone of influence of coal face operations (Figure 4,a,b). In Figure 5 and 6 shows the technology of anchoring on coal seam K12 tailgate and headgate 23K7-z the use of two-level system of fastening in the Karaganda coal basin, allowing to maintain the layered roof in the mining condition of the mine workings behind the face on the border with the mined-out space.

By the example of a Kuzembaev mine technological schemes (Figure 7) combined support (arch support with anchors) of mine workings on the formation K10 with a finished section of 11.9 m² (Figure 7, a) and 14.5 m² (Figure 7, b) and driving respectively 14.0 m² and 18.1 m², including coal seam is 13.0 m² and 14.7 m², and 1.0 m² and 3.4 m² rock. The use of anchors in the faces in this technological scheme with mixed fastening is not provided.

**Conclusion**
The assessment of mining conditions of application of technological schemes of mine workings fastening at preparatory work and es-
Establishment of effective technological schemes of conducting and fastening the contours of preparatory mine workings in coal mines to increase the stability of their contours.

The presented methodical approach will allow to make a choice of effective ways and means of fixing of mine workings for coal mines, and the generalized passports of fixing of mine workings will allow to form the database which can be considered as the basis and the preconditions for creation of the progressive typical technological schemes of carrying out, maintenance of mine workings and substantiation of parameters of fixing.

The peculiarity of the presented methodology of technology, anchoring systems and means of contour anchoring is that it will effectively use the yield pressure of the host rock, which will significantly reduce the material intensity, the cost of anchoring rock support and will increase the stability of the contours of mine workings.

This research has been/was/is funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP13268841).

REFERENCES


Оценка эффективности применения технологии крепления выработок для повышения устойчивости их контуров

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Аннотация. Поддержание выемочных выработок требует значительных затрат на их ремонт как до, так и после ввода их в эксплуатацию, особенно в зоне влияния очистных работ. Поддержание и увеличение объема подземной добычи угля возможно лишь при наличии высокоэффективной технологии проведения и поддержания подготовительных выработок. Целью исследований явилась оценка параметров управления устойчивостью контуров горных выработок, закрепленных анкерной крепью, для создания технологии интенсивного и безопасного проведения выемочных горных выработок на основе выявленных закономерностей поведения примыкающих к ним массивов горных пород. Идея подхода заключается в использовании техногенного напряженно-деформированного состояния для разработки эффективной технологии крепления приконтурного горного массива. Исследован механизм деформирования, сдвижения и обрушения пород в структурно нарушенном неоднородном горном массиве для оценки состояния породного массива вокруг горных выработок. Разработаны технологические предпосылки для крепления приконтурных пород почвы с учетом состояния горного массива вокруг выработки и определены параметры эксплуатации анкерной крепи на шахтах для закрепления штанг в выработках в целях обеспечения безопасности ведения горных работ.

Ключевые слова: горное дело, изучение деформационных процессов, параметры упрочнения, геомеханические процессы, проявление горного давления, технологические схемы, устойчивость горных выработок, горные факторы, напряженно-деформированное состояние, массив.

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