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IMPLEMENTATION OF THE EFFECTIVE SOLUTION TO ROCK SWELLING IN MINE WORKING

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ВПРОВАДЖЕННЯ ЕФЕКТИВНОГО СПОСОБУ БОРОТЬБИ ЗІ ЗДИМАННЯМ ГІРНИЧИХ ВИРОБОК

Purpose. Increased resistance of outcrops in production taking into account the ways of development of the effect of the mining-and-geological and mining-and-technical factors of mining operation.

Methodology. There have been applied the following methods: comparative analysis, mathematical modeling and forecasting.

Findings. There have been introduced the results of experimental-industrial works to reduce swelling of the subsoil in different mining operation conditions, observing and monitoring the manifestations of rock pressure, bedrock deformation, the displacement of host rocks on the side of workings and roof. Different types of timbering have been applied considering the complicating factors of mining, taking into account the geomechanical conditions of conducting and maintaining workings. It is recommended to apply a technology to maintain the bedrock that will improve the stability of rock outcrops in the development considering the ways of manifestation of the effect of geological and mining factors of mining.

Originality. An anchoring technology has been worked out aimed at reducing the swelling of the subsoil in different mining conditions, while using different types of timbering considering all the complicating factors of mining, as well as taking into account the geomechanical conditions of operation and maintenance of workings.

Practical value. It is recommended to make an installation of anchors into the soil in advance of the following effect of confounding factors (bearing pressure zone in front of the lava, and others), mainly in the district workings exposed to mining operations (extraction front, overworking and underworking zones, zones with increased rock pressure). It is also recommended to collar the inclined holes under the anchors inclined at an angle 20-40° to the vertical. The length of the holes is calculated considering their technical capability of drilling and is assumed to be 1.6, 2.4 and 2.9 m with a cross installation of the anchors.

Keywords*: stress-strain state, mounting options, geomechanical processes, roof bolting, mining engineering factors*

Introduction. Swelling is manifested while maintaining mine workings in the conditions of the occurrence of mild and solid rocks in the areas of clay, loam, sand-and-clay deposits and deposits containing organic rocks and soils that are prone to swell, when driving or during an operation.

Soil deformation of rocks in the form of squeezing them inside the workings are quite common while engineering coal deposits. Swelling is usually most intensively manifested in preliminary development. Due to the nature of the genesis of coal deposits, the immediate soil strata are usually composed of the weaker ones compared to other rocks. Furthermore, they have well-developed shear zones, caused by different degree of compaction and subsequent rock tectonic processes.

Defining the main problem. Soil rock swelling complicates the mining operations; the experience shows that even when the amount of swelling of the workings is more than 300–350 mm, it is necessary to apply technological measures to deal with it.

The intensity and the absolute value of displacement while swelling are associated with geological and production factors.

Analysis of the research results. The analysis allows distinguishing two main types of rock heaving while processing mine workings: clay rock heaving as a consequence of swelling related to some specific features of the mineralogical and colloidal chemical composition of clay soils, and rock heaving as a manifestation of rock pressure as a result of mine works.

During the in-seam development workings in case of the occurrence of the coalbeds of laminated mudstones and siltstones in the soil, the process of rock destruction and soil heaving includes the following stages: stratification on the surface of the stratum without fault of the stratified rocks; the fault of the stratified rocks under the workings into the blocks in the form of multijointed arches; the destruction of the rocks of the soil under its sides with their following extrusion into the working [1–3].

The swelling of the bedrocks is a consequence of the extrusion of the mild rocks out from the toe of the entry stumps or intact rock massif.

The analysis of the production activity of the mines of the Karaganda coal basin, operating at great depths (mostly more than 500–600 m) in case of mild bearing strata, shows that a significant portion of extended workings is constantly in a state of repair or activities related to their maintenance in a satisfactory operational state. About 10–12 % of inside workers are occupied with carrying out such kind of lowly-mechanized work, being structurally related primarily to the liquidation of the consequences of rock heaving during workings (60 %) and reinforcement (40 %).

Thus, in 2014 the specific volume of reinforcement of workings at functioning mines of the Karaganda coal basin reached 5.5 m for 1000 tons of extraction, labor costs for repair and workings maintenance reached 200 manshifts a year for 1 km length output, or about 20 manshifts for 1.000 tons of extraction. These activities are labor-consuming (0.2 manshifts/m), they require additional financial costs (3–5 thous. RUR/m) and reduce the rate of working off reserves by 30–40 %.

At mines with an annual increase of the length of mine workings which are in a poor state by 2–3 %, about 30–50 % of workings are reinforced that need to be repaired.

Based on current assumptions and relying on production experience, some methods and means for preventing or reducing the intensity of the process are being developed.

The manifestation of rock pressure in the workings in the form of swelling rocks occurs due to the influence of a great number of natural geological and operational technological factors. However, the stability of rock outcrops and adjoining rocks mainly depends on the physical and mechanical properties of rocks and their operating stress, conditioned by the weight of the overlying rocks, tectonic faults, diagrams and order of mining operations. Therefore, all the measures to reduce the rock swelling are aimed at changing the parameters of these two groups of factors or the use of the most favorable combination.

All the measures to prevent rock heaving in outputs can be divided into five groups: the use of favorable geological and technical conditions (carrying out the workings skin-to-skin to the goaf behind the longwall in collapsed and compacted rocks); rocks fortification (roof bolting usage, polymeric soil reinforcement and the usage of resins); rock mass decongesting (cavity blast cleanup of a rock mass, excavation stability control of a blasting rubble strip, the structure of decongesting cavities, rock mass decongesting drilling out the formation, roof rock torpedoing in the excavation workings); combined methods (active discharge followed by fortification and formation of an invert, blast fortification with simultaneous rock massif decongesting and its consolidation, soil decongesting using drill and fire system with the following usage of reinforcing lining and square-set sills and hydraulic props); specific control methods (the usage of closed and reinforcing linings, as well as combined linings).

The best effect to deal with swelling is achieved by decongesting the massif that contains workings from the high stress. The following methods of decongestion can be used there: carrying out decongesting excavations, formation of slots and holes of all types, rock blasting forming the crushing zones in the soil, etc. These solutions are characterized by highly complicated work technologies, great labor content and cost.

This leads to the fact that in the practice of mining operation blasting of swelled rocks still remains the main method, that is to say that finally we get the consequences of this phenomenon eliminated, but not its cause. In this case we achieve only a short-term and little effect while a long term process of combatting swelling requires high financial and labor costs.

Lately, they have successfully begun to use the method of fixing the roof (of the soil) with steel polymeric and other types of anchor chains of high load-bearing capacity.

Presentation of the main research. Below we review some technological elaborations using anchor linings, aimed at reducing and preventing rock swelling in mine workings.

Anchoring is used to maintain a sufficient level of solidity of the marginal rocks by limiting their displacement into workings, which allows increasing the efficiency, solidity, maximum maintenance-free service and operation safety.

We can also control swelling processes including the shape of transverse section of the outputs with the location in relation to the rocks of the roof in the shape of reverse trapezoidal line of the load-bearing arch, which allows increasing the sole stability in mine workings.

We can consider the method of active reinforcement effect on the rocks of workings by the means of anchoring very progressive. To realize it, we need to determine the necessary thickness of the reinforcing stratum of the rocks in the soil, due to the reinforcement layer of the anchors set into the soil, with the formation of the supporting blocks to sustain the bearing arch [4, 5] (Fig. 1), based on the depth of distribution of swelling in the zone of workings, which can be defined using the famous method of the prof. P. M. Tsimbarevich [3]

$$x_0 = \frac{H_1 \operatorname{tg}^4\left(\frac{90^\circ - \varphi}{2}\right)}{1 - \operatorname{tg}^4\left(\frac{90^\circ - \varphi}{2}\right)}, \qquad (1)$$

where H_1 is a height of soil surcharge, brought to specific weight of the rocks, m;

$$H_1 = h\frac{\gamma_b}{\gamma_p}, \qquad (2)$$

where h is a height of the walls of workings, m; γ_b is specific weight of the side rocks, t/m^3; γ_p is specific weight of the soil rocks, t/m^3; φ is an angle of the internal friction of the rocks, degrees.

We have analyzed the degree of the dependence of X_0 depth of swelling distribution in soil workings in relation to the specific weight of side rocks, soil rocks and the height of the walls of workings [1]:

- h = 3.0; 3.5 and 4.0 m;
- γ_b = 2.0; 2.5; 3.0 t/m^3;
- H_1 varies from 4.0; 5.0 to 6.0 m.

Here is a nomogram based on the assumption of the calculated values – Fig. 2.

As you can see from the calculations above, within the increase of the volume weight of the roof rocks, the less is the depth of the distribution of the heaving zone in the soil of workings and the more is the parameter of the volume weight of the side rocks and the height of the walls of production, the greater is the depth of the distribution of the heaving zone [6–8].

A technology of the anchor lining has been also developed aimed at the reduction of subsoil swelling in different mining technical conditions of operation using different types of lining, taking into account all the complicating factors of mining and geomechanical conditions of holding and maintaining the workings.

The anchor installation technology for the ground anchors involves the installation of the anchor chain into the ground along the sides of excavation. The inclined holes are collared at an angle of 20–40° to the vertical. The length of the holes is calculated considering their technical capability of drilling and is assumed to be 1.6, 2.4 and 2.9 m. The cross installation of the anchors (at the right angle) into the rocks stratum of the soil is also admitted (Fig. 3). It is recommended to determine the length of the anchors installed into the soil of workings using the following formula

$$L = \frac{6.75 \cdot B_b \cdot H_n}{N_n}, \qquad (3)$$

where 6.75 is empirical coefficient; B_b is the width of the workings in the rough, m; H_n is rocks swelling value, m; N_n is compressive strength/pressure of the soil, MPa.

A setting increment of the cross oriented ground anchors is recommended to be equal to the double quantity of the number of arches of the roof bolting for 1 running meter of the output.

A series of experimental industrial works has been fulfilled to reduce swelling under the soil in different types of mining environment with the observation of

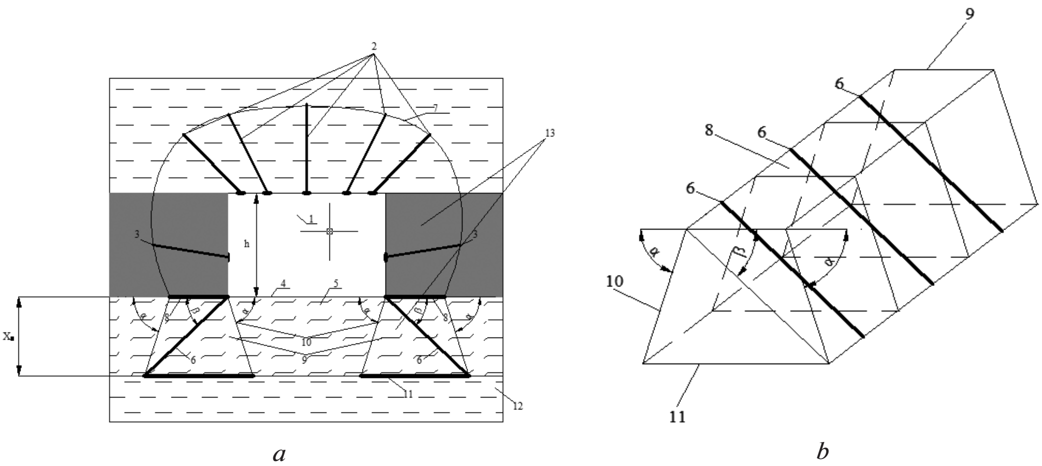

Fig. 1. Formation of the bearing blocks in the soil to support its arch:

a – the way of lining and rocks fortification; b – bearing blocks in the soil; 1– workings; 2 – steel polymeric roof anchors; 3 – steel polymeric side anchors; 4, 5 – swelling soil strata/layers; 6 – steel polymeric anchors entering the soil workings; 7 – the line of the bearing arch of workings ; 8 – the foundation of the bearing arch; 9 – bearing blocks; 10 – glide lines of the heaving rocks; 11 – lower base of the bearing block; 12 – stable rocks stratum; 13 – fortification zone of the rocks around the workings

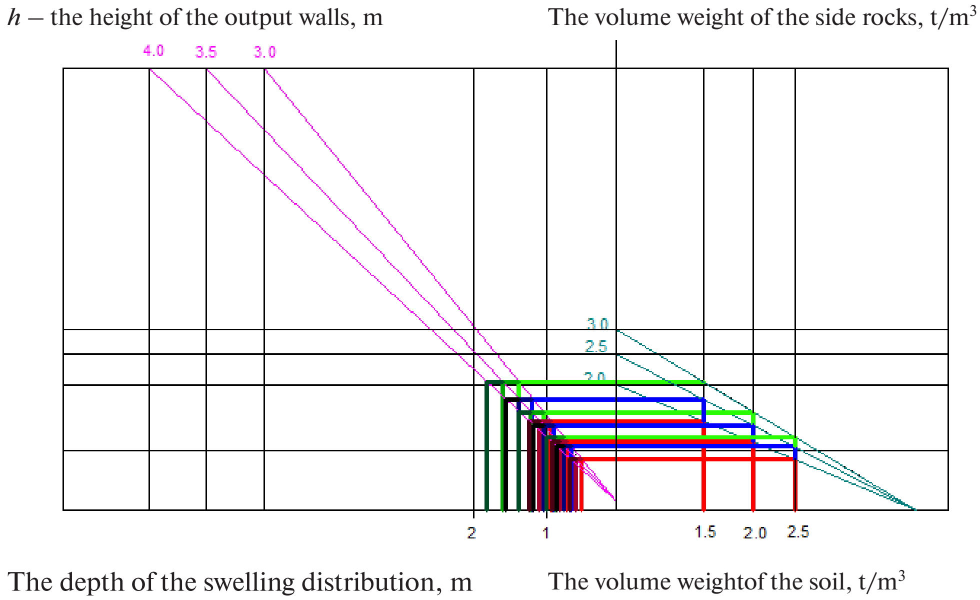

Fig. 2. Nomogram to define the depth of the distribution of the swelling zone in the soil of workings depending on the influencing factors

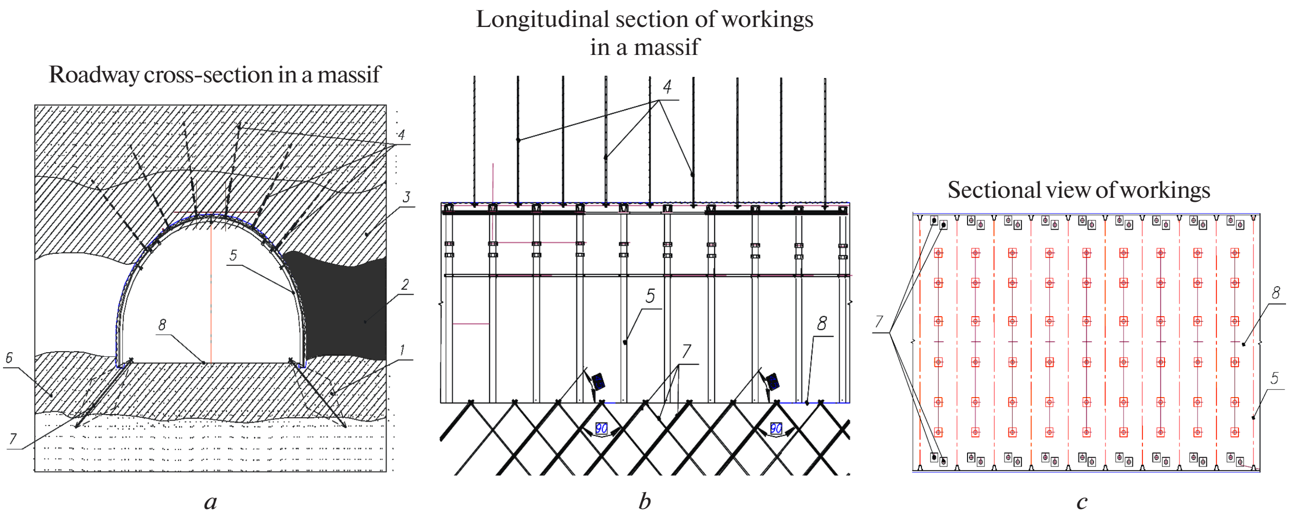

Fig. 3. Cross-section (a), longitudinal (b) section of workings with ground anchors and a sectional view – installation setup of the ground anchors relatively to the arches of the roof bolting (c):

1 – fortification zone; 2 – coalbed; 3 – rocks of immediate roof; 4 – roof anchors; 5 – roof bolting; 6 – types of soil; 7 – ground anchors; 8 – workings soil

symptoms and monitoring the rock pressure, rocks deformation, displacement of the rocks enclosed into the sides and roof rocks using different types of lining taking into account the complicating factors of mining, as well as any geomechanical conditions of holding and maintaining the workings based on the provided inspection certificate of support, geological and mining-technical information.

Workings with anchor lining unalloyed:

1) "*Kazakhstanskaya*" *mine, stratum entry 22t_3-в (Karaganda coal basin)*:

- across the pitch workings, angle of dip of stratum 10–14°, operation depth 402–360 m;
- yield, rock section: height – 3800 mm, width – 6000 mm, finished section – 22.8 m^2, in the rough – 22.8 m^2;
- lining: per meter – 1.33 framing linings, 16 roof boltings with a length of 2.4 m and 4 side steel polymeric anchors with a length of 2.4 m, stratum t_3 with a width 1.65 m and compressive strength of 15 MPa;
- type of rocks: mudstone, prone to swelling with pressure of 25 MPa, width – 5 m.

2) "*Abaiskaya*" *mine, stratum entry 221k_{18}-c:*

- across the pitch workings, angle of dip of stratum 12–18° (up to 20°), operation depth 402–360 m (about 365 m);
- yield, rock section: height – 3500 mm, width – 6000 mm, finished section – 21,0 m^2;
- lining: per meter – 15 roof boltings 2.9 m and 6 side steel polymeric (3) and fiber glass plastic (4) anchors with a length of 1.6 m, fixed under the shredded-

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and-pulled net of MM type, stratum k_{18} with a width of 2.0 m and compressive strength of 10 MPa;

- types of rocks: mudstone-pressure – 15–22.5 MPa, width – 1.0 m; aleurolite-pressure – 37.0 MPa, width –1.0 –3.0 m.

Workings with a mixed (frame-anchor) lining:

1) *mine by Kostenko, 3a Eastern airway k_4:*

- across the pitch workings, angle of dip 20°, operation depth 402–360 m;

- yield, rock section: height – 3750 mm, width – 5810 mm, finished section 14.4 m^2;

- lining: per meter – 1.33 framing linings, 10.64 roof steel polymeric anchors, stratum k_4 with a width of 3.78–4.08 m and compressive strength of 15 MPa;

- types of rocks: pressure – 17 MPa, width – 5.8 m.

2) "*Abaiskaya*" *mine, stratum entry 221k_{18}*-с:

- across the pitch workings, angle of dip 20°, operation depth 402–360 m;

- yield, rock section: height – 3500–3700 mm, width – 5800–6000 mm, finished section 14.4 m^2;

- lining: per meter – 2 framing linings, 11 roof steel polymeric anchors 2,4 m, stratum k_{18} with a width of 2.0 m and compressive strength of 10 MPa;

- types of rocks: mudstone-pressure – 15–22.5 MPa, width – 1.0 m; aleurolite-pressure – 37.0 MPa, width – 1.0–3.0 m.

3) "*Saranskaya*" *mine, inclined ventilation crosscut k_{10} (eastern direction):*

- waste workings, angle of dip 9°, operation depth 402–660 m; about 620 m;

- yield, rock section: height – 3735 mm, width – 5570 mm, finished section 14.4 m^2;

- lining: per meter – 2 framing linings, 11 steel polymeric anchors with a length of 2.4 m, stratum k_{10} with a width of 4.65 m and compressive strength of 15 MPa;

- types of rocks: pressure – 35 MPa, width – 22.5 m.

4) "*Kazakhstanskaya*" *mine, stratum entry 22*$т_3$*-в:*

- across the pitch workings, angle of dip 10–14°, operation depth 402–360 m;

- yield, rock section: height – 3660 mm, width – 5810 mm, finished section – 14.5 m^2, in the rough – 18.3 m^2;

- lining: per meter – 1.33 framing linings, 10.65 roof steel polymeric anchors with a length of 2.4 m, stratum t_3 with a width of 1.65 m and compressive strength of 15 MPa;

- types of rocks: mudstone, pronetos welling with pressure – 25 MPa, width – 5 m.

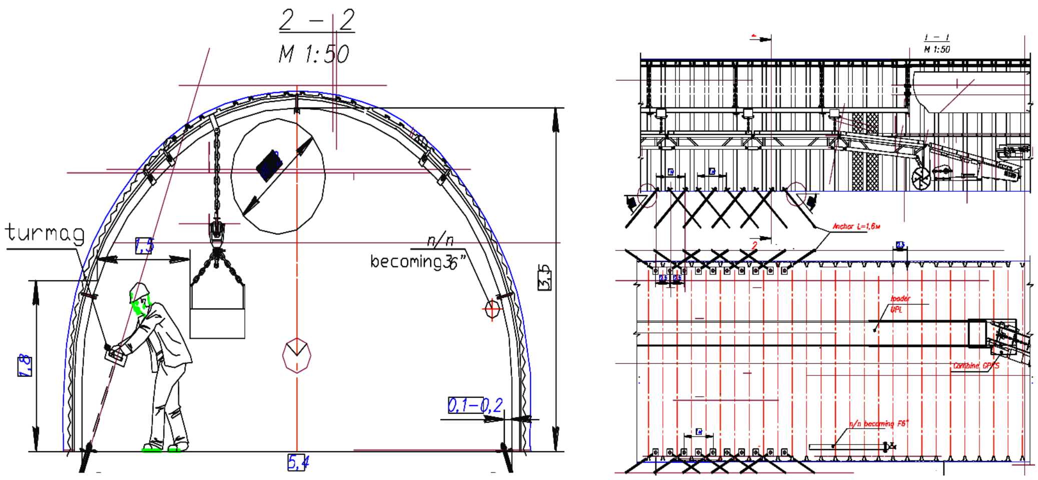
Experimental observations, analysis and evaluation of sustainability, defectiveness and deformation processes will allow us to establish the consistent patterns of interaction between the lining and a rock massif in the workings.

Operation technology for the installation of the lining of the ground anchors.

We have provided the installation of the roof boltings into the ground along the sides of the exploration mining workings at the experimental area with a length of 10 m. The inclined holes shall be collared under the anchors at the angle of the dip 20–40° to the vertical (with a gradation for 5 ranges by 5°). The length of the holes is calculated considering their technical capability of drilling and is assumed to be 1.6, 2.4 and 2.9 m with a cross installation of the anchors.

We have provided the installation of steel anchors with a diameter of 21.6 mm (as an option we have a UPC lining with notching and a collet properly equipped for the drilling rig) on polymeric ampoules for complete filling of the cavity of the hole. Along the length of the hole we used ampoules with delayed congelation time (3 min.), and the last ampoule (the first relatively to the mouth of the hole) shall be used with a substance of accelerated congelation (20–25 sec.) to create a preliminary tension of the anchor in the hole.

In the process of experiment we defined the bearing capacity of the installed anchors.



a *b*

Fig. 4. Testing of the technology of anchoring aimed at reducing the rock swelling at "Abaiskaya" mine: a – section; b – profile

The installation of anchors in the operation area was made in advance, before the exposure of the influence of the complicating factors (the zones of abutment pressure in front of the lava, etc.), mainly in the district workings prone to the influence of mining operations (cleaning working area, ground and underground zones, increased rock pressure).

To conduct experimental works on reducing the rock swelling while maintaining workings with mixed and anchor linings, we installed reference metering stations in every other 5 meters. The evaluation of the stability of the rocks in the projected workings, considering the ways of manifestation of the effect of mining geological and geotechnical operation factors, will allow us to substantiate the technical decisions aimed at its maintenance made at the design stage. Here are some kinds of typical framing deformation of workings and their possible causes. According to the results of the experiments, the following information is available: a timbering plan, mining geological and geotechnical information, data on the dynamics of the rock pressure, the pictures of the analyzed workings in the specified operation conditions for the optimization of the output. For experimental testing of the anchoring technology aimed at reducing rock swelling, at "Abaiskaya" mine the anchors were installed on the belt road 22k12-c at the area of PK55 + 3m – PK56 + 3m – Fig. 4.

At "Saranskaya" mine certain works were done aimed at bedrock consolidation on the belt road 52k7-3 along with installation of 7 coupled anchors with a length of 1.6 m into the holes with a diameter of 42 mm per 6 chemical ampoules AMK-350 each one.

Conclusions. An effective way of dealing with rock swelling in preparatory mining workings has been developed and tested. The use of this technology will allow increasing the stability of the rock exposure in the workings taking into account the ways of manifestation of the effect of mining geological and geotechnical operation factors.

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Мета. Підвищення стійкості породних оголень у виробці з урахуванням форм прояву дії гірничо-геологічних і гірничотехнічних факторів введення гірських робіт.

Методика. Застосовані методи порівняльного аналізу, математичного моделювання, прогнозування.

Результати. Наведені результати експериментально-промислових робіт, спрямованих на зниження здимання порід ґрунту в різних гірничотехнічних умовах розробки, з проведенням спостережень проявів і моніторингу гірського тиску, деформацій порід ґрунту, зсувів вміщуючих порід боків і покрівлі виробок. Застосовні різні види кріплення з урахуванням ускладнюючих чинників ведення гірських робіт з урахуванням геомеханічних умов проведення та підтримання виробки. Рекомендована технологія з підтримання порід грунту, що дозволить підвищити стійкість породних оголень у виробці з урахуванням форм прояву дії гірничо-геологічних і гірничотехнічних факторів ведення гірських робіт.

Наукова новизна. Розроблена технологія анкерного кріплення, спрямована на зниження здимання під ґрунтами в різних гірничотехнічних умовах розробки, при застосуванні різних видів кріплення з урахуванням ускладнюючих чинників ведення гірських робіт, з урахуванням геомеханічних умов проведення та підтримки виробки.

Практична значимість. Рекомендовано установку анкерів до грунту виробки здійснювати завчасно до дії впливу ускладнюючих факторів (зони опорного тиску попереду лави та ін.), переважно в дільничних виробках, схильних до впливу гірничих робіт (фронту очисних робіт, зон надробки, підробки пластів, підвищеного гірського тиску). Здійснювати забурення похилих шпурів під анкери під кутом 20–40° до вертикалі. Довжина шпурів передбачається із розрахунку технічної можливості їх буріння та приймається рівною 1,6; 2,4 і 2,9 м з перехресною установкою анкерів.

Ключові слова: *напружено-деформований стан, параметри кріплення, геомеханічні процеси, анкерне кріплення, гірничотехнічні фактори*

Цель. Повышение устойчивости породных обнажений в выработке с учетом форм проявления действия горно-геологических и горнотехнических факторов ведения горных работ.

Методика. Применены методы сравнительного анализа, математического моделирования, прогнозирования.

Результаты. Приведены результаты экспериментально-промышленных работ, направленных на снижение пучения пород почвы в различных горнотехнических условиях разработки, с проведением наблюдений проявлений и мониторинга горного давления, деформаций пород почвы, смещений вмещающих пород боков и кровли выработок. Применены различные виды крепи с учетом осложняющих факторов ведения горных работ с учетом геомеханических условий проведения и поддержания выработки. Рекомендована технология по поддержанию пород почвы, которая позволит повысить устойчивость породных обнажений в выработке с учетом форм проявления действия горно-геологических и горнотехнических факторов ведения горных работ.

Научная новизна. Разработана технология анкерного крепления, направленная на снижение пучения под почвами в различных горнотехнических условиях разработки, при применении различных видов крепи с учетом осложняющих факторов ведения горных работ, с учетом геомеханических условий проведения и поддержания выработки.

Практическая значимость. Рекомендовано установку анкеров в почву выработки производить заблаговременно до воздействия влияния осложняющих факторов (зоны опорного давления впереди лавы и др.), преимущественно в участковых выработках, подверженных влиянию горных работ (фронта очистных работ, зон надработки, подработки пластов, повышенного горного давления). Производить забуривание наклонных шпуров под анкеры под углом 20–40° к вертикали. Длина шпуров предусматривается из расчета технической возможности их бурения и принимается равной 1,6; 2,4 и 2,9 м с перекрестной установкой анкеров.

Ключевые слова: *напряженно-деформированное состояние, параметры крепления, геомеханические процессы, анкерная крепь, горнотехнические факторы*

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