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CONTROL OVER GEOMECHANICAL PROCESSES INTENDED TO IMPROVE A COAL-AND-ROCK MASSIF STABILITY

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УПРАВЛІННЯ ГЕОМЕХАНІЧНИМИ ПРОЦЕСАМИ ДЛЯ ПІДВИЩЕННЯ СТІЙКОСТІ ВУГЛЕПОРОДНОГО МАСИВУ

Purpose. To develop progressive technological schemes of the roof bolting for mine workings with respect to stress distribution around workings.

Methodology. Methodology of selection of the support system included the study of stress-strain state, rock pressure manifestations, conditions of working maintenance depending on mining-and-geological, mining-and-technological and mining-engineering parameters in order to determine their influence on the roof bolting efficiency and substantiate the support pattern; ensure stability and reduce deficiency and costs of driving and maintenance.

Results. The stress-strain state, mining pressure manifestations, conditions of working maintenance taking into account mining and technological parameters were studied. The study allowed us to determine the extent of influence of the mentioned factors on the efficiency of roof bolting support of workings.

Originality. We determined the consistent patterns of change of plastic range of stress and its evolution with time, the stability of working contours depending on mining-and-geological and mining-engineering factors, and the parameters for reliable operation of workings. Based on analytical modelling, the technology, systems and means for driving workings that promote decreasing the deficiency of contours were developed.

Practical value. The results of studies focused on development of the technology of intensive and safe working driving on the basis of the revealed regularities of the behaviour of the adjoining rock massifs were presented and optimization of the parameters of technological schemes of first workings were presented. They allow controlling the anthropogenic stress-strain state and raise the efficiency of the technology of marginal rock massif support.

Keywords: *mine working, deformation process, parameters of support, geomechanical process, roof bolting, mining pressure, mining-and-technological factor, scheme of mining operations development, stress-strain state*

Introduction. Present day technologies of supporting underground workings include consecutive consideration of the following issues: determining the parameters of mining pressure and physical-and-mechanical properties of enclosing rocks; assessing the technology, means and types of support in coal mines; analysing the theories used in the design substantiation of the working support parameters; principles of support work, geomechanical models and experience of use; ways of driving and supporting workings; support designing procedures; monitoring the condition of supporting a working; laboratory and industrial studies of various design supports with various fixing materials.

Statement of the main problem. Mining pressure means stresses arising in the rock massif, near the working walls, wells, in pillars and on the 'rock-support' contact surfaces as a result of action of gravitational forces, as well as tectonic forces and temperature changes in the crust top layers. The types of mining pressure manifestation are as follows: side mining pressure (extraction); mining pressure from the soil of the working (swelling); vertical mining pressure (in the untouched massif, in the drifted workings); basic mining pressure (stopes, developed workings); mining pressure in the pillars.

The following schemes of the roof bolting are distinguished: a single-level scheme of the roof bolting with a metal arch support (Fig. 1), a single-level scheme of the roof bolting (Fig. 2), and a two-level scheme of the roof bolting (Fig. 3).

There exist the following types of the roof bolting used in mines that can be divided by their core design into the following: metal locked bolts; metal explosive charge fired bolts; wooden bolts; ferroconcrete bolts; steel-mineral bolts; steel-polymer bolts; plastic bolts; basalt plastic bolts; frictional bolts; injection bolts; self-drilling bolts; rope bolts; bunch bolts [1, 2].

There are five main theories used in the design substantiation of the roof bolting parameters: suspension of the immediate roof to stable rocks; forming the weight bearing structure; compression of the supporting rocks; joint work of the support and the massif; power theory.

Analysis of the recent research. The present day trends of developing the technologies of the roof bolting (ways of driving and supporting workings, etc.) include the use of the two-level roof bolting in the following conditions: supporting workings and interfaces up to 12 m wide and wider; previously drifted and formed dismantling cameras; interface of the cutting furnace with the conveyor working 19.7 m wide; strengthening the working supports for their reuse and non-pillar development of the coal reserves; for work of the breakage face without a powered support of interface; for their preserving for the purpose of gas-control, drainage, providing emergency exits; in the zone of the advancing basic pressure; in unstable rocks, in zones of geological violations; mounting suspended monorail roads; foundationless mounting of tape conveyor stations.

The type of the working immediate roof is taken into account (Table).

Presenting the main material. To ensure a high level of loads of the breakage face, its advancing is to make 8 to 12 m/day, and to prepare the stocks the rates of driving development workings are to be not less than 15 to 25 m/day.

In present day conditions in the world practice the following three schemes of the non-pillar technology are used in coal mines with long breakage faces: with preserving workings for reuse; with skin-to-skin to the developed space working driving; with driving coupled workings with dredging a pillar between them by an adjacent long wall face.

The most progressive scheme of the non-pillar technology is the technology of preparing and working out the layers by preserving extraction workings at the border with the extraction space when working out the adjacent long wall face. At this, stability of reusable workings is provided by developing a bearing layer of rocks using a two-level deep-laid bolting and a high bearing ability in combination with a strengthening support.

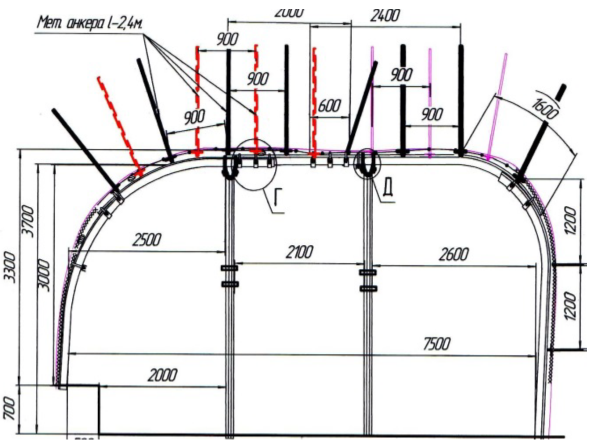


Fig.1. A single-level diagram of the roof bolting with a metal arch support

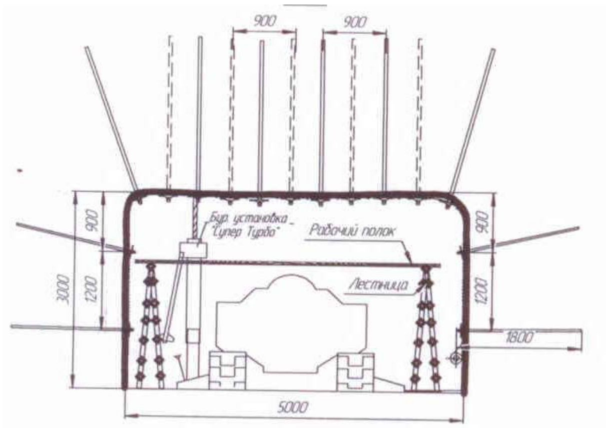


Fig.2. A single-level diagram of the roof bolting

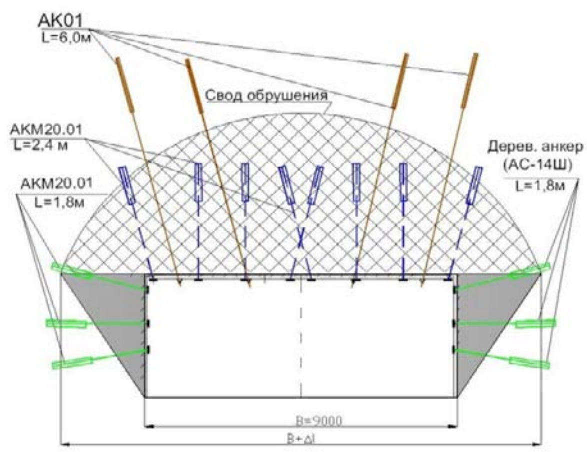


Fig. 3. A two-level diagram of the roof bolting

Table

Working immediate roof types

I roof type	II roof type	III roof type
Uniform, from laminated slate, mainly clay sandy-argillaceous and sandy ones (soap stones and aleurolites), $R_c < 60$ MPa	Non-uniform, massive sandstones and limestones, mainly $R_c > 80$ MPa	Non-uniform, with intensive jointing in the zones of plicative and disjunctive violations

The second level roof bolting mounted in a repeatedly used working when the roof rocks displace to 50 mm after mounting the main roof bolting, develops a bearing layer of rocks perceiving loadings from the overlying deformed rocks of the roof which arise in the zone of the stopping effect whose bearing ability decreases with increasing displacements in the reusable working.

Decreasing the extent of effect of the prism of slipping in the sides the reusable workings fixed by both a frame and an anchor support, is reached by mounting in them an anchor support with the rod length determined by hardness of the side rocks which does not exceed 2.0 m including a two-level steel polymer anchor support with the rod length of 3.0 m and longer, the effort of the rood fixing in the rock – 130 to 160 kN, defining the sequence of mounting a steel polymer anchor support of both the first and second levels taking into account the enclosing rocks hardness, the working flight and coefficients of cavability and stability; this provides a steady condition of the reusable workings that are in the zone of the stoping effect.

It was established that in the range of time before working supporting with a strengthening roof bolting at any stage of the mining pressure intensity, the roof rock displacements are not to exceed 50 mm; displacements of 50, 100, 150, 200 mm lead to decreasing the bearing ability of the consolidated system of 'the deformed rocks stitched with anchor rods' by 15, 50, 55, 65 per cent respectively. Due to the prisms of slipping in the sides of workings, the flight increment by the double size of the roof rock displacement in the middle of the working occurs and makes 0.5–1.7 m. To eliminate these negative phenomena in the sides of workings there is mounted a roof bolting with the rod length determined by the depth of the working laying making 2.4–5.2 m; simultaneously the width of the zone of the rock destruction in the sides for medium depths is 2.1–2.6 times less than the width of the prism of slipping, and at larger depths it is 1.7–2.2 times less provided the rock destruction occurs under the conditions of mono-axial compression. At a larger distance the rocks of the prism of slipping are under the volume compression, the 2.0 m long and more bolt rods, fixed in this area, have the value of the wrest effort of 60–80 kN, thus providing reduction of the rock displacement in the sides of workings to 200–250 mm.

When operating mines with the growth of the working depth, one of the problems requiring a solution is ensuring stability of workings. Sheeted workings are most subject to the effect of mining pressure. Their cross-sectional area losses reach 60–70 %. It leads to 20 % of workings being annually repaired and re-supported. The share of costs of driving, fastening and supporting workings reaches 15–20 % of the coal mining cost. More than 10 % of underground workers are engaged in the working repair.

The experience of using the profiles of a large standard size and increasing the density of the metal frame support (MFS) mounting shows that with a significant increase in metal consumption of workings and accordingly with labour input for constructing a frame support, the cumulative effect turns out insignificant. Practice of its implementation revealed a number of serious shortcomings which lead to considerable deformations of workings: crossbars flattening, pressing of side legs into the section cavity, failure of lock connections, insufficient realization of the support pliability. Thus, constructive modernization of the support itself and the technology of its mounting cannot essentially provide the workings stability and reduce the costs of their supporting.

The weakest link in the solution of the issues of increasing efficiency of using progressive technology of the roof bolting is insufficient study of geomechanical processes near workings.

The conditions of supporting workings with different types of fastening in the zone of the stoping effect are studied by the example of a conveyor intermediate entry of $49K_{10^{-3}}$ long wall face at Kostenko mine (Karaganda region, the Republic of Kazakhstan). The extracted K_{10} layer thickness in the western wing of the mine makes 3.7–4.0 m. The immediate roof changes across the pitch from 3 to 7 m and is presented by argillites. The main roof is formed by weakly joineds and stones of 24–32 m thickness. The maximum value of the heaving floor after two years of supporting the working made 0.55 m. To provide the needed cross section in front of the long wall face at the distance of 50–80 m there was made the entry ripping to 0.5–0.6 m.

The optimum conditions of supporting were provided on the part of conveyor intermediate entry $49K_{10^{-3}}$ of Kostenko mine (Karaganda coal basin, the Republic of Kazakhstan) of a semi-arch form 50 m long fixed with a mixed support (bolts in combination with MFS) with the density of 1.33 frames per running meter. This part of the working features the following changes in the support state: deformation of the crossbar and its rush on the lines of runs – 60 %; deformation of compound racks in the vertical plane – 1.5 %; deviation of frictional racks from the vertical position, mainly through the first run from the breakage face – 70 %.

In this regard studying the features of the rock massif deformation around development workings with a roof bolting at various angles of the layer and depth of anchoring, substantiation of the roof bolting parameters and definition of the rational area of its use is a topical task of mining.

The purpose of the studies is to develop a technology of intensive and safe driving extraction workings on the basis of the revealed regularities of the adjoining rock massif behaviour, and optimizing the parameters of technological schemes of the preparatory work providing increase in the efficiency of underground mining functioning. The idea of the studies consists in controlling the anthropogenic stressed-and-strained state (SSS) for developing the efficient technology of fastening the near-contour massif.

The variety of mining-and-geological and mining technological conditions of using workings and the related mechanism of interaction of the rocks and the support has caused the emergence of a number of various geomechanical models of the rock massif condition around workings. Moreover,computer-assisted mathematical modelling is the most perspective at present.

In the studies presented, the analytical modelling is carried out with the use of a numerical method of finite elements. The modelling is performed for the conditions of sheeted conveyor development of K_{10} layer at Kostenko mine (Karaganda coal basin) with the depth of development of 400 m and the layer thickness of 3.8 m. The studies were carried out on mathematical models with the use of the ANSYS software complex that permitted establishing the effect of mining-and-geological factors on the service conditions of mining workings supports.

In the ANSYS software complex a model of the enclosing rocks massif was built corresponding to the K_{10} layer bedding conditions.

The effect of the working section form and the layer angle on the value of the arising maximum stresses in the rock massif is studied when fastening a working with the roof bolting.

With a vaulted (arch) shape of the extraction development cross section normal stresses (σ_y) grow with increase in the layer angle (α) from 10° to 40° according to the exponential function in the range from 10 to 13.5 MPa.

For the rectangular shape of the extraction working cross section, maximum normal stresses σ_y grow at α = 10–20° from 1.2 to 3.5 MPa, and then fall a little at α = 20–40° from 3.5 to 3.0 MPa. Longitudinal stresses (σ_x) increase from 49 to 53.4 MPa at α = 10–30°, then drop sharply to 52 MPa at α = 40°. Tangential stresses (τ_{xy}) grow according to a weakly expressed exponent function from 18 to 38 MPa with changing a = 10–40°.

For a polygonal shape of an excavation working cross section, tendencies of changing stressed-and-strained state approximately follow the nature of changing the dependences with a rectangular shape of the working section. Only stresses σ_y are 1.5 times higher; on the contrary, σ_x is by 2–3 MPa lower, and τ_{xy} is 1.5–2.0 times higher [3, 4].

The studies conducted permit drawing a conclusion regarding the preference of using the rectangular shape of the extraction working section with the roof bolting of enclosing rocks for the development of the K_{10} layer at Kostenko mine.

Studies of stressed-and-strained state of enclosing rocks depending on the layer thickness of the easy-to-break rocks with different length of their bolting have also been carried out. The studies were performed applying a working with a trapezoid shape of cross section with the following parameters of the design scheme: the 15° angle of seam inclination, 3.8 m thickness; 400 m depth of development; 15.5 square metres of the working section; 0.022 m bolt diameter.

The nature of changing and distributing stresses in the roof, soil and sides of the working has been studied. With the layer of the easy-to-break rocks from 1.03 to 6.0 m and the bolt length from 2.4 to 5.0 m the following changes of stresses occur around the working. The maximum and minimum normal stresses with the growing length of the bolt (from 1.5 to 6.0 m) and increase in the layer thickness of the easy-to-break rocks (for example, made of argillite) from 1 to 6 m grow with the proportional linear dependence (Fig. 4, *a*).The changes of stresses in the considered range in the longitudinal plane with the growing length of the bolt and increase in the layer thickness of easy-to-break rocks have the following tendencies: stretching stress decreases, and squeezing stresses make a jump with the bolt length 3.0–3.5 m and on the whole are in a narrow range (42–48 MPa).

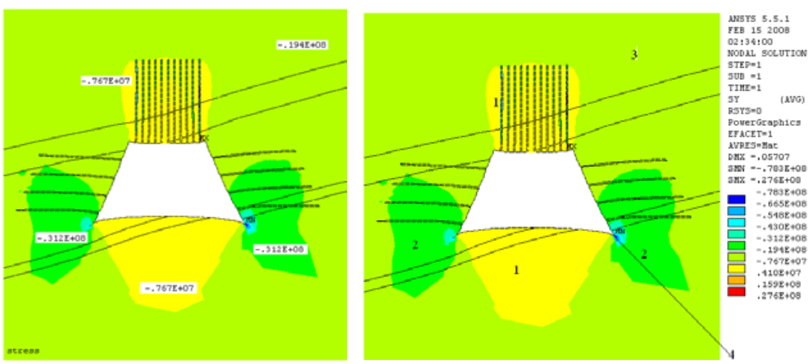
The regularities of changing tangential stress have an increasing tendency with the layer thickness of argillite to 5 m, and with the layer thickness of argillite of 1.0–3.5 m increase with changing the bolt length from 1.5 to 3.0 (3.5) m, and then decrease. Moreover, the increasing diameter of blastholes (to 0.05 m) affects the arising stresses negatively and leads to their double growth within the entire range.

The conducted studies of stressed-and-strained state of enclosing rocks depending on the layer thickness of the easy-to-break rocks with different length of bolting allowed establishing the nature of the side rocks behaviour in the zones of their arrangement [3, 4].

In Fig. 4 there is presented the distribution of normal and longitudinal stresses with the argillite layer of 7.5 m around the excavation working contour.

The analysis of stress distribution shows that around a working there are zones of unstable rocks. In a larger extent, it concerns the roof and the soil of the working, as well as its sides in the field of the lower part of lateral faces of the working contour. The maximum value of normal stress arises in the bolt located on the working roof in the right extreme bolt in the place of its fixing. The maximum value of longitudinal stress arises in the bolt located on the right side surface of the working (the first one from below).

The above-mentioned theoretical and practical recommendations allow developing progressive technological schemes of the roof bolting of mining workings one of which is presented below.



a *b*

Fig. 4. Distribution of normal (a) and longitudinal (b) stresses: 1 – very unstable zone; 2 – unstable zone; 3 – unstable zone; 4 – zone of middle stability; stable zone at the minimum point

The way of supporting a development working. The purpose of this way is to ensure works on support setting in the zone with increased stress in the near-contour rocks, especially while driving workings on outburst-prone layers.

The implementation of the proposed way of supporting development workings will allow fixing the rocks in the zone of raised stress in advance. This will prevent deformations (they decrease by 20–30 %) at their exposure in the course of driving workings [5–8].

The way of supporting a development working when the layers of enclosing rocks are fixed with bolts and are declined to the bedding, be distinctive in that the bolts are placed directed forward to the zone with the raised stress located at the angle on the front of the driven working determined by the formula

$$\beta = \frac{\gamma_m + \gamma_n}{2},$$

where γ_m and γ_n are directions of the vertical and lateral stress vectors respectively.

Fig. 5, *a* presents the longitudinal type of the way of supporting a development working, and Fig. 5, *b* shows a plan view.

The zone of increased basic mining pressure *1* (1.3–1.5 γH, where γ is the density of enclosing rocks, t/m^3; *N* is the depth of driving a working, m) is located in the roof and sides of the working contour and adjoins directly the mobile plane *2* of the driving face and its wave *3* goes ahead the front of the working advance.

When breaking the next cycle *4* of the mining weight on the front *5* of the working advance in the roof and sides, blast-holes are drilled and bolts *6* and *7* are established in the zone of the increased stress beforehand, which allows achieving the 'stitching' of side rocks in this zone. The angle of the fixing bolts arrangement is β.

The specific implementation of this way of mounting a front line support is presented in Fig. 6.

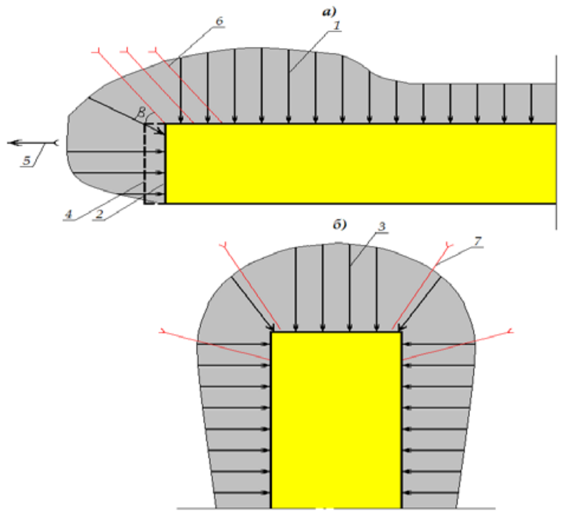
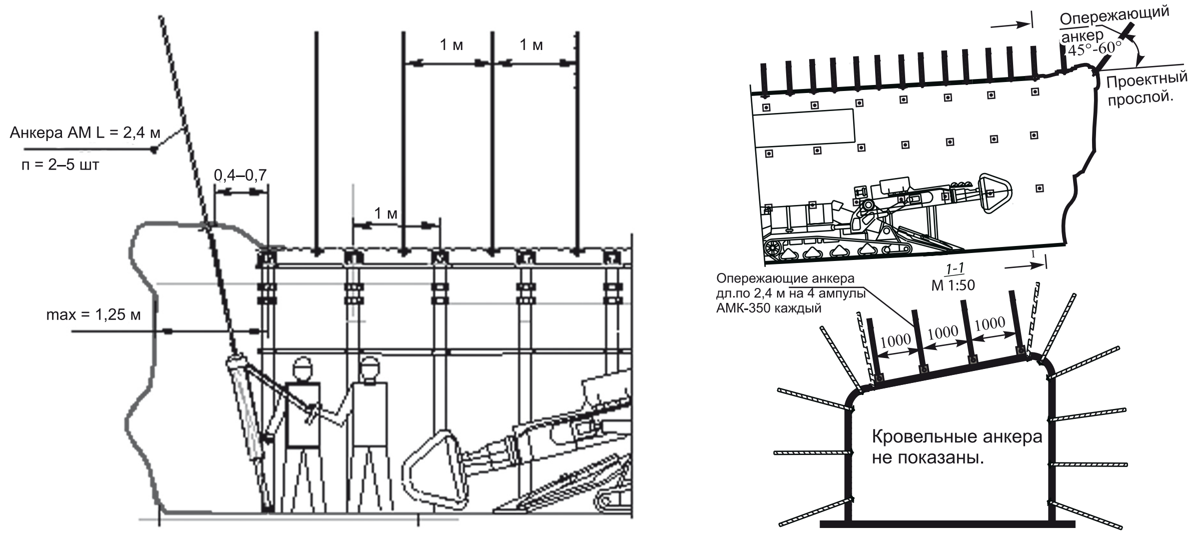


Fig. 5. Way of supporting development workings: 1 – zone of increased mining pressure; 2 – mobile plane of the advancing face; 3 –mining pressure wave up front of the working advance; 4 – minerock breaking cycle; 5 – direction of the working frontal zone; 6, 7 – bolts mounted respectively up-front at the angle to the layers and in the zone of increased stresses; a – longitudinal view of the working, b – plan view

Conclusions. When the roof collapses as a consequence of violation of stability of enclosing rocks while leaving the wall face of more than 0.75 m – with the roof bolting and 1.25 m with the mixed supporting, the mounting of inclined steel-and-polymer bolts in the working roof is performed.

The methods of controlling geomechanical processes when carrying out mining operations at the deep levels of coal mines have been developed.



a *b*

Fig. 6. Specification of using the front line support with the unstable roof (Saranskayamine, Karaganda coal basin): a – erection process; b – technological scheme: longitudinal view and cross section

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Мета. Розробити прогресивні технологічні схеми анкерного кріплення гірських виробок у залежності від розподілу напруги навколо виробок.

Методика. Методика вибору способу кріплення: дослідження напружено-деформованого стану, проявів гірського тиску, умов підтримки виробок у залежності від гірничо-геологічних, гірничотехнічних і технологічних параметрів для встановлення міри їх впливу на ефективність анкерного кріплення виїмкових виробок і обґрунтування паспортів кріплення із забезпеченням стійкості, зниження дефектності й витрат на їх проведення та підтримку.

Результати. Досліджені напружено-деформований стан, прояви гірського тиску, умови підтримки виробоку залежності від гірничотехнічних і технологічних параметрів. Дослідження дозволили встановити міру їх впливу на ефективність застосування анкерного кріплення виїмкових виробок.

Наукова новизна. Наукова новизна запропонованих у роботі способів полягає в наступному:

- встановлені закономірності зміни зон непружних деформацій з розвитком їх у часі та стійкості контурів виробки в залежності від гірничо-геологічних і гірничотехнічних чинників з визначенням параметрів кріплення для надійної експлуатації виробки;

- створення на базі аналітичного моделювання технології, систем і засобів для проведення гірських виробок, що сприяють зниженню дефектності їх контурів.

Практична значимість. Представлені результати досліджень зі створення технології інтенсивного й безпечного проведення виїмкових гірських виробок на основі виявлених закономірностей поведінки масивів гірських порід, що примикають до них, оптимізації параметрів технологічних схем підготовчих робіт з управлінням техногенним напружено-деформованим станом для підвищення ефективності технології кріплення приконтурного гірського масиву.

Ключові слова: *гірські виробки, деформаційні процеси, параметри кріплення, геомеханічні процеси, анкерне кріплення, гірський тиск, гірничотехнічні чинники, схеми розвитку гірських робіт, напружено-деформований стан*

Цель. Разработать прогрессивные технологические схемы анкерного крепления горных выработок в зависимости от распределения напряжений вокруг выработок.

Методика. Методика выбора способа крепления: исследование напряженно-деформированного состояния, проявлений горного давления, условий поддержания выработок в зависимости от горно-геологических, горнотехнических и технологических параметров для установления степени их влияния на эффективность анкерного крепления выемочных выработок и обоснования паспортов крепления с обеспечением устойчивости, снижения дефектности и затрат на их проведение и поддержание.

Результаты. Исследованы напряженно-деформированное состояние, проявления горного давления, условия поддержания выработок в зависимости от горнотехнических и технологических параметров. Исследования позволили установить степень их влияния на эффективность применения анкерного крепления выемочных выработок.

Научная новизна. Научная новизна предложенных в работе способов заключается в следующем:

- установлены закономерности изменения зон неупругих деформаций с развитием их во времени и устойчивости контуров выработки в зависимости от горно-геологических и горнотехнических факторов с определением параметров крепи для надежной эксплуатации выработки;

- создание на базе аналитического моделирования технологии, систем и средств для проведения горных выработок, способствующих снижению дефектности их контуров.

Практическая значимость. Представлены результаты исследований по созданию технологии интенсивного и безопасного проведения выемочных горных выработок на основе выявленных закономерностей поведения примыкающих к ним массивов горных пород, оптимизации параметров технологических схем подготовительных работ с управлением техногенным напряженно-деформированным состоянием для повышения эффективности технологии крепления приконтурного горного массива.

Ключевые слова: *горные выработки, деформационные процессы, параметры крепления, геомеханические процессы, анкерная крепь, горное давление, горнотехнические факторы, схемы развития горных работ, напряженно-деформированное состояние*

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