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STABILITY ANALYSIS OF TWO-LEVEL ANCHOR SUPPORT INSTALLED IN THE WEAKLY METAMORPHOSED ROCKS

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АНАЛІЗ СТІЙКОСТІ ДВОРІВНЕВОГО АНКЕРНОГО КРІПЛЕННЯ У СЛАБО МЕТАМОРФІЗОВАНИХ ПОРОДАХ

Purpose. Determination of the effective interaction parameters of cable anchors and other elements of combined bolting system while maintaining the recessed development in unfavorable geological conditions to increase its stability.

Methodology. The main method of study was a comparative statistical analysis of results of computational experiments carried out by the non-linear finite element formulation for the geomechanical problem. Modeling of water content, cracks content and rheological characteristics of the rock massif was carried out in the form of correction coefficients, and specifies a family of curves with three control parameters. The heterogeneity of the rock mass was set geometrically.

Findings. Quantitative and qualitative indices of the impact of rope anchors on the change in the stress intensity of resin-grouted roof bolts were defined. The basic area of reducing the stress intensity is directly adjacent to the circuit output. The degree of exposure of a combination of roof bolting to heterogeneity of the enclosing rock massif and non-linear mechanical characteristics was determined.

Originality. The dependence of stress-strain state of resin-grouted roof bolts on the parameters of the installation of rope anchors with increasing depth of the weak development in the host rocks was estimated. The characteristics of the interaction of rock layers and rope anchors on the recessed dome of mine working were obtained.

Practical value. Parameters were worked out for application of combination of roof bolting as a bolting system element in mines located in the areas of geological faults, water-bearing rocks, upon the availability of thin inter layers of coal, calcite or carbon-bearing mudstones within more than 0.7 depths of anchors jointing. The limits of the angle of installation of rope anchors are developed, providing increase in the carrying capacity of the bolting system of resin-grouted roof bolts.

Keywords: *anchor, rope anchor, SSS, rock massif, extraction mine working*

Introduction. At the present time, a vast majority of mine workings of coal mines is done involving the use of anchor support. At the same time, technological capabilities of underground mining of mineral deposits enhance. Simultaneously, new tasks connected with anchor bolting arise.

Mines in Ukraine as well as those of Altai, Buriatia and Kazakhstan, have gained considerable experience of application of two-level anchor support to solve the following tasks: support of mine workings and roadheads up to 12 m wide; preliminarily driven and formed dismantling chambers; reinforcement of roadways support for their reuse [1] and non-pillar mining of coal reserves [2]; reinforcement of roadway support for stoping face operation without mechanized face-end support [3]; strengthening of mine workings support for their preservation with the purpose of gas-control, drainage, providing emergency openings [1, 4]; strengthening of roadway support in the zone of the advancing rock pressure [1, 2]; ensuring stability of near-the-contour massif of rocks of mine workings at shall depths, unstable rocks, in zones of geological faults [1, 3]; installation of suspension-type monorail [2], etc.

Statement of the problem. Redistribution of stresses in the rock massif during the drivage and support of mine workings and junctions is followed by significant horizontal and vertical displacements of rocks, both along the mine working line, and in bearing massif. Formation of deformation zones at disintegration of the massif promotes increase in the actual supported span of mine workings from its width (from B to $B + \Delta l$) and stratification height to $(0.5–0.7)B$ which makes it impossible to support mine workings without additional reinforcement of support [1].

Traditionally, prop, mixed and frame supports are used for support reinforcement of wide mine workings. Compared with them, anchor support has the following advantages: low material inputs and metal consumption; low labor intensity at delivery and installation; it does not obstruct the passage of people and transportation of the equipment; it does not require support remounting while installing equipment in mine workings.

Therefore, to provide a steady condition of wide mine workings and their junctions for the whole period of exploitation, it is the most appropriate to apply the two-level scheme of anchor bolting, where deep laying anchors (level 2) are used apart from anchors up to 3 m long (level 1). Anchors of second level are fixed in steady roof rocks outside the dome of natural rockfall taking into account weakening and deformation of mine working walls (Fig. 1). At the same time, unstable roof rocks are bolted with anchors of the first level and "suspended" on anchors of the second level to steady roof rocks outside the dome of natural rockfall.

The objective of the conducted research is the search of acceptable and optimal parameters of the two-level anchor system installation for supporting the dome of mine workings in weakly metamorphosed rocks**.**

Description of the computational model. The size of the computational model made 35 m wide, 23 m high and 0.4 m deep (along the mine working axis) in the main calculations and 4 m in the test ones. Restrictions in the form of conditions of symmetry of stress-strain state (SSS) in a continuous body were imposed on sides of the calculated area. On the top and lower edges of models, loading in the range from 5 to 10 MPa was applied which corresponds to the depth ranging from 400 to 800 m regarding the Western Donbas.

TYSS Frame support (Tent-shaped Yielding Stable Support) is modeled by real geometry of cross-section of SCP (Special Concave Profile) with thickness of a special profile of 123 mm and 149.5 mm wide for SCP-27. The special profile is made of St5 steel with the following mechanical characteristics: fluidity point of $\sigma_F = 270$ MPa, module of elasticity $E = 21 \cdot 10^4$ MPa, Poisson›s ratio $\mu = 0.3$. Widely-mashed steel lattice, which is put between a rock contour of mine working and frame support, is used to ensure communication between anchors and a frame, as well as to prevent free rockfalls in cavity of mine workings. Modeling of the given technological object is performed by means of insertion into the model a special 50 mm thick interlayer with the lowered strength characteristics, concerning the material of a real lattice, and the small value of resistance to transverse effort.

The anchors that were modeled within the test calculation are 2.4 m length with the diameter of 22 mm. The side anchors (Fig. 1, *a*) are installed at a distance of 800 mm from the average with an angle of slope of 30 to the vertical. The scheme of anchors installation is taken from passports of drivage and bolting of roadways at "Yubileina" and "Stepova" mines.

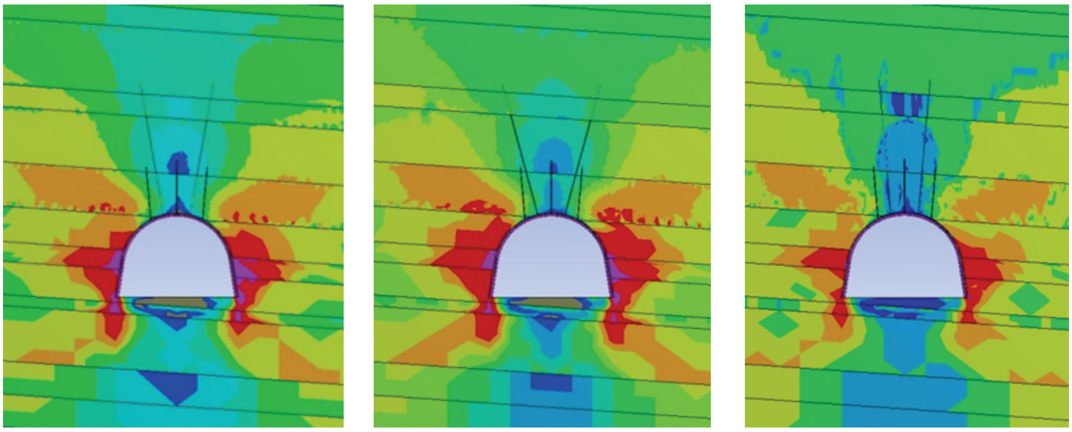
While modeling the rope anchors their length made 6 m, the "working" diameter of model of a rope was 26 mm. The step of installation of the rope anchors made 1 m, which does not coincide with a step of installation of other elements of the support, therefore, the case with the smallest mutual influence of the frame, resin-grouted and rope anchors is chosen for calculation when the distance between these objects made 200 mm in the direction of the mine working axis.

The workings layout towards the coal seam can be performed with underbreaking up to 1.0...1.5 m. Therefore, for the testing model, a value of under breaking of 1.1 m was chosen from seam up-dip. It allows keeping adequacy of the model to real features of in-seam mine workings bedding within a linear error to 10 % of SSS system field of the system around frame support props [1]; in other areas of the model the error is significantly lower.

Calculation conducted in elastic-plastic statement with regard to weakening factors of near-the-contour rocks is quite enough to define the characteristics of rope anchor behavior [3]. The bilinear diagram of stresses and deformations relation is used for the description of materials behavior of the model in a limit and out-of-limit state. The computing error accepted during the given computing experiment made 4 % that cannot negatively affect quality and absolute measures of obtained values of SSS of the considered system.

Testing of computational model. On the basis of testing calculation, estimation of minimum permissible sizes of the model on vertical Y, horizontal X and Z coordinates (model depth) is performed. The analysis (Fig. 2) of the diagrams obtained has allowed concluding that influence of cross symmetry, in this case, does not lead to perceptible distortion of the stresses field. Values of stresses did not differ more than by 0.07 MPa which makes no more than 11 % of an error during comparison in distinguishing points of the separate planes of the model cross section. Thus, it becomes possible to conduct calculations without a large number of frames, which allows significantly reduce dimension of a problem.

Along the upper and lower boundaries of the model (depth of the mine working axis layout is $H = 600$ m, $\gamma = 75$ kN/m^3) almost uniform (deviations to 1.2 %) (7 MPa on the upper boundary and 8.5 MPa on lower one) distribution of vertical component σ_y is established that is equal to the value of untouched massif and indicates accepted vertical sizes of the model. In the sides of mine working, perturbations σ_y are fading at a distance, approximately, twice as small as the layout of the side boundaries of the model. Unloading zones σ_y are formed in the roof and bottom, in the sides, basic pressure is



a *b* *c*

Fig. 1. Stress intensity at the depth of H = 800 m with an angle of anchor installation of 85° (a), 80° (b) and 75° (c)

formed, which corresponds to existing geomechanical research studies. The analysis of the diagram of the given stresses distribution shows their full stabilization on the lower boundary of the model, on the upper boundary of the model, perturbations σ are rather small (to 4.7 %) and are caused by influence of rock layers falling on distribution of efforts on the bedding planes. Near the roadway, the distinct area of the unloaded rocks in roof and bottom is observed, and the sides of mine working feature concentration of stresses that intensifies the process of bottom heaving of weak rocks. These results are in agreement with the developed representations [1–3] about geomechanical processes nearby mine working.

Presentation of the main research. The analysis of influence of an angle of installation of rope anchors on internal effort distribution in the geotechnical system of extraction mine working in complicated mining-and-geological conditions will be based on changing the characteristics of a stresses maximum in the computational model. Since the change of the installation angle of the anchor implies redistribution of influence on its behavior of various a stresses components, usage of diagram of stresses σ intensity is the most preferable while analyzing calculation results (Fig. 1).

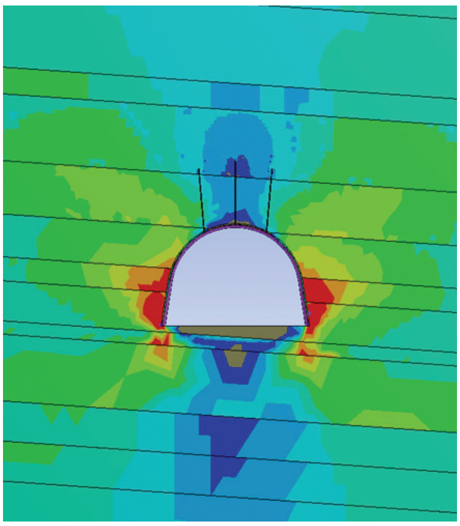


Fig. 2. Distribution of vertical stresses that were obtained while solving testing problem at the depth of H = 600 m

At the installation angles of rope anchors which are close to the vertical, 85 to 88°, distribution of intensity pattern has a number of features caused, first of all, by peculiarities of geological structures of the massif. Fig. 1, a shows clearly that rope anchors do not transfer load on a meter layer of sandstone. Thereby, the scheme of a suspension of the immediate roof of mine working to the main roof is not implemented. As a result, excessive difference between the main stresses in the sole occurs (Fig. 1, *a*) leading to an intensive rock heaving. At the same time, rather small zones of high intensity of stresses σ are observed in the walls of mine workings. It creates illusion of effective operation of rope anchors. However, similar redistribution of stresses leads to significant value of maximum difference between the main stresses in the construction of the frame-anchor support. It means that under such mining-and-geological conditions, the large installation angles of rope anchors result in rapid growth of pushing away efforts of mine working bolting.

From the value of an installation angle of rope anchors of 83° onwards, distribution of stresses intensity pattern in rock massif changes sharply. Firstly, diagrams (Fig. 1) show that rope anchors complete the main task of supporting the immediate roof of mine workings, stresses intensity increases sharply in that part of the anchors which passes through a sandstone layer. Secondly, in the sole, intensity of stresses has the minimal value; therefore, a possibility of starting the mechanism of rock heaving becomes minimal. Thirdly, in the walls of mine workings, zones of high intensity of stresses are formed that means that significant shearing stresses occur. It is caused by decreasing pressure on the boundaries of lithologic differences and leads to increasing wall pressure upon frame props, at the same time values of a vertical component of rock pressure decrease.

At the installation angles of rope anchors of 72 to 83°, insignificant growth of stresses intensity, close to linear, in the walls of mine workings is observed. If you compare the respective areas of diagram stresses in Fig. 1, *c* and Fig. 1, *b*, you will see that the growth is followed by increasing unloading zone in the immediate roof of mine workings. It is indicative of increasing efficiency of rope anchor operation with increase in an installation angle. However, improvements of such index are followed by decreasing operation of resin-grouted roof bolts, in other words in the "frame-anchor support-rope anchors" system there occur changes of components in the load-bearing construction resulting in the growth of stresses in frame with the loading on resin-grouted roof bolts decreasing. Distortion in the distribution of internal efforts support construction that can cause premature failure of one of its elements occurs.

Thus, it is necessary to consider the most effective installation angle of the rope anchor proceeding from two conditions: firstly, the influence of the installation angle on distribution of stresses in near-the-contour massif; secondly, mutual influence of support structural elements at various installation angles of rope anchors. Results of the analysis of the first situation can be presented in the form of a set of diagrams which clearly demonstrate extent of degree of influence of rope anchors on the maximal values of stresses intensity (Fig. 3).

The second situation requires an independent analysis of interaction in two systems: "rope anchors – resin-grouted roof bolts" and "rope anchors – frame support". We choose the main calculation with rope anchors established at an angle of 80° at laying depth of mine working of $H = 600$ m as the basis of the analysis.

Based on comparison of the obtained results, it is obvious that influence of rope anchors on resin-grouted roof bolts leads to decreasing stress intensity in bodies of the last ones. In the illustrated example, unloading of side resin-grouted roof bolts made about 14 %, which is equal to about 21 MPa in absolute values. At the same time, the main zone of decreasing stress intensity situated directly along the rock contour of mine workings. It allows drawing a conclusion of reduction of stress gradient in the dome of mine workings that means decreasing probability of active crack content formation in this area of the computational model. On the other hand, the given result calculations shows that changes of SSS in the central resin-grouted roof bolt towards the testing calculation made about 4 % that is comparable to a computing error.

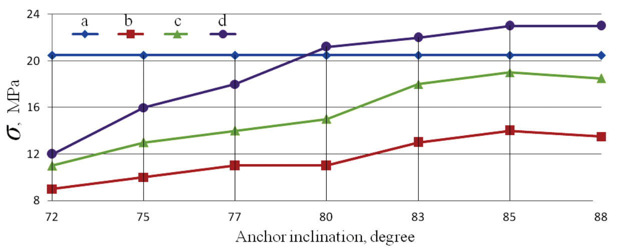


Fig. 3. Diagrams of maximum stress intensity changing in rock massif for testing calculation H = 600 m (a) and at different installation angles of anchor at depths of: H = 400 m (b); H = 600 m (c) and H = 800 m (d)

However, from the installation angle of rope anchors of 83° onwards, the pattern of their interaction with resin-grouted roof bolts begins to change. The central resin-grouted roof bolt unloads in the calculation option as well with the installation angle of anchors of 88°, the size of unloading reaches a maximum of 12 % that is followed by growth of load on side anchors by the value of 9 % concerning the calculation for the installation angle of rope anchors of 83°. Dependences of changing condition of resin-grouted roof bolts on the depth of mine working drivage and an angle of rope anchors inclination are given in Fig. 4.

The obtained dependences (Fig. 4) coupled with stress pattern (Fig. 1) allow drawing a firm conclusion of qualitative change that is of non-linear character, featuring characteristics of the anchor system of the level 1 during the measurement of rope anchor layout (level 2). At the same time, construction features of resin-grouted roof bolts – including length and angle of inclination – influences the distribution of internal efforts in rope anchors of deep laying in a less degree rather than vice versa. The extent of influence of the angle of inclination of the rope anchor grows proportionally to the depth of laying of supported mine workings and has the characteristics close to linear.

Now it is necessary to consider the features of interaction of the frame and rope anchors revealed as a result of calculations. During the analysis of vertical stresses diagrams (Fig. 1, 2) two features of changing distribution of vertical stresses in frame support were revealed while applying rope anchors: firstly, rope anchors provide decreasing stretching stress value at the top part of the frame to 37 %; secondly, the density of the change and value of gradient of vertical stresses in props of

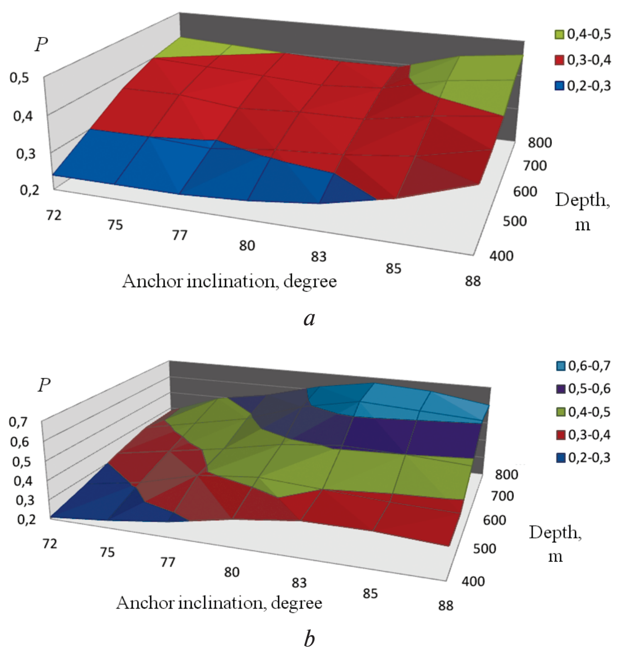


Fig. 4. Degree of impact of an installation angle of rope anchors on stress distribution in the side (a) and central (b) resin-grouted roof bolts taking into account the depth of mine working drivage

frame support decreases consequently by 22 and 9 %. These indices unambiguously indicate improvement of operational conditions of frame support during application of rope anchors in the given mining-and-geological conditions.

Diagrams of maximums of vertical displacements arising in props of frame support during installation of rope anchors under various angles are represented in Fig. 5. In general, proceeding from the presented pattern, it is necessary to make a conclusion of positive impact of rope anchors on stability and constructive durability of frame support. At the same time, it is necessary to notice that dependence between the installation angle of a rope anchor and value of stress maximum is of pronounced non-linear character and with an increasing angle the extent of the anchor influencing the SSS in props of a frame falls.

Thus, all the features of influence of depth of mine working layout and the installation angles of rope anchors on formation of stress-strain state of the "anchors – support – massif" system have been considered during the complex analysis. This analysis has allowed receiving a number of non-linear dependences characterizing peculiarities of applying rope anchors at "Yubileina" and "Stepova" mines, PJSC "DTEK Pavlohradvuhillia" that allowed increasing dome stability of extraction mine workings at the available production units.

Conclusions. Application of resin-grouted roof bolts as the only type of bolting is not acceptable in mine workings located in zones of geological faults, water-bearing rocks if there are thin interlayers of coal, calcite or carbon-bearing mudstones within more than 0.7 depths of anchor jointing. The bearing capacity of the "anchor-rock" system in this case decreases by 2–3 times on tangential stresses, which does not provide dome stability of mine workings.

The two-level system allows keeping a stable condition of dome of mine workings performed in complicated mining-and-geological conditions by decreasing a gradient of internal efforts to 20–30 % that reduces probability of growth of horizontal and vertical cracks by coefficient 0.17 while determining optimum indices of geometry of rope anchors and resin-grouted roof bolts installation. It allows increasing the term of exploiting mine workings which are under the influence of intensive rock pressure.

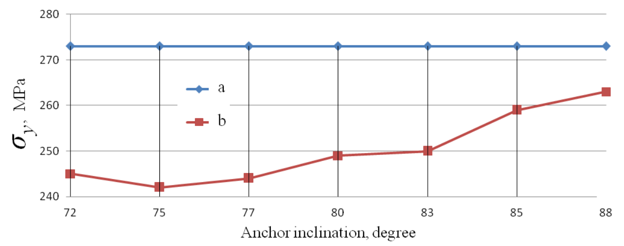


Fig. 5. Diagrams of vertical intensity maximum changes in frame support depending on installation angle of rope anchors at the depth of 600 m (b) in comparison with the testing calculation (a)

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Мета. Визначення ефективних параметрів взаємодії канатних анкерів та інших елементів комбінованої кріпильної системи при підтримці виробки в несприятливих гірничо-геологічних умовах для підвищення її стійкості.

Методика. Основним методом дослідження став порівняно-статистичний аналіз результатів проведених обчислювальних експериментів, виконаних методом кінцевих елементів при нелінійній постановці задачі геомеханіки. Моделювання обводненості, тріщинуватості та реологічних характеристик породного масиву було виконано у вигляді поправочних коефіцієнтів і завдання сімейства кривих з використанням трьох керуючих параметрів. Неоднорідність породного масиву задавалася геометрично.

Результати. Визначені якісні та кількісні показники впливу канатних анкерів на зміну величини інтенсивності напружень у сталеполімерних анкерах. Виявлена основна зона зниження інтенсивності напружень, що примикає безпосередньо до контуру виробки. Визначено ступінь впливу на комбіноване анкерне кріплення неоднорідності породного масиву та його нелінійних механічних характеристик.

Наукова новизна. Встановлена залежність зміни НДС сталеполімерних анкерів від параметрів установки канатних анкерів зі зростанням глибини закладення вироблення у слабких породах. Отримана характеристика взаємодії породних шарів і канатних анкерів над склепінням виробки.

Практична значимість. Вироблені параметри застосування комбінованого анкерного кріплення в якості елемента кріпильної системи в гірничих виробках, розташованих у зонах геологічних порушень, обводнених порід, при наявності тонких пластів вугілля, кальциту або вуглистих аргілітів у межах глибини загортання анкерів. Визначені межі кута установки канатних анкерів, що забезпечують підвищення несучої здатності кріпильної системи сталеполімерних анкерів.

Ключові слова: *анкер, канатний анкер, породний масив, виймальна виробка*

Цель. Определение эффективных параметров взаимодействия канатных анкеров и других элементов комбинированной крепежной системы при поддержании выемочной выработки в неблагоприятных горно-геологических условиях для повышения ее устойчивости.

Методика. Основным методом исследования стал сравнительно-статистический анализ результатов проведенных вычислительных экспериментов, выполненных методом конечных элементов при нелинейной постановке задачи геомеханики. Моделирование обводнёности, трещиноватости и реологических характеристик породного массива было выполнено в виде поправочных коэффициентов и задания семейства кривых с использованием трех управляющих параметров. Неоднородность породного массива задавалась геометрически.

Результаты. Определены качественные и количественные показатели воздействия канатных анкеров на изменение величины интенсивности напряжений в сталеполимерных анкерах. Выявлена основная зона снижения интенсивности напряжений, примыкающая непосредственно к контуру выработки. Определена степень воздействия на комбинированную анкерную крепь неоднородности вмещающего породного массива и его нелинейных механических характеристик.

Научная новизна. Установлена зависимость изменения напряжено-деформированного состояния сталеполимерных анкеров от параметров установки канатных анкеров с ростом глубины заложения выработки в слабых вмещающих породах. Получена характеристика взаимодействия породных слоев и канатных анкеров над сводом выемочной выработки.

Практическая значимость. Выработаны параметры применения комбинированной анкерной крепи в качестве элемента крепежной системы в горных выработках, расположенных в зонах геологических нарушений, обводненных пород, при наличии тонких прослойков угля, кальцита или углистых аргиллитов в пределах глубины заделки анкеров. Определены пределы угла установки канатных анкеров, обеспечивающие повышение несущей способности крепежной системы сталеполимерных анкеров.

Ключевые слова: *анкер, канатный анкер, породный массив, выемочная выработка*

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CRITERION TO SELECT RATIONAL PARAMETERS OF SUPPORTS TO REDUCE EXPENDITURES CONNECTED WITH CONSTRUCTION AND MAINTENANCE OF DEVELOPMENT WORKING

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КРИТЕРІЙ ВИБОРУ РАЦІОНАЛЬНИХ ПАРАМЕТРІВ КРІПЛЕННЯ ДЛЯ ЗНИЖЕННЯ ВИТРАТ НА СПОРУДЖЕННЯ ТА ПІДТРИМАННЯ ПІДГОТОВЧОЇ ВИРОБКИ

Purpose. Substantiation of the parameter allowing predicting cost of mine working construction and maintenance under certain mining conditions taking into account a type of the mine working support, its parameters, repair size and cost as well as lifetime.

Methodology. Methods for generalization and comparative analysis, processing of underground investigation data, mathematical (numerical) modeling of geomechanical processes, and evaluation of economic efficiency have been applied.

Findings. Methodology to determine total costs for construction and maintenance of an extended mine working has been substantiated. A parameter of a mine working repairability has been proposed. The parameter considers intensity of rock contour displacements and cost of repair operations resulting from critical displacements of roof and