UDC 622.28.04242

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OPTIMIZATION OF PARAMETERS OF OVERWORKED MINING GALLERY SUPPORT WHILE CARRYING OUT LONG-WALL FACE WORKINGS

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ОПТИМІЗАЦІЯ ПАРАМЕТРІВ КРІПЛЕННЯ ВИРОБКИ, ЩО НАДПРАЦЬОВУЄТЬСЯ ПРИ ВЕДЕННІ ОЧИСНИХ РОБІТ

Purpose. The goal is to reach optimization of the supporting system of the Eastern intermediate drift of "Stepna" mine of DTEK Mine Office "Pervomaiske" to ensure reliable and effective maintenance of working over the entire life.

Methodology. Investigation and consideration of the geological conditions of mining and mining and technical features of overworking a single mine working when developing the overlying seam; conducting of computational experiments to determine the stress-strain state of the rock mass and support systems construction; rationale for the recommended support system parameters considering the use of "deep" strengthening of rocks.

Findings. The stress-strain state of rock, rock pressure manifestation and condition of maintaining workings depending on mining and processing parameters are investigated. Studies have established the rate of their impact on the effectiveness of applying support system at overworked workings. Eventually we have developed and justified recommendations for changing the supporting system, considering the use of "deep" strengthening of rocks. With respect to the estimated steel yield strength, the main length if racks is loaded on the level of 85–94 % and is in a pre-limit state.

Originality. It is to establish the characteristics of changes in the stress state of the rock mass and the degree of influence of the bearing pressure zone in front of the long-wall face onto the underlying area.

Practical value. We have developed recommendations for efficient and reliable supporting of the Eastern intermediate drift of "Stepna" mine of DTEK Mine Office "Pervomaiske" allowing the features of supporting of overworked workings.

Keywords: *bolting, computer experiment, stress-strain state, overworked mine working (mine gallery)*

Introduction. Conditions of carrying stoping and development operations at the mines of Western Donbas are greatly complicated by the weak unstable rocks of the roof and the ground when the rock strength is lower than that of the mined coal. Additionally they are influenced by a number of negative natural and technogenic factors: fracture, water content, volume of gas, etc. These circumstances must be taken into account when substantiating rational parameters of supporting the workings during coal seams mining.

Setting the problem. This case of the maintenance of the Eastern intermediate drift (EID) horizon 400 m is complicated by additional mining factors. Apart from complex geological conditions, a significant impact on the stability of working is made by a periodic overworking with lavas, mining the overlaying seam c_6. Being affected by the front bearing pressure zone in front of the face leads to a redistribution of the stress-strain state (SSS) of rock mass around a single working, which has a negative effect on its stability.

To offer an effective recommendation on supporting the given working, taking into account factors of overworking, we carried out a number of additional research studies that are based on a thorough study of the geological conditions of mining operations at the site of a mine field.

For a more specific review of the above-described case of using data at the site 171 of the of seam lava c_6, whose mining of which is being held this year. Fig. 1 shows the copy of the plan of mining operations, which indicates the relative positions of the overworked EID at the peg 106 + 5 – peg 109, which approximately corresponds to the middle of extraction pillar.

Let us consider separately the mining and geological prognosis of EID behavior hor. 400 m (Fig. 2), as well as physical and mechanical properties of the rocks.

The basic version of the intermediate fastening east drift horizon 400 m (Fig. 3) includes the use of type KSPU-11.7 support with special profile SIP-27. Installation close-

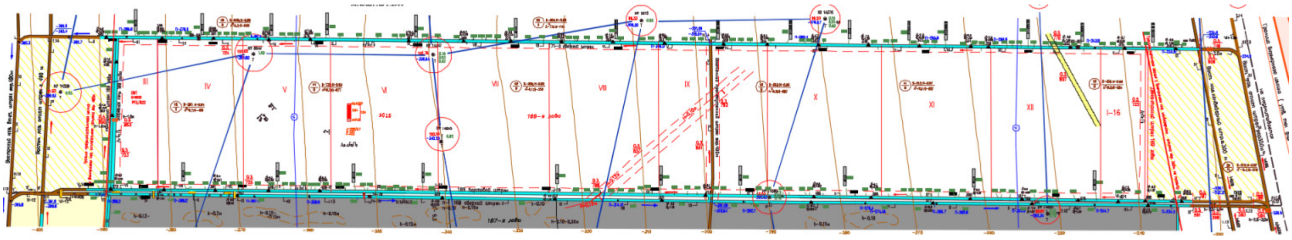


Fig. 1. The copy of the plan of mining operations of c_6 layer

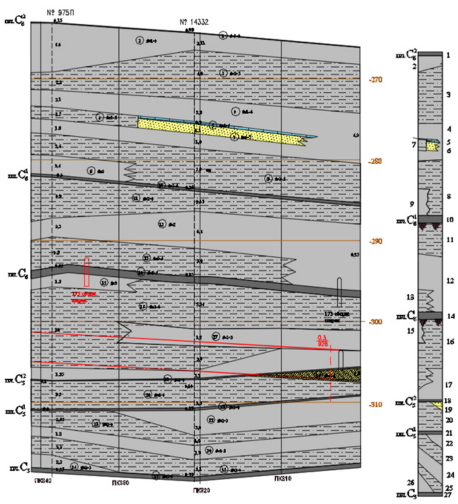


Fig. 2. Mining and geological section along the EID horizon 400 m

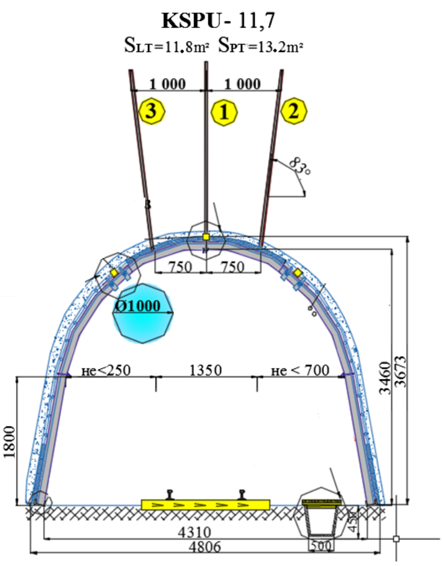


Fig. 3. The basic version support of EID horizon 400 m

ness of the three-tier frame support is 1.25 frame/m. At the working roof we set three polymer steel anchors with a length of 2.4 m.

A number of earlier studies on accounting factors affecting the stability of the working during the periodic overworking by lavas, mining the overlying coal seam [1, 2] revealed the features of the influence of rock pressure when moving the long-wall face. The feature of this mine technical situation is not typical influence of bearing pressure on the roof of the production. Moreover, the intensity of rock pressure is not constant but has three phases (the growth – peak – damping) depending on the location of the face.

This feature should be considered when developing a passport of supporting EID hor. 400 m, where the developing seam is located at 7 m vertically from the roof.

To some extent, the basic variant of supporting takes into account this feature, where anchorage is used for strengthening roof rock, consisting of three anchors which are installed at a distance of 0.75 m from each other.

However, considering the given significant size of the spread of the bearing pressure zone in front of the long-wall face, such closeness of installation of anchors is a visible lack of the basic variant of the support. Further studies are needed to determine the feasibility of this option.

Researching. To analyze the effectiveness of the existing system of supporting the Eastern intermediate drift at horizon 400 m, we have developed geomechanical model of the rock mass (Fig. 4). The model consists of 22 layers of rock, the thickness and physico-mechanical properties of which are set, based on the data of mining and geological prognosis (Fig. 2) and measuring with IGTM. Angle of bedding layer is 3 degrees. During a series of computing experiments we simulated moving long-wall face of lava 171 seam c_6 of EID working at horizon 400 m.

The series of experiments included different locations of the face relating to the overworking mine gallery during mining. This approach is necessary for a detailed consideration of various stages of the investigated mine and technical situation and establishment of laws of SSS distribution of the rock mass.

For presentation of the obtained results we used only diagrams of the stress intensity σ. We decided not to bring to the article the data about diagrams of stress displacements, vertical and horizontal σ_y, σ_x relatively.

When lava approaches to the mine working (Fig. 5, *a*) there occurs a merge of bearing pressure zones ahead of the face and in the side of working, that characterizes the increase in the influence of rock pressure on mine working. Dimensions of the area with stress of 20–30 MPa is 8–12 m across the width and up to 15 m heightwise. With longwall work approaching, the stress in vicinity of workings increases, which adversely affects the stability; the most complicated situation is observed in the face just above the drift (Fig. 5, *b*). Increased stress (20 MPa) applies to the entire area between the mountain range between the coal seam and the output, which makes 13–15 m across the width and 12 m heightwise. Undoubtedly, this is the most difficult period for the drift mainte-

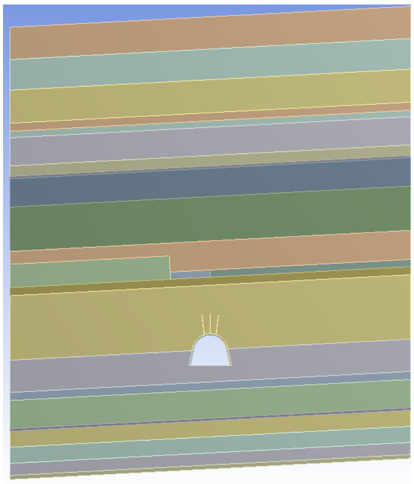


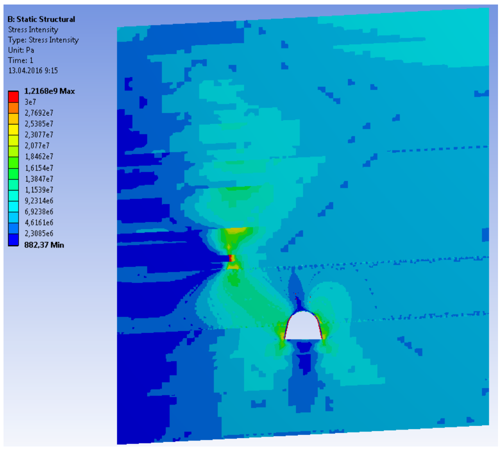
Fig. 4. Computer model of the rock mass when mining lava 171

nance, as after the passing of the long-wall face there is a discharge zone formed above the working due to the emergence of worked out area after the caving in coal seam (Fig. 5, *c*).

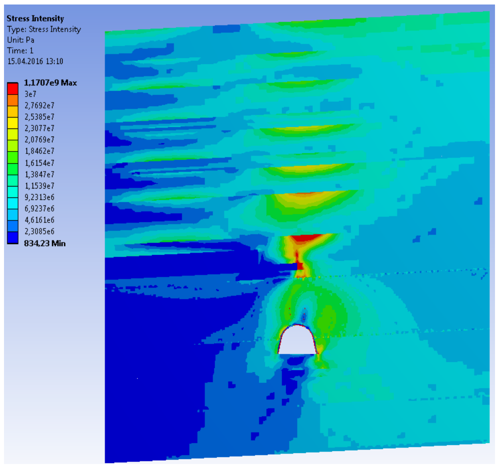
Research studies showed the main feature of overworking stone drift – a significant redistribution of rock mass SSS around the drift and increasing influence of the front bearing pressure zone ahead of the face on top of the working. We should note that massif SSS change occurs in time, depending on the rate of extraction operations. As a result, you can identify three phases of development: a gradual increase in stress during face approach – maximum peak of impact on working at the location of the face above the drift – a gradual reduction in the level of stress at the back down of mining operations to a level below the initial one.

There is a traditional discharge arch σ in the roof of EID, which has a very limited distribution only on the right side to a height of 1.8 m and a width of up to 0.5 m; the unloading area is localized only around the right polymer steel anchors in the roof of the drift. The remaining volume of the roof rock (up to the seam c_6) is exposed to concentrations force σ that usually exceeds the calculated resistance to compression. Therefore, it is reasonable to assume softening of floor rock of seam C_6 throughout the entire depth to the EID contour. This given distance is an average of about 8 m and corresponds to the vertical load on the support EID 800–850 kN at closeness of support setup 1. 25 frame/m. The applied support KSPU-11.7 is not able to handle the load like this, since according to data [3] at its manufacture from SIP-27, working resistance is 250 kN and limit load bearing capacity is 589 kN.

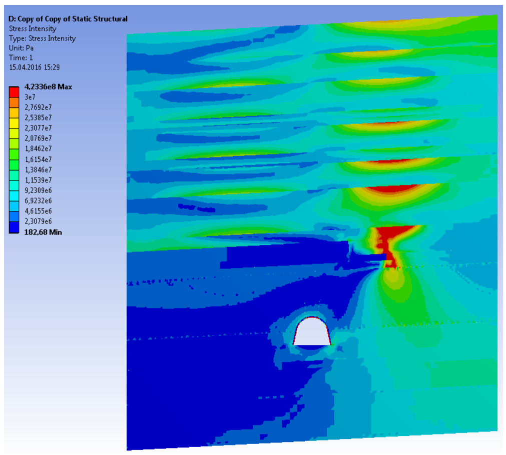
Thus, by a factor of vertical rock pressure, weight of softening rock is about in 1.5 times higher than the estimated value of the bearing capacity of KSPU-11.7 and taking into account the errors at its installing, the real discrepancy will be more significant. Hence the conclusion is that a real support needs serious strengthening to ensure a steady state of EID. It should be noted that we did not take into account the area of broken rocks at the top of the bed c_6 (above lava 171), which is connected to



a



b



c

Fig. 5. Diagrams of stresses intensity σ at a different position of face:
a – 10 m to the working; b – directly above the working; c – 10 m after the passage of working

the area of disturbed rocks in the soil of bed c_6. The final circumstance even more intensifies the development of the vertical rock pressure and positions the task of ensuring the stability of the EID (and other similar openings) as very relevant.

The next task of the research was to study the state of base supporting system, including frame support KSPU-11.7 and three polymer steel anchors in the roof of EID. A diagram of stress intensity σ, represented in Fig. 6, was subjected to analysis.

The frame beam is in a highly loaded condition unlike its relative unloading which is traditional for conditions of Western Donbas. There is a certain asymmetry in the distribution σ, due to the influence of the working face of lava 171. On its part, starting from the flexible joint, there is an area where σ is 77–84 % of the calculated yield strength steel SIP: this beam site is 1.1–1.2 m in length and is still in a state of prelimit, but any impact of additional factors, weakening the rock, can lead to plastic deformation of SIP. This state is observed in the central part of beam with a length of 1.5 m; here it is possible to predict a flattening of beam, despite the installation of three polymer steel anchors. Only the remaining peripheral area of the beam from the massif side (relating to the lava 171) is in a state of moderate stress σ = 54–69 % of the yield strength of the steel.

The frame leg holds approximately equivalent distribution σ with some influence of overworking EID.

There is an extended (up to 1.9 m) section of the plastic state of the SIP by lava 171 side in a frame leg; its placement approximately in the middle rack height provokes alternating bending, but mainly in the cavity of the drift. Loss of a stable form of the rack with a corresponding reduction in its load-bearing capacity is very likely.

In the column by the massifside, there is an area of the plastic state with a length of up to 2.4 m which extends up to the support. There also occurs alternating bending with a very probable loss of stability.

Assessing the state of the frame support KSPU-11.7 as a whole we need to focus on extensive areas of the plastic state of the SIP both in a beam and in the two columns, which makes the preservation of the EID section at technologically acceptable level problematic.

Polymer steel anchors in a drift roof experience plastic deformation of the armature on its dynes (from 47 to 92 %), i. e. they are in highly loaded state. However, this does not give the desired effect on unloading the beam and frame racks and here again it is necessary to emphasize the relevance of the "deep" hardening of rock of the drift roof.

In connection with such a situation it was proposed to fundamentally change the approach of provision the sustainability of the EID: not to oppose directly the vertical rock stress, but to implement the so-called "deep" strengthening of rock of the drift roof, which allows forming the load-carrying rock reinforced structure and eliminating part of the unstable rocks off the formation process of rock pressure on the supporting system EID.

The implementation of this approach is seen as follows. There are 2 rope anchors installed at the drift roof (along its longitudinal axis) symmetrically about a vertical axis of opening with the step of 1.6 m (one after one-frame KSPU-11.7). The layout of the cable anchor is shown in Fig. 7.

Shanks of cable anchors are located at a distance of 1.0 m with respect to drift vertical axis, and cable anchors themselves with 6.0 m long are placed at an angle of 75° to the horizontal. At this scheme, the rope anchors are linked to a height of not less than 5.5 m exfoliating and broken vertical cracks in the blocks of the roof rocks, not allowing any further development of their softening; the anchors force them to deform together by limiting the horizontal and vertical movements of layers and blocks [4, 5]. This action provides two important factors:

1. Firstly, the joint deformation of several layers of rock increases their resistance to vertical rock pressure proportionally to the square power of the capacity of rock reinforced load-bearing structure [6–9]; for example, the rope anchors with length of 6.0 m strengthen the roof rocks with the capacity by 2.5 times greater than polymer steel anchor (a length of 2.4 m); therefore, the bearing capacity of such a rock reinforced plate is by 2.5 times higher than in the base case of strengthening a roof with polymer steel anchors.

2. Secondly, limitation of the horizontal movements of rock layers and blocks creates conditions for the formation of the strut system, the bearing capacity of which is directly proportional to the capacity of the strut structure and the resistance value to a vertical rock pressure is not only commensurate with the frame supports, but often surpasses it manifoldly.

SSS investigations of recommended supporting system were carried on each major element of it with the scrutiny of all stress components. But for the sake of brevity presentation, only the results of stress intensity were presented.

Let us enhance the features of vertical stress distribution in the recommended supporting system with analysis of a curve of stress intensity (Fig. 8), which generalizes the SSS and establish the rate of loading on each element in relation to the yield strength of SIP steel or anchor fixture.

The frame beam is characterized by a very uniform distribution σ in the cross section of the SIP, which confirms the previously established fact of lack of any significant bending moment. Throughout the beam length the distribution σ changes with weak gradient: by the ends of the capping top near the flexible joints the value σ is minimal at the level of 21–83 MPa, which is 7.8–30.7 % of the calculated yield strength of SIP steel. When moving to the central part of the arch, stress intensity value increases up to 54–69 % of theoretical yield strength of SIP steel. As we can see, the state of beam is far from the limit one, in contrast to the base supporting system and it is explained by a protective effect of rock reinforced plate in the roof.

Legs of the frame support are more loaded than capping top and explanation of the results was given previously in the analysis of the vertical stress. Below flexible locks, the figure σ has reduced value of order with 83–187 MP at a curved section (a length of 160–300 mm), which is 32–69 % relating to the calculated yield strength of SIP steel and cannot cause its plastic state. In the area of pillar support to a height of 0.4–0.5 m there is considerable uneven distribution of σ in the cross section of SIP: on its inner surface of σ = 42–208 MPa and on the

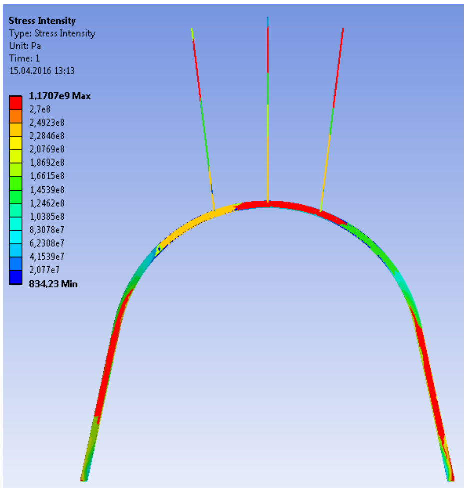


Fig. 6. The diagram of stress intensity σ in the supporting system of Eastern intermediate drift system

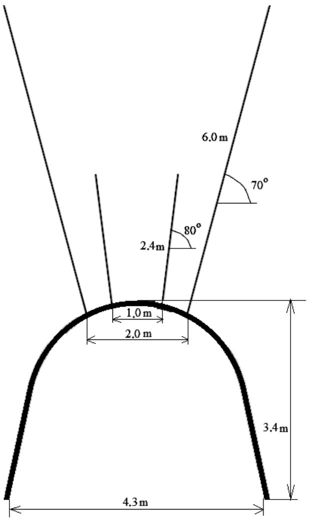


Fig. 7. Recommended supporting system EID

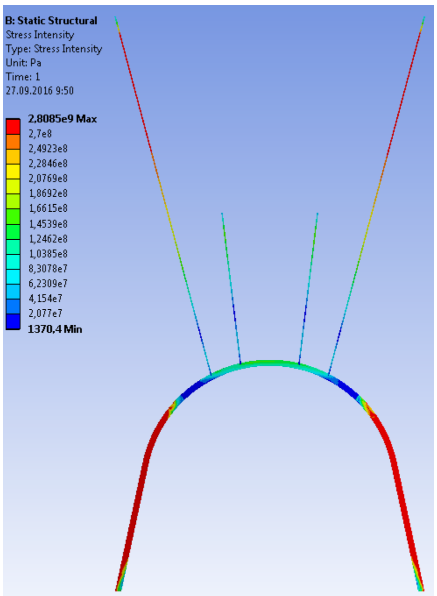


Fig. 8. The diagram of stress intensity σ in the recommended EID supporting system

outer one it reaches 250–260 MPa; the latter values are already close to the rated yield strength of steel, but still do not reach this value, remaining below 3.7–7.4 %. Nevertheless, the site in the area of pillar support experiences significant bending moment and if there are any anomalies in the lateral rock pressure, the transition of this area in a limit state with a plastic bending is possible. On the remaining and main length of the legs there is a very uniform distribution σ of both their height and cross-sectional SIP, i.e., there is almost no bending moment. This result is adjacent to the reduced values of the stress intensity (σ = 230–255 MPa) compared to the base case of EID supporting system; with respect to the estimated steel yield strength,the main length if racks is loaded at the level of 85–94 % and is in a pre-limit state.

Thus, we should focus on the fact that all the frame support elements are characterized by pre-limiting condition and none of the sites has plastic deformations appeared. This evidences the effectiveness of the decision on the formation of the rock reinforced plate with high load-carrying capacity in the roof. It perceives a part of rock pressure and protects the frame supports against overloads.

Previous research studies have revealed two major trends in the tension rate in the nearby massif and supporting system elements in overworked mine working:

- stress intensity σ in the supporting system increases with the $\frac{H}{R}$ ratio, which is equal to the growth of the load on it by the rock massif;
- stress intensity σ decreases with the distance h of working moving away into the floor of mining seam, the load of supporting elements is reduced.

Both trends are nonlinear: gradient of changes σ decreases as parameters $\frac{H}{R}$ and h grow; furthermore, a certain distance further of h the further increase of this parameter does not affect the state of the elements of the supporting system.

These trends were the basis of sorting options of supporting system parameters and of selecting the most appropriate means of its fastening, in terms of the conditions of stability of working with minimal material consumption.

Conclusions. We carried out the analysis of the mining and geological conditions and mining technical features of the maintenance of the Eastern intermediate drift of "Stepna" mine. During research studies we developed a geomechanical model of the rock mass and the supporting system for the determination of stress-strain state during the passing of the long-wall face by the overlying coal seam. It is reasonable to assume softening of floor rock of seam C_6 throughout the entire depth to the EID contour. This given distance is an average of about 8 m and corresponds to the vertical load on the support EID 800–850 kN at closeness of support setup 1.25 frame/m. Applying support KSPU-11.7 is not able to handle the load like this, since being manufactured from SIP-27 it has working resistance of 250 kN and limit load bearing capacity of 589 kN according to the data. It was found that a significant portion of the frame and anchor support is exposed to plastic deformation, which indicates insufficient bearing capacity of the support system. Eventually, we have developed and substantiated recommendations for changing the supporting system, considering the use of "deep" strengthening of rocks. The proposed variant was tested using computational experiment, the results of which confirmed the effectiveness of the recommendations. Compared to the base case of EID supporting system and with respect to the estimated steel yield strength, the main length of racks is loaded at the level of 85–94 % and is in a pre-limit state.

Acknowledgement. The research is carried out within the framework of scientific topics GP-497 "Resource-saving geotechnical and hydrodynamic parametrization of the extraction of low-capacity mineral raw materials in a technogenically loaded environment", financed by the state budget of Ukraine.

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Мета. Оптимізація системи кріплення східного проміжного штреку ш. „Степова" ДТЕК ШУ „Первомайське" для забезпечення надійного та ефективного підтримання виробки протягом усього терміну служби.

Методика. Дослідження та облік гірничо-геологічних умов і гірничотехнічних особливостей надпрацювання одиночної виробки при відпрацюванні вугільного пласта, розташованого вище, проведення обчислювальних експериментів для визначення напружено-деформованого стану гірського масиву й конструкції системи кріплення, обґрунтування параметрів рекомендованої системи кріплення з урахуванням використання „глибинного" зміцнення порід.

Результати. Досліджено напружено-деформований стан, прояви гірського тиску, умови підтримки виробок у залежності від гірничотехнічних і технологічних параметрів. Дослідження дозволили встановити ступінь їх впливу на ефективність застосування кріплення виробок, що надпрацьовуються. Розроблені та обґрунтовані рекомендації щодо зміни кріплення з урахуванням використання „глибинного" зміцнення порід. По відношенню до розрахункової межі текучості сталі, основна довжина стійок навантажена на рівні 85–94 % і знаходиться в дограничному стані.

Наукова новизна. Полягає у встановленні особливостей зміни напруженого стану гірського масиву й ступеня впливу зони опорного тиску попереду очисного вибою на розташовану нижче виробку.

Практична значимість. Розроблені рекомендації щодо ефективного й надійного кріплення Східного проміжного штреку ш. „Степова" ДТЕК ШУ „Первомайське" з урахуванням особливостей підтримки виробок, що надпрацьовуються.

Ключові слова: *анкерне кріплення, обчислювальний експеримент, напружено-деформований стан, виробка, що напрацьовується*

Цель. Оптимизация крепежной системы восточного промежуточного штрека ш. „Степная" ДТЭК ШУ „Первомайское" для обеспечения надежного и эффективного поддержания выработки на протяжении всего срока службы.

Методика. Исследование и учет горно-геологических условий и горнотехнических особенностей надработки одиночной выработки при отработке вышележащего пласта, проведение вычислительных экспериментов для определения напряженно-деформированного состояния горного массива и конструкции системы крепления, обоснование параметров рекомендуемой системы крепления с учетом использования „глубинного" упрочнения пород.

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 крепления надрабатываемых выработок. Разработаны и обоснова-

ны рекомендации по изменению крепления с учетом использования „глубинного" упрочнения пород. По отношению к расчетному пределу текучести стали основная длина стоек нагружена на уровне 85–94 % и находится в допредельном состоянии.

Научная новизна. Заключается в установлении особенностей изменения напряженного состояния горного массива и степени влияния зоны опорного давления впереди очистного забоя на нижерасположенную выработку.

Практическая значимость. Разработаны рекомендации по эффективному и надежному креплению восточного промежуточного штрека ш. „Степная" ДТЭК ШУ „Первомайское" с учетом особенностей поддержания надрабатываемых выработок.

Ключевые слова: *анкерная крепь, вычислительный эксперимент, напряженно-деформированное состояние, надрабатываемая выработка*

Рекомендовано до публікації докт. техн. наук В. І. Бондаренком. Дата надходження рукопису 01.11.16.

UDC 622.831.3

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DISTRIBUTION OF DISPLACEMENTS AROUND A SINGLE MINE WORKING DRIVEN IN STRATIFIED ROCK MASS

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РОЗПОДІЛ ПЕРЕМІЩЕНЬ НАВКОЛО ОДИНОЧНОЇ ВИРОБКИ, ЩО ПРОЙДЕНА В ШАРУВАТОМУ ПОРОДНОМУ МАСИВІ

Purpose. To estimate displacements in the neighborhood of a development working driven under mining and geological conditions of mines in Western Donbas and situated within the area of mining effect for further improvement of full-scale measurements being an important stage in the process of geomechanical model verification.

Methodology. A number of sequential operations of numerical modeling were involved making it possible to demonstrate deformational processes progressing in the neighborhood of "mine working-longwall" geotechnical system with a probability of 0.95 including those resulting in loss of elastoplastic resistance of marginal rock mass weakened either by mine working or by a network of underground cavities. Features of geomechanical processes taking place in the neighborhood of a mine working were analyzed with the help of complicated technical "mine working-pillar-rock mass" system being developed gradually within the rock mass.

Findings. The results of the numerical experiment helped determine rules of stratified rock mass formation around a mine working located within mining space effect in terms of difference levels of protective structure rigidness within longwall as well as estimate its effect on the integrity of entire geomechanical system.

Originality. For the first time the fact of both vertical and horizontal displacements of far point of deep benchmark station in the context of varying width of protective structure in longwall has been proved and their regularities have been determined.

Practical value. The determined regularities can be quite useful while estimating displacements of floor rocks and roof rocks in the process of full-scale measurements performed with the help of the leveling method.

Keywords: *stress-strain state, development working, protective structure, deep benchmark station, displacements of roof rocks, full-scale measurements, numerical modeling*

Introduction. Papers by E. Hoek [1], F. Tajdus, M. Cala, K. Tajdus [2], O. O. Sdvyzhkova [3, 4], S. M. Gapieiev [5], O. M. Shashenko [6, 7], Yu. M. Khalimendyk [8] and others concern the analysis of stress-strain state in the neighborhood of underground mine workings and open-cut workings. Above-mentioned researchers are representatives of schools of rock mechanics in Canada [1], Poland [2] and Ukraine [4–9]. Techniques being applied in this context vary from substantiation of empiric strength criterion [1] and analytical calculations [2–7] up to full-scale experiments [8]. As a result, the combination of different approaches helps obtain adequate geomechanical conditions. Objective of the research is in further correction of a technique verifying numerical models as they are advanced at the moment.

Features of geomechanical processes taking place in the neighborhood of complicated technical "mine working-pillar-rock mass" system developed in rock mass grad-