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GEOMECHANICAL SUBSTANTIATION OF PARAMETERS FOR SAFE COMPLETION OF MINING THE COAL RESERVES ADJACENT TO MAIN WORKINGS

Purpose. Geomechanical substantiation of the parameters for conducting stope operations, ensuring the operational state of main workings.

Methodology. The research is performed using an algorithm which includes the sequential execution of interrelated stages: analysis of mining-geological and mining-technical conditions for maintaining the network of main workings; mine observations of their state with the identification of specifics of rock pressure manifestations and predicting the probable negative consequences of conducting stope operations in the immediate vicinity; preliminary substantiation of possible technological options for mining the coal seam, taking into account the preservation of operational state of main workings. Scientific calculations for determining the most expedient option are based on the development of geomechanical models of the rock mass behavior around the main workings when mining the adjacent extraction site; analysis of the mass stress-strain state with the prediction of probable rock pressure manifestations; development of recommendations for limiting (or completely eliminating) the negative consequences of conducting stope operations near main workings. The above algorithm of actions uses a combination of experimental mine research methods with technologies for performing computational experiments based on the finite element method.

Findings. A systematic analysis of the mining-geological and mining-technical conditions for maintaining the network of main workings has been performed, the results of which are used to substantiate ideas about the mechanism for the occurrence of specifics of rock pressure manifestations, recorded during instrumental observations of their state. Three options have been developed for completing the mining of the extraction site adjacent to the mine horizon main workings. For each of them, a geomechanical model has been constructed for calculating the stress-strain state of the adjacent coal-bearing mass. Its analysis makes it possible to formulate a number of recommendations regarding the rational parameters for conducting stope operations, as well as structural and technological solutions to increase the stability of the main workings and maintain the conditions for their safe operation.

Originality. New dependences of influence of the extraction sites on the main working network stability depending on the texture and mechanical properties of lithotypes have been obtained based on the research on the stress-strain state of a weakly metamorphosed mass. For the first time, geomechanical models have been developed of the mutual influence of main workings on the parameters for conducting stope operations.

Practical value. The presented recommendations simultaneously reduce the loss of coal reserves and preserve the network of main workings in proper operational state.

Keywords: *rock mass, mine working, stability, modeling, stress-strain state*

Introduction. In the current geopolitical situation, the Western Donbas in Ukraine has become the main structure providing its energy security in the field of coal mining, generation of thermal and electrical energy. Despite the limited coal reserves, reserves for extending the life of mines are being sought, including through their more complete mining in the "problematic" seam areas near the existing main workings. Their safe operation is a non-negotiable priority. The need to complete mining of the remaining reserves is realized by studying geomechanical processes in the area of conducting stope operations and adjacent main workings, searching for compromise ways to positively solve this mining situation with substantiation of safe parameters for mining such coal reserves in the conditions of the Western Donbas weakly metamorphosed rocks.

Literature review. The studied geomechanical problem differs from analogues in three main peculiarities: firstly, the basic option considers the possibility of conducting stope operations in the immediate vicinity of the main workings – the distance between the extraction site and the nearest main working is only 1–2 m; secondly, the main workings have been exploited for about 15–20 years, and during this period there have been known transformations in the texture of the boundary rocks in the form of their stratification and weakening in the roof, sides and bottom; thirdly, weakly metamorphosed lithotypes of the coal-bearing stratum have strongly pronounced rheological properties, and low deformation characteristics contribute to significant displacement of border rocks into the mine working cavity.

The noted peculiarities limit the possibilities of analyzing any similar studies on geomechanical processes. However, there are other options for the development of stope operations in the studied mining-technical situation, when the main attention is paid to the parameters of frontal and lateral bearing pressure zones as key indicators for substantiating technical solutions for the safe completion of mining the coal reserves near main workings. From this point of view, there are a sufficient number of publications that are of interest for this scientific research.

In the work [1], based on a combination of mine observations of rock pressure manifestations and modeling of geomechanical processes using finite element method (FEM), ideas about the mechanism and patterns of coal-bearing stratum displacement during coal mining under conditions of weakly metamorphosed rocks have been further developed. Here, a number of interrelated tendencies in the textural transformations of the coal-overlaying formation, the influence of the mechanical characteristics of its lithotypes, and the formation of the load on the support of stope faces and extraction drifts have been consistently studied. Thus, a complex of mine studies has been performed on the development of the contour displacements in the extraction drifts as the longwall face approaches and retreats from the fixed sections of mine workings, where the benchmark stations are set. A number of extraction sites at the Western Donbas mines are covered, while determining some peculiarities conditioned by the texture and mechanical properties of the coal-bearing stratum of weakly metamorphosed rocks. The longwall face influence is noticeable at a distance closer to the face from 15–20 to 30–40 m, that is, the bearing pressure zone is shortened, which is conditioned by a higher ratio of the rigidity of coal seams and weak, easily deformable roof and bottom rocks. Another peculiarity is a significant increase in the ratio of convergences in the mine working sides to the roof and bottom convergences: in contrast to the recommendations of normative documents, this ratio not only approaches unity, but also exceeds it in some areas of the mine workings. A number of other peculiarities, due to the specific Western Donbas conditions, have also been identified and explained. In general, the work [1] provides new knowledge that is used when conducting this research: from general ideas about the peculiarities of displacements in the coal-overlaying formation of weakly metamorphosed rocks [2] to the disclosure of the mechanism for the formation and development of technogenic fractures in rock layers with the formation of a hinged-block displacement zone; tendencies of changes in the parameters of the bearing pressure zones depending on the texture and mechanical properties of the mass, the repulse reaction of the stope face powered support [3], the influence of factors weakening the rock, such as moisture saturation, fracturing and rheology (Baryshnikov A.S.). The experimental results of monitoring the loading of powered support sections, depending on the technological parameters of stope operations, are also of great interest.

In the work [4], large-scale research has been performed on the experimental study of the rock mass discontinuity around the extraction drifts and end areas of longwall faces, which are very useful for quantifying the sizes of the discontinuity areas in the coal-bearing stratum and predicting the rock pressure manifestations. The results obtained in [5], including the FEM modeling, are used to substantiate the parameters of the geomechanical models in the present research.

The second task is to substantiate the methods and means for maintaining the main workings operated for a long period within the requirements of the relevant safety regulations. In this case, based on the performed mine observations of the rock pressure manifestations, the opinion is formed on the feasibility of using roof bolting, including the so-called deep-laid rope bolts [6]. In this regard, a number of works on this topic have been analyzed, where the experience [7] is studied specifically for the Western Donbas conditions, mine [8] and computational experiments have been performed to calculate the stress-strain state of a mass [9] strengthened with roof bolting. The closest of all the studies is the publication [10], which provides a geomechanical substantiation and proves the feasibility of using combinations of resin-grouted rockbolts and rope bolts, as well as flexible yielding couplings of roof-bolts and frames to counteract increased lateral rock pressure; recommendations are also given on the choice of parameters for strengthening support for conditions of increased vertical and oblique rock pressure, and a methodology for predicting heaving of bottom rocks is proposed. All this information is extremely useful and is used in current research [11]. Also of interest are some peculiarities of the operation of roof-bolts in terms of their strengthening effect even in partially disturbed rocks [12], especially in the mine working sides, which are described in the work [13].

In general, despite the research topic specificity, the analysis of some works in the closest areas of development of ideas about the geomechanics of the weakly metamorphosed coal-bearing mass behavior in the zone of stope operations influence turned out to be useful for improving the formulation and subsequent implementation of relevant tasks.

Problem formulation. In the Western Donbas, the problem of depletion of coal reserves during the planned closure of some existing mines is quite acute, including for environmental reasons due to global trends in the predominant development of renewable energy technologies [14]. However, the current geopolitical situation [15] corrects this concept in view of the need to replace (for a certain period) temporarily limited resources with coal to ensure the energy security of Ukraine and a number of European countries [16]. Therefore, the problem of maintaining the coal production volume is extremely relevant, and its comprehensive solution in the form of maintaining mine capacities, more complete mining of reserves and preservation of jobs has a certain prospect in the current conditions [17].

The plan for the development of mining operations at one of the leading mines in the region (Zakhidno-Donbaska Mine of PJSC DTEK Pavlohradvuhillia) provides for the temporary use of a network of main workings in the c_8^b seam, for example: Western Main Conveyor Drift No. 1-bis, Western Main Conveyor Drift No. 3, Eastern Main Ventilation Drift of the 420–445 m horizon, Southern Main Haulage Drift, their junctions in the form of inclines and slits, as well as a number of other mine workings. Over time, the corresponding main workings in the c_5 seam will be put into operation, and the need to maintain mine workings through the c_8^b seam can disappear.

At the same time, the situation is complicated by the fact that in order to maintain the mine capacity and more fully mine the reserves of the c_8^b seam, it is planned to mine an area in the mine field with the 850 longwall face, which at some of its length will be located close to the Western Main Conveyor Drift No. 1-bis (a coal pillar remains here with a width of only 1–2 m). This is shown in the excerpt from the plan of the c_8^b seam mine workings (Fig. 1).

Such a technical solution requires a comprehensive substantiation with a possible adjustment of the technological parameters of mining the 850 extraction site. The main attention is paid to the research on the state of the mass surrounding the Western Main Conveyor Drift No. 1-bis, since it is this main working that will be subjected to the maximum impact of stope operations in the 850 longwall face. Prediction of this impact (relative to a specific mining-technical situation) is not provided for in any of the current normative documents of the coal industry in Ukraine. Therefore, new studies are needed on the geomechanics of displacement of the rock mass surrounding the Western Main Conveyor Drift No. 1-bis with an assessment of its state when driving the 850 longwall face along the main working.

In the light of the above, a preliminary assessment of the current mining-technical situation indicates the need to develop several options for solving the problem of maintaining the operational state of the Western Main Conveyor Drift No. 1-bis and other adjacent main workings:

- adopt the existing plan for the development of mining operations with the fastening system strengthening of the

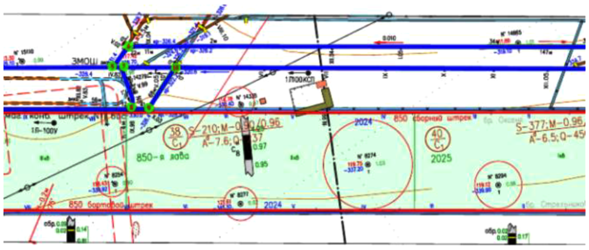

Fig. 1. Fragment of the mining plan for the c_8^b seam

Western Main Conveyor Drift No. 1-bis in the hazardous area;

- stop the stope face of the 850 longwall face at a safe distance, which will be enough to eliminate the impact of stope operations;

- when approaching the Western Main Conveyor Drift No. 1-bis to a safe distance, shorten the length of the 850 longwall face with the formation of a protecting coal pillar between the 850 prefabricated drift and the Western Main Conveyor Drift No. 1-bis.

Research methods. The algorithm for performing research, which is summarized in the abstract, provides for the use of a complex of well-known proven methods, namely: analysis of mining-geological and mining-technical conditions for maintaining the network of main workings of the c_8^b seam; mine instrumental observations of their state with fixation of the characteristic peculiarities of rock pressure manifestations, as well as explaining the mechanism of their occurrence and development; substantiation and construction of geomechanical models for studying the state of the rock mass surrounding the main workings for calculating its SSS based on the FEM, determining the zones of unstable rock mass state and predicting the rock pressure manifestations. The final result is the development of a set of recommendations for the selection of rational parameters for conducting stope operations at the *850th* extraction site and maintaining the network of main workings of the c_8^b seam.

During the research, the following is used: technical documentation and geological information provided by the mine administration, the research results of Dnipro University of Technology [18] and M. S. Polyakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine in terms of modern methodological properties of lithotypes in the Western Donbas, information from mining-technical literature on the specificity of rock pressure manifestations and mechanical characteristics of the Western Donbas coal-bearing stratum [19].

An analysis of modern research in the field of geomechanics of coal-bearing mass displacement of weakly metamorphosed rocks makes it possible to more substantively assess the specific mining-geological and mining-technical conditions for maintaining the network of main workings of the c_8^b seam and the consequences of conducting stope operations at the adjacent 850 extraction site. In order to gain a more objective and complete understanding of the mining-technical situation, mine research has been conducted with fixing the residual dimensions of the main workings, especially in hazardous areas. These observations make it possible to systematize the most typical cases of disturbances of the operational state of mine workings in terms of the peculiarities of rock pressure manifestations. A preliminary (at the level of expert assessments) prediction of changes in the state of main workings during mining of the 850 extraction site has been made, and ways of eliminating the negative consequences of stope operations have been formulated. To substantiate a reasonable technical decision-making on this problem, the results of computational experiments based on the FEM, as well as two geomechanical models reflecting the three previously formulated options for mining the 850 extraction site, are used. Based on the above set of studies, recommendations have been developed for the safe mining of the 850 extraction site and for maintaining the network of main workings of the c_8^b seam in proper operational state within the planned period of time.

Research results. At the first stage, the mining-geological and mining-technical conditions for maintaining the network of main workings of the c_8^b seam have been studied, taking into account the prospect of mining the 850 extraction site in the immediate vicinity of them. It has been determined that outside the zone of stope operations influence, the height of the area of unstable rocks in the roof of the nearest mine working (Western Main Conveyor Drift No. 1-bis) ranges within 1.0–3.0 m and generates a vertical load of 115–350 kN/m; this value corresponds to the yield load of frame supports of the TSYS and KMK-4 series and is approximately twice as low as their maximum load-bearing capacity. It should be noted here that calculations according to normative methodologies give the height of the ultimate equilibrium arch in the range of 1.2–1.6 m, which approximately corresponds to expert estimates. The lateral load on the frame support in the range of 40–115 kN/m is relatively moderate, which makes it possible to prevent excessive convergence of the frame prop stays and the loss of their cross-sectional area over most of the length of the main workings. Moderate heaving of bottom rocks is also predicted which may well be compensated by periodic dinting during the remaining period of conducting the main workings.

Mine instrumental observations of the state of the studied network of main workings generally confirm the previous conclusions that their satisfactory state is recorded in most areas. This is evidenced, first of all, by the value of the residual section area, which varies within 10–15 m^2 and is quite sufficient for the factor of reliable horizon ventilation. Clearances for the factor of transport and people movement also do not violate the relevant safety rules. In general, it can be argued about moderate rock pressure on both types of frame support (TSYS and KMK-4 series), which provide satisfactory state of mine workings.

At the same time, in some areas of the main workings, especially at their junctions, the most common (according to observational data) type of support deformation is observed with excessive convergence of its prop stays (Fig. 2). Another common case is excessive vertical rock pressure, which deforms not only the cap board (it flattens out with a decrease in the lifting boom), but the entire frame (Fig. 3). Other periodically occurring disturbances of the operational state of mine workings have also been identified, such as: intensive pressing

Fig. 2. Fragment of the state of the Western Main Ventilation Drift (PK 244)

Fig. 3. Fragment of the state of the Western Main Conveyor Drift (PK 58)

of the TSYS-series frame support prop stays into bottom rocks; there is also such a level of the support deformation, at which any strengthening of it does not make sense and it is necessary to further fasten this local mine working area.

All facts are given an appropriate geomechanical explanation in terms of the mechanism of excessive multi-vector rock pressure development. Structural and technological ways for solving the problem of increasing the studied network stability of the c_8^b seam main workings are proposed.

On the other hand, the impact of stope operations in the 850 longwall face certainly intensifies the rock pressure manifestations, especially in the nearest Western Main Conveyor Drift No. 1-bis. In this case, special research on the state of the mass surrounding the main workings is needed in a specific geomechanical situation of mining the 850 extraction site.

Therefore, the second stage of research is devoted to substantiation and construction of geomechanical models of the coal-bearing mass behavior around the network of main workings of the c_8^b seam during mining of the 850 extraction site. They are used to calculate the SSS of an adjacent mass (using FEM technologies), its analysis and issuance of appropriate recommendations.

Geomechanical models have been developed on the basis of geological information about the texture and mechanical properties of the rock mass surrounding the network of the c_8^b seam main workings. Previously, the need to consider three options for mining the 850 longwall face at the end of its extraction site has been substantiated, and this makes it possible to comprehensively study the current geomechanical situation. To study them, two geomechanical models have been constructed. The only difference between the two models is the absence (Fig. 4) and the presence (Fig. 5) of a protecting coal pillar up to 20 m wide.

According to the first option of mining the 850 extraction site, the maximum lateral bearing pressure is determined, which affects the Western Main Conveyor Drift No.1-bis, and a decision is made on the feasibility of such a technology based on its value; in this case, the first geomechanical model is used (Fig. 4).

According to the second option, the safe distance of stopping the 850 longwall face is determined by the length of the frontal bearing pressure zone. The criterion is the condition that the initial geostatic vertical pressure $\sigma_y = \gamma H$ does not exceed by 15–20 %, that is,

$$\sigma_y \leq (1.15 - 1.20)\gamma H, \qquad (1)$$

where γ is weight-average unit specific gravity of the rocks in the coal-overlaying formation; H is depth of placing the 850 longwall face and the Western Main Conveyor Drift No. 1-bis. In this case, the first geomechanical model is also used (Fig. 4).

According to the third option of mining the 850 extraction site, the width of the lateral bearing pressure propagation is determined and, according to the criterion (1), the safe width ΔX of the coal pillar between the Western Main Conveyor Drift No. 1-bis and the 850 prefabricated drift is selected. In this case, the second geomechanical model is used (Fig. 5).

The methodology for substantiating the parameters and constructing geomechanical models includes three stages. The first stage provides the rationale for the sufficient dimensions of the models, with regard to the implementation of the requirement to obtain a satisfactory level of adequacy and reliability of the computational experiment results. This problem is substantiated on the basis of long-term experience in modeling geomechanical processes, which is described in sufficient detail, for example, in the publication [6]. As a result, the following model dimensions have been determined (to accurately reflect the geomechanical processes of displacement in the coal-overlaying formation): height $Y = 60$ m, width (to the dip, rise) $X = 60$ m, length (along the strike) $Z = 300$ m.

The second important component of the substantiation and construction of geomechanical models is the formation of

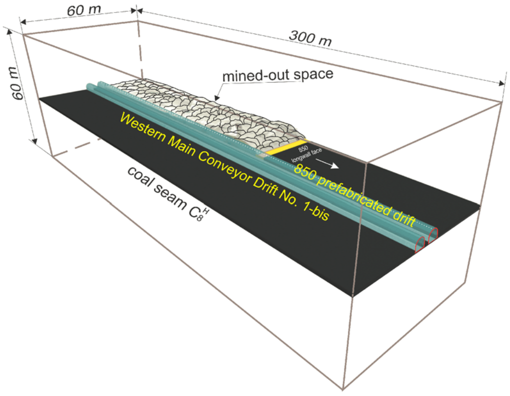

Fig. 4. Geomechanical model of mining the 850 extraction site of the c_8^b seam with the location of the 850 prefabricated drift at the undercut to the Western Main Conveyor Drift No. 1-bis

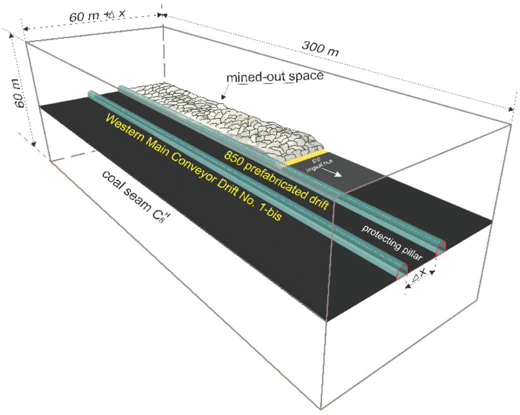

Fig. 5. Geomechanical model of mining the 850 extraction site of the c_8^b seam with leaving the protecting pillar between the 850 prefabricated drift and the Western Main Conveyor Drift No. 1-bis

boundary conditions that are close to real ones. In this case, the classical provision is used, such as initial vertical geostatic pressure of an undisturbed mass

$$\sigma_y = \gamma H;$$

initial pressure on the YX and YZ side surfaces

$$\sigma_x = \sigma_z = \frac{\mu}{1-\mu}\gamma H,$$

where μ is transverse deformation coefficient of rock layers.

On the lower horizontal surface of the model, a widely used condition is taken – a rigid support. Other boundary conditions include modeling of disturbed contacts between adjacent lithotypes, repulse reaction of the 850 powered support and the actual dimensions of mine workings.

The third component is the reflection of the mass texture, assigning to each of its rock layers real mechanical characteristics on the basis of the available geological information, using extensive information from the results of testing lithotype samples from the Western Donbas. In the mined-out space, the texture and mechanical properties are modeled by two classical zones –uncontrolled collapse and hinged-block displacement.

Thus, all the basic conditions for an adequate and reliable reflection of the current geomechanical situation with obtaining reliable SSS calculation results of two geomechanical models have been met.

Analysis of the rock mass SSS is performed on three main components – vertical σ_y, horizontal σ_z along the strike and horizontal σ_x to the dip (rise) of the coal seam; one more indicator is added to them, which integrally reflects the surrounding mass state – stress intensity σ – and is used in determining the areas of weakening and destruction of rocks.

One of the most informative SSS indicators is the field of vertical stresses σ_y distribution, which clearly reflects the disturbances in the rock mass state in the form of bearing pressure and destressing zones. For both geomechanical models, Figs. 6 and 7 show the spatial curves of vertical stresses σ_y, the main fragments of which do not contradict the existing ideas about the coal-bearing mass deformation processes during stope operations.

Priority is given to frontal and lateral bearing pressure zones; the latter is not visible in Figs. 6 and 7, as it is in the middle of the model, and in order to clearly show and study it, cross sections are made in the *YX* plane along the *Z* coordinate of acting maximum frontal bearing pressure. With the same purpose of a more detailed study on the frontal bearing pressure parameters, a number of longitudinal sections of the *YZ* spatial model are made, which, thus, make it possible to study the vertical stress field σ_y parameters (as well as other SSS components) at arbitrary points and sections of the rock mass. The results of the σ_y field analysis indicate a high probability of the development of intense rock pressure manifestations in the immediate vicinity of the Western Main Conveyor Drift No. 1-bis, which are caused by the stope operations influence according to the first technological option for mining the 850 extraction site of the c_8^b seam.

Firstly, the height of the ultimate equilibrium arch reaches dimensions that contribute to the vertical load formation of the level of 1000–1150 kN/m and exceeds the ultimate load-bearing capacity of the supports of the TSYS and KMK-4 series even with a 0.5 m step of setting.

Secondly, the dimensions of the arch do not even allow fastening securely the rope bolts in holistic roof rocks of the Western Main Conveyor Drift No. 1-bis. Therefore, it is only possible to counteract excessive vertical load by setting wooden prop stays of the strengthening support.

Thirdly, the extensive distribution of the area of weakened and destroyed rocks in the sides of the Western Main Conveyor Drift No. 1-bis, for the same reason, does not allow using rope bolts to increase the resistance to lateral load. Its value will cause an intensive convergence of the prop stays in the TSYS frames with their corresponding excessive deformation; the KMK-4 support is able to withstand the predicted lateral pressure.

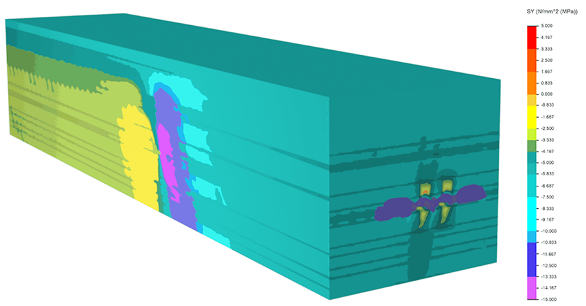

Fig. 6. Curve of vertical stresses σy in the first spatial model for the option of the 850 prefabricated drift located at the undercut to the Western Main Conveyor Drift No. 1-bis

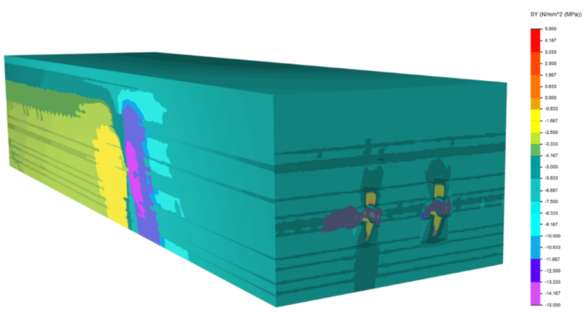

Fig. 7. Curve of vertical stresses σy in the second spatial model for the option of leaving the protecting pillar between the 850 prefabricated drift and the Western Main Conveyor Drift No. 1-bis

Fourthly, it is predicted that there is an increased heaving of the bottom rocks in the Western Main Conveyor Drift No. 1-bis with a probable loss of its required operational state.

The analysis of other SSS components (horizontal $\sigma_{x,z}$ and stress intensity σ) generally confirms the negative prediction of the state of the Western Main Conveyor Drift No. 1-bis according to the first option of the 850 prefabricated drift location almost at the undercut to it. The following should be noted here. Horizontal stresses $\sigma_{x,z}$ very clearly visualize the bending deformations of the rock layers around the Western Main Conveyor Drift No. 1-bis, which cause the formation of tension cracks in the bedding plane: the rock layers are divided into blocks and this process originates ahead of the 850 longwall face and in its sides above the 850 prefabricated drift and the Western Main Conveyor Drift No. 1-bis. A zone of hinged-block displacement is created and it activates the displacements of the rocks in the roof, sides and bottom around the Western Main Conveyor Drift No. 1-bis. The peculiarities of the stress intensity field σ confirm the formation of widespread areas of rock weakening in the roof, sides, and bottom of the Western Main Conveyor Drift No. 1-bis.

To give a better idea of the degree of the 850 longwall face influence in the zone of maximum frontal bearing pressure, the cross section *YX* is shown (Fig. 8), which shows the level of increase in multi-vector rock pressure anomalies (in the component σ_y) around the Western Main Conveyor Drift No. 1-bis during the implementation of the first technological option for mining the 850 extraction site.

The second technological option for mining the 850 extraction site of the c_8^b seam involves stopping of the 850 longwall face at a safe distance from the Western Main Conveyor Drift No. 1-bis. For this, the spatial curve σ_y is used in Fig. 6, and a special attention is focused on the *YZ* plane, especially the frontal bearing pressure zone ahead of the stope face, which in the *Z* coordinate propagates almost the same distance in the area of the lateral bearing pressure zone; the latter has a radical effect on the state of the Western Main Conveyor Drift No. 1-bis.

It has been determined that the maximum frontal bearing pressure (the maximum vertical stresses σy concentration) acts at a distance of 3–4 m ahead of the longwall face, where its concentration coefficient K_y reaches $K_y = 2.0–3.6$ and causes the destruction of weak roof and bottom rocks in the c_8^b seam. The maximum σ_y concentration propagates up to 5.6 m into the roof and up to 4.8 m into the bottom of the seam, but we are more interested in the propagation of excessive concentrations of σy in the *Z* coordinate, that is, into the depth of the undisturbed mass ahead of the longwall face. In this regard,

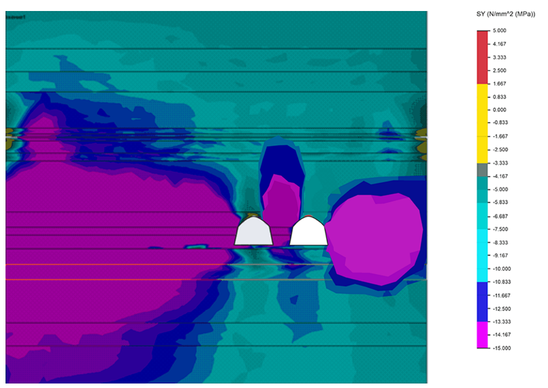

Fig. 8. Curve of vertical stresses σy distribution in the first technological option for placing the 850 prefabricated drift almost close to the Western Main Conveyor Drift No. 1-bis

the propagation distance of maximum σ*y* concentrations is determined up to 4.2 m, and they are definitely destructive.

With the advancement of the coal-bearing mass into the depth (in the *Z* coordinate), the concentration σ*y* decreases, but still poses a danger to the stability of the Western Main Conveyor Drift No. 1-bis. Thus, the level of K_y – 1.4–1.7 concentration propagates to a distance of 8–9 m ahead of the longwall face, and the rock pressure increased by 40–70 % in combination with weak rocks contributes to the formation of an excessive load on the support of the Western Main Conveyor Drift No. 1-bis. In view of the foregoing, the question arises as to the safe distance ahead of the longwall face, at which the frontal bearing pressure decreases so much that it has little effect on the SSS of the mass surrounding the Western Main Conveyor Drift No. 1-bis. In this sense, the initial geostatic pressure can be increased to 15–20 % according to criterion (1). With a certain reserve of calculations for poorly predictable random rock pressure manifestations, a distance of about 20–25 m from the longwall face is recommended. That is, it is considered expedient to stop the 850 longwall face at a distance of 20–25 m from the Western Main Conveyor Drift No. 1-bis. Thus, the negative impact of stope operations on the stability of the mine working is eliminated, which is currently in a predominantly satisfactory operational state and performs the proper functions.

At the same time, the studied second technological option for mining the 850 extraction site has a certain disadvantage, due to the loss of some part of the c_8^b seam reserves. Therefore, the third technological option is studied, the essence of which is to reduce the length of the 850 longwall face by 10–12 powered supports (by 15–18 m); then, between the 850 prefabricated drift and the Western Main Conveyor Drift No. 1-bis, a 16–19 m wide coal pillar is formed, which performs the function of protecting it, as it prevents the distributed influence of the lateral bearing pressure from the 850 longwall face onto the Western Main Conveyor Drift No. 1-bis. This technical solution makes it possible to reduce the coal losses by up to 10–13 times compared to the second technological option for the complete mining of the c_8^b coal seam.

To substantiate the third technological option, an appropriate geomechanical model has been constructed (Fig. 5) and its SSS has been calculated (Fig. 7). For a more obvious representation of changes in the curve of vertical stresses σ_y, a cross section (in the *YX* plane) of the area of acting maximum frontal bearing pressure is provided (Fig. 9). The main differences in the distribution of σ*y* are as follows.

Firstly, the lateral bearing pressure from the 850 longwall face does not reach the boundary rocks around the Western Main Conveyor Drift No. 1-bis: an area is formed across the coal pillar width, where the vertical stresses σ_y almost correspond to the initial geostatic pressure γH of the virgin mass – the excess is not more than 8–10 % of γH. This makes it possible to predict the rock mass stable state in the coal pillar area closest to the Western Main Conveyor Drift No. 1-bis.

Secondly, a zone of lateral bearing pressure is formed in the sides of the Western Main Conveyor Drift No. 1-bis, which is caused only by the existence of the mine working itself. It is significantly smaller in size than in the first technological option for complete mining of the c_8^b coal seam. Thus, the maximum concentration of K_y = 2.0–3.6 propagates into the roof up to 3.6 m and into the bottom up to 2.6 m – the area is reduced in the roof by 35 % and in the bottom – by 46 %. The concentration σ*y* of K_y = 1.4–1.7 level is also dangerous; it decreases in the roof by 35 % and in the bottom by 32 %, and the width of the area decreases by 31–38 %.

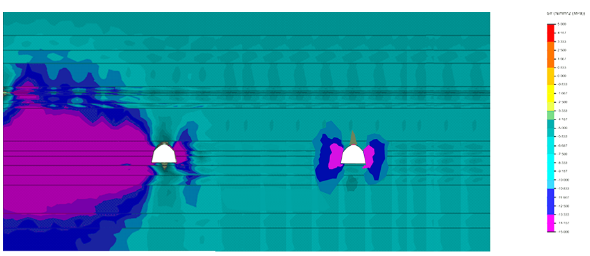

Fig. 9. Curve of vertical stresses σ_y distribution in the third technological option with leaving the protecting pillar between the 850 prefabricated drift and the Western Main Conveyor Drift No. 1-bis

The data presented indicate a significant improvement in the geomechanical situation around the Western Main Conveyor Drift No. 1-bis, when it is separated from the 850 prefabricated drift by a protecting pillar up to 20 m wide. A decrease in the vertical, oblique and lateral load on the support of the Western Main Conveyor Drift No. 1-bis is predicted, which contributes to maintaining its operational state. Other main workings should not be under the impact of stope operations in the 850 longwall face, as they are separated from the extraction site by thicker protecting pillars, for example, the nearest Western Main Haulage Drift has a protecting pillar of at least 75 m. As for the current state of the network of main workings in the c_8^b seam, recommendations have been developed for their safe operation, provided the mining operations are developed under the third technological option for mining the 850 extraction site.

Conclusions. In accordance with the purpose set, an algorithm has been developed for studying the integrated assessment of the impact on the stability of network of main workings in the c_8^b seam when mining the extraction site in the immediate vicinity of them. For its implementation, an analysis of the texture and mechanical properties of lithotypes occurring around the network of main workings, as well as instrumental observations of their state were performed, on the basis of which the need to consider three possible technological options for the development of mining operations has been substantiated.

The existing geomechanical situation has no closest analogues and it differs from the known ones, which necessitates the substantiation and development of two geomechanical models of three technological options for mining an extraction site near the main workings for a comprehensive assessment of the degree of stope operations impact.

The performed SSS analysis of geomechanical models has confirmed the significant impact of stope operations. If the extraction drift is practically adjacent to the main working, the formation of a high vertical and oblique load is predicted, which is up to 2 times higher than the maximum load-bearing capacity of the frame support types used; lateral pressure definitely plastically deforms the frame prop stays with a significant loss of the cross-sectional area of the mine working and a violation of its operational state as a whole.

The study on the technological option of stopping the stope face at a safe distance to the main working with an analysis of frontal and lateral bearing pressure propagation makes it possible to set this safe distance at a level of up to 20–25 m.

The geomechanical model of the technological option for mining the extraction site with a reduction in the longwall face length by 10–12 powered support sections is characterized by the formation of a protecting pillar 16–19 m wide. The surrounding mass SSS analysis with such a technological solution proves a significant reduction in the load on the support: vertical – by 1.54–1.56 times, lateral – by 1.57–1.62 times; in addition, the areas of weakened rocks in the mine working bottom are limited up to 1.47–1.85 times. Such results make it possible to predict a satisfactory state of the main workings.

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Геомеханічне обґрунтування параметрів безпечного доопрацювання запасів вугілля поблизу магістральних виробок

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Мета. Геомеханічне обґрунтування параметрів ведення очисних робіт із забезпеченням експлуатаційного стану розташованих поряд магістральних виробок.

Методика. Дослідження виконувалися при застосуванні алгоритму, що включає послідовне виконання взаємопов’язаних етапів: аналіз гірничо-геологічних і гірничотехнічних умов підтримки мережі магістральних виробок; шахтні спостереження за їх станом з виявленням особливостей проявів гірського тиску та прогнозуванням імовірних негативних наслідків ведення у безпосередній близькості очисних робіт; попереднє обґрунтування можливих технологічних варіантів виймання вугільного пласта з урахуванням збереження експлуатаційного стану магістральних виробок. Наукові викладки зі встановлення найбільш доцільного варіанту ґрунтувались на розробці геомеханічних моделей поведінки гірського масиву навколо магістральних виробок при відпрацюванні суміжної виїмкової ділянки; аналізі напружено-деформованого стану масиву з прогнозуванням імовірних проявів гірського тиску; розробці рекомендацій з обмеження (або повного усунення) негативних наслідків ведення очисних робіт поблизу магістральних виробок. Наведений алгоритм дій використовує поєднання експериментальних методів шахтних досліджень із технологіями виконання обчислювальних експериментів на базі методу скінченних елементів.

Результати. Виконано системний аналіз гірничо-геологічних і гірничотехнічних умов підтримки мережі магістральних виробок, результати якого використані при обґрунтуванні уявлень про механізм виникнення особливостей проявів гірського тиску, що зафіксовані при інструментальних спостереженнях їх стану. Розроблені три варіанти доопрацювання виїмкової ділянки, що межує з магістральними виробками горизонту шахти. Для кожного з них побудована геомеханічна модель з розрахунку напружено-деформованого стану прилеглого вуглевмісного масиву, аналіз якого дозволив сформувати низку рекомендацій щодо раціональних параметрів ведення очисних робіт і конструктивно-технологічних рішень для підвищення стійкості магістральних виробок і збереження умов їх безпечної експлуатації.

Наукова новизна. Отримані нові залежності впливу ділянок, що відпрацьовуються, на стійкість мережі магістральних виробок залежно від текстури й механічних властивостей літотипів на базі дослідження напружено-деформованого стану слабометаморфізованого масиву. Уперше розроблені геомеханічні моделі взаємовпливу магістральних виробок на параметри ведення очисних робіт.

Практична значимість. Надані рекомендації дозволять одночасно зменшити втрати запасів вугілля та зберегти мережу магістральних виробок у належному експлуатаційному стані.

Ключові слова: *гірський масив, гірнича виробка, стійкість, моделювання, напружено-деформований стан*

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