INFLUENCE OF ROCK LEAVING IN THE LONGWALL FACE GOAF ON THE EXTRACTION DRIFT STABILITY

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ABSTRACT

The research is devoted to studying the actual problem of positive changes in the extraction working stability during the rock pack formation in the goaf area during underground coal mining. The mining-geological conditions of the Zakhidno-Donbaska mine, PJSC "DTEK Pavlohradvuhillia", are chosen for the research. A geomechanical model of a rock mass around an extraction drift when using traditional technology, as well as selective coal seam mining technology with leaving the rock in the goaf area, has been substantiated and constructed. The curves of stress field development around the extraction drift, when using traditional mining technology with complete caving of rocks and selective mining technology with leaving the rock in the goaf area, have been obtained. The patterns of changes in the rock contour displacements in the mine working with various mining technologies have been determined. The possibility of reusing extraction workings with backfilling the goaf area behind the longwall face has been substantiated, which is confirmed by the improvement in the stress state of the rock mass and support elements.

Keywords: coal seam, rock mass, extraction working, extraction drift, mine rocks, backfilling, stress-strain state.

1. INTRODUCTION

Rational nature management in developed countries is an important component when mining various types of mineral resources, since environmental protection is the most important principle in modern society. Much attention is paid to the coal-mining industry, since the implementation of a number of technological processes in mining production has a negative impact on the natural environment [1]. The coal-mining industry is still an important component of the economy in a number of countries, such as Poland, China, India, Australia, Ukraine, USA, where coal is a raw material for energy and metallurgy [2]-[4].

In the bowels of Ukraine, out of 33.9 billion tons of coal (4% of world reserves), 80% is concentrated in seams with a thickness of less than 1.0 m. This is the lowest index among coal deposits exploited in the developed countries of the world. The mines of PJSC "DTEK Pavlohradvuhillia" (Western Donbass), which develop mainly low-thickness coal seams (0.8-1.0 m), produce 65-70% of the total coal volume by underground mining method [5], [6]. This testifies to the important strategic significance of this region in the energy balance of the state. Modern mining equipment for stope operations (longwall mining) in the Western Donbass mines, according to technical peculiarities, allows mining the coal seams only with a geological thickness of at least 1.0 m. Therefore, when mining the coal seams of 0.7-0.9 m, at present, the shearer-loader is forced to undercut waste rocks in the roof or bottom of the seam, which leads to mixing of broken rocks with valuable coal and a decrease in its quality (ash content 40-50%) [7]. Mineral quality issues in mining are always important and relevant [8], [9]. According to studies [10], up to 40-50% of the mine rocks come to the daylight surface as a result of stope operations (undercutting) from the total volume of rocks stockpiled in dumps.

It is possible to improve the ecological situation in mining regions that develop coal reserves in extremely difficult conditions through the development and implementation of environmental resource-saving mining technologies, one of which is the use of backfilling the goaf area [11]-[13]. However, for these conditions, a particularly acute problem is the challenging issue of creating efficient mining technologies with backfilling the goaf area directly for thin coal seams. There is a series of studies on mining the thin coal seams with backfilling the goaf area [14]-[16]. However, to form a backfill mass of the required strength in conditions of a dense location of settlements, mainly cementitious materials are used, which has a significant impact on the coal mining cost. For thin coal seams in the Western Donbass, a new method has been developed for selective mining of thin coal seams with backfilling the goaf area based on mine rocks from undercutting by a shearer-loader [17], [18].

The placement of waste mine rocks from undercutting the coal seam bottom as backfill material in the goaf area of stope faces leads to the improvement of a number of technological, environmental and economic aspects in the mine's technological system.

Firstly, an important positive shift specifically for the technology of mining operations conducted in extremely difficult mining-geological conditions is the transformation of the stress-strain state of the rock mass surrounding the stope face. In contrast to controlling the roof by complete caving, the use of backfilling the goaf area leads to a significant reduction in the rock mass deformations [19], [20]. The use of backfilling eliminates the occurrence of such negative phenomena as landing of a powered support on a "rigid base" and the occurrence of emergency situations [21]-[23]. In [24], [25], in particular for Ukrainian conditions, an improvement in the stress state of the mass surrounding the stope face and a decrease in the frontal bearing pressure stress values are substantiated.

Leaving the rock in the mined-out area of the longwall can significantly prevent the release and accumulation of coal mine methane [26].

Secondly, filling the goaf area leads to a decrease in the values of daylight surface subsidence, which is especially important for maintaining the integrity of infrastructural industrial and civil facilities [27]-[29].

In addition, a significant consequence is the preservation of aquifers and the prevention of the daylight surface waterlogging.

Thirdly, leaving of mine rocks in the underground space reduces the rock flow movement from the underground space to the surface and prevents the growth or appearance of rock heaps on the daylight surface [30]-[32]. Solving the problematic issues of rock accumulation on the daylight surface leads to an improvement in the state of the natural environment, in the sense of reducing toxic pollution of soils and water bodies [33]-[35].

An important factor for the highly efficient and economical mining of coal from the extraction panels by longwall faces is to ensure the stability of extraction workings [36]-[38]. Due to the stress state improvement of the rock mass surrounding the stope face by forming a rock backfill mass in combination with a frame-roof-bolt support, it becomes possible to reuse extraction drifts, which undoubtedly makes economic sense [39]-[41].

Figure-1 shows the generalized positive changes that are achieved by leaving of mine rocks in the goaf area of stope faces.

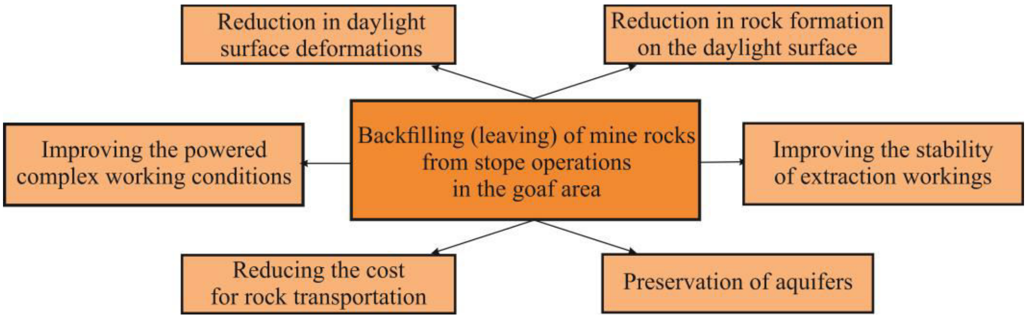


Figure-1. Positive changes in the backfilling (leaving of rocks) the goaf area of mines.

Insufficient attention has been paid in the scientific literature and research to the actual issues of the influence of the rock pack formed in the goaf area during the selective mining of a thin coal seam.

Therefore, the presented paper presents the analytical research results of the quantitative and qualitative changes in the stress-strain state of the rock mass surrounding the extraction drift during the rock pack formation in the goaf area in comparison with the traditional technology of controlling the roof by complete caving. The rock pack formation in the goaf area is ensured by applying the selective mining of coal seam reserves according to the developed new method [18].

2. RESEARCH METHODS

2.1 Choosing and Characteristics of the Research Object

To achieve the research purpose, the mining-geological conditions of the Zakhidno-Donbaska mine are chosen (Figure-2), for which the most promising is the selective coal-mining technology with leaving the rock in goaf area, given the very limited coal reserves in the seams that are mined at full capacity without undercutting the wall rocks.

The mine field geological data analysis shows that the bulk of coal reserves within the mine field boundaries is concentrated in seams less than 0.8 m thick (69.7% of industrial reserves).

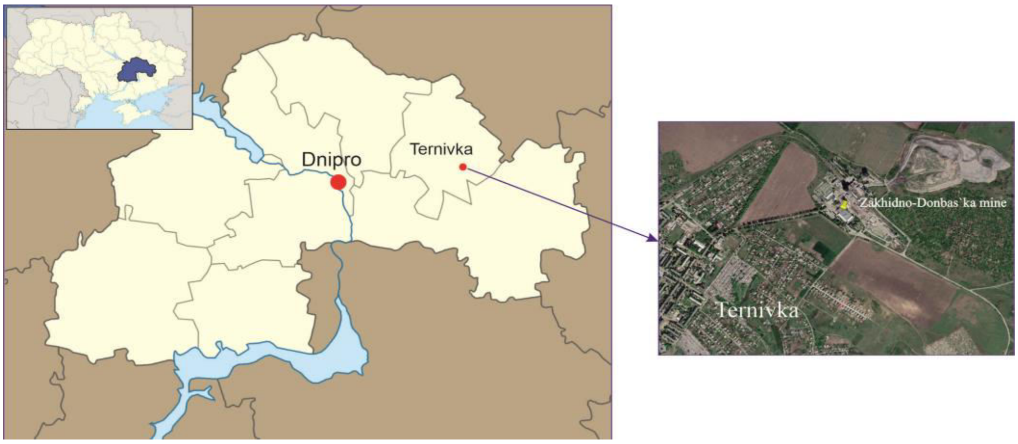


Figure-2. Layout of the Zakhidno-Donbaska mine, PJSC “DTEK Pavlohradvuhillia”

For example, 58.7% of the total volume of reserves are located in the mined seam in the thickness range of 0.55-0.8 m. This implies a further increase in the volume of wall rock undercutting to 0.45 m and, accordingly, an increase in technological ash content in the longwall faces by more than 60% when using traditional (gross) coal-mining technology. To develop a coal-bearing mass geomechanical model, the Zakhidno-Donbaska mine conditions are taken when mining the 861st longwall face of the C_8^b seam. The starting position in this research is to fulfill the requirements for the most adequate and reliable reflection of the mining-geological conditions of the seam mining in the geomechanical model development.

One of the main peculiarities of conducting mining operations through the seam C_8^b is its overworking during mining of the upper seams C_9 and C_8^u. The vertical distances between the indicated seams vary in a rather narrow range of 22-28 m when predominantly weak rocks with a hardness coefficient occur in the interlayer with periodic appearance of stronger sandstone ($f = 3$-6) of different thickness. Another main peculiarity is the geological structure variability in the coal-bearing stratum along the length of the longwall face extraction panel; moreover, the structure variation occurs mainly in the roof rocks of the seam C_8^b. Almost along the entire length of the longwall face extraction panel, there is a rather consistent bedding of the seams with a relatively small fluctuation in the thickness of the interlayer (argillite) within the range of 3.6-3.85 m. The compressive resistance of argillite in the sample is 9-20 MPa. In the main roof of the seam, there is a more significant change in the structure along the length of the longwall face extraction panel with a very large fluctuation in the thickness of lithotypes, as well as their replacement. In the low part of the extraction panel, under thick sandstone (4.3-15.6 m), there is a siltstone (5.2-9.1 m thick) replaced with argillite up to 5.5 m thick.

The geological section fragment of the 861st extraction site with the most unstable state of the roof rocks is shown in Figure-3.

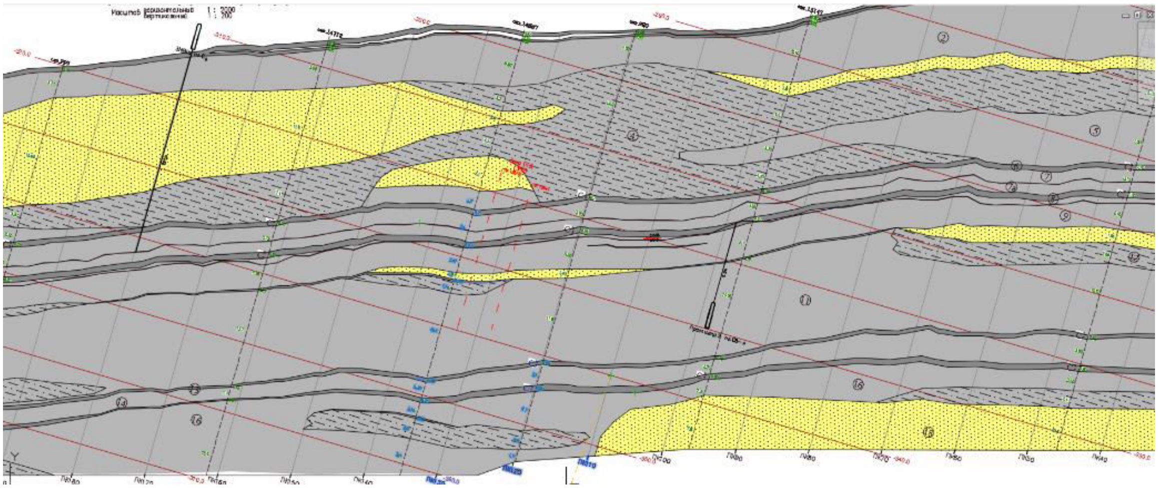


Figure-3. Geological section along the extraction panel length of the 861st longwall face.

The selected area of the 861st extraction site is dangerous in terms of the intensity of rock pressure manifestations, which is taken for modeling by performing a computational experiment. Of considerable scientific interest is the assessment of the influence of a rock pack formed in a goaf area on the stability of extraction drifts under conditions of high intensity of rock pressure manifestations.

2.2. Geomechanical Model Substantiation of the Coal-Bearing Stratum Behavior During the Seam Mining

To conduct computational experiments, the ANSYS software package is used, which has a rather wide range of capabilities for solving geomechanical problems based on a finite element analysis system. The selected software package for calculating the stress-strain state, as well as the methodological approach to substantiating and constructing a geomechanical model, make it possible to obtain reliable results. These results have a high convergence with the results of mine experiments, which is confirmed by studies conducted by a wide range of specialists [42]-[44].

The main task of the geomechanical research block is to determine the peculiarities of the stress-strain state (SSS) of the coal-bearing stratum around the extraction drift. Comparing the SSS parameters (distribution of stress components, their concentration values and sizes of distribution areas, length of mass destruction areas and other geomechanical anomalies) of selective mining technology with leaving the rock in the longwall face goaf area and traditional mining technology of conducting stope operations with complete caving of roof rocks, in addition to the known advantages (leaving the rock in the mine, reducing the ash content of coal, etc.), it is possible to assess the prospects for reusing the extraction drifts.

The methodological aspect of the research involves the construction of two models: for the basic technology (for a comparative assessement) and selective mining of the seam with leaving the rock in the goaf area.

These models differ from each other by the presence in the goaf area of a rock pack from the seam bottom rocks, undercut in the stope face.

Computational models consisting of 14 rock layers have been constructed. The height of the models (along the *y* coordinate) is 55 m, the dip/rise width is 60 m (coordinate *x*), the seam dip angle is 3 degrees. The main mechanical characteristics of the coal-bearing stratum, taken in the modeling, are given in Table-1. A view of the model containing the rock pack is shown in Figure-4.

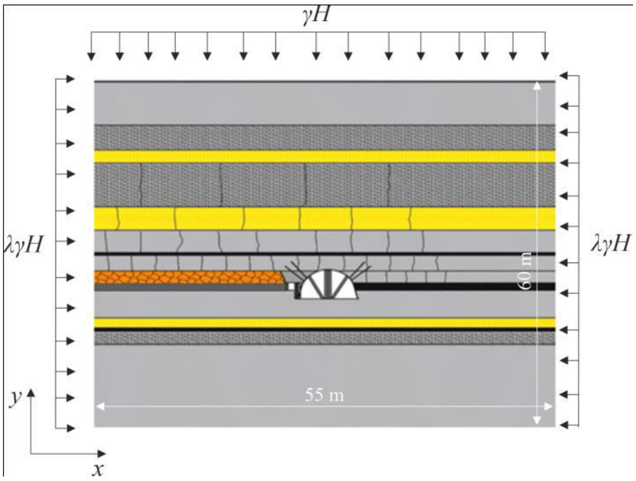


Figure-4. Geomechanical model for assessing the state of the mass adjacent to the prefabricated drift.

Table-1. Mechanical characteristics of the coal-bearing rock stratum.

No.	Thickness, m	Rock type	σ_{comp}, MPa	σ_{tens}, MPa	γ, kg/m^3	E·10^4, MPa
1	0-0.72	Siltstone	26.8	2.2	2.33	1.0
2	0-0.60	Argillite	11.0	0.7	2.7	0.5
3	1.02	Coal seam	26.0	1.3	1.24	0.3
4	3.05-7.2	Siltstone	26.8	2.2	2.33	0.2
5	6.0-9.0	Sandstone	40.0	2.7	2.6	2.0
6	3.0-5.4	Siltstone	26.8	2.2	2.33	2.0
7	5.6-12.4	Argillite	11.0	0.7	2.7	0.1
8	1.5-2.0	Argillite	11.0	0.7	2.7	0.1
9	0.74-0.8	Coal seam	31.0	1.3	1.24	0.3
10	0.95-2.2	Argillite	10.0	0.81	2.22	0.1
11	1.31-1.8	Sandstone	37.9	2.7	2.6	2.0
12	0.1-0.3	Coal seam	27.0	1.3	1.26	0.25
13	2.4-15.0	Siltstone	26.8	2.2	2.33	0.2
14	11.6-14.3	Argillite	10.0	0.8	2.2	0.15

The mechanical characteristics of lithological varieties have been obtained from the data of the mining-geological prediction for the prefabricated drift of the 861st longwall face. The influence of weakening factors of fracturing, water-cut and rheology is taken into account in accordance with normative documents [45], [46] and research results [47], [48]. The mechanical characteristics of fastening materials are taken into calculation according to the data of reference books [49]. Based on the analysis of the deformation properties of lumpy backfill materials from mine rocks [50], [51], the following mechanical characteristics of the rock pack formed in the *goaf area*, corresponding to the period of compressive load action, are taken. The rock pack deformation properties after shrinkage are taken as follows: deformation modulus is E = 50 MPa, transverse deformation coefficient is μ = 0.4.

In the section of the mine working model, the support TSYS-14.4 (SCP-27 profile) is set with four timber rows with a section of 0.1×0.15 m and a length of 3.2 m. The step of setting the frame support is 0.8 m. Three rows of wooden prop stays (diameter - 0.2 m, length - 2.3 m) on the bottom of the drift and one row of wooden prop stays (diameter - 0.2 m, length - 1.2 m) on the bottom of the longwall face are set along the goaf area of the longwall face. Roof-bolt support consists of four roof-bolts 2.4 m long and 22 mm in diameter, set in the mine working walls on each side. Roof-bolts are set in a mass between the frames with a step of 0.8 m.

The stress-strain state is calculated in an elastic-plastic setting with the presentation of a real “stresses - relative deformation” diagram of each lithological variety and fastening elements of the stope and extraction workings. This makes it possible, taking into account plastic deformations of the geomechanical system elements, to avoid significant failures in the calculation technology and increase the reliability of its implementation.

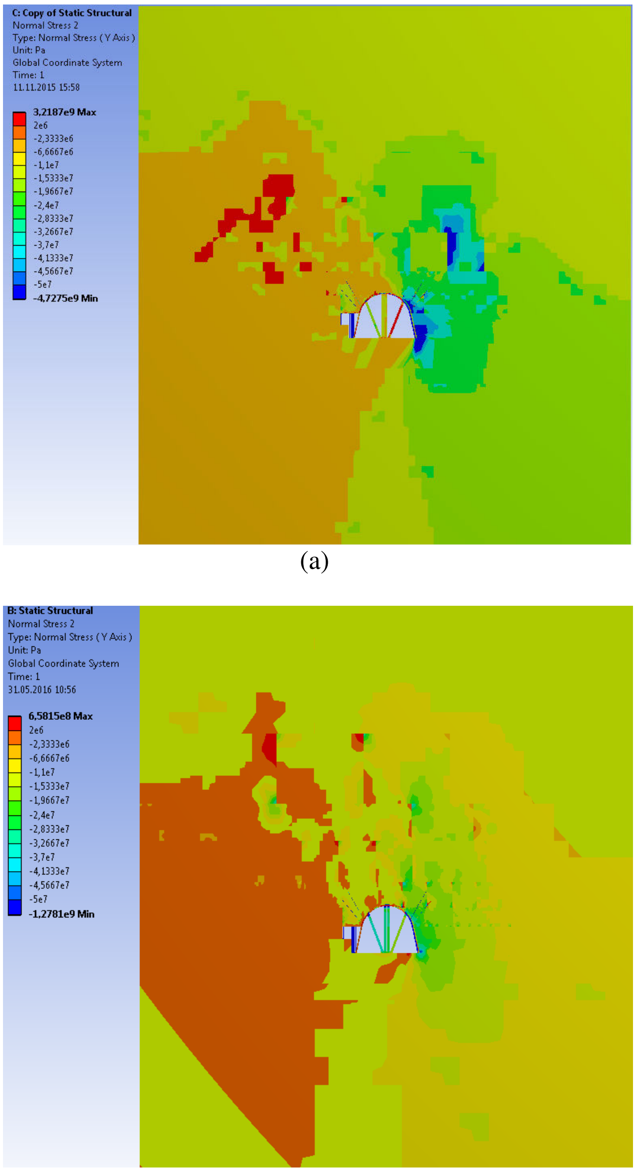
3. NUMERICAL MODELING RESULTS OF THE EXTRACTION DRIFT STABILITY AT COMPLETE CAVING AND LEAVING THE ROCK IN THE GOAF AREA

It is known that the most intense rock pressure manifestations develop after stope face driving, and it is this area of the drift that is very relevant in terms of the possibility of its repeated use. The algorithm for studying the geomechanical system behavior contains a primary assessment of anomalous zones in the adjacent mined-out rock mass. The sequential study of vertical σ_y, horizontal σ_x and stress intensity σ components has been performed.
Curves of vertical stresses presented in Figure-5 are characterized by a number of parameters, which in qualitative terms correspond to current results of modeling the behavior of the mass surrounding the extraction workings behind the stope face. In terms of quantity, the following peculiarities are observed.

From the side of the goaf area, there is a large area of destressed rocks in the roof and bottom of the seam C_8^b with a range of $\sigma_y = 2.3\text{-}6.7$ MPa. In relation to the initial non-hydrostatic state of the undisturbed mass $\sigma_y = \gamma H$, the degree of destressing is 0.21-0.61. This area extends into the roof up to 16.6 m, affecting the upper layer of sandstone, which is the boundary between the zones of hinged-block displacement and smooth deflection of the layers without discontinuity. The zone of destressing extends to the entire model depth, that is, more than18.4 m into the seam bottom. Inside the specified area, within the thickness of hinged-block displacement zone, there are places of complete destressing ($\sigma_y \approx 0$) with the transition to tension up to 2 MPa. Such a phenomenon does not contradict the existing ideas about the coal-bearing stratum displacement in the vicinity of the stope face.

The weight of rocks in the roof, which is stratified and collapses, creates a certain concentration in the areas of security and support elements that resist the displacement process: single-row breaker prop, rows of side and central prop stays of the strengthening support. However, the concentration value is relatively small ($\sigma_y / \gamma H = 1.40\text{-}1.79$), which is conditioned by the low resistance reaction of the whole row of the wooden prop stays in the breaker prop, as well as the yielding property of the prop stays in the strengthening support.

From the side of the undisturbed mass, a zone of lateral bearing pressure is formed. Its sizes with a relatively small concentration coefficient ($\sigma_y / \gamma H = 1.40\text{-}1.79$) extend into the roof up to 14.2 m, and into the bottom - to the entire depth of the model. Such concentrations are destructive (according to the factor σ_y action) for argillite in the immediate roof and bottom, as well as argillite in the main roof, which occurs below the sandstone. The width into the mass of the possible weakening area reaches 6.6 m, while the formation of significant oblique and lateral stresses is possible.



(a)

(b)

Figure-5. Curves of vertical stresses σ_y in the coal-bearing rock stratum surrounding the prefabricated drift in the basic (a) and selective with rock pack (b) technologies of the seam mining.

Concentrations of $\sigma_y / \gamma H = 3.4\text{-}6.0$, unambiguously, destroy the border rocks and are located in the mine working wall up to a width of 1.8 m and a height of up to 4.5 m. Of particular danger is a limited area with $\sigma_y / \gamma H \geq 4.5\text{-}5.0$, the sizes of which are 1.9 m in height and 0.8 m in width.

Its negative effect is in its location under the coal seam to a depth of the lower ripping and further under the bearings of the frame prop stays. Here, the destroyed rocks create (under lateral pressure) a high bending moment acting on the low part of the prop stays, on the one hand, and on the other hand, they create conditions for intensive pressing of the prop stay bearings into the drift bottom with a corresponding loss of its section.

Sandstone, as a harder and stronger rock, is a stress concentrator due to its increased resistance, and this is consistent with the existing ideas of rock mechanics. But this area up to 4.5 m high and 1.4 m wide with its destruction provokes the loss of continuity more than the upper rock layers; they can be deformed quite freely, and the spacer system of rock blocks (in the hinge-block displacement zone) sharply loses its resistance to rock pressure. Then the entire large rock volume in the main roof (up to 10-12 m high) with its weight creates a load on the fastening system (several times greater than the frame support load-bearing capacity), without counteracting it at least partially.

In terms of assessing the bottom rock stability (according to the factor of vertical stresses action), an increased intensity of swelling from the undisturbed mass side can be predicted, where the lateral bearing pressure plays a primary role in this process. All these peculiarities of σ_v distribution indicate the necessity to significantly strengthen the frame support of the drift.

When using the selective technology of coal seam mining with leaving the rock in the goaf area, the distribution of vertical stresses differs significantly from the basic variant. The main attention is paid to the areas of σ_v concentration, which are of the greatest interest in terms of forming the load on the fastening and security systems of the prefabricated drift. The general conclusion is a decrease in concentrations and a decrease in the areas of their action due a decrease in the deformations of the roof rock layers, which are lowered onto a wide bearing from a rock pack.

Firstly, from the side of the goaf area, the concentration of compressive σ_v in the immediate roof above the three rows of side wooden prop stays of the strengthening support has completely disappeared. This is conditioned by the fact that, despite the sufficient rigidity of the wooden prop stays, their total resistance to the lowered roof layers is ten times less compared to the total resistance of the rock pack formed in the goaf area. For the same reason, the sizes (up to 95% in height, up to 3.2 times in width) are sharply reduced of the minimum concentration of $\sigma_v / \gamma H \leq 1.4$ in the immediate roof above a row of wooden prop stays in the breaker prop; higher concentrations disappeared completely. The data presented indicate an increase in the continuity of rock blocks in the immediate roof and a decrease in the probability of “escaping” of wooden prop stays in the strengthening support and breaker prop.

Secondly, the size of the areas of acting relatively moderate concentrations $\sigma_v / \gamma H = 1.40\text{-}1.79$ has sharply decreased. Previously, in one large area (in the basic technology), such a range of σ_v concentration was divided into two parts: in the main roof, up to 4.8 m high and up to 2.1 m wide; in the immediate roof and bottom, the total height was 11.4 m, and the width was up to 4.2 m. Compared to the basic technology of seam mining, the areas of acting moderate concentrations σ_v have decreased many times, although for the sake of objectivity it should be noted that such a level of vertical stresses can cause weakening only of weak argillites.

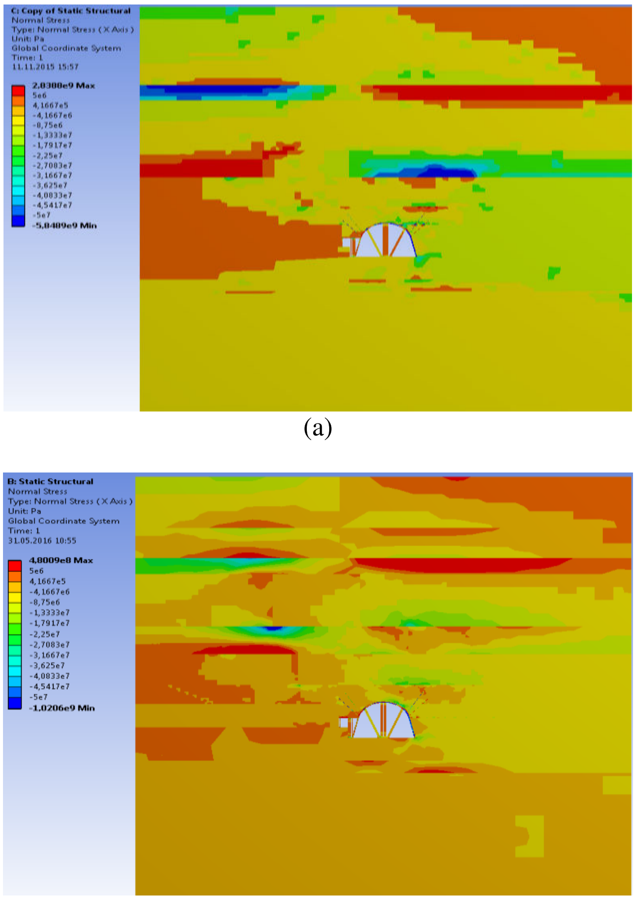
Thirdly, concentrations of the level 1.79-2.18 already cause the destruction of weak lithotypes of the coal-bearing mass and occur only in fairly local areas:

- in the upper sandstone up to 1.7 m high, up to 0.8 m wide, the absolute values of the acting σ_v on average by 1.5-3.0 times lower than the compressive resistance of sandstone;
- in the main roof low layer (argillite), an area up to 1.5 m high, up to 0.9 m wide is most likely prone to destruction, but its relatively small sizes do not allow, in our opinion, to sharply reduce the spacer-block system stability in this layer;
- the most significant area of this concentration σ_v is located from the mine working side, up to 4.5 m high and 1.8 m wide; here, the destruction of argillites in the immediate roof and bottom is predicted, but the coal seam retains a continuous state; based on the rock volume of possible destruction, it is possible to predict a moderate obliquely directed rock pressure on the fastening system in the immediate roof and lateral pressure on the frame prop stays from the side of the immediate bottom.

The positive effect of forming a rock pack in the goaf area is revealed when comparing the above concentration areas $\sigma_v / \gamma H = 1.79\text{-}2.18$ with those in the basic technology: extension to the roof up to 10.0 m, to the bottom up to 5.3 m, along the strike up to 6.6 m; that is, there is a multiple decrease in the area of acting concentrations σ_v that destroy the weakest lithotypes in the coal-bearing stratum. As for the concentrations that weaken or completely destroy stronger lithotypes (coal and sandstone), they practically disappear in selective technology of the seam mining; the exception is a very limited area (0.5-0.4 m) under frame prop stay bearing from the side of the mass, which does not significantly affect the prefabricated drift stability. Thus, according to the factor of acting vertical stresses, it is possible to state a significant decrease in dangerous concentrations and a decrease in the areas of their distribution.

Afterward, the distribution of horizontal stresses σ_x is analyzed, the curves of which are shown in Figure-6. The horizontal component most clearly reflects the deflection of the rock layers and its direction, which is quite clearly observed in the main roof of the drift. Sandstone layers, as harder and stronger lithotypes, are intensely loaded. Thus, in sandstone located at a height of 5.0-5.5 m from the contour of the mine working arch, a large area of compressive concentrations σ_x is formed (8.7-13.2 times higher than the initial undisturbed mass state), which extends through the seam thickness up to 1.8 m, and along the stratification plane - up to 8.4 m. The sandstone layer deflection is directed towards the mine working, and a high concentration of σ_x indicates its active resistance to rock pressure. With the loss of sandstone stability, the siltstone located above it (with a high probability of water saturation) can also be intensively weakened (insufficient bearing from below). And then it is possible to develop the height of the ultimate equilibrium arch to the next (in height) sandstone layer, and this distance is 14.0-14.5 m to the mine working contour. In the case of a negative development of events, not a single, even strengthened, frame support will not withstand the rock pressure.

On the side of the drift, from the side of the goaf area, there is an area of almost completely destressed rocks with the occurrence of tensile stresses σ_x up to 3-5 MPa. Given that there are an uncontrolled collapse and hinged-block displacement zones, the action of tensile stresses σ_x further enhances the disintegration of rocks and creates a semblance of a large rubble band. Therefore, the assumption of provoking (a single-row breaker prop and three rows of side prop stays of the strengthening support) the caving in the immediate and low layers of the main roof in order to create bearing, when the roof is lowered, has the right to exist. Moreover, there is a relatively small gradient σ_x of change in the roof height (from the side of the goaf area) up to the coordinates of the sandstone occurrence at the zone boundary of the smooth deflection of the layers without discontinuity.



(a)

(b)

Figure-6. Curves of horizontal stresses σ_x in the coal-bearing rock stratum surrounding the prefabricated drift in the basic (a) and selective with rock pack (b) technologies of the seam mining.

This relative uniformity of σ_x distribution (except for hard sandstone) indicates low-intensity deflections of the main roof layers, and, consequently, the similarity of the rubble band from collapsed rocks to a certain extent performs its function of creating a proper bearing. On the side of the drift, from the side of undisturbed mass, against the background of a general low-manifested concentration of σ_x (in the range of 1.0-2.8), there are two local areas with a concentration coefficient of up to 4.0-5.0. The upper area is located near the arch spring (yielding joists of the frame). The low area of σ_x concentration is located near the bearings of the frame prop stays.

In the very bottom of the drift, there is a rather homogeneous field of σ_x, which is disturbed by local areas of destressing and small areas of σ_x concentration, caused by varying rigidity of argillite, sandstone and coal seam during their deflection towards mine working cavity. Therefore, in general, it is possible to predict a rather moderate swelling of bottom rocks, but mainly from the side of the mass, by the factor of σ_x.

Summing up the analysis results, attention should be focused on the prediction of a rather intensive development of geomechanical processes of displacement in the coal-overlaying formation and active rock pressure manifestations due to their extreme asymmetry relative to the vertical mine working axis. Large and remote areas of stress-strain anomalies lead to the rejection of the "standard" methods of counteracting rock pressure by strengthening the fastening system, and the involvement of selective technology with leaving the rock in the goaf area, thereby reducing both the asymmetry of rock pressure and its value.

Processing of numerical modeling results makes it possible to determine the patterns of a change in the rock contour (Figure-7) with traditional technology and selective technology with leaving the rock in the goaf area when mining the seam.

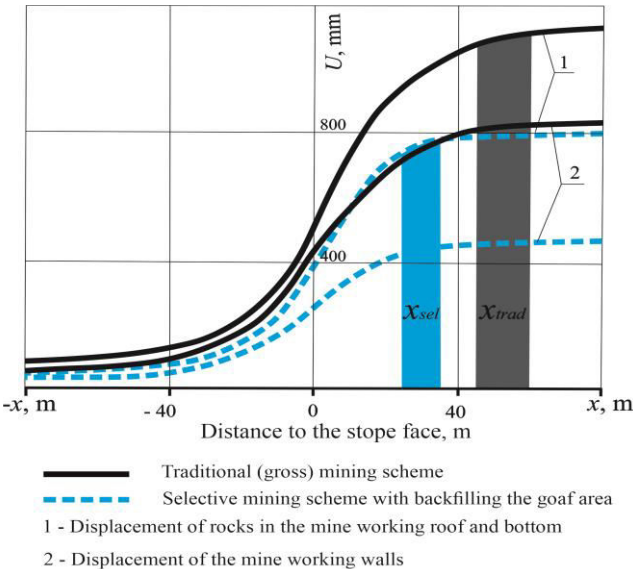


Figure-7. Patterns of displacements U development in the mine working rock contour from the distance x to the stope face and scheme of the seam mining.

Let us study the main differences in the distribution curve of horizontal stresses in selective technology of the seam mining.

Firstly, the concentrations in the more distant sandstone, which is (most likely) the upper boundary of the hinge-block displacement zone, have significantly decreased. Thus, from the side of the goaf area, the concentration of compressive stresses σ_x has decreased by 1.65-2.7 times with a relatively small (up to 10-15%) reduction in the size of their distribution along the strike. The absolute value of these concentrations is no longer capable of weakening sandstone. From the side of the mass, the size of the area of acting tensile stress $\sigma_x > 5$ MPa is limited to 15-20%, which, however, does not improve the situation with the division of sandstone into blocks, since its tensile strength is much lower ($\sigma_s = 1.6$ MPa). At the same time, the penetration depth of tensile stresses σ_x (through the sandstone thickness) is reduced to 60%, which makes it possible to suggest an increase in the stability of the spacer system made from sandstone rock blocks.

Secondly, the low thick siltstone layer, in which the most dangerous concentrations of compressive stresses σ_x do not exceed its compressive resistance, resists rock pressure more actively.

Thirdly, the sandstone layer closest to the mine working has also sharply increased its stability: there are no destructive concentrations of compressive stresses σ_x in it, and the areas of acting tensile stresses are very limited.

Fourthly, in the main roof (argillite) low layer, the concentrations σ_x that can lead to its partial weakening are localized; their penetration into argillite does not exceed 20% of its thickness, and along the strike the length of local places does not exceed 0.8-1.0 m.

In general, based on the SSS analysis results of the coal-bearing mass surrounding the prefabricated drift, it is necessary to state a number of positive changes in its state when creating a rock pack in the goaf area:

- according to the factor of vertical stresses σ_y action, dangerous concentrations are reduced up to 1.8 times and the areas of their distribution are reduced;
- according to the factor of horizontal stresses σ_x action, almost all the main roof rock layers form stable spacer-block systems that can actively resist rock pressure;
- indicated factors contribute to reducing the activity of rock pressure manifestations and increasing the prefabricated drift stability.

In resin-grouted rockbolts, there is a decrease in the component σ_x, especially active from the side of the mass. Thus, tensile stresses σ_x completely disappear in the upper rockbolt, while in the low rockbolt the area of their action decreases by 1.9-2.2 times; this is conditioned by a decrease in the intensity of the immediate roof rock displacement with the selective technology of mining the coal seam with leaving the rock in the goaf area. In other fastening system elements, the distribution field has not practically changed.

Thus, a comparative analysis of the state of the scheme elements for maintaining the prefabricated drift has revealed a number of positive changes when using the selective technology of mining the seam with leaving the rock in the goaf area:

- in the frame support and resin-grouted rockbolts, the plastic state areas of SCP and reinforcement are limited to 60-80%, or they are excluded completely;
- the transition of the side wooden prop stays of the strengthening support to a stable state with a maximum resistance reaction to the rock displacement in the immediate roof and low layers of the main roof;
- the listed factors make possible to assert an increase in the stability of mine working as a whole.

4. CONCLUSIONS

The main comparative analysis results of the extraction drift stability with both traditional technology and selective technology of mining the coal seam with leaving the rock in the goaf area can be presented as follows:

- according to the factor of acting vertical stresses σ_y, not only the transition to a stable state of most scheme elements for maintaining the drift has been proven, but also their active resistance to differently vectored rock pressure at a level close to the load-bearing capacity value, thus indicating the effectiveness of their operating modes;
- according to the factor of acting horizontal stresses σ_x, a significant improvement in the state of the frame support and resin-grouted rockbolts has been revealed, while maintaining the load on the wooden fastening and security elements at the same level;
- the convergence value of the rocks in the roof and bottom decreases by 1.42 times, not exceeding 790 mm during selective technology of mining the seam; most of it is the bottom heaving (460 mm), while the lowering of the roof (330 mm) slightly exceeds the constructive yielding property of the TSYS support, but it can still be limited due to the “deep” strengthening of the roof rocks;
- the convergence of the drift walls is reduced by 1.84 times, not exceeding 450 mm; this value is more than twice the lateral yielding property of the frame, but there is a considerable reserve for reducing lateral displacements due to the formation in the roof of an armoured and rock plate with a high load-bearing capacity and strengthening the wall rocks with resin-grouted rockbolts;
- the general increase in the extraction drift stability indicates significant prospects for its repeated use in an almost unrepaired condition.

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