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GEOMECHANICAL SUBSTANTIATION OF THE PARAMETERS FOR COAL AUGER MINING IN THE PROTECTING PILLARS OF MINE WORKINGS DURING THIN SEAMS DEVELOPMENT

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ABSTRACT

The paper focuses on mining hard-to-reach coal reserves, concentrated in the protecting pillars of main mine workings using auger technology. One of the Western Donbass coal enterprises - Pavlohradska Mine of PJSC DTEK Pavlohradvuhillia - is selected for the research, where in the conditions of C_4 seam the use of the Auger machine BShK-2DM is considered for coal extraction from protecting pillars of one of the main mine workings. The initial data have been substantiated and a geomechanical model has been constructed for numerical modelling the pillars stress state of the system “rock mass - drilled well”, with the varied width of the interwell pillar. It has been determined that the horizontal rock pressure component, which forms destructive tension stresses, is of predominant importance to substantiate the dimensions of interwell pillars. The pillar optimal width of the C_4 seam eastern section behind the Pivdenno-Ternivskyш fault at a depth of 120 m may be a value not less than 0.25 m. The accepted interwell pillar width is 0.3 m. The level of coal losses during its extraction from protecting pillars of one of the main mine workings has been determined, which is in the range of 20-30%.

Keywords: auger mining, thin coal seam, protecting pillars, interwell pillar, stress, drilled well, geomechanical model.

1. INTRODUCTION

Bituminous coal is one of the main strategic fuel and energy resources of Ukraine, which is able to ensure the development of various economic sectors, in particular, the production of electric-power and metallurgy for the next 300-400 years. Using bituminous coal, 35% of the country’s total electric power is generated at thermal power plants [1]-[3]. The balance reserves of coal seams for 2020 are estimated at 4.19 billion tons, off-balance reserves - at 17.3 billion tons [4]. The main difficulty when mining the balance coal reserves is that almost 80% of them are concentrated in coal seams with a thickness of less than 1.0 m. The problem of coal mining from thin seams is especially acute in the Western Donbass mines. PJSC DTEK Pavlohradvuhillia is the leader of the Ukrainian coal industry, whose mines annually produce more than 60-70% of all Ukrainian coal in the range of 18-20 million tons [5], [6]. Despite the increased mine output indexes compared to the public sector, the geological conditions of mining have significantly worsened, thereby increasing the total costs for coal mining. This is caused by the small geological thickness of coal seams and the associated mined coal dilution (ash content).

Today, coal enterprises are introducing coal mining technologies based on powered support and mining assemblies (shearer-loaders, mining ploughs), which, according to technical parameters, are not capable of mining out the seams less than 1.0 m. This forces to perform cutting the rocks of the coal seam bottom, which leads to an increase in the ash content of the coal and deterioration of its quality. This fact is evidenced by the analysis of output indexes of the Western Donbass mines over the past 10 years, where the operational ash content of mined coal has increased by 3.5% and is 44.3% [7], [8].

There are also balance reserves, which have remained within the closed mine fields of Ukraine and are estimated at 1.0 billion tons. A significant part of them is concentrated in protecting pillars. Protecting and barrier pillars cannot be extracted due to the subsidence of the daylight surface, but protecting pillars of main mine workings are promising for extraction. Thus, in the allotments of the Western Donbass coal mines, the coal reserves in protecting pillars of mine workings are estimated at 10-15 million tons.

In present-day conditions, when the production economic efficiency is a key factor in the functioning of enterprises, the completeness of coal reserves extraction from the mine field with the simultaneous extension of the mines’ life is an urgent issue. The modern development of the direction for integrated mining of valuable coal reserves should be based on a synergistic approach. The latter is characterized by mining the basic reserves (traditional technologies) [9], [10] and additional reserves (using special technologies), which are concentrated in pillars, complicated by geological faults or debited as off-balance ones. These additional reserves can be extracted from the subsoil using auger mining technology [11], [12] or by thermochemical conversion during underground gasification [13]-[15]. The maximum recovery of the reserves of the mine field, including under the protected objects, is possible only using the technology of mining with backfill [16]-[19]. The synthesis of technologies for the main and additional coal mining within the mine field will significantly increase the technical-and-economic indicators of the enterprise. If to compare the indicated technologies for possible additional coal mining, provided significantly lower initial capital costs and terms of commissioning, auger mining may be considered expedient.

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Nowadays, the auger machines are widely used in many countries of the world, such as China, USA, South Africa, Australia, where hard-to-reach coal reserves are extracted in mines with the help of these machines [20]-[22].

One of the most important tasks of effective auger mining of coal reserves is to substantiate the parameters of this technology, especially the stability of interwell and supporting pillars, which are formed to prevent roof caving when drilling out coal from the seam. In mining, significant attention is paid to determining the parameters of pillars in terms of the safety of mining operations and the volume of minerals lost in the bowels.

2. SELECTION OF THE RESEARCH OBJECT AND CHARACTERISTICS OF COAL MINING TECHNOLOGY

One of the Western Donbass coal enterprises - Pavlohradska Mine of PJSC DTEK Pavlohradvuhillia - is selected for research, where, according to the development program from 2015 to 2030, was planned to develop the coal reserves in the abandoned area of the C_4 seam eastern wing.

Coal seam C_4 is on the area of mining out a simple structure with geological thickness of 0.78-1.06 m, on average - 0.85-0.90 m. In the main part of the panel, the seam is sustained both to the dip and on the strike, the dip angle of the seam is 2°. The coal is hard (f = 1.2-4.4), fractured, and fractures are filled with calcite, a system of fractures (coal cleavage) is observed. The seam is of natural moisture.

Siltstone, argillite, C_4^1 and C_5 coal seams, sandstone occur in the main and immediate roof. Siltstone occurs in the bottom. The water cut of the stoping faces will be associated with the overlying coal seams and sandstone, the inflow will be up to 1.5 m^3/hour. Coal seam is not dangerous for rock bumps, coal and rock outbursts. Coal seam is not dangerous for rock bumps, coal and rock outbursts. It is not prone to spontaneous combustion. The seam C_4 has been uncovered from the operating mine workings of the seam C_5, horizon 235 m with conveyor cross-cut #2 of the seam C_4, haulage cross-cut #2 of the seam C_4, oblique cross-cut of the seam C_4. Extraction panels are bounded with prefabricated drift and boundary entry, and the prefabricated drift is gobbed following the longwall face advance, and the boundary entry is used for mining out the next longwall face, and is used again, but already as a prefabricated drift. To protect the main mine workings from the negative influence of the bearing rock pressure, coal pillars are left in front of the longwall face, the length of which ranges from 60-200 m.

To increase the annual mine output, reduce in the ash content of the mined rock mass and increase the completeness of coal extraction from the mine field, the reserves concentrated in the protecting pillars of mine workings are proposed for development using auger technology. To mine out the coal reserves concentrated in the protecting pillars of the main mine workings, the seam C_4 eastern section behind the Pivdenno-Ternivsky fault is taken for research (Figure-1), the characteristics of which are given in the Table-1.

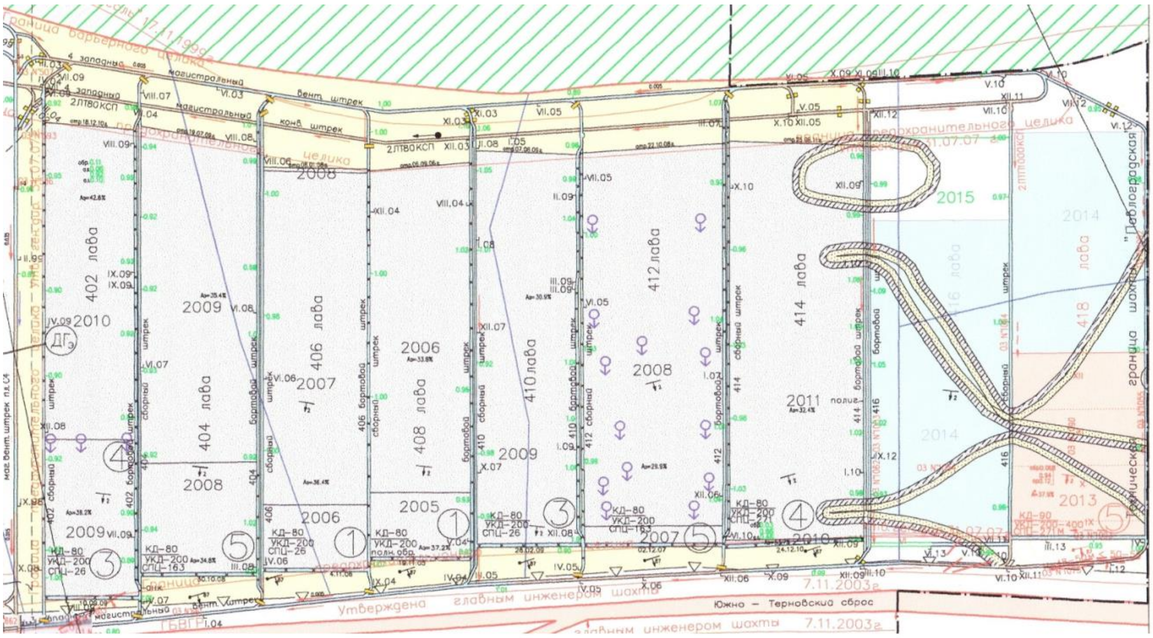

Figure-1. Eastern section of the seam C_4 behind the Pivdenno-Ternivskyi fault, where the protecting pillars development using the Auger complex is considered

The mining plan analysis of the C_4 seam eastern section behind the Pivdenno-Ternivskyi fault and its mining-geological and mining-engineering indicators allows to assert that the technical parameters of the auger mining method fully comply with these conditions, therefore, it can be effectively used while mining coal reserves in the protecting pillars. The experience of using the BUG-3, BZM-1m, BShK-2DM, KBV auger machines is widespread. The greatest domestic and foreign recognition has been received by the BShK-2DM machine, which has no analogues in the world.

To plan coal mining from protecting pillars of the main mine workings of the C_4 seam, the Auger machine BShK-2DM is considered, which corresponds to the mining-geological conditions of the selected eastern section of the C_4 seam behind the Pivdenno-Ternivskyi fault.

The auger mining complex BShK-2DM is designed for coal mining (without the presence of people in the working space) by drilling out blind extraction strips of 1.905-2.105 m wide, up to 100-120 m long, with preparatory mine workings with a cross-sectional area of at least 11.2 m^2 in the clear, with an angle of inclination 3°, with a bottom rocks ripping of at least 0.6 m and air supply due to the general mine ventilation pressure [23].

Table-1. Mining-and-geological indicators of a mine field section.

Indicators	Values
Immediate roof and bottom rocks m = 0.4-4.4 m	Siltstone and argillite, fractured
Immediate roof and bottom stability	Unstable ($B_1 – B_2$), medium stability and low stability ($P_1 – P_2$)
Hardness coefficient of host rocks in: - main roof - immediate roof - bottom	 f =1.8-5.0 f = 1.5-2.0 f = 1.8-5.0
Coal cutting resistance A_{cut}, kN/m	up to 350
Seam water-cut, m^3/day	5 - 8
Dip angle of the seam, deg	2
Specific weight of coal, t/m^3	1.25
Specific weight of rocks, t/m^3	2.37
Seam thickness: - geological, m - average dynamic, m	 0.75-1.0 0.85
Hardness coefficient of coal	f = 3.5

The general view of the BShK complex is shown in Figure-2, and its technical characteristics are shown in Table-2.

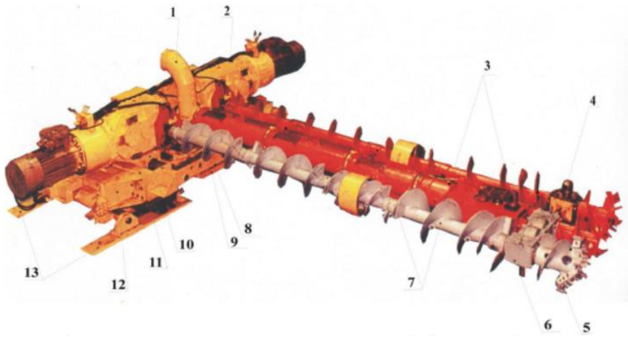

Figure-2. Auger complex BShK-2DM: 1 - ventilation system; 2 - drive unit; 3 - dust suppression system; 4 - support; 5 - bits; 6 - executive body reducer; 7 - auger bit; 8 - centering block; 9 - supports; 10 - drive frame; 11 - hydrosensor unit; 12 - orientation unit; 13 - shoes

Table-2. Basic technical characteristics of the Auger complex BShK-2DM.

Parameter	Indicator
Technical performance t/min	1.2-1.5
Diameter of drilling bits, mm	525, 625, 700
Width of wells, mm	1610-2130
Length of wells, m	100-120
Installed power of motors, kW	2×110
Pulldown of the working body, ts	50
Level of commercial coal production, t/day	up to 1100

Mining is conducted by drilling out the coal seam with extraction strips 1.9-2.0 m wide and 100-120 m long. A computer model of auger mining of coal from protecting pillars has been developed in the Autocad 2019 software package (Figure-3).

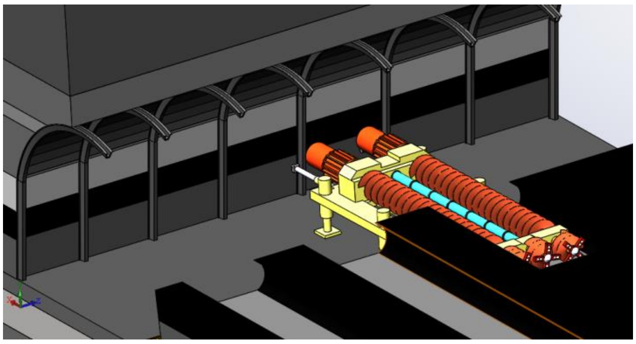

Figure-3. Computer model view of the auger mining of coal.

The use of the auger complex in the conditions of the operating coal mine is characterized by a number of positive peculiarities [24]:

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- commercial coal products are mined from the wells with ash content close to those in the seam (12-20%);
- the extraction of low-ash rock mass significantly saves the costs for its transportation, beneficiation, as well as wear and maintenance of transport systems of the underground and surface mine's infrastructure;
- it becomes possible to mine out off-balance reserves (in terms of the seam thickness), seams with a complex structure, mothballed reserves under civil and industrial facilities;
- enterprise management becomes more flexible, because output can be regulated within wide limits and depends on the number of machines at the enterprise;
- the costs for technical re-equipment are reduced, since the cost of the auger complex is 8-10 times less than the cost of a powered one, the payback period is 7-8 months;
- labor productivity of a worker at the auger complex (t/month) is 3-5 times higher than in the stoping face equipped with a powered complex;
- the risk of industrial injuries is significantly reduced and the efficiency of degassing of the mined-out space is increased.

To mine out the coal reserves concentrated in the protecting pillars of the C_4 seam eastern section, it is proposed to use the auger complex according to the technological scheme shown in Figure-4.

The technological scheme provides for mining the coal from protecting pillar of the main mine working, where the longwall face mined-out using the Auger complex BShK-2DM was stopped. The coal reserves of a pillar between the prefabricated drift and boundary entry is a panel for mining. Supporting panel pillars remain near the drifts. From the main ventilation drift, the Auger machine BShK-2DM gradually drills out coal strips to the technological length of the well in the direction from one to another drift, leaving interwell pillars between the mined-out strips for the stability of the roof rocks overlying the coal pillar.

To implement the coal mining technology according to the scheme in Figure-4, the primary task is to determine the optimal sizes of interwell coal pillars at which the stability of the rock mass is ensured. Determination of their size will make it possible to predict the level of coal losses during auger mining of coal from protecting pillar.

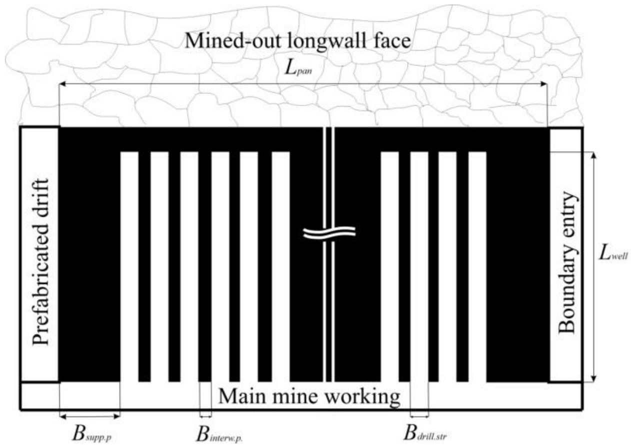

Figure-4. Technological scheme for mining the protecting pillar section of main mine working: $B_{supp.p}$ - supporting pillar width, m; $B_{interw.p}$ - interwell pillar width, m; $B_{drill.str}$ - drilled-out strip width, m; L_{well} - well length (chamber), m; L_{pan} - panel length, m.

3. METHODS OF RESEARCH

Various methods of modelling the stress-strain state of the mass have been widely used to study geomechanical problems during the mineral deposits development [25]-[28]. The finite element method makes it possible to reflect the formation of mass stress state similarly to natural conditions, provided that the problem is adequately formulated and initial data set [29]-[31]. This research uses numerical modelling by finite element method in the SolidWorks 2016 software package. The task of numerical modelling is to determine the stable optimal parameters of interwell pillars during auger mining of coal. The initial data for modelling are the following:

- lithological composition of rocks (average lithological thickness according to mining-and-geological prediction);
- physical and mechanical properties of rocks according to mining-and-geological prediction (Table-3);
- average depth of dipping the seam C_4 eastern section behind the Pivdenno-Ternivskyi fault - 120 m;
- the value of load that is applied to the model - 2.2 MPa (with an average density of sediments and mass 1.8 t/m^3 and the depth of mine working occurrence 120 m);
- design and technological parameters of the production well created by the drilling string assembly (well diameter 0.650×3 of the drilling assembly ≈ 1.91 m).

The lithological composition of the mine working roof rocks is as follows:

- roof: argillite - 1.7 m, argillite - 1.0 m, argillite - 3.0 m, argillite - 8.0 m, argillite - 2.5 m, argillite - 1.5 m;

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- bottom: siltstone - 6.5 m, coal seam - 0.3 m, argillite - 2.0 m, siltstone - 6.0 m, siltstone - 6.2 m.

Physical and mechanical properties of rocks have been determined by the results of sample tests when performing mining-and-geological prediction of the mine and are presented in Table-3.

The boundary conditions are fulfilled to eliminate the influence of the edge effect on the stresses formation around the production well. The accepted dimensions of the geomechanical model are as follows:

- in vertical direction - 28 m, 14 m towards the roof and bottom from the coal seam;
- in horizontal direction - 20 m.

Table-3. Averaged physical and mechanical rock properties of the seam C_4 eastern section behind the Pivdenno-Ternivskyi fault.

Name	Argillite	Siltstone	Coal
Deformation modulus, E, MPa	6400	8900	3700
Poisson's ratio, μ	0.24	0.31	0.27
Density, γ, kg/m^3	2500	2400	1250
Ultimate compressive strength, σ_{comp}, MPa	17.0	15.0	37
Ultimate tensile strength, σ_{tens}, MPa	1.7	1.5	3.7

Based on the experience of performing numerical modeling of stress-strain state of the rock mass around extraction mine workings by the finite element method, the dimensions of the stress state zones that develop from the mine contour into the depths in the sides, roof and bottom of the rock mass usually do not exceed the size of its width and height, respectively. Therefore, the sufficiency of the used geometrical dimensions of the model is predicted.

If, according to the analysis results of the obtained curves of stresses along the upper and lower boundaries of the model, the components σ_y, which correspond to the stress (γH) of virgin mass (2.2 MPa), are uniformly distributed, and in the sides of the roof and the bottom of the extraction mine working, the stresses σ_y attenuate at a distance much smaller than the lateral boundaries of the model, the geometrical dimensions of the geomechanical model are accepted correctly.

Based on the initial data, a computational scheme for modelling the stress state of the "rock mass - drilled well" system pillars in the seam C_4 eastern section behind the Pivdenno-Ternivskyi fault has been constructed, which is shown in Figure-5. While modelling, the interwell pillars width is varied with a step of 0.25; 0.5; 1.0 and 1.5 m. The width of the strip, which is drilled out, is accepted as 2.1 m, taking into account 3 drill bits in the BShK-2DM executive body with a diameter of 0.7 m.

The stress state is calculated in the SolidWorks 2016 software package, which is based on the finite element method (FEM). The Mohr-Coulomb failure criterion is accepted to envisage the material destruction, if the main maximum stresses exceed the stress limit that the material can withstand.

4. THE RESULTS OF NUMERICAL MODELLING OF THE INTERWELL PILLARS STABILITY DURING AUGER MINING OF COAL RESERVES

The primary task of the research into the mass stress state is to determine the stable parameters of the interwell pillars for preventing the seam roof rocks caving into the mined-out space.

A series of computational experiments has been conducted for modelling the stress state of a rock mass containing drilled-out strips 2.1 m wide (3×0.7 m) and interwell pillars (variation step 0.25, 0.5; 0.75 and 1.0 m).

As a result of a computational experiment, the curves of vertical *SY* and horizontal *SX* stresses distribution in a rock mass have been obtained with different parameters of auger mining.

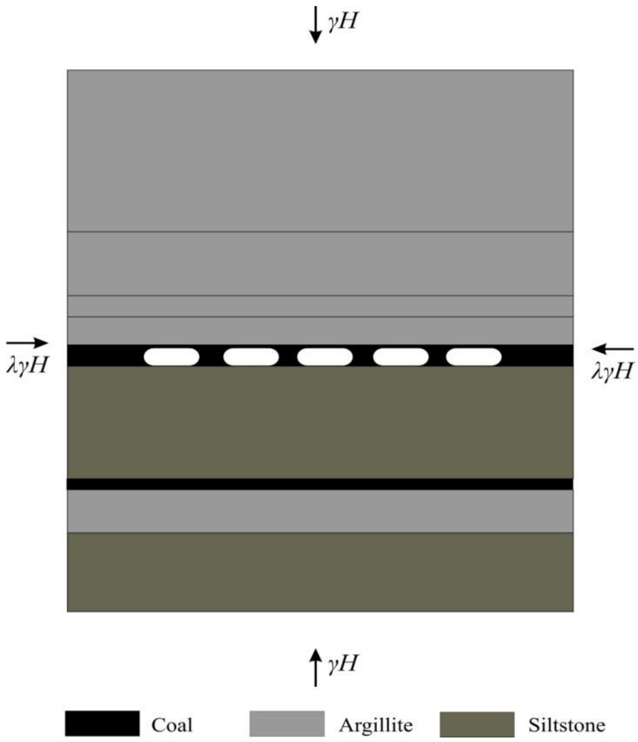

Figure-5. Computational scheme for determining the rock mass stress state in pillars between the wells.

The pattern of stresses distribution in the curve in the context of the edge stresses absence indicates the correctness of the accepted geometrical dimensions of the model.

Analysis of the *SY* curve (Figure-6a) shows that tensile stresses close to 0 MPa in values are formed in the coal patch roof of the drilled-out strip, thereby indicating the stable roof state. Also, the rock pressure vertical component in coal pillars with a width of 1.0 m forms a weak field of compressive stresses with a value of 7.5-

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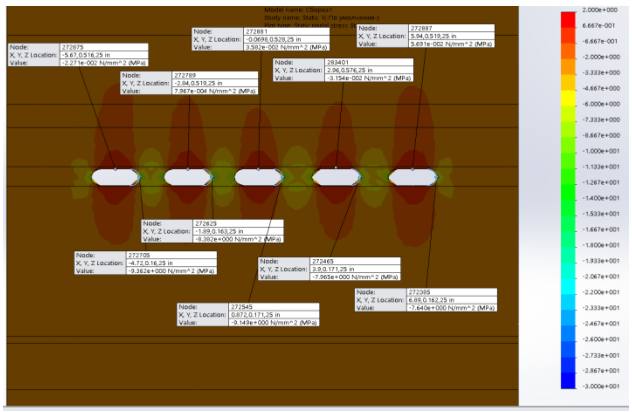
9.5 MPa, and the ultimate compressive strength of coal is 37 MPa, which does not pose a threat of destruction.

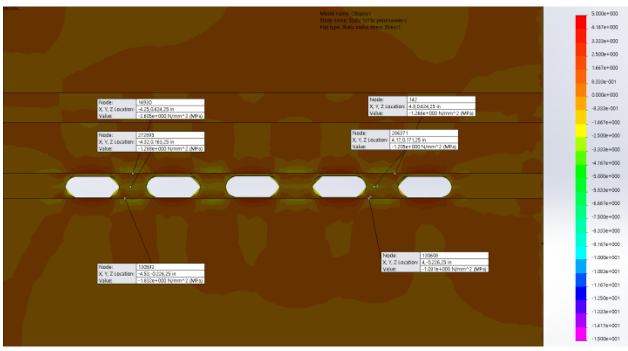
Analysis of the *SX* curve (Figure-6b) shows that the rock pressure horizontal component forms a balanced stress field around the drilled-out strips and in the interwell pillars, close to virgin rock mass (γH = 2.2 MPa), with the values of insignificant compressive stresses in the range of 1.2-2.6 MPa. There is no a threat of destruction in the under-roof patch of coal and pillars.

Analysis of the *SY* curve (Figure-7-a) shows that tensile stresses are also formed in the coal patch roof of the drilled-out strip, but their values slightly increase and reach 0.3-0.5 MPa, which also indicates the stable roof state, because the coal tensile strength is 3.7 MPa. Also, the rock pressure vertical component in coal pillars forms a weak field of compressive stresses with a value already higher, up to 9.0-11.0 MPa, and the ultimate compressive strength of coal is 37 MPa, which does not pose a threat of destruction.

Analysis of the *SX* curve (Figure 7-b) shows that the action of the rock pressure horizontal component enhances the stress field around the drilled-out strips and pillars with values of insignificant compressive stresses up to 6.0 MPa. There is also no a threat of destruction in the under-roof patch of coal and pillars (Figure-7b). However, dangerous tensile stresses with a value of up to 3.5 MPa begin to manifest themselves in the interwell pillar from the side of the roof and bottom in local areas, approaching the ultimate tensile strength of coal 3.7 MPa.

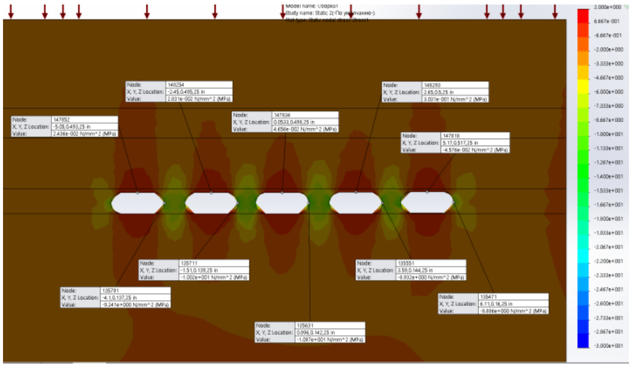


(a)

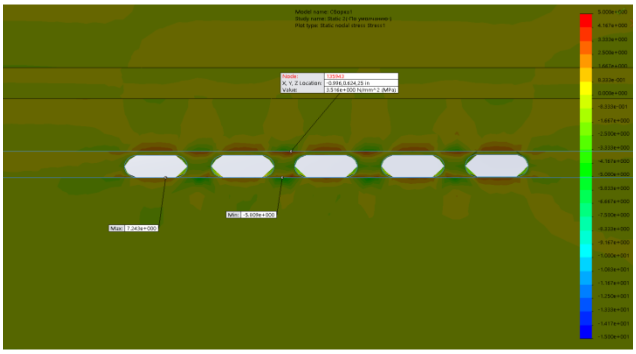


(b)

Figure-6. Curves of vertical stresses *SY* (a) and *SX* (b) with a width of the interwell pillar of 1.0 m.



(a)



(b)

Figure-7. Curves of vertical stresses *SY* (a) and *SX* (b) with a width of the interwell pillar of 0.75 m.

Analysis of the *SY* curve (Figure-8a) shows, that tensile stresses are also formed in the coal patch roof of the drilled-out strip, but their values slightly increase and reach 2.0 MPa, which also indicates the stable roof state, because the coal tensile strength is 3.7 MPa. Also, the rock pressure vertical component in coal pillars forms a weak field of compressive stresses with a value already higher, up to 15 MPa, and the ultimate compressive strength of coal is 37 MPa, which does not pose a threat of destruction. Analysis of the *SX* curve (Figure-8b) shows that the action of the rock pressure horizontal component enhances the stress field around the drilled-out strips and pillars, with values of insignificant compressive stresses up to 7.3 MPa. There is also no a threat of destruction in the under-roof patch of coal and pillars. However, dangerous tensile stresses with a value of up to 5.7 MPa also are manifested and increase in the interwell pillar from the side of the roof and bottom in local areas, exceeding the ultimate tensile strength of coal 3.7 MPa. In these areas, the initial fracturing will be observed in the coal pillar.

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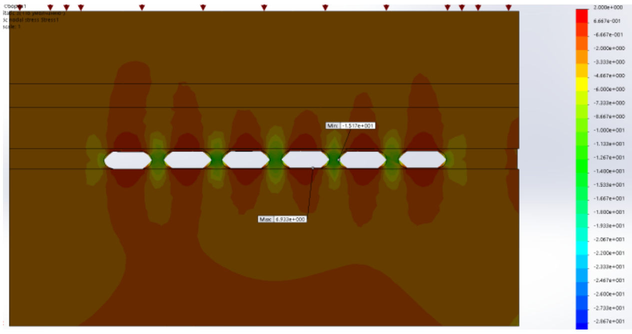

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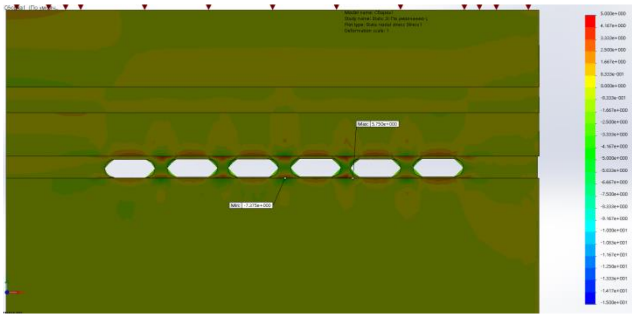
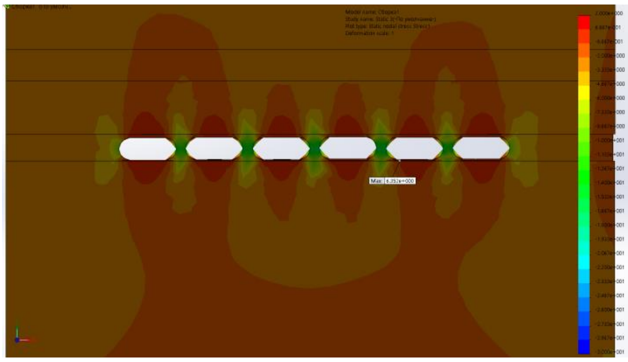


(b)

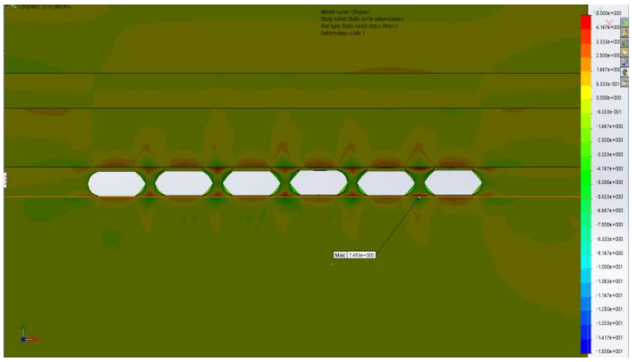
Figure-8. Curves of vertical stresses *SY* (a) and *SX* (b) with a width of the interwell pillar of 0.5 m.

Analysis of the *SY* curve (Figure-9a) shows, that tensile stresses are also formed in the coal patch roof of the drilled-out strip, but their values slightly increase and reach 2.5 MPa, which also indicates the stable roof state, because the coal tensile strength is 3.7 MPa. Also, the rock pressure vertical component in the coal pillars forms a field of compressive stresses with a value already higher, up to 18 MPa, and the ultimate compressive strength of coal is 37 MPa, which does not pose a threat of destruction. Tensile stresses with a value of 6.3 MPa are manifested in the drilled-out strip bottom, which can lead to heaving, but this aspect does not pose a threat to the technology, since the rock stresses are manifested in the mined-out area.

Analysis of the *SX* curve (Figure-9b) shows that the action of the rock pressure horizontal component enhances the stress field around the drilled-out strips and pillars with values of insignificant compressive stresses up to 9.0 MPa. There is also no a threat of destruction in the under-roof patch of coal and pillars. However, dangerous tensile stresses with a value of up to 7.5 MPa increase in the interwell pillar from the side of the roof and bottom in local areas, exceeding the ultimate tensile strength of coal 3.7 MPa. In these areas of the coal pillar, initial fracturing and gradual loss of stability will be observed.



(a)



(b)

Figure-9. Curves of vertical stresses *SY* (a) and *SX* (b) with a width of the interwell pillar of 0.25 m.

Then, a graph of the change in the tensile stresses *SX* in the pillars is plotted, depending on their accepted width (Figure-10). Analysis of Figure-10 shows that the value of maximum tensile Stresses changes according to the polynomial law depending on the interwell pillar width.

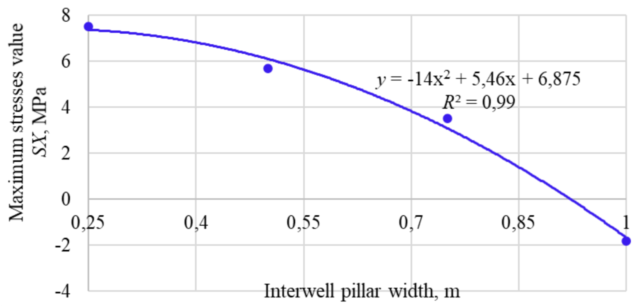


Figure-10. Dependence of the value of maximum tensile stresses on the vertical pillar width.

Given the fact that at a depth of 120 m in the conditions of the seam C_4 eastern section behind the Pivdenno-Ternivskyi fault, the areas of maximum tensile stresses are formed not in the entire pillar thickness, but locally (in the roof and bottom of the pillar), then, in our opinion, it is expedient to take the width of the interwell pillar 0.5 m, despite the fact that the maximum stresses in it reach 5.7 MPa, but this is pointwise and will not lead to destruction and loss of pillar stability.

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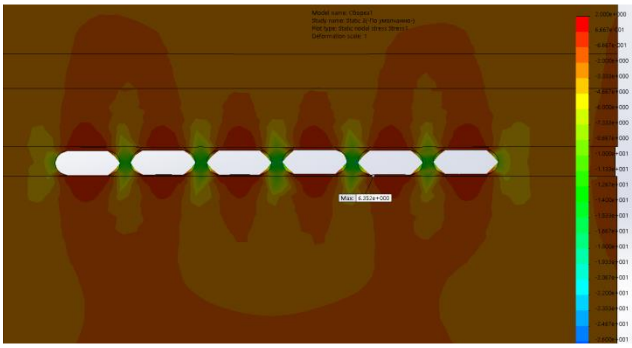
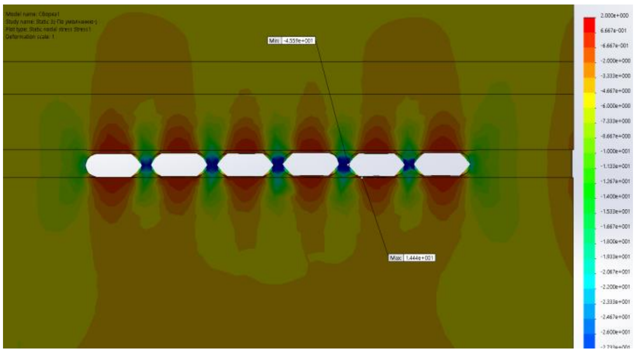
The depth of mining operations and, as a result, the rock pressure have a significant impact on the mass stress-strain state distribution around the drilled-out strips and pillars. Thus, for descriptive reasons, we have conducted modelling at a greater depth of mining (300 m) and compared it with a similar result at 120 m, which is typical for the conditions of the seam C_4 eastern section behind the Pivdenno-Ternivskyi fault (Figure-11). Analysis of the *SY* curve (Figure-11a) shows that tensile stresses with values of more than 3.7 MPa are also formed in the coal patch roof of the drilled-out strip, which, taking into account the tensile strength of coal of 3.7 MPa, will lead to the destruction of the coal patch roof. Also, the rock pressure vertical component in the coal pillars forms a high field of compressive stresses with a value of up to 45 MPa, and the ultimate compressive strength of coal is 37 MPa, which will lead to the complete destruction of pillars 0.25 m wide.



(a)



(b)

Figure-11. Comparison of the *SY* vertical stresses curve at interwell pillar width 0.25 m and depths H = 120 m (a) and H = 300 m (b).

Thus, it has been determined that the horizontal component of the rock pressure *SX*, which forms destructive tensile stresses, is of prevailing importance to substantiate the dimensions of the interwell pillars. The value of at least 0.3 m is the optimum width of a pillar in the seam C_4 eastern section behind the Pivdenno-Ternivskyi fault.

5. DETERMINING THE COAL LOSSES WHEN MINED FROM PROTECTING PILLAR USING THE AUGER COMPLEX

To determine the coal losses in the protecting pillar (or panel) planned for mining, it is necessary to determine the parameters of the supporting and interwell pillars. The determined value of the interwell pillar of 0.3 m is recommended to be accepted.

The value of the supporting pillar along the border of the protecting pillar (panel) can be analytically determined using the formula for determining the compressive stresses in the supporting pillar:

$$\sigma_{com.st} = \frac{B_{s.p.} + L_{well}}{B_{s.p.}} \cdot \gamma H \text{ , MPa,} \tag{1}$$

where $B_{s.p.}$ – supporting pillar width, m; L_{well} – production well length (drilled-out strip), m; γ – overlying rocks density, t/m^3; H – depth of the supporting pillar occurrence, m; $\sigma_{com.st}$ – ultimate compressive strength of coal, $\sigma_{com.st}$ = 37.0 MPa;

$$B_{s.p.} = \frac{L_{well} \cdot \gamma H}{\sigma_{com.st} - \gamma H} = \frac{120 \cdot 2.2}{37 - 2.2} = 7.54 \text{ m.} \tag{2}$$

In the technological scheme of mining out the protecting pillar, the supporting pillar width will be 8 m.

The coal losses during mining with the use of auger complex are determined on the example of the protecting pillar of the mined-out 414 longwall face, which was left to protect the 4th Western main haulage drift (Figure-12). The pillar is 108 m wide and 216 m long. Coal reserves in pillar - 27.96 thousand tons. Further, a computational scheme is proposed for determining coal losses (Figure-12).

Coal losses in the protecting pillar will be:

$$C_{los} = B_p \cdot L_p \cdot m_{seam} \cdot \gamma_{coal} \text{ , t,} \tag{3}$$

where B_p – the width of the supporting or interwell pillar, m; L_p – the length of the supporting or interwell pillar, m; m_{seam} – thickness of the coal seam in the protecting pillar, m; γ_{coal} – coal density, t/m^3.

According to analytical calculations, the total width of interwell pillars reaches 25 m.

Coal losses in the supporting pillars will be:

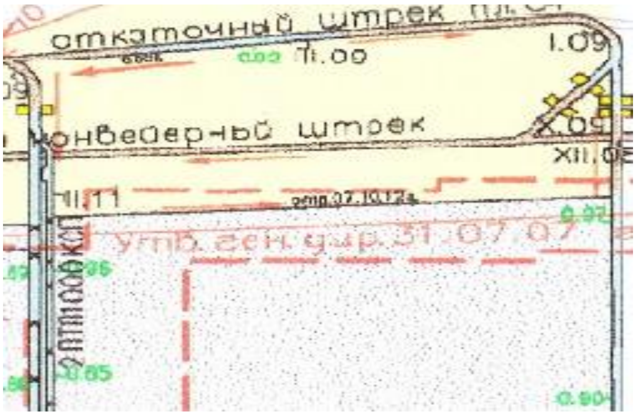
$$C_{los}^{s.p.} = 16 \cdot 108 \cdot 0.97 \cdot 1.25 = 2010 \text{ t.} \tag{4}$$

Coal losses in the interwell pillars will be:

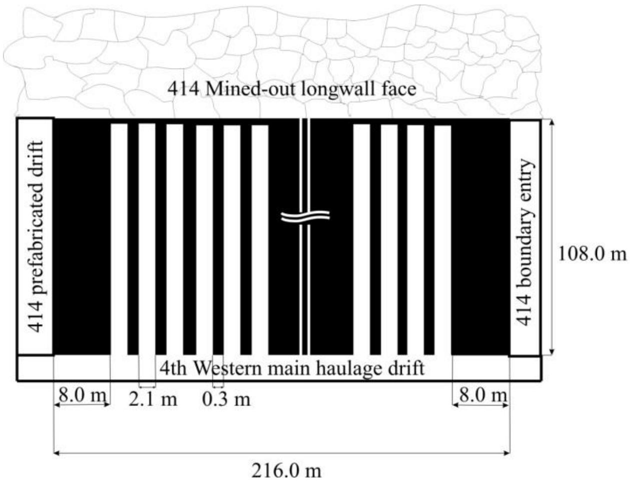
$$C_{los}^{in.p.} = 25 \cdot 108 \cdot 0.97 \cdot 1.25 = 3275 \text{ t.} \tag{5}$$

The total coal losses in the pillars will be:

$$C_{los}^{sum} = C_{los}^{s.p.} + C_{los}^{in.p.} = 2010 + 3275 = 5285 \text{ t.} \qquad (6)$$



(a)



(b)

Figure-12. Determining costs when mining-out a protecting pillar: general view of the coal pillar, left to protect the 4th Western main haulage drift from the bearing pressure of the 414 longwall face (a); computational scheme for determining coal losses when mining the protecting pillar of the 414 longwall face (b)

Then, the level of coal losses will be:

$$k = \frac{C_{los}^{sum}}{Z_p} = \frac{5285}{27960} = 19\% . \qquad (7)$$

Depending on the protecting pillar length (ranging from 60 to 200 m), the level of coal losses can be different in the range of 20-30%, which is due to the maximum well length of 120 m according to the technological characteristics of the Auger complex BShK-2DM.

6. CONCLUSIONS

a) When analysing the plan of mining the seam C_4 eastern section behind the Pivdenno-Ternivskyi fault and its mining-geological and mining-engineering indicators, it can be argued that the technical parameters of the Auger mining complex BShK-2DM fully comply with these conditions, therefore, it can be effectively used while mining coal reserves in protecting pillars.

b) A computational scheme for modelling the stress state of the “rock mass - drilled well” system pillars in the seam C_4 eastern section behind the Pivdenno-Ternivskyi fault has been constructed. While modelling, the interwell pillars width is varied with a step of 0.25; 0.5; 1.0 and 1.5 m, taking into account 3 drill bits in the BShK-2DM executive body with a diameter of 0.7 m.

c) It has been determined that the horizontal component of the rock pressure *SX*, which forms destructive tensile stresses, is of prevailing importance to substantiate the dimensions of the interwell pillars. The pillar optimal width of the C_4 seam eastern section behind the Pivdenno-Ternivsky fault at a depth of 120 m may be a value not less than 0.25 m. The accepted interwell pillar width is 0.3 m.

d) It has been determined that depending on the protecting pillar length, the level of coal losses can be different in the range of 20-30%, which is due to the maximum well length of 120 m according to the technological characteristics of the Auger complex BShK-2DM.

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