Substantiating the Patterns of Geomechanical Factors Influence on the Shear Parameters of the Coal-Overlaying Formation Requiring Degassing at High Advance Rates of Stoping Faces in the Western Donbas

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Abstract

The issues of developing ideas about the mechanism of coal mining from gas fields and two components of providing the country with energy carriers are studied: coal mining and methane utilization from coal-bearing stratum. These issues are inextricably linked with the mining of deposits with high-velocity longwall faces. The actual problem of resolving the above contradictions is studied. The patterns of the geomechanical factors influence based on the finite element method (FEM) modeling of the coal-overlaying formation shear parameters are studied from the point of view of substantiating the location schemes for the site outgassing wells at high advance rates of stoping faces in the Western Donbas. The obtained results of computational experiments are compared with the corresponding studies of specialists. The conclusions about the degree of geomechanical factors influence and the need to take them into account are substantiated. Three calculation models have been developed and substantiated in terms of the shape and size of the calculation zone, the rock mass texture, the mechanical properties of its lithotype, the loading conditions at the model boundaries, the characteristics of the link between stresses and deformations in the model elements, and the criteria for determining the limiting state. The significant influence of the longwall face location depth and the mass texture on the shear parameters of the coal-overlaying formation has been proved. Based on the data of computational experiments, the corresponding dependences and regression equations have been obtained. The conducted research makes it possible to choose appropriate location schemes for outgassing wells.

Keywords: *coal seam, drift, longwall face, powered support, mine*

1. INTRODUCTION

The coal industry is the main sector in ensuring Ukraine's energy independence and remains so for the long term. The country has all the possibilities to minimize dependence on resource imports [1–3]. Despite the experts' statements, the dynamics of demand for coal in the world markets indicates an increase in its consumption [4]. For example, over the past two years, the global coal consumption volume has increased by 5.7% [5], and the thermal coal cost has risen to $430 per ton. Thus, the energy component will continue to play a key role in the country's energy independence. Currently, there are two components of energy supply: coal mining and methane utilization from the coal-bearing stratum. However, gas emission limits the coal mining rates during the operation of modern high-velocity longwall faces. Modern high-performance stoping equipment in the Western Donbas often fails to achieve its technical targets due to the emission of excess methane. Therefore, the parameters of the site outgassing technology are an influential factor in increasing the productivity of coal mining. The choice of expedient site outgassing parameters is related to the shear patterns of coal-overlaying formation and its main characteristics [6, 7]. In this sense, there is an opinion among experts that the process of the coal-overlaying formation shear is most adequately reflected by modern methods of modeling geomechanical objects, of which the finite element method is the most common [8–11]. As for the Western Donbas conditions, a lot of experience has been gained in the studies [12–16], which were used to determine the patterns of influence of mining-geological and mining-technical factors on the process of transforming the texture of a rock mass adjacent to the area of stope operations [17–19]; it is worth recalling here that, according to existing ideas, stratification, weakening, fracturing, etc. in the coal-overlaying formation lithotypes have a significant influence on the gas emission in the undermined mass [20, 21].

2. PROBLEM FORMULATION

Research is performed by conducting a series of computational experiments, which determine the distribution fields of the main stress components: vertical σy, horizontal $\sigma x,z$ and

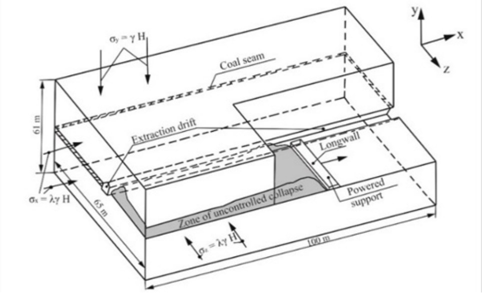

Fig. 1. Calculation scheme of the geomechanical model for mining the extraction site
Rys. 1. Schemat obliczeniowy geomechanicznego modelu eksploatacji miejsca wydobycia

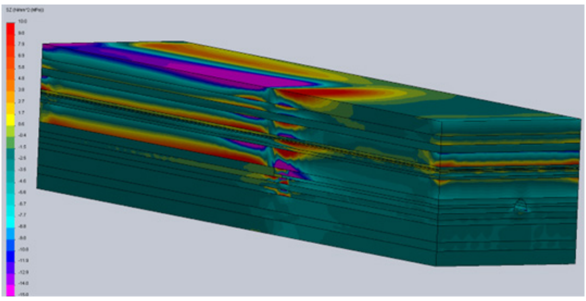

Fig. 2. The curve of horizontal stress σx distribution in a spatial model of predominantly thin- and medium-bedded textures
Rys. 2. Krzywa rozkładu naprężeń poziomych σx w przestrzennym modelu z przewagą cienko- i średniowarstwowych tekstur

the integral stress intensity index σ. Since we are particularly interested in the stratification and bending deformation of rock layers, close attention during the stress-strain state (SSS) analysis is paid to the horizontal stresses σx,z, which most clearly reflect these types of deformations. In this case, the research algorithm involves the identification (according to σx,z curves) of the distribution peculiarities of maximum bending zones of lithotypes in the rock mass under the influence of geomechanical and technological factors [22–24]. Among the experts, it is noted that a number of factors have a significant impact on the outgassing process, such as, for example, bearing pressure, physical-mechanical properties, the degree of stratification and disturbance of the coal-overlaying formation rocks, the depth of stope operations, the longwall face advance velocity, the dimensions of the mined-out area, etc [25–28]. Therefore, within the framework of the research, it is planned to study the patterns of influence of such geomechanical factors as the depth of stope operations, texture and mechanical properties of the coal-overlaying formation lithotypes, parameters of bearing pressure and de-stressing zones; the influence of the stoping face advance velocity and the parameters of outgassing wells location are also studied, but at the subsequent stages of this comprehensive research.

The own results of computational experiments are compared with the corresponding studies of other specialists, and then conclusions are drawn on the degree of influence of the listed factors and the need to take them into account at the subsequent stages of this complex program. The deformation mechanism of the coal-overlaying formation lithotypes has convincingly proved the spatial nature of this process, that is, the need to consider it simultaneously in terms of the rise – dip and along the strike of the coal seam [29]. Therefore, an objective situation requires the construction of spatial geomechanical models, which provide the opportunity to study these processes in any direction [30–33].

It is also necessary to study the influence of rock pressure anomalies in the form of frontal bearing pressure zones ahead of the longwall face, lateral bearing pressure in the non-working wall of the extraction working, and de-stressing zone behind the longwall face. To do this, appropriate sizes of geomechanical models are selected in order to fully represent the anomaly parameters.

The declared study of the texture and mechanical properties of the coal-overlaying formation lithotypes is implemented as follows. A basic texture model has been selected, which reflects the mining-geological conditions of 501 and 503 extraction sites at the Heroiv Kosmosu mine, PJSC "DTEK Pavlohradvuhillia". This model is necessary for further comparison with other textures. For this purpose, two more, typical for the Western Donbas conditions, textures of the coal-overlaying formation are modeled.

The mechanical properties of lithotypes are averaged, which is conditioned by the action of such factors. Firstly, among the mechanical properties are compressive strength and elasticity modulus (deformation). The tensile strength of lithotype samples is very low (on average 1–4 MPa), and given the impact of fracturing and moisture, it is practically absent. The same applies to adhesion along the surfaces of stratification of lithotypes, which is sometimes insignificant, and sometimes completely absent. Secondly, the data of geological survey and laboratory testing of samples provide a rather large variety in compressive strength indicators – usually, the range is 2–3 times. This relative uncertainty is enhanced by the action of weakening factors of fracturing and moisture saturation. Therefore, the error in assigning the compressive resistance index is quite large; the same relates to the index of elasticity modulus. Thirdly, weakly metamorphosed Western Donbas rocks are mainly characterized by fairly stable indicators of lithotype types. All these arguments give grounds to average the indicators of mechanical properties of lithotypes, and in order to increase

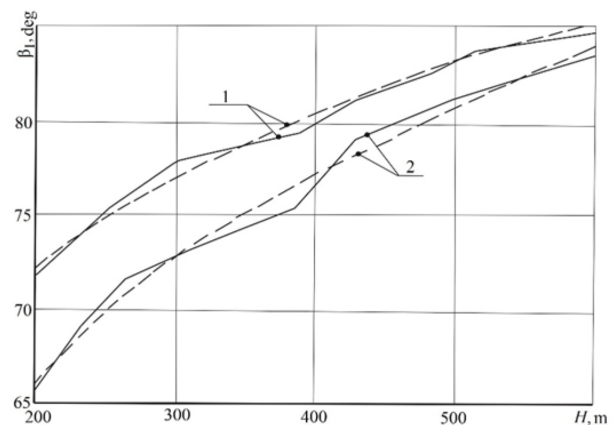

Fig. 3. The dependence of the angle β1 of the line of changing curvature sign of the coal-overlaying formation lithotypes on the depth H of stope operations: 1 – predominantly thin- and medium-bedded texture; 2 – predominantly thick- and medium-bedded texture; –––– FEM calculation results; ------regression equation

Rys. 3. Zależność kąta β1 linii zmieniającego się znaku krzywizny litotypów formacji nadwarstwowych węgla od głębokości H operacji stopowych: 1 – tekstura z przewagą cienko- i średnioławicową; 2 – tekstura z przewagą grubo- i średnioziarnistą; –––– wyniki obliczeń MES; ------ równanie regresji

the reliability of the modeling results, the lower limit of their variation has been chosen, which precisely corresponds to the mining-geological conditions of the Heroiiv Kosmosu mine.

The last paragraph of the general provisions should highlight the requirement for the selection of a physical model of the behavior of the rock mass lithotypes. In our opinion, the elastic-plastic model is the most appropriate for use, which is also substantiated in the following papers [30, 31]. This model allows, on the one hand, to take into account the plastic deformations of the Western Donbas weak rocks, and, on the other hand, it is not too complicated (in a bilinear formulation) and requires a moderate computational resource. In addition, the step-by-step calculation technology makes it possible to vary the depth of conducting stope operations within the framework of one computational experiment.

3. RESEARCH METHODS

The object of research – the processes of gas emission during the coal-overlaying formation shear – has a component related to the study of rock pressure anomalies in the area of stope operations, which for the Western Donbas conditions is described in detail in many scientific papers [12, 15, 20]. Therefore, when constructing a geomechanical model and substantiating its parameters, a number of proven recommendations from these studies are used.

Any geomechanical model is substantiated according to the generally defined FEM principles according to the following components: the shape of the calculation zone, its dimensions, the rock mass texture, the mechanical properties of its lithotypes, the conditions of their interaction along the contact planes, the loading conditions at the model boundaries, the characteristic of link between stresses and deformations in the model elements, and the criteria for determining the limiting state. Based on the above components, the parameters of three geomechanical models are substantiated. Such a quantity is caused by the need to determine the tendencies of the coal-overlaying formation texture influence on the parameters of its shear into the mined-out area.

According to the existing recommendations, the rectangular parallelepiped shape is chosen, which is the most appropriate for displaying the zone of a stratified rock mass, containing a mine working and part of the longwall face with a powered support. With regard to the objectivity and reliability of the calculation zone, it should reflect the following objects:

– a part of the virgin rock mass ahead of the longwall face, which completely encloses the propagating frontal bearing pressure (usually this distance is up to 20–30 m);

– a part of the undermined mass behind the longwall face, where rock pressure manifestations are gradually stabilizing (usually the distance is estimated to be 40–60 m);

– a part of the virgin rock mass from the non-working wall of the extraction working, where lateral bearing pressure is formed (usually this SSS anomaly propagates deep to a distance of 20–30 m);

– a part of the rock mass from the side of the longwall face; in this direction, the coal-overlaying formation SSS is stabilized at a distance of up to 20–30 m from the extraction working;

– in the coal seam roof rocks, the active coal-overlaying formation shear ceases in the zone of smooth bending of the rock layers without discontinuity; for the Western Donbas conditions, the lower zones of uncontrolled collapse and hinge-block shear occupy up to 12–15 m in height;

– in the coal seam bottom rocks, rock pressure anomalies propagate to a depth of 15–20 m.

Based on the data presented, the minimally sufficient dimensions of spatial geomechanical models characterizing three coordinates have been substantiated: Y – the height (depth) of the mass; X – the length to the dip (rise) of the seam, that is, the direction along the extraction working; Z – the width along the strike of the seam, that is, the direction along the longwall face. The geomechanical model itself and its dimensions are represented in Fig. 1 and with a certain reserve of the previously specified distances, the model has: length to the rise X = 100 m, the width along the strike Z = 65 м, height Y = 61 m, extraction working width – 5 m, extraction thickness of the seam – 1.0 m.

The coal-bearing mass texture variants are consistent with the mine's geological documentation. Special attention is paid

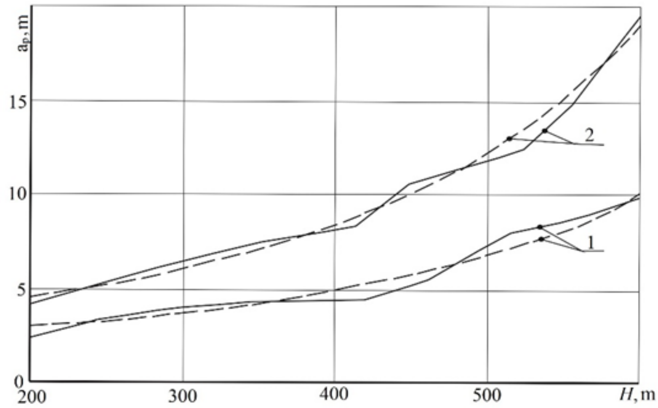

Fig. 4. An example of the dependence of the maximum bending distance ap of the most rigid lithotypes in the undermined mass bottom hole zone on the longwall face location depth H: 1 – lithotype is at a height of 14.6 m from the seam bottom; 2 – lithotype is at a height of 19.2 m; ––– FEM calculation results; ------ regression equation

Rys. 4. Przykład zależności maksymalnej odległości ugięcia ap najsztywniejszych warstw od głębokości usytuowania przodka w strefie poeksploatacyjnej H: 1 – litotyp znajduje się na wysokości 14,6 m od dna pokładu; 2 – litotyp znajduje się na wysokości 19,2 m; ––– wyniki obliczeń MES; ------ równanie regresji

to the modeling of two zones behind the longwall face: the uncontrolled collapse and hinge-block shear zones. Textural disturbances, thickness and mechanical properties of rocks in these zones are represented in accordance with the recommendations [12, 13, 15].

The mechanical properties of the roof and bottom lithotypes in the C5 seam are selected from the data of the relevant mining-geological sections, and other required mechanical characteristics are taken from the research data [34, 35] exclusively for the Western Donbas conditions. The calculated compressive resistance is determined according to the normative document [36] with supplements [13], taking into account the action of weakening factors, such as fracturing, moisture and rheology.

In accordance with the existing data of geological survey and numerous studies of the coal-bearing stratum texture in the Western Donbas, the condition of lack of adhesion between lithotypes along the planes of their bedding is accepted. This condition, while requiring additional computational resources, has a significant impact on the mass SSS [3, 13, 15] and its stability as a whole and creates a certain safety reserve for SSS calculations.

The boundary conditions on the model surfaces are selected according to proven recommendations [12]. A geostatic vertical pressure is applied to the upper horizontal surface

$$\sigma_y = \gamma H, \tag{1}$$

where γ – the weight-average unit specific gravity of rocks in the coal-overlaying formation;
H – the depth of conducting stope operations.

On the lower horizontal surface there is a rock bearing that balances the vertical pressure σy. To eliminate the local impact of a rigid bearing, a layer of damping material with the mechanical properties of argillite is placed on its surface.

On the lateral vertical surfaces of the model, according to the proven "symmetry" condition, a horizontal geostatic pressure is automatically applied

$$\sigma_{x,z} = \lambda \gamma H, \tag{2}$$

where $\lambda = \mu / 1 - \mu$ – the side thrust coefficient;
μ – the lateral deformation coefficient (in the elastic formulation – Poisson's ratio).

For the rock behavior physical model, the elastic-plastic formulation of the SSS calculation problem is chosen in the form of the so-called bilinear deformation diagram in the "stress-relative deformation" coordinates. The first linear section represents the elastic rock state with the appropriate deformation characteristics. The second linear section models the plastic (almost ideal) rock state with a very low proportionality modulus (Eel = 5 MPa) and Poisson's ratio μel = 0.5. The conjugation point of two linear sections is determined by the condition

$$\sigma = R, \tag{3}$$

where σ – the stress intensity according to the von Mises strength theory [37];
R – calculated compressive resistance of the rock, which is determined according to [13].

As for the operation of the longwall face powered support, according to the recommendations [12, 13], it is very convenient to model the real performance of hydraulic-resistant sections using a bilinear deformation diagram. The powered support is displayed as a rectangular parallelepiped, and the deformation-strength characteristics of its material completely model the section resistance. This approach is substantiated in the studies [12, 15], and for the maximum powered support resistance of up to 500–650 kPa, the elasticity modulus for the simulator material is chosen as E = 50 MPa, which takes into account the backlashes in the hinges of the hydraulic prop stays and the "lifting" of their rods at the initial stage of resistance.

Regarding the support and protection of the extraction working, it is decided not to model these structures, since their resistance affects the SSS of the adjacent rocks by no more than 1–3%.

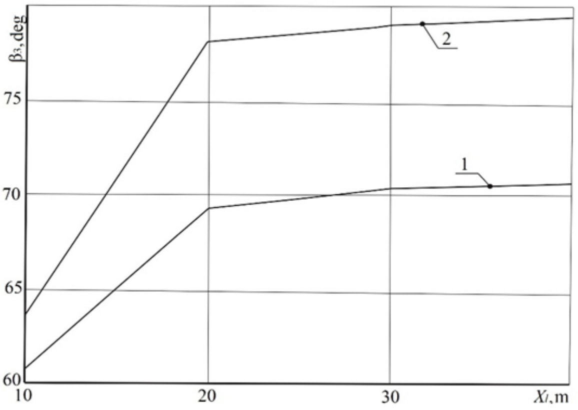

Fig. 5. Dependence of the inclination angle β3 of changing curvature line of bending the lithotypes as the distance Xl from the longwall face increases: 1 – H = 200 m; 2 – H = 600 m

Rys. 5. Zależność kąta nachylenia β3 zmieniającej się linii krzywizny zagięcia litotypów wraz ze wzrostem odległości Xl od przodka ściany: 1 – H = 200 m; 2 – H = 600 m

4. RESEARCH RESULTS

One of the main geomechanical factors is the depth H of the extraction site location, and the task arises to assess its influence on the coal-overlaying formation shear parameters, which primarily include: coordinates of lines of complete advances, areas of change in the curvature sign for bending the lithotypes (angle β_1 to the dip and angle β_3 along the strike of the coal seam), distance a_p of the maximum bending of the most rigid lithotypes in the bottom hole zone ahead of the longwall face.

The bending deformations of the rock layers are most clearly displayed on the horizontal stress $\sigma_{x,z}$ curves. For example, Fig. 2 shows a spatial curve σx in the geomechanical model of predominantly thin- and medium-bedded texture for H = 420 m elevation. The field σ_x parameters do not contradict the assumption about the frontal bearing pressure propagation ahead of the longwall face and the associated transformations of the coal-overlaying formation rock texture:

- weakening occurs in the immediate and adjacent main roof layers at a distance of up to 7–8 m;
- the tension cracks occur and develop over a distance of 12–20 m.

The bending of the rock layers in the direction of the coal seam continues above the longwall face, but immediately after the spread of powered support sections at a distance of up to 1–2 m, the bending first disappears, and then the bending curvature sign changes. It is well known that this zone of intense fracturing and stratification is recommended for crossing it by outgassing wells. Geometric characteristics of the area of change in the curvature sign of bending the lithotypes in the roof are as follows:

- it begins in the uncontrolled collapse zone at a distance of up to 2–3 m behind the section fence;
- the area extends into the main roof at an angle β₁ = 75–80° to the bedding plane.

These peculiarities (for the Western Donbas) prove the approach to the longwall face of the area of change in the curvature sign of bending the roof lithotypes. It is therefore expedient that outgassing wells are also concentrated near longwall face: with the simplest geometric constructions, an outgassing well should be drilled at a distance of up to 8–10 m from the section fence.

With regard to the influence of increasing depth H, it is well known that there is an increase in stresses and deformations in the adjacent mass, as well as an expansion of the zones of weakening and stratification of roof rocks. This causes a more intense bending, the collapse of rock and an approach of the line of changing curvature sign to the longwall face, that is, an increase in the gradient angle β₁.

The analysis results of the link between β₁ and H are presented in the graphs of Fig. 3 for two opposite mass textures: regardless of the texture type, there is a pattern of increasing gradient angle β₁ with increasing H – the essence of this tendency is increasing geostatic pressure. It has been determined that in the range 200 m ≤H≤ 600 m, there is an increase in β₁ by 12.8° for predominantly thin- and medium-bedded textures (from 71.8 to 84.6°) and by 17.8° for predominantly thick- and medium-bedded textures (from 65.6 to 83.4°).

Based on the above results, it is necessary to pay attention to two peculiarities:

- firstly, the specified tendencies are observed for different texture types when conducting separate independent computational experiments, which, though implicit, confirms their reliability;
- secondly, the patterns for two quite opposite texture types approach each other at great depths (as for the Western Donbas conditions); this is explained by the significant geostatic pressure influence on the process of coal-overlaying formation advance into the mined-out area.

As a result of the above research, a conclusion can be drawn about the importance of taking into account the depth H of conducting stope operations when determining the angle β₁. It is possible to use the revealed patterns from the graphs in Fig. 3 or regression equations obtained from the data of computational experiments using known methodologies:

- for thin- and medium-bedded textures

$$\beta_1 = 178 - 200H^{-0.12}, \text{ deg;} \tag{4}$$

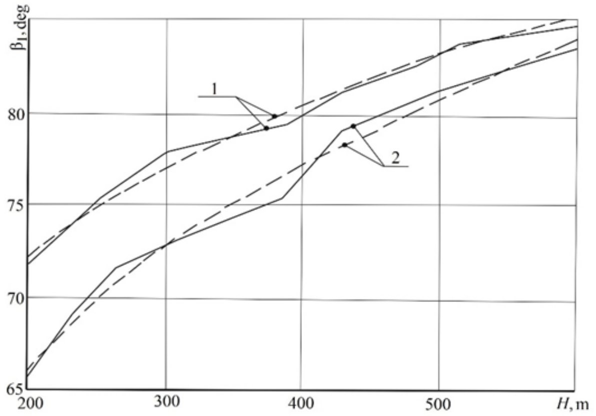

Fig. 6. Dependence of the inclination angle β₃ of the line of changing curvature sign for bending the lithotypes in the coal-overlaying formation on the depth H of conducting stope operations: 1 – predominantly thin- and medium-bedded textures; 2 – predominantly thick- and medium-bedded textures; ––– FEM calculation results; ------- regression equation

Rys. 6. Zależność kąta nachylenia β₃ linii zmieniającego się znaku krzywizny zagięcia litotypów w nadkładzie na głębokości H prowadzenia operacji postojowych: 1 – dominują tekstury cienko- i średnioławicowe; 2 – przeważają tekstury grubo- i średnioziarniste; ––– wyniki obliczeń MES; ------ równanie regresji

– for thick- and medium-bedded textures

$$\beta_1 = 236.7 - 290.3H^{-0.10}, \text{ deg.} \tag{5}$$

In expressions (4) and (5), the depth H is substituted in meters, while the parameter β₁ is determined in degrees.

Another important factor related to the fracture formation is the zone of the most active bending of the rock layers immediately ahead of the stoping face. From the point of view of gas emission, these zones are the primary link in the release and transfer of methane volumes into the longwall face working space. As can be seen from Fig. 2, the degree of bending of roof lithotypes is different and is mainly determined by three factors: the thickness of layers, their mechanical properties and the value of load on a particular lithotype.

Under the classical provisions of rock mechanics, a thicker layer with increased deformation characteristics experiences high rock pressure compared to other easily deformable lithotypes. For example, a thick sandstone experiences a higher load than the adjacent thin argillites and siltstones, which is quite clearly reflected on the curve σ_x (see Fig. 2); the same is also observed on the curve σz. At the same time, the sandstone is usually a gas-saturated lithotype, and, therefore, it is necessary for the outgassing well to cross this lithotype in the zone of maximum bending in the area ahead of the longwall face.

Thus, the second requirement has been formulated for the appropriate coordinates of the location of outgassing wells. To implement this requirement, it is necessary to determine the coordinates of the zone of formation of maximum bending deformations. Naturally, the formation of these zones depends on the texture and mechanical properties of the rocks in the coal-overlaying formation; however, the influence of the depth H of conducting stope operations is also predicted, since with its growth, the zones of plastic deformation of rocks expand, affecting both the value and the distance of propagation of a significant degree of lithotype bending.

The variation of longwall face location depth within the range of 200 m ≤H≤ 600 m provides the following results. First, at relatively small H values, the location of the maximum bending zones of the most rigid lithotypes remains almost unchanged, and mainly the bending deformations increase. However, with the expansion of the plastic state areas of the lithotypes, the bending deformations of the rock layers increase more rapidly (as H increases) than horizontal stresses σx. In this case, the second tendency occurs – the expansion of the zone of weakening bending deformations along the bedding planes of lithotypes. The indicated tendency has a predominant direction away from the stoping face into the still undermined rock mass.

Therefore, with an increase in the depth H of the longwall face location, two tendencies are noted regarding the coordinates of acting maximum bending deformations, which is identical to intense fracturing:

- at relatively shallow depths (H ≤ 300–350 m), the distance ap (from the face plane) of the maxima σx location increases rather slowly;
- when moving to deeper horizons (H >350 m), the distance ap begins to increase more intensively in proportion to H according to a non-linear dependence.

An example of the determined patter is given in Fig. 4 for a fixed height hp of gas-bearing sandstone occurrence relative to the coal seam, as well as its constant thickness m_p. Usually, h_p and m_p parameters influence on the link between ap and H, but the function a_p(H) is very important from the point of view of substantiating an expedient route for outgassing wells.

An example of determining the function a_p(H) for a predominantly thin- and medium-bedded textures is given, where several gas-bearing layers of increased rigidity can be located throughout the coal-overlaying formation height. This texture variant is shown on the σ_x curve (see Fig. 2), where two layers of increased rigidity are located in the main roof at once – at a height of 14.6 m and 19.2 m from the seam bottom to the upper layer surface. Note that concentrations of tensile σx stresses also occur higher in the roof, but they have a limited distribution and are located at a considerable distance.

For the selected two rigid layers, two patterns of the change in the a_p parameter have been obtained, which is calculated from the middle part of the width of acting maximum tensile

σ_x stresses. According to the two experimental dependences (for different hp), two regression functions have been obtained:

– with $h_{P_1} = 14.6$ m $\quad a_{P_1} = 1.9 + 1.1\exp\left(\frac{H}{200} - 1\right)$, m; (6)

– with $h_{P_2} = 19.2$ m $\quad a_p = 2.25\left[1 + \exp\left(\frac{H}{200} - 1\right)\right]$, m. (7)

As for the peculiarities, it should be additionally noted the more distant maxima σ_x location in the layers occurring above the coal seam bottom. The value a_p indicates the expediency of turning the outgassing well in such a way as to cross the gas-saturated lithotypes at some distance from the stoping face and thereby, in part, perform something like preliminary outgassing. Moreover, the distance a_p increases along the height of the mass and it is possible to cross both layers in the desired zone with one inclined well.

The constructed spatial model is used to monitor the influence of the longwall face location depth H on the process of coal-overlaying formation shear along the strike of the coal seam (along the longwall face) that provides the required number of sections in the vertical YZ planes along an arbitrary X coordinate of the location of these sections.

When considering the process of the roof rock deformation into the mined-out area, the most influential (in relation to gas emission) parameter has been substantiated – the coordinates of the zones of curvature change of lithotypes bending along the strike, which are characterized (throughout the coal-overlaying formation height) by the inclination angle β_3 of the line connecting the indicated zones with the extending coal seam. It is logical to predict that as the longwall face retreats, the angle β_3 will change at a certain distance simultaneously with a decrease in the intensity of rock pressure manifestations. To confirm this prediction, YZ sections are cut at a distance of 10 m, 20 m, 30 m and 40 m from the longwall face. These prosedures are taken for the spatial curve σz for the variant of predominantly thin- and medium-bedded textures at two extreme depth values: H = 200 m and H = 600 m. For each section, the inclination angle β_3 is specified relative to the coal seam bedding plane and, based on the obtained indicators, the graphs are plotted (Fig. 5). As can be seen, the tendencies in the β_3 parameter change from the Xl coordinate of the YZ section location behind the longwall face remain unchanged: an active increment in β_3 occurs in areas of Xl ≤ 20 m, and then the value of β_3 stabilizes at a certain level, and this occurs regardless of the depth H of conducting stope operations.

Based on the revealed tendencies, the question arises: at what distance behind the longwall face should the dependence β_3(H) be determined? In our opinion, the value of β_3 should be determined in the zone of the most active disturbances of the coal-overlaying formation, that is, near the longwall face; here there is an intense stratification and destruction of rocks, many fractures and cavities with a corresponding increase in gas emission occur. Therefore, it is consider appropriate to determine the parameter β_3 on an area of 10 m ≤ Xl ≤ 20 m and choose its calculated value as an average.

According to this algorithm, the β_3 angle values are calculated over the entire range of 200 m ≤H≤ 600 m. As an example, Fig. 6 shows the corresponding graphs.

The β_3(H) function is close to linear one with a gradual increase in the range of 65°≤ β_3 ≤ 71° for predominantly thin- and medium-bedded textures and in the range of 58°≤ β_3 ≤ 66° for predominantly thick- and medium-bedded textures. The influence of depth H is relatively small: in the range of 200 m ≤H≤ 600 m, the angle β_3 increases by only 6° and 8° for the corresponding textures of the coal-overlaying formation. However, on the length of the outgassing well lw = 40–50 m, these β_3 variations correspond to a change in the location of its deepened part up to 5–7 m, which can be an important factor in terms of the most appropriate coordinates for the location of wells with the maximum flow rate of methane gas. Based on the above results of computational experiments, the corresponding regression equations for calculating the angle β_3 have been obtained:

– for thin- and medium-bedded textures

$$\beta_3 = 62 + 0.015H, \text{ deg;} \tag{8}$$

– for thick- and medium-bedded textures

$$\beta_3 = 54 + 0.02H, \text{ deg.} \tag{9}$$

Thus, a number of dependences of the depth H and texture on the shear parameters of the coal-overlaying formation into the mined-out area has been obtained; they make it possible to choose appropriate parameters for the location of outgassing wells based on the influence of geomechanical factors. In this way, it has been proven that effective outgassing is associated with disturbances in the mass texture, when it experiences intense stratification and destruction in the process of subsidence of the coal-overlaying formation. An analysis of the peculiarities of deformation of weakly metamorphosed Western Donbas rocks, given the increased advance velocities of the stoping faces, makes it possible to formulate an idea of the mechanism of texture transformations of stratified weak rock mass in terms of the outgassing technology parameters for an extraction site of a coal mine.

5. CONCLUSION

1. Quantitative patterns of the coal-overlaying formation shear parameters under the influence of geomechanical factors have been determined using FEM. For this purpose, the parameters of a spatial geomechanical model have been substantiated, which contains zones of a stratified weakly metamorphosed mass ahead and behind the longwall face with a part of virgin coal-rock stratum from the side of the adjacent extraction site. They contain the end longwall face area with a powered support simulator, the extraction drift and their conjugation. In accordance with generally recognized requirements, the spatial model dimensions, the texture and mechanical properties of the lithotypes, the boundary conditions of loading along all model planes at its boundaries have been substantiated. The expediency of using an elastic-plastic physical model of the behavior of rock layers and the deformation-strength characteristic of a powered support has been proven.

2. Based on the results of computational experiments, a significant influence of the longwall face location depth H and the mass texture on the shear parameters of the coal-overlaying formation has been proven:

– there is an increase in the inclination angle β_1 of the line of changing curvature sign for bending the lithotypes to the rise of the seam – for predominantly thin- and medium-bedded textures in the range of 71.8–84.6°; for predominantly thick- and medium-bedded textures in the range of 65.6–83.4°;

– with an increase in H, two tendencies have been noted relative to the coordinates of acting maximum bending deformations of lithotypes (ahead of the longwall face), which is identical to intense fracturing: at relatively shallow depths (H≤ 300–350m), the distance a_p of the location (from the face plane) of maximum horizontal stresses increases rather slowly – up to 30–50%; when moving to deeper horizons (H> 350 m), the distance ap begins to increase intensively (up to 3.3–4.2 times) according to a non-linear dependence;

– along the strike of the coal seam, there is a tendency of increasing inclination angle β_3 of the line of changing curvature sign for bending the lithotypes when moving away from the stoping face, and an almost linear influence of H adds an increase in the value of β_3: up to 6° for predominantly thin- and medium-bedded textures and up to 8° for predominantly thick- and medium-bedded textures.

3. It is possible to use revealed patterns with the help of a number of graphs of the corresponding dependences or regression equations obtained from the data of computational experiments. Thus, a quantitative relationship between the coal-overlaying formation shear parameters and geomechanical factors has been determined, which makes it possible to choose appropriate schemes for the location of outgassing wells.

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Uzasadnienie wzorców wpływu czynników geomechanicznych na parametry ścinania formacji nadkładu węgla, wymagającej odgazowania, z dużymi prędkościami posuwu ścian postojowych w Zachodnim Donbasie

W artykule rozważane są zagadnienia opracowania koncepcji mechanizmu wydobywania węgla ze złóż gazowych oraz dwóch składowych zaopatrzenia kraju w nośniki energii: wydobycie węgla i zagospodarowanie metanu z warstwy węglonośnej. Zagadnienia te są nierozerwalnie związane z eksploatacją złóż przodkami ścianowymi o dużych postępach. Badany jest rzeczywisty problem rozwiązania powyższych sprzeczności. Wzory wpływu czynników geomechanicznych na podstawie modelowania metodą elementów skończonych (MES) parametrów ścinania formacji nadkładkowych badane są pod kątem uzasadnienia schematów lokalizacyjnych dla otworów odgazowujących miejsca przy dużych prędkościach postępu przodków w Zachodnim Donbasie. Uzyskane wyniki eksperymentów obliczeniowych są porównywane z badaniami prowadzonymi przez specjalistów. Wnioski dotyczące stopnia oddziaływania czynników geomechanicznych i konieczności ich uwzględnienia są uzasadnione. Opracowano i uzasadniono trzy modele obliczeniowe pod względem kształtu i wielkości strefy obliczeniowej, tekstury górotworu, właściwości mechanicznych jego litotypu, warunków obciążenia na granicach modelu, charakterystyki związku naprężeń i odkształceń w elementy modelu oraz kryteria wyznaczania stanu granicznego. Wykazano istotny wpływ głębokości zalegania przodka oraz tekstury masy na parametry ścinania formacji nadkładu. Na podstawie danych z eksperymentów obliczeniowych otrzymano odpowiednie zależności i równania regresji. Przeprowadzone badania pozwalają na wybór odpowiednich schematów lokalizacji otworów odgazowujących.

Słowa kluczowe: *pokład węgla, sztolnia, przodek ścianowy, obudowa zmechanizowana, kopalnia*