







Optimizing the load on powered support during intensity fluctuations of rock pressure manifestations

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Abstract

Purpose. The research aims to identify the peculiarities of rock shear in the coal-overlying formation in the mining-geological conditions of Western Donbas and to substantiate the mechanism of loading the stope complex support during fluctuations in the intensity of rock pressure manifestations.

Methods. The research was based on an analysis of the mining-geological conditions of the extraction site, the collection and statistical processing of long-term data on the rock mass state, and mine monitoring of pressure in the hydraulic prop stays of powered support sections under different technological parameters of stoping face operation. Graphical and comparative analyses were used to assess the influence of roof rock texture, deformation and strength characteristics, rheological properties, stoping face advance velocity, and stoppage duration on the load acting on the powered support.

Findings. Analysis of existing ideas about the deformation processes of roof rocks in the area of the stope face has enabled the development of a scheme for coal-overlying formation shear. A mechanism of loading the powered support has been developed, taking into account geomechanical and technological factors. Qualitative patterns of the influence of parameters on the load of powered support have been obtained in the context of a system planning tool for research in mine conditions.

Originality. The patterns of the influence of the texture and mechanical characteristics of roof rocks, including their rheological properties, have been identified; stope face advance velocity, time of its stoppage, step of the main roof settlement and the bearing reaction of support on the mechanism of the coal-overlying formation shear.

Practical implications. The established relationships between the pressure in powered support hydraulic prop stays, the longwall face advance velocity, roof rock texture, main roof caving step, and face stoppage duration can be used to adjust the operating parameters of powered support and stope operations. This makes it possible to identify potentially hazardous loading conditions, select a rational face advance rate, and reduce the risk of powered support overloading during main roof settlement and prolonged longwall stoppages.

Keywords: coal; geomechanics; rock pressure; powered support; optimization

1. Introduction

Mineral resources form the foundation of the modern global economy and are crucial for the sustainable development of human civilization. The effective mining of minerals depends on a number of factors (mining-engineering, geomechanical, environmental, economic, social, etc.). Effective consideration of the interrelationships and mutual influence of these factors, as well as a balanced resolution of the contradictions that inevitably arise in the mining industry, forms the basis for the further innovative development of the economy [1], [2]. Undoubtedly, it is impossible to cover in this research the interaction of all factors influencing the development of the mining industry; however, certain factors require particular attention, which is the purpose of this research.

Coal has historically played an important role in the development of European industry and remains a significant com-

ponent of the global energy system [3]-[5]. The further development of the mining sector is closely related to the introduction of innovative mining technologies, improved production planning and more efficient management of mining processes [6]-[8]. Fuzzy monitoring and human-in-the-loop control have been applied to complex technological systems [9], while adaptive methods regulate energy-dependent parameters under changing conditions [10]. The complexity of modern mining is also reflected in studies addressing rock mass stability in open-pit mining, mineral-resource potential, the influence of waste dumps on underground workings, groundwater dynamics within mine fields and environmental processes associated with coal-mining waste [11]-[16].

In recent years, the coal industry in the leading coal-mining countries of the world has seen increased concentration of production processes, increasing the quality, capacity,

Received: 12 January 2026. Accepted: 15 June 2026. Available online: 30 June 2026

© 2026. H. Sumanovych et al.

Mining of Mineral Deposits. ISSN 2415-3443 (Online) | ISSN 2415-3435 (Print)

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and reliability of equipment, ensuring the stability of production processes [5], [7]. The efficient operation of traction and transport machinery used in mining also depends on the power-flow distribution and transmission ratios in hydrostatic-mechanical transmission systems [17], [18]. In this regard, from the perspective of technical and technological policy, an increase in production volumes is possible provided that mining operations are concentrated and underground mining is intensified through the introduction of modern machinery and advanced technologies [19]. The broader trend towards mining intensification is also reflected in the development of high-capacity systems based on controlled and continuous in-line stopeing [20]. At the enterprise level, the selection of strategies for finalizing industrial coal reserves can be supported by structured multi-criteria decision-making methods, including the analytic hierarchy process [21]. Optimization solutions regarding the load on powered support during fluctuations in the intensity of rock pressure manifestations play a key role in solving the issue of ensuring the stable functioning of mining operations [22]-[25]. More generally, integrated approaches to sustaining technogenic mine structures are required to control their stability under changing mining and geomechanical conditions [26].

As is well known, a rock mass is characterized by a wide range of texture parameters and mechanical properties, which significantly influence the development of geomechanical processes during mineral resource mining [27], [28]. Numerical modelling is widely used to assess the stress-strain state of stratified rock masses and to identify critical or near-failure conditions around underground excavations and unfilled voids [29]. Reliable assessment of the rock mass state also requires consideration of its structural and tectonic heterogeneity, fracturing, fault systems, and geodynamic activity, which can be investigated using geophysical methods [30]. When performing the research, calculations were made for the difficult mining-geological conditions of the mines in Western Donbas (Ukraine) [31]-[33].

An adequate and reliable solution to the problem of optimizing the load on powered support during the mining of coal seams in Western Donbas generally require consideration of the peculiarities of rock shear in the coal-overlying formation and the construction of ideas about the load-formation mechanism during the subsidence of the rock mass into the mined-out space and the development of rock pressure anomalies in the area of stope operations.

A wide range of scientists and specialists have studied and continue to study the issues of the rock mass state during coal seam mining in Ukraine, as well as the patterns of stress and strain distribution around stope workings [22]-[28]. As a result, a set of interrelated provisions has been formulated concerning the main shear processes of the coal-bearing rock mass and their parameters. These fundamental provisions, developed over many decades of studying the rock mass behaviour, are the basis for developing a mechanism for the stope complex interaction with the adjacent rock mass, taking into account the specific mining-geological conditions of Western Donbas.

Related geomechanical studies have also addressed the prediction of mining-induced outgassing and the assessment of mine-working decommissioning based on the geomechanical factor [34], [35]. Research into the state of the coal-bearing mass during stope operations is primarily aimed at studying the mechanism by which powered support is loaded,

depending on the geomechanical and technological parameters of stopeing, which generate fluctuations in the intensity of rock pressure manifestations. In this regard, existing ideas about the peculiarities of conducting stope operations in Western Donbas [33], [36] were analyzed with the aim of substantiating a model for the coal-overlying formation behaviour that corresponds to real conditions, during its interaction with powered support.

It is generally believed that as the length of the rock cantilevers increases, the load on the powered support increases until the moment of the main roof settlement; after that, the load drops sharply, and the process of its gradual increase is repeated as the longwall face advances [36], [37].

An analysis of existing methods for predicting the load on powered support has led to the conclusion that they are generally based on two basic provisions that are temporary in nature, that is, they develop not only in space, but also over time:

- an increase in the length of rock cantilevers when advancing the longwall face to the boundaries of the step of the main roof settlement;

- the process of lowering the upper layers onto the lower ones, which also causes an increase in the load on the support.

However, the existing approaches do not sufficiently account for the specific behaviour of the stratified weak rock mass of Western Donbas, where the load on powered support may be governed primarily by the sequential lowering of roof layers rather than by the formation of long overhanging rock cantilevers. Therefore, the purpose of this research is to identify the peculiarities of rock shear in the coal-overlying formation under the mining-geological conditions of Western Donbas and to substantiate the mechanism of powered support loading during fluctuations in the intensity of rock pressure manifestations.

2. Materials and methods

2.1. Study area and mining-geological conditions

The mine monitoring was conducted within extraction site 871 of the Zakhidno-Donbaska Mine, Western Donbas, Ukraine. The selection of the study area is consistent with previous analyses of mine field preparation and coal mining conditions in Western Donbas [38].

Several monitoring sections were selected along the length of the extraction panel (Fig. 1a-c) to identify the influence of roof rock texture and the depth (H) of stope operations on the load formation on the powered support. The selection and representation of the monitoring sections based on mining-geological and lithological data are consistent with the data geometrization approach used to substantiate coal mining parameters under specific geological conditions [39]. The texture of the coal-overlying formation is predominantly medium- and thick-bedded, while the C_8^r , C_8^{r1} , and (C_9) coal seams introduce thin-bedded features. The depth of the longwall face location varied within ($H = 342-437$ m), corresponding to a variation of up to 20%. Mining depth was considered as a separate geomechanical factor because its influence on the displacement field of rocks around in-seam workings has been demonstrated in previous studies [40].

To identify the separate influence of roof texture, four monitoring sections were selected in two pairs located relatively close to each other but characterized by significantly different main roof textures.

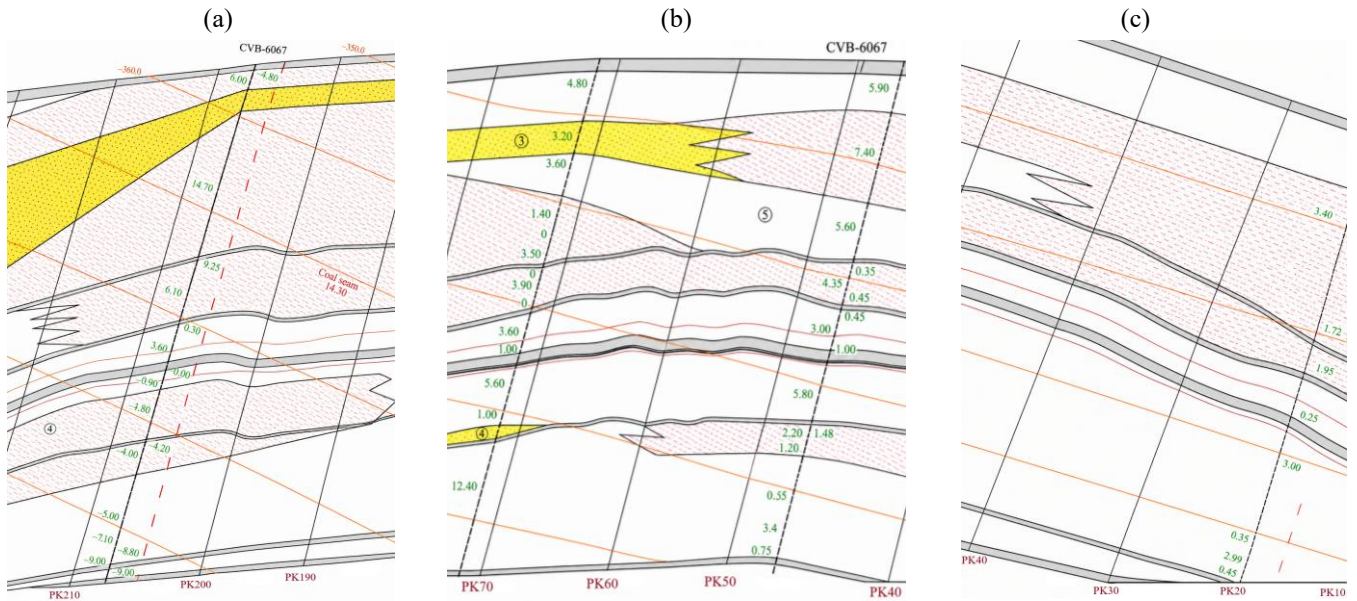


Figure 1. Fragments of the mining-geological sheet for longwall panel 871: (a) near the beginning of the extraction panel; (b) near the middle part of the extraction panel; (c) near the end of the extraction panel

Particular attention was paid to the main roof thickness because it makes the most significant contribution to load formation on the powered support. For clarity and to facilitate the implementation of the methodological provisions, all five examined roof textures are presented in Figure 2, which also illustrates the approximately constant thickness of the examined main roof.

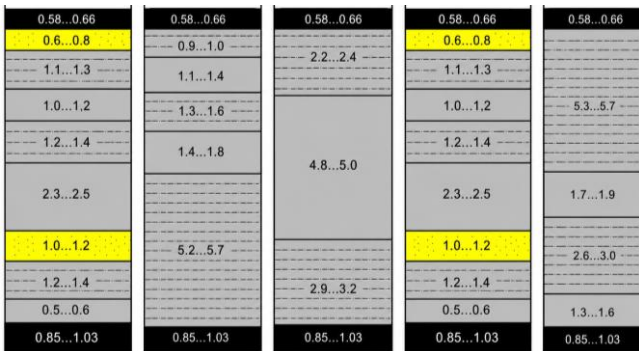


Figure 2. Fragments of roof textures in monitoring sections to assess their influence on the load formation on the powered support

The influence of the main roof texture was assessed by pairwise comparison of the pressure readings (P) in the hydraulic prop stays for sections No. 1 and No. 2 and for sections No. 4 and No. 5. Sections No. 1 and No. 5 are characterized by thicker layers, predominantly representing a medium- to thick-bedded texture, whereas the adjacent sections No. 2 and No. 4 consist mainly of thinner layers, predominantly representing a medium- and occasionally thin-bedded texture. The influence of the longwall face depth (H) was assessed using sections No. 1, No. 3, and No. 5, in which the main roof is characterized by a medium- to thick-bedded texture and consists of identical litho-types with approximately equivalent mechanical properties.

2.2. Analytical framework for powered support loading

Within the adopted analytical framework, a boundary was substantiated for the volume of rocks (from the side of the

mined-out space) which, due to their own weight, form a load on the powered support. This boundary lies adjacent to the line of changing curvature sign of bending the roof layers; it is more dependent on the texture and properties of the coal-overlying formation, and to a lesser extent – on the technological parameters of stoping, primarily the average daily velocity V of the stoping face advance, the feed velocity V_{Ls} , and the grip width B of the executive body of the coal-mining machine (longwall shearer or plough). This statement is based on existing ideas about the hanging of rock cantilevers (behind the powered support) in the coal-overlying formation [41]-[43]. More generally, the adopted analytical framework follows established concepts of stress-strain redistribution, rock mass deformation, and control of the rock mass state around underground workings [44]-[46].

Each of the two identified factors in a single process of the coal-overlying formation shear may have a predominant influence depending on the mining-geological conditions under which the stope operations are conducted. It was previously noted that one of the distinctive peculiarities is the short length of rock cantilevers due to the low strength and deformation characteristics of the rock seams. Therefore, the factor of increasing the length of rock cantilevers within the step of the main roof settlement (this process is weakly expressed) is of secondary (subordinate) importance when forming the load on the powered support, unlike other Donbas regions. Then, the main factor of loading the powered support is the development of the process of lowering the rock layers above the working space of the longwall face, and the load value will depend on the volume of the roof layers that are in contact with the support by means of mutual transfer of part of the rock pressure to each other and are in an unstable state.

Usually, the following parameters are distinguished that have the greatest influence on the process of load formation on the powered support:

- the texture of the roof rocks, the thickness m_i of individual layers and the adhesion forces c_i of their contacts with adjacent layers;

- strength (compression σ_{comp}^i and tension σ_{ten}^i resistance), deformation (deformation modulus E_i) and rheological (the most commonly used rheological index $(x/\beta)_i$) properties of each layer according to the thickness of the main roof;
- the step of the main roof settlement, which is a function of the first two groups of parameters, as well as of other geomechanical factors (mining depth, influence of adjacent extraction sites, undermined seams, their water content, etc.);
- velocity V of the stoping face advance and the time t of its stoppage;
- the grip width B of the executive body of the coal-mining machine and its feed velocity $V_{l.s.}$;
- the reaction $P(Z)$ of the powered support sections along the length Z of the longwall face when strutting the hydraulic props stays and at their maximum resistance (load-bearing capacity).

The mechanism of influence of the first group of parameters (texture of the roof rocks and the thickness m_i of individual layers) is as follows. To illustrate this more clearly, Figure 3 shows a scheme for loading a separate roof layer, which is also used to explain the mechanism of the influence of other factors. In the deformation scheme of an individual i -th layer of thickness m_i , the load acting on it is divided into three components: the weight q_i of the layer itself; the load $q_{i+1}(x)$ from the adjacent upper layer; and the load $q_{i-1}(x)$ in the form of a reaction from the adjacent lower layer. Points 1 and 2 characterize the boundary where contact between adjacent roof layers ceases due to their stratification; the value of the exposure of cavities $y_i(x)$ and their length along the stratification planes of adjacent layers decreases with increasing distance from the longwall face, – therefore, point 1 shifts to the right (towards the mined-out space) relative to point 2.

As is well known [47], the deformation of any beam or plate, the section height m_i of which is several times smaller than the span length, is determined mainly by the bending moment $M_i(x)$ resulting in stresses that are one or two orders of magnitude greater than the stresses caused by normal and cutting forces. Therefore, below the schemes for loading the rock layer, a high-quality curve of bending moment (Fig. 3b) is given as the primary characteristic of the state and durability of the i -th layer.

In the area of stratification and loss of contact with adjacent layers (up to point 1), the i -th layer bending is determined only by its own weight q_i , and the bending moment $M_i(x)$ increases according to the classical parabolic dependence. In the section between points 1 and 2, an additional load $q_{i+1}(x)$ acts from the upper rock layer, which increases the gradient of the bending moment as the i -th layer approaches non-rigid fixing. To the left of point 2, on the i -th layer, the reaction $q_{i-1}(x)$ of the underlying rocks begins to act, which exceeds the load $q_{i+1}(x)$ under the equilibrium condition. Then, the increase in $M_i(x)$ slows down and at point 3 reaches a maximum M_{max} , and as the forces $q_{i+1}(x)$, q_i and $q_{i-1}(x)$ deepen into the mass, compensate each other, and the bending moment asymptotically approaches zero.

The maximum bending moment M_{max} (point 3) characterizes the most likely fault section of the i -th layer, at which its right part completely rests on the underlying rocks and, ultimately, on the powered support. In this regard, the position of point 3 (X coordinate) will determine the volume of the i -th layer rocks that form the load on the support, and the task is to reveal the mechanism of influence of previously identified parameters on the X coordinate of point 3.

The analytical framework also takes into account the deformation, strength and rheological properties of the roof rocks.

In existing methods for predicting the load development on the powered support, where one of the key factors is the length l_3^i of rock cantilever, the main focus is on the deformation modulus E_i of the rock layer. Here, it is necessary to specify the value of E_i with respect to the well-known physical rock heterogeneity, depending on the sign of the applied load: for example, in [48] it is stated that the deformation modulus of the rock in tension E_i^{ten} is 8-10 times lower than the deformation modulus E_i^{comp} of the rock in compression, and most researchers attribute this to the presence of fracturing and stratification in the coal-bearing thickness of Donbas rocks. It is recommended that this “multi-modulus” of the rock be taken into account by applying the so-called generalized deformation modulus, which is denoted through E_i , and its value is equal to:

$$\frac{4E_i^{comp} \cdot E_i^{ten}}{(\sqrt{E_i^{comp}} + \sqrt{E_i^{ten}})}, \tag{1}$$

will be approximately four times lower than E_i^{comp} , determined in laboratory conditions.

The strength characteristics of rocks (resistance to compression σ_{comp}^i and tension σ_{ten}^i) are not usually taken into account very often when describing the processes of shear and caving of the roof layers above the stoping face and in the mined-out space. Here, given the insignificant resistance to tension of lithological varieties in the weak rocks of Western Donbas, it is advisable to focus solely on the resistance of rocks to compression σ_{comp}^i , especially since this characteris-

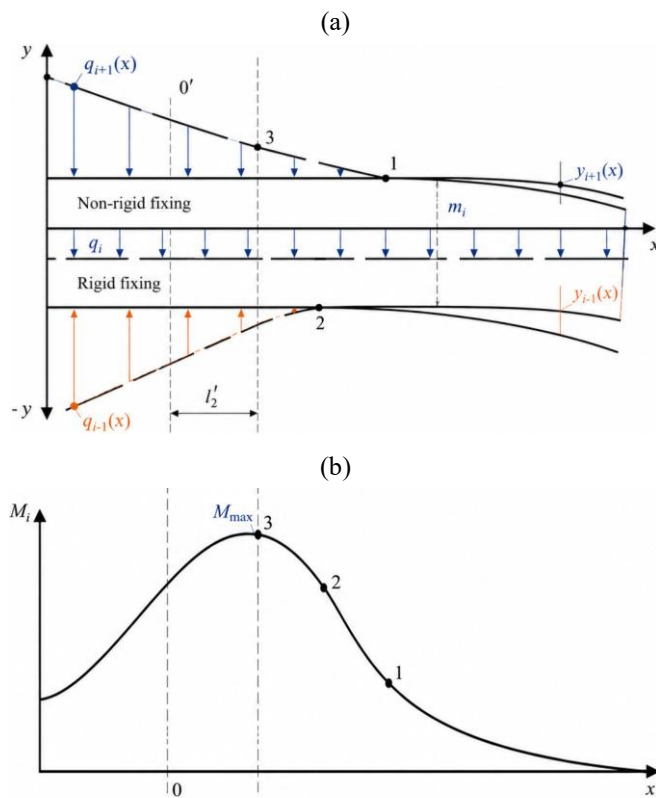


Figure 3. Scheme (a) for loading a separate roof layer above the stoping face and the corresponding curve (b) of the bending moment

tic has been sufficiently studied in Western Donbas [49], [50]. These studies also provide a detailed analysis of the rheological properties of rocks in Western Donbas; this information will be used to study the mechanism by which load on powered support develops over time, in the perspective of deterioration of the strength and deformation characteristics of rock seams during stope operations.

The moment that prevents the rock cantilever from caving is determined as:

$$M_b^i = \sigma_c^i W_i. \quad (2)$$

Then, the influence of the rheological properties of rock layers on the mechanism of loading the powered support is examined, since these properties are most evident in the weak rocks of the stratified coal-bearing stratum of Western Donbas.

When studying the influence of rheological properties, two trends are generally distinguished:

– the development of deformations over time under a constant load, which in the theory of elastic-plastic creep is accounted for by a decrease in the elasticity modulus depending on the time t of the load action, and the value of the long-term deformation modulus E_i^∞ (at $t \rightarrow \infty$) is related to its conditional-instantaneous value of the ratio:

$$E_i^\infty = E_i \left[1 - \left(\frac{\chi}{\beta} \right)_i \right], \quad (3)$$

where:

$\left(\frac{\chi}{\beta} \right)_i$ – the rheological index of the i -th rock layer;

– a decrease in time t in the resistance of the rock to compression, the long-term value of which $(\sigma_{comp}^i)^\infty$ is related to the conditional-instantaneous value σ_{comp}^i by the formula:

$$(\sigma_{comp}^i)^\infty = \sigma_{comp}^i \sqrt{1 - \left(\frac{\chi}{\beta} \right)_i}. \quad (4)$$

The given ratios are easy to use, and the rheological index $\left(\frac{\chi}{\beta} \right)_i$ has been studied in detail for rocks of Western Donbas based on many years of research [49], [50].

The rheological factor is necessary to consider when analyzing the processes of coal-overlying formation shear for a number of reasons:

– firstly, stope operations occur over time, and the conditional-instantaneous position of the face reflects only one state out of an infinitely large number of positions over a certain (finite) time interval;

– secondly, all lithological varieties of coal-bearing weak rock stratum in Western Donbas are characterized by distinct rheological properties;

– thirdly, technological parameters such as the velocity V of the working face advance and the idle time t are functions of time;

– fourthly, although weakly expressed, a factor such as the step L of the main roof settlement in a stratified mass of weak rocks is still evident, and this factor also has a time frame in the process of the stopping face advance.

Therefore, all these parameters and factors should be considered in relation to one another, where one of the conditions that unites them is the time of geomechanical processes within the framework of technological operations. First of

all, the study analyzes the influence of rheological properties of rocks in the perspective of the development over time of their creep and the related phenomenon of decrease in resistance to compression and deformation modulus. These trends contribute to an intensification of lowering the roof layers, which causes a change in the position of two contours that limit the rock volume loading the powered support: from the side of the mined-out space – line of change in the curvature sign of bending the rock layers; from the side of the stopping face – arch contour of load formation on the support.

The mechanism of influence of the stopping face advance velocity V and the time t of its stoppage, determined by the distinct rheological properties of the Western Donbas rocks, is qualitatively and quantitatively studied under mining conditions by monitoring the pressure in the hydraulic prop stays of powered support sections.

2.3. Mine monitoring and data processing

The accumulated research experience indicates a number of factors that significantly influence the rock pressure manifestations in the longwall face, the state of powered support and the rhythmic high-performance operation of the stope complex as a whole. The main factors can be divided into two groups: technological and geomechanical.

The methodology of the approach is based on a fundamental concept – the regular monitoring of pressure in hydraulic prop stays of powered support sections as the most objective information about the rock pressure manifestations in the stopping face, depending on the current values of key influential factors and geomechanical parameters at a given moment in time. The main source of information includes regular measurements of P_i pressure readings in the piston cavities of the hydraulic prop stays of the support sections, data from mining-geological predictions and testing of mechanical properties of the coal-bearing mass lithological varieties, as well as technological parameters of the extraction site operation. Although the present study relies on hydraulic pressure measurements rather than geodetic observations, the general principle of repeated monitoring combined with analytical or numerical interpretation is consistent with modern approaches to deformation assessment of engineering structures [51], [52].

To form the database required for analysis, the following parameters should be recorded simultaneously in “real-time mode”:

- pressure P_i in the hydraulic prop stays of the i -th section;
- average daily velocity V_{av} of the stopping face advance;
- the position of the face (X -coordinate) at the time of pressure measurement – the corresponding coal-overlying formation texture, the depth H of the longwall face location, and the distance from the last roof settlement are determined;
- the time t that has elapsed since the face stopped, if such a stoppage occurred;
- the position of δ_i section relative to the face plane.

In accordance with the tasks set, data were collected on the pressure readings P_i in hydraulic prop stays of each section along the entire length L of the longwall face at various average daily velocities V_{av} of the stopping face advance.

To obtain more general $P(V_{av})$ patterns, the pressure P_i was averaged for groups of 12-15 adjacent sections; these groups include sections with different positions relative to the face plane, which eliminates sharp pressure P_i drops

(along the shortened section in the Z coordinate) and in integral form gives an idea of the degree of the velocity V_{av} influence on the load of the support as a whole.

Pressure readings P were taken in the selected sections at least 8 times a day, provided that the average daily velocity of the stoping face advance was sufficiently stable ($\pm 10\%$).

The collected and averaged pressure data were used to analyze the influence of the average daily stoping face advance velocity, roof rock texture, mining depth, main roof caving step, section position relative to the face plane, and longwall face stoppage duration on the powered support loading.

3. Results

3.1. Peculiarities of rock shear in the coal-overlying formation

There are certain peculiarities in the correlations between the mechanical properties of the coal seam and the roof rocks, which alter the traditional scheme of coal-overlying formation shear in the seams of Western Donbas [53], [54]. The zone of frontal bearing pressure ahead of the stoping face – according to the data of existing studies, bearing pressure begins to occur in the extraction drifts at a distance of 20-30 m to 150-200 m ahead of the longwall face, and the maximum concentration of vertical stresses $\sigma = (1.5-8.5) \gamma H$ is located at a distance $l_1 = 2-15$ m from the stoping face, depending on the mechanical characteristics of the coal-bearing stratum and the technological parameters of stope operations (Fig. 4).

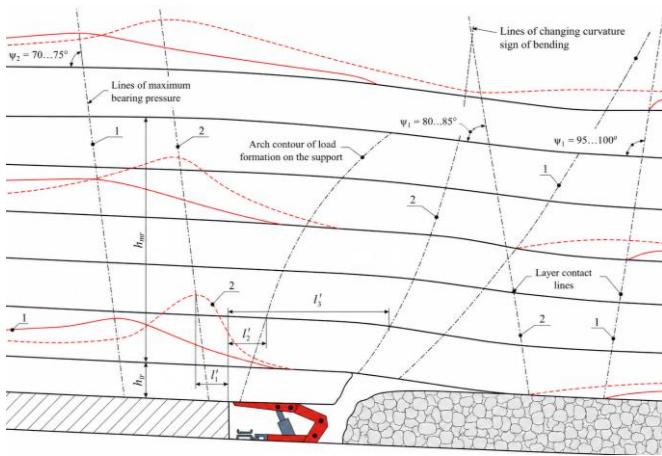


Figure 4. Peculiarities of the scheme of coal-overlying formation shear in Western Donbas (line 2) in relation to traditional ideas (line 1)

The relatively strong coal of Western Donbas exhibits moderate resistance to the influence of bearing pressure, as its compressive strength in the sample $\sigma_{compr} = 30-45$ MPa is many times higher than the initial vertical stresses in the undisturbed rock mass $\sigma_y = 5-15$ MPa at the current mining depth H . In the zone of acting maximum bearing pressure, the relative continuity of the seam is predicted, since it is in a three-component stressed state under the action of also compressive horizontal stresses $\sigma_{x,z}$ at which the resistance to vertical forces σ_y increases by 2.0-2.5 times or more. That is, even taking into account the concentrations σ_y in the bearing zone, no significant weakening of the seam is expected, as confirmed both by the results of computational experiments and by the weakly expressed coal squeezing in the stoping face [55]-[57].

The patterns identified previously confirm this conclusion, which is also consistent with the existing views of famous scientists and specialists [58], [59]. The mechanism for the phenomenon of clustering of maximum concentrations in the bearing pressure zone near the stoping face (Fig. 4) with hard seam and easily deformed roof is explained in Figure 5.

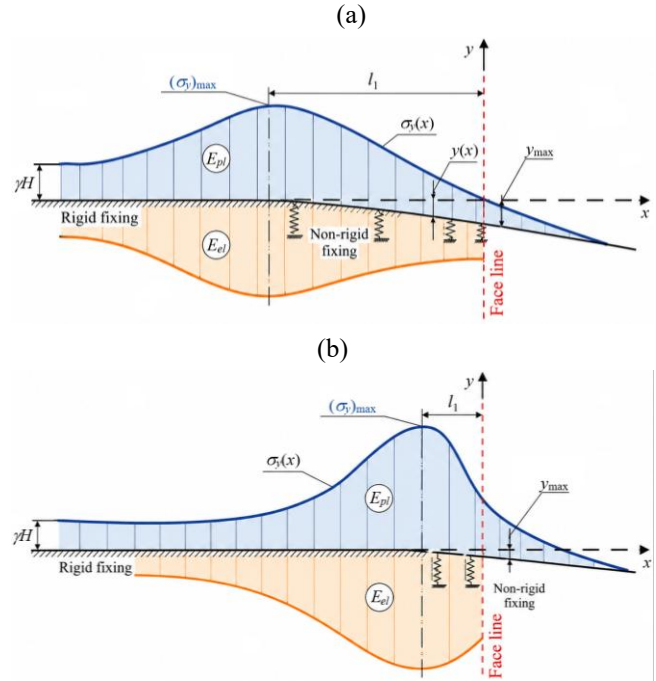


Figure 5. On the mechanism of bearing pressure zone formation at the ratio of coal seam hardness and roof rocks: (a) $E_{el} < E_{pt}$; (b) $E_{el} > E_{pt}$

The classical ideas about the cantilever beam bending [47] can be conventionally divided into two sections. The first is the so-called non-rigid fixing, when the supporting part in the fixing has a certain yielding property (similar to the “Winkler base” in an elastic setting), and the upper layer part (due to a certain roof stratification) only partially restricts the cross-section rotation during its bending. The degree of fixing rigidity (restriction on the cross-section rotation during the layer bending) gradually increases with advance into the depth of the seam, as its rigidity (volumetric deformation modulus) increases and its weakness decreases; at the same time, the stratification of the roof rocks decreases. As a result, non-rigid fixing of any rock layer gradually turns into rigid fixing; the beginning of this (second) section can be taken as the maximum $(\sigma_y)_{max}$ of bearing pressure (Fig. 5), and the end – a zone where the vertical stresses $\sigma_y(x)$ stabilize at the level of initial state γH of undisturbed rock mass.

The second, directly opposite option for forming the bearing pressure zone (Fig. 5b) is characterized by the coal seam hardness, which significantly exceeds that of the roof rock layers. Here, in the peripheral part of the seam, an increased load $\sigma_y(x)$, is concentrated, as the hanging rock cantilevers overlap one another due to their increased deformability, and the vertical displacements $y(x)$ of the seam are small due to its increased hardness. The roof stratification above the stoping face is partially compensated by intensive lowering of the upper layers, – the vertical load in the rock cantilevers of the near-bottomhole space increases and is transferred to the edge of the coal seam, which, due to its low yielding

property, cannot distribute the concentration σ_y over a wide section l_1 by transferring the bearing pressure deeper into the seam. The length l_1 of the non-rigid fixing section is small, and the main part of the bearing pressure is distributed across it, resulting in high values of maxima $(\sigma_y)_{\max}$.

The patterns described do not contradict accepted ideas about the shear processes, and the coal-bearing rock mass in Western Donbas is primarily characterized by the presence of increased maxima of bearing pressure near the plane of the stope face, with increased load on the powered support of the stope complexes (Fig. 4).

Thus, the mechanism of the main roof caving is substantiated, which is presented as the closing of some fractures in the upper and lower parts of each rock layer and the formation of main fractures throughout the entire thickness of the main roof; their horizontal coordinate is located near the coordinate of the change in the curvature sign of each layer bending. In the conditions of Western Donbas, the change in the curvature sign of bending occurs near the fencing of powered support sections; consequently, the length of the rock cantilevers is small, and their growth along the height of the main roof slows down due to the approach to the vertical of the inflection line of the distant rock layers. The line of change in the curvature sign of bending of the rock layers (according to the main roof thickness) will restrict the rock volume from the side of the mined-out space that create a load on the powered support. This load varies periodically from a minimum value (after the main roof settlement) to a maximum value (before the main roof settlement). From the side of the stoping face, the boundary of the contour of the rocks that subside and load the powered support depends on the geomechanical and technological parameters of stope operations.

3.2. Influence of roof texture and mechanical properties

The mechanism of influence of an individual layer thickness m_i on the powered support load is examined; their interaction is a complex process, the study of which requires the use of all available research methods. In terms of quality, the following mechanism of influence of coal-overlying formation texture can be assumed.

Examine the option of a thin-bedded texture of the roof rocks occurring above the rock layer at a constant texture of lower layers. The upper low-thickness layers m_{i+k} (where $k = 1, 2, 3, \dots n$), having a low moment of inertia I_{i+k} and a small resistance moment W_{i+k} of the cross-section, are exposed to significant deflections and discontinuity, and are lowered onto the examined rock layer with a thickness m_i . The load $q_{i+k}(x)$ increases simultaneously with the movement of the contact loss point l' to the right (Fig. 3a). In this case, the rock cantilever m_i is exposed to a high bending moment M_i , which is many times greater than its load-bearing capacity; this is due to two factors:

- on the one hand, the combined action of increased load and its resultant force moment arm;
- on the other hand, the resistance moment of the cross-section of the layer remains unchanged.

Thus, the thin-bedded texture of the roof rocks under their own increased deflection contributes to a significant load on the i -th layer, leading to the development of its gradual caving; in this case, rock cantilevers are formed with a short overhang length beyond the boundaries of non-rigid fixing, and the arch contour of load formation on the

support acquires a more vertical position, which increases the volume of unstable rocks above the stoping face and the load on the powered support.

In this situation, load limitation is only possible provided there is a sufficiently strong i -th layer, which, due to its high rigidity, fully absorbs the rock pressure from the overlying seams and transfers it to the caved rocks in the mined-out space, on the one hand, and to the near-bottomhole mass ahead of the longwall face, on the other hand. Where the rock mass has a medium-bedded texture, the arch contour of load formation shifts towards the mined-out space, and the volume of unstable rocks above the stoping face decreases.

The next stage of the research involves revealing the mechanism by which the deformation properties of coal-overlying formation influence the load formation on the powered support in stope complexes, taking into account the peculiarities of coal seam mining in Western Donbas. This interpretation is consistent with previous studies of the deformation and failure of coal-bearing strata and the behaviour of thin-layered weak rocks during longwall mining [60]-[62].

Examine how a change in the deformation characteristics of the layers influences the load formation on the powered support in accordance with the scheme of coal-overlying formation shear (Fig. 4), where the main focus is on the location of the arch contour above the stoping face. For this purpose, Figure 6 provides a schematic representation of this process.

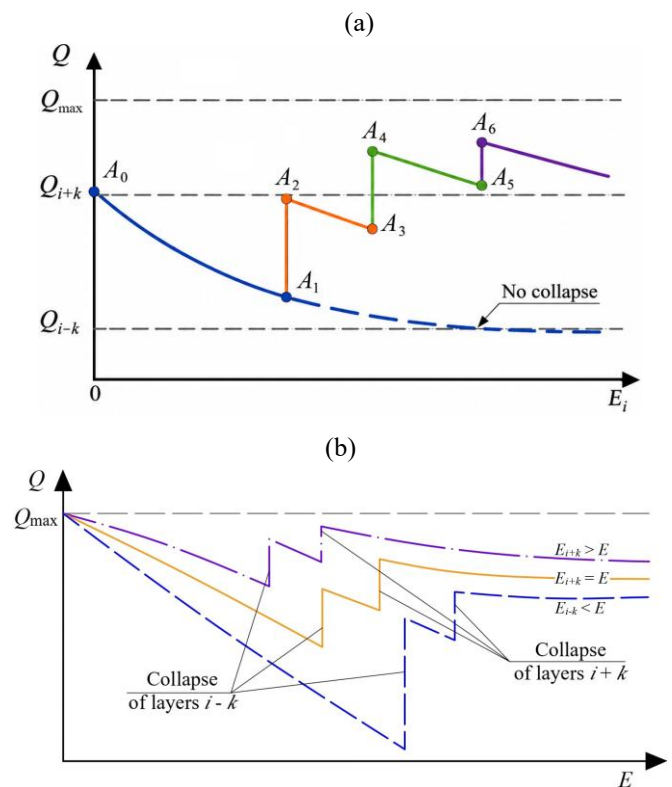


Figure 6. Schematic representation of the powered support load Q : (a) dependence on the deformation modulus E_i of the i -th layer; (b) dependence on the deformation moduli E of the roof as a whole

First, examine the relationship between the load Q on the powered support and the deformation modulus E_i of the i -th layer, taking into account the previously applied multi-stage load and the caving of the roof layers (Fig. 6a). For constant

deformation moduli E_{i+k} of the upper and lower rock layers, a qualitative change in the load Q on the powered support can be observed, starting from the extreme value $E_i \rightarrow 0$ (point A_0), with a specific load Q_{i+k} corresponding to it.

As E_i increases, the i -th layer, due to its own increasing rigidity, reduces the transfer of load to the lower layers, taking on an increasingly larger part of the load from the upper layers; hence, the load Q on the support decreases (section A_0-A_1). This trend cannot continue indefinitely, as indicated by a dotted line, which asymmetrically approximates the Q_{i-k} load value from the lower layers; with a thin and medium-bedded roof texture, at point A_1 , there is a caving of the i -th layer due to a high load from the side of the upper layers and a low reaction from the lower layers; the caving of a certain length of the i -th layer cantilever causes a sudden increase in the load on the support Q (section A_1-A_2).

A further increase in E_i reduces the load Q again (section A_2-A_3), but less intensively, since the newly formed hanging cantilever already has a shorter length. However, at a certain its value, there is another caving of the cantilever for the reasons mentioned above (point A_3), and again the load Q increases abruptly (section A_3-A_4) by the weight of the corresponding rock volume. Here, the load at point A_4 may exceed the initial value Q_{i+k} (point A_0), as the steadily increasing rigidity of the i -th layer provokes the caving of shortened cantilevers of the i -th layer according to the described mechanism. As a result, at $E_i \rightarrow \infty$, the length of the hanging cantilever approaches zero, and the entire volume of the i -th layer, as well as most of the upper rocks, is involved in forming the load on the powered support, which approaches the theoretically maximum value Q_{\max} .

Next, examine the patterns of elasticity moduli E influence of all the main roof layers on the formation of the load Q on the powered support (Fig. 6b). With a homogeneous roof (the deformation modulus of all layers is the same, $E_{i+k} = E$, solid line), improving the deformation properties of all layers simultaneously reduces the intensity of their lowering and, consequently, the load on the support until the moment of caving of the lower part of layers – the load increases abruptly. In this case, the resistance from the side of the lower layers disappears in the area of caved cantilevers and the durability of the upper layers decreases; with a further increase in E , caving of the upper layers also occurs, – again the load increases sharply and the $Q(E)$ pattern cycle repeats.

In the second option, with a reduced deformation modulus of the lower layers ($E_{i-k} < 1$, dotted line), dependence $Q(E)$ decreases more intensively in the first section, as the less rigid lower layers form the main part of the load. Having reached a certain limit length (which is greater than that of homogeneous rocks due to their own yielding properties), the cantilevers of the lower layers cave first, and the weight of part of the rock cantilever length is transferred to the support – the load Q increases abruptly, while the reaction to the upper layers decreases; they become unstable and part of them also cave, triggering another sudden increase in load on the powered support. This process may be repeated, but the general trend is that the load on the powered support at $E_{i-k} < 1$ is still lower than in a homogeneous roof, since, on the one hand, part of the more rigid upper rock layers does not cave, and, on the other hand, due to their own rigidity, these layers transmit a reduced load to the support.

In the third option (dash-dotted line in Fig. 6b) the first section of the $Q(E)$ dependence is similar to the previous ones, but the line is positioned higher than in the other options.

The general conclusion regarding the patterns of influence of the deformation modulus E on the powered support load is as follows:

- before and after the stages of caving the rock cantilevers, the load Q decreases as their deformation moduli E increase, due to the limited deflections of the more rigid rock layers;
- during the period of caving, the load increases rapidly due to the weight of the rock volumes lowering onto the support;
- the caving process has the character of a chain reaction and typically begins from the lower layers to such a height when a stable state of the approximate upper layer occurs along the length of its span – from the face plane to the point of contact with the rocks caved into the mined-out area;
- in this process, the occurrence of thicker lithological variety with an increased deformation modulus (e.g., sandstone) in the main roof sharply increases the layer rigidity and can lead to both the closing of roof arch with the formation of a reduced load on the support, and to an increase in the load during the caving of layer within the working space of the longwall face and the adjacent area of the mined-out space.

The influence of the resistance to compression σ_{comp}^i of the i -th rock layer and the main roof as a whole throughout its entire thickness was then analyzed. According to Equation (2), the general trend is such that as σ_{comp}^i increases, the moment M_b^i that prevents the cantilever from caving increases linearly which leads to an increase in its length l_2^i . However, as the l_2^i increases, the load Q_i increases linearly due to the own weight of the cantilever (Fig. 3a). In this case, given the parabolic relationship [63], it can be concluded that the ratio of the “holding” and bending moments M_b^i/M_i will decrease as the cantilever length increases, despite an increase in σ_{comp}^i ; therefore, increasing the length of the cantilever is limited to a more intensive decrease in its durability. On the other hand, unlike the influence of E_i , the rigidity of the cantilever does not change as the σ_{comp}^i increases; accordingly, the load $q_{i+k}(x)$ from above and the reaction $q_{i-k}(x)$ from below on the i -th cantilever remain unchanged, and there is no significant load redistribution between the upper and lower rock layers during the period of increasing the cantilever length until the moment of its caving. It is quite possible that this process indirectly influenced the fact that most empirical formulas for predicting the length of hanging cantilevers do not reflect the influence of rock resistance to compression.

Next, analyze how increasing the σ_{comp}^i of the i -th layer influences the change in the load on the powered support. At very low $\sigma_{comp}^i \rightarrow 0$, the length of the durable rock cantilever also approaches zero ($\sigma_2^i \rightarrow 0$), and practically the entire volume of the i -th layer is lowered to the lower layers; the load on the powered support corresponds to a certain value of Q_{i+k} , which is the maximum for the given conditions. As σ_{comp}^i increases, the length l_2^i increases, and a trend similar to the influence of E_i is observed (Fig. 6a, section A_0-A_1). However, the intensity of the decrease in $Q(\sigma_{comp}^i)$ is much lower here, since the durable cantilever itself transfers part of its weight to the lower rocks within the arch of load formation on the support.

On the other hand, for the above reasons, the active growth of the function $l_2^i(\sigma_{comp}^i)$ cannot occur because the bending moment increases much faster than the holding moment M_i^p ;

the function $l_2^i(\sigma_{comp}^i)$ aligns, asymptotically approaching a certain constant value of $(l_2^i)_{max}$ at $\sigma_{comp}^i \rightarrow \infty$. Therefore, the function $Q(\sigma_{comp}^i)$ stabilizes at a certain level, slightly lower than the initial value of Q_{i+k} . In our opinion, the main reason for this limited influence of σ_{comp}^i is that this parameter does not lead to significant changes in the process of interaction between the main roof layers and the load distribution curve between them, and thus in the position of the arch contour of load formation on the powered support (Fig. 4).

Similar trends are also observed when considering the influence of the resistance to compression of the seam groups and the entire main roof as a whole.

3.3. Influence of the powered support bearing reaction

It is also essential to study the mechanism by which load develops on powered support, dedicated to the analysis of its resistance reaction P influence on the process of moving the roof over the stopping face. It is considered reasonable generally accepted statement about the layer-by-layer roof lowering, starting with direct contact with the support and extending to the main roof until the load formation stabilization occurs Q .

In addition, the P reaction has little effect on the process of closing cavities between layers that have the greatest exposure precisely in the areas of “bending”. Then, as the reaction P increases, the load Q on the support from the weight of the lowering roof rocks decreases, as shown schematically in Figure 7a. Given this pattern, the rational value of the support bearing reaction P_r will be such that an arch with a weight Q_r equal to P_r is formed in the roof; in any other situation, either the support reaction ($P > P_r$ at $Q < Q_r$ – part of the lines to the right of the points 1, 2, 3), or the load on the support ($P < P_r$ at $Q > Q_r$ – part of the lines to the left of points 1, 2, 3), for balancing which an increase in P is still necessary.

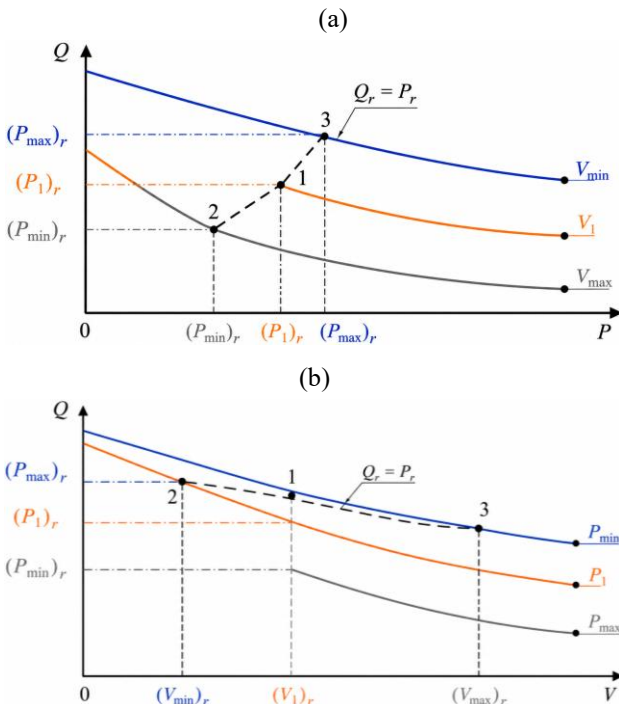


Figure 7. Qualitative patterns of the powered support bearing reaction P : (a) influence on load Q formation from the weight of the lowering rocks; (b) change in the rational bearing reaction P

Of course, other factors will also influence these patterns, such as the velocity of the stopping face advance; in that case, we obtain a set of functions $Q(P)$, for which at each value of V there is its own rational value of P_r (Fig. 7b). In conclusion, there is a pattern of the $P_r(V)$ reaction value depending on the velocity of the stopping face advance. This pattern will vary depending on the degree of manifestation of other influential factors (texture and properties of the roof rocks, mining depth, etc.), but within a certain area of a conditionally stable geomechanical situation, the $P_r(V)$ pattern allows for the rapid adjustment of technological parameters of stope operations to prevent an emergency state of overloading the powered support and the stope complex settling onto a “rigid base”. The need to adjust the powered support operating parameters to the current geomechanical conditions is also consistent with previous studies on the selection of support operating modes, equipment reliability and interaction between support elements under loading [64]-[67].

3.4. Influence of the longwall face advance velocity

Figure 8 shows graphs of the change in averaged pressure P (by section group) along the length of the longwall face Z , depending on its average daily advance velocity V_{av} , recorded as three values (3.2; 7.7 and 11.4 m/day) provided the minimal influence of other factors. The general pattern is that as V_{av} increases, the pressure P in the hydraulic prop stays of the section groups decreases along the entire length of the longwall face; moreover, in the interval $V_{av} = 3.2-7.7$ m/day, there is a more significant decrease in P than in the interval $V_{av} = 7.7-11.2$ m/day, although the ranges of these intervals (4.5 and 3.7 m/day) do not differ significantly from each other. Thus, in the central part of the longwall face, there is a decrease in P to 15-27% in the interval of 3.2-7.7 m/day and only to 2-4% in the interval of 7.7-11.2 m/day. However, such a significant increase in the pressure change gradient P at relatively low velocities V_{av} is not observed in all sections along the length of the longwall face: near the sections No. 25-60 and No. 120-150, the pressure drop gradient P is approximately the same throughout the entire interval $V_{av} = 3.2-11.4$ m/day and is 7.0-14.8 Bar per 1 m/day increase in the velocity V_{av} of longwall face advance.

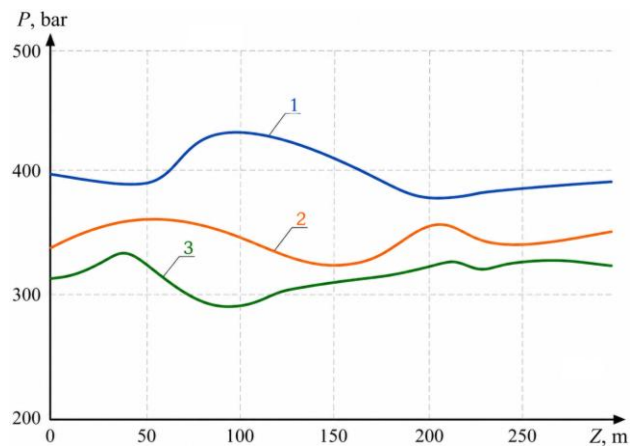


Figure 8. Change in averaged pressure values P in hydraulic prop stays of sections along the length Z of the longwall face, depending on the average daily velocity V_{av} of the stopping face advance: 1 – $V_{av} = 3.2$ m/day; 2 – $V_{av} = 7.7$ m/day; 3 – $V_{av} = 11.4$ m/day

The consistent pattern of decreasing pressure P as V_{av} increases still tends to decrease the gradient as V_{av} increases; that is, the function $P(V_{av})$ shows properties of an asymptotic approximation to a certain constant value at high V_{av} velocity values, as can be seen graphically in Figure 9. Several sections along the length of the longwall face (central part and end sections) are distinguished, where the dependence $P_i(V_{av})$ is divided relative to sections pushed to the face plane ($\delta = 0.5$ m), and non-pushed sections ($\delta > 0.8$ m). Here, the influence of the δ parameter is manifested in the form of a slightly different intensity of decrease in P_i as the velocity V_{av} increases – the pressure drop gradient in the non-pushed sections is noticeably greater.

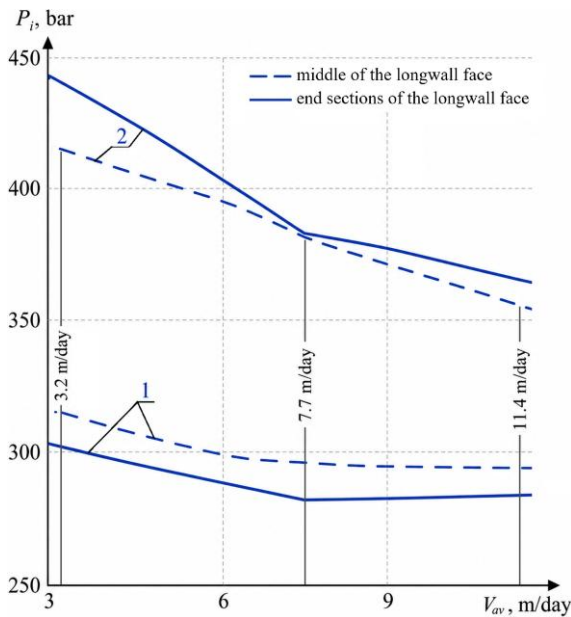


Figure 9. Change in pressure P_i in the hydraulic prop stays of the sections depending on the average daily velocity V_{av} of the stopping face advance: 1 – $\delta \leq 0.5$ m; 2 – $\delta > 0.8$ m

Obviously, the impact of the face acts here, restraining the lowering of the bedded roof layers, which intensifies as the distance δ increases; however, the increase in velocity prevents this lowering from occurring to its full extent, since the support section has time to shift to a new section.

This pattern confirms the concepts of existing ideas about the processes of coal-overlying formation shear in terms of development in time and space of lowering the roof rocks and their stratification during the longwall face removal. Thus, it has been determined that the average daily velocity V_{av} of the stopping face advance consistently influences the pressure P_i in the hydraulic prop stays of the sections, regardless of the Z coordinate of section location along the length of the longwall face and their position δ relative to the face plane. For non-pushed sections, the pressure drop gradient P_i with increasing velocity V_{av} is, as a rule, higher, which is due to a more intense roof lowering as the distance δ from the face plane increases. In the studied range (3.2-11.4 m/day) of V_{av} velocity values for the average daily stopping face advance, a pattern is observed of weakening of the V_{av} influence on pressure P_i at high V_{av} values, and in general, in this range V_{av} , the pressure value decreases from 15 to 43%. The identified influence of the longwall face advance velocity is consistent with previous studies in which the face advance

rate was considered an important factor governing stress-strain anomalies and the shear parameters of the coal-overlying formation in Western Donbas [63], [68].

3.5. Influence of the main roof texture

An analysis of the $P(Z)$ indices for the first pair of sections, No. 1 and No. 2, was conducted at a depth $H = 429$ - 437 m of the longwall face location. Here, to exclude the influence of the section positions relative to the face plane by the parameter δ , the graphs were plotted for two extreme values $\delta \leq 0.5$ m and $\delta > 0.8$ m. Therefore, for each of the two textures in Figure 10, two graphs $P(Z)$ are given.

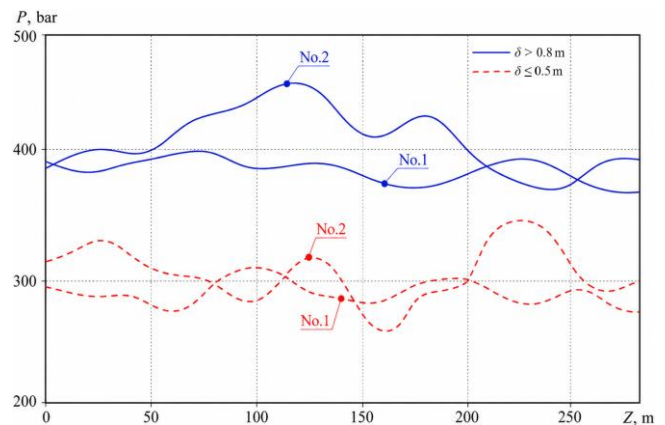


Figure 10. Change in pressure P in hydraulic prop stays of the section groups along the length Z of the longwall face during mining of sections No. 1 and No. 2

Analyze the distribution of pressure P in the hydraulic prop stays of sections located at least 0.8 m away from the face plane (Fig. 10, solid lines). The average pressure deviation along the length of the longwall face is by 5.6% higher for texture No. 2; for it, the maximum P_{max} is by 11.3% higher, while the minimum P_{min} almost coincides with that of texture No. 1.

Thus, there is a noticeable increase in the load on section No. 2, which has a more stratified texture; a relatively low layer thickness leads to their more intense lowering on the support, and the height of the load formation contour extends slightly higher into the roof. This tendency is consistent with the established mechanisms of deformation and failure of stratified weak rocks above longwall workings [60]-[62] and with studies of longwall mining under poor-strength surrounding strata. However, the difference in pressure readings is not very significant with differences in the textures of the main roof. To confirm this, a similar comparative analysis was conducted of the pressure readings in the hydraulic prop stays of sections No. 4 and No. 5, located at a depth of 342-350 m. The results confirmed the insignificant influence of the main roof texture on forming the load on the support.

3.6. Influence of the main roof caving step and face stoppage

The research revealed a certain peculiarity of the change in pressure P along the coordinate $X = 20$ - 25 m of the length of the extraction site, related to the influence of the step l of the main roof caving (Fig. 11). When substantiating the mechanism of interaction between roof rocks and powered support, it was noted that in mostly thin- and medium-bedded weak rocks, there is no hanging rock cantilevers of any significant length.

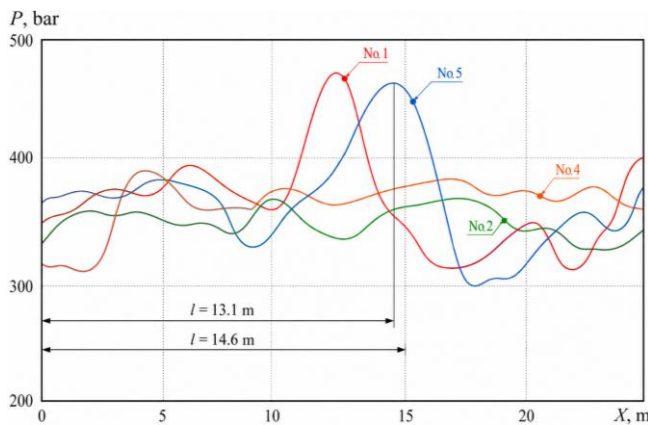


Figure 11. Change in pressure P in hydraulic prop stays of the section groups along the length X of the extraction site when mining sections No. 1, No. 2, No. 4, and No. 5 with the corresponding main roof texture

Therefore, manifestations of the main roof subsidence are hardly noticeable. Indeed, if we examine the change in pressure P in hydraulic prop stays of the section groups (averaged values) along the length X of the mined-out area, the stability of the function $P(X)$ can be observed for the thin- and medium-bedded textures No. 2 and No. 4. The maximum amplitude of fluctuations is 10.1% for section No. 2 and 6.6% for section No. 4, with a measurement length of $X = 25$ m; that is, it can be concluded that there is practically no phenomenon of the main roof settlement under conditions of textures No. 2 and No. 4.

When analyzing the $P(X)$ fluctuations within the identified amplitude range, a certain periodicity of this process can be observed, with a period of 5-6 m; it can be argued that the main roof caving occurs immediately behind the section [69].

In the medium- and thick-bedded textures of the main roof (sections No. 1 and No. 5), load disturbances are observed in the sections, which are identical to the active and local increase in $P(X)$ pressure function as these sections are mined. This “anomaly” was attributed to the step l of the main roof settlement, which consists (except for other layers) of relatively strong aleurolite (strength coefficient is up to 4) of almost the same thickness from 5.2 m to 5.7 m for both sections. These characteristics of aleurolite make it possible to predict the hanging of a long cantilever, which is also facilitated by its location in the upper part of the main roof, when a significant volume of caving rocks is no longer predicted above the aleurolite, and the elongated rock cantilever can be in a stable state.

Therefore, the intense increase in pressure P in the hydraulic prop stays of the sections is explained by the increase in the length of the thick aleurolite hanging cantilever during the period preceding its caving, that is, before the main roof is erected. Here, in the section $X = 3-5$ m before caving, the rock cantilever, increasingly deforming, is nearly completely lowering onto the lower rocks and transferring the load through them to the powered support. Thus, the combined action of the factor of increasing cantilever length (as the stoping face advances) and the factor of its continuous lowering with the additional loading of the lower rocks leads (in caving rock) to a rapid increase in pressure in the piston cavities of the hydraulic prop stays, which, even when averaging the readings, reaches a value of $P = 450-460$ Bar –

activation of the safety valves of hydraulic prop stays – and the support operates at maximum load. The occurrence of such peak loading conditions also confirms the importance of considering roof-fall risk, powered support reliability and the interaction of support elements under deformation-induced loading [66], [67], [70].

After reaching the maximum of $P(X)$, following the completion of the main roof installation, the pressure drops rapidly and, as the face advances another 3 m, reaches its minimum $P_{\min}(X)$, the value of which is 25% less than $P_{\min}(X)$ in sections No. 2 and No. 4 of the main roof with increased stratification. This is due to the fact that after caving, the rock cantilever of the thick aleurolite has a short overhang, remains stable with a minimal deflection value, and contributes little to the formation of the load on the support – it is unloaded. As the face advances, the pressure gradually increases and the cycle repeats; however, due to the limited length of texture sections No. 1 and No. 5, it is impossible to determine the stability of the loading cycle for these sections.

Next, a study was conducted to examine the influence of the depth of stope operations, the load on the support in the process of the main roof settlement, and the influence of long-term stoppage.

The results show that, regardless of the face position relative to the step of the main roof settlement, the velocity V_{av} has a significant influence on the increase in P during the idle time t . Thus, immediately before the main roof settlement, the increase in pressure P ($V_{av} = 4.5$ m/day) was 16.1-18.7% in the first three hours of idle time and an additional 8.5% at $t \geq 6$ hours. As can be seen, there is a trend toward a decrease in the influence of V_{av} with increasing duration of idle time t ; this is explained by the action of rheological factors, which, over time, partially offset the decrease in the rock volume that forms the load on the support, which is achieved due to the high V_{av} velocity of the stoping face advance. This trend is most clearly manifested when hanging elongated rock cantilevers before the main roof settlement, which has a predominantly medium- to thick-bedded texture.

Over the remaining length of the main roof settlement step (for the examined texture), the influence of the V_{av} velocity changes slightly. When comparing two velocities of the stoping face advance (3.6 and 10.3 m/day), the degree of influence of V_{ave} during the process of the face stoppage is equalized: for the first 3 hours of idle time, this influence was 9.0-14.8%, and after 9 hours of idle time, it was 11.4-11.7%. This is also due to the development of the process of lowering the rock cantilevers onto the support; given their relatively short length, the reduction in load (due to the increased V_{av}) is compensated for in idle time. The observed increase in pressure during the longwall face stoppage is consistent with the need to consider the time-dependent evolution and redistribution of stresses in a stope equipped with powered support [71].

The research conducted leads to the conclusion that the most dangerous situation is a prolonged longwall face stoppage immediately prior to settling of the main roof, which has a predominantly medium- to thick-bedded texture; therefore, it is recommended to mine these sections at an increased V_{av} velocity of the longwall face advance to ensure a safety factor for the bearing reaction of the support in the event of forced stoppages. The quantitative relationships obtained in this study reflect the specific mining-geological and technological conditions of extraction site 871 of the

Zakhidno-Donbaska Mine. Their application to other extraction panels requires additional monitoring and consideration of local mining depth, roof texture, mechanical properties of the rocks, and powered support characteristics.

4. Conclusions

Analysis of existing ideas about the deformation processes of roof rocks in the area of the stope face has enabled the development of a scheme of the coal-overlying formation shear, taking into account the peculiarities of the stratified weak rock mass in Western Donbas.

This research considers the mechanism of load formation on powered support, depending on the main influential factors (both geomechanical and technological in nature), based on the fundamental peculiarities of coal seam mining in the stratified weak rock mass of Western Donbas – the load on the support is largely determined not by overhanging rock cantilevers and their subsequent caving, but by the sequential (along the main roof thickness) lowering of mainly thin- and medium-bedded rocks with distinct rheological properties and a virtually complete lack of adhesion between the layers.

Based on the developed mechanism for loading the powered support, a provision has been substantiated that the load is determined by the coordinates of two boundaries (in the cross-section of the longwall face): from the side of the mined-out space – line of change in the curvature sign of bending the rock layers, beginning almost immediately beyond the support section fencing; from the side of the face plane – arch contour of load formation on the support, composed of the “remnants” of rock cantilevers that maintain durability.

The mechanism of influence on the process of load formation on the support of geomechanical (texture and mechanical properties of the roof rocks, including their rheological properties) and technological (velocity of the stoping face advance and the duration of its stoppage, feed velocity of the coal-mining machine and the grip width of its executive body, the step of the main roof settlement and the bearing reaction of the support) parameters has been revealed.

The examined general trends and qualitative patterns of the influence of geomechanical and technological parameters on the load of powered support serve as a system planning tool for research in mine conditions by monitoring the coal mining equipment operation.

Author contributions

Conceptualization: HS, GS; Data curation: RH, IV; Formal analysis: SM; Funding acquisition: HS, GS; Investigation: HS; Methodology: HS, GS; Project administration: HS; Resources: RH, IV; Software: GS, IS, RH; Supervision: HS, IS; Validation: SM; Visualization: IS, RH, IV; Writing – original draft: HS, GS, IS; Writing – review & editing: SM, RH, IV. All authors have read and agreed to the published version of the manuscript.

Funding

The scientific and practical results presented, obtained within the framework of projects implemented by the Ministry of Education and Science of Ukraine, include identify the peculiarities of rock shear in the coal-overlying formation in the mining-geological conditions of Western Donbas, which corresponds to the results of the project “Geomechanical and

technological foundations for the mining and processing of critical raw materials based on the principles of the circular economy” (No. 0126U001578), as well as the development of a mechanism of loading the powered support taking into account geomechanical and technological factors of the project “Creation of information and geomechanical systems for innovative mineral mining in the post-war period of Ukraine’s restoration” (No. 0124U000547).

Acknowledgements

We would like to extend our heartfelt appreciation to the peer reviewers who generously dedicated their time and expertise to review and provide constructive feedback on this research paper.

Conflicts of interests

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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Оптимізація навантаження на механізоване кріплення при коливаннях інтенсивності проявів гірського тиску

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Мета. Метою дослідження є виявлення особливостей зсуву порід надвугільної товщі в гірничо-геологічних умовах Західного Донбасу та обґрунтування механізму навантаження кріплення очисного комплексу при коливаннях інтенсивності проявів гірського тиску.

Методика. Дослідження виконано на основі аналізу гірничо-геологічних умов відпрацювання дільниці, збору та статистичного опрацювання даних про стан масиву гірських порід, а також шахтного моніторингу тиску в гідростійках секцій механізованого кріплення за різних технологічних параметрів роботи очисного вибою. Для оцінювання впливу текстури, деформаційних, міцнісних і реологічних властивостей порід на навантаження кріплення застосовано графічний та порівняльний аналіз установлених залежностей.

Результати. Аналіз існуючих уявлень про процеси деформування порід покрівлі в районі очисного вибою дав змогу розробити схему зсуву надвугільної товщі. Розроблено механізм навантаження механізованого кріплення з урахуванням геомеханічних і технологічних чинників. Отримано якісні закономірності впливу параметрів на навантаження механізованого кріплення в контексті інструменту системного планування досліджень у шахтних умовах.

Наукова новизна. Визначено закономірності впливу текстури та механічних характеристик порід покрівлі, включно з їх реологічними властивостями, швидкості посування очисного вибою та часу його зупинки, кроку посадки основної покрівлі та реакції відсічі кріплення на механізм зсуву надвугільної товщі.

Практична значимість. Установлені залежності між тиском у гідростійках секцій механізованого кріплення, швидкістю посування очисного вибою, текстурою порід покрівлі, кроком обвалення основної покрівлі та тривалістю зупинки лави можуть бути використані для коригування режимів роботи механізованого кріплення й параметрів ведення очисних робіт. Це дає змогу визначати потенційно небезпечні умови навантаження, обирати раціональну швидкість посування вибою та знижувати ризик перевантаження секцій механізованого кріплення під час осідання основної покрівлі й тривалих зупинок лави.

Ключові слова: вугілля; геомеханіка; гірський тиск; механізоване кріплення; оптимізація

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