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Methodical principles of experimental-analytical research into the influence of pre-drilled wells on the intensity of gas-dynamic phenomena manifestations

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Abstract

Purpose. The research aims to substantiate the general provisions on coordination of the experimental-analytical research results of the influence of pre-drilled wells on the intensity of gas-dynamic phenomena manifestations (using the example of the mining-geological conditions of the phenomena at the PJSC Mine Administration Pokrovske, Ukraine).

Methods. The research uses an integrated methodology consisting of indirect experimental methods for studying the adjacent rock mass state and tendencies.

Findings. It has been proven that indirect experimental indicators of the rock mass state around the tunneling face are related to the peculiarities of the distribution of its stress-strain state components. Based on this research, the well lengths of up to 10-15 m has been determined to effectively and safely de-stress the rock mass. The experimental research validity is confirmed by conducted computational experiments, in the course of which the dependence of the propagation parameters of the stress-strain state component concentrations on the degree of hardness of the lithotypes is revealed, and a geomechanical substantiation to the tendencies of propagation of rock pressure anomalies near stoping and tunneling faces is given. The new knowledge obtained is the basis for creating a method for calculating rational parameters for the location of de-stressing pre-drilled wells.

Originality. An objective assessment of the degree of adequacy and reliability of the computational experiment results has been made under the condition of using a new geomechanical model with mine studies of seismic-acoustic signal parameters and the initial gas release velocity. The main tendencies of vertical σ_y, horizontal σ_x and σ_z, as well as stress intensity propagation have been identified. The obtained results of exploring the bottom-hole mass are aimed at substantiating the parameters of anti-outburst measures for all preparatory mine workings.

Practical implications. The conducted research is implemented in creation of a calculation method and recommendations for the selection of rational parameters for the location of de-stressing pre-drilled wells for the purpose of weakening the rock mass, surrounding the tunneling face, and reducing the probability of gas-dynamic phenomena occurrence due to the controlled weakening of adjacent rocks.

Keywords: *mine, gas-dynamic phenomena, pre-drilled wells, stress-strain state, field and in-seam working*

1. Introduction

To date, research in the field of coal mining indicates a relationship between the Gas-Dynamic Phenomena (GDP) manifestations and increasing mining depth. These very hazardous phenomena are represented by sudden coal, rock and methane gas outbursts.

The problem of sudden outbursts has been relevant for many years [1]-[7] and is the most hazardous in underground coal mining. The works [8]-[11] cover many fundamental and applied studies performed by many generations of foreign and Ukrainian scientists.

Also, in the works [12]-[14], a number of mining-geological and mining-technical conditions influencing the stress-strain state (SSS) distribution, the intensity of technological processes and, accordingly, the distribution of outburst-hazardous zones have been studied. At present, research on the process of development and occurrence of gas-dynamic phenomena consists of storing additional internal energy with subsequent active coal generation as a result of its structure destruction. If we consider the technology of using wells, then this additional internal energy is used for outgassing and reducing the risk of outbursts in coal seams [15]-[17].

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The analysis of available local means and methods for preventing sudden outbursts of coal, rock and gas [18], [19] has proven that many of them reduce the rate of construction of mine workings. In this sense, the pre-drilling method of de-stressing wells is a positive one, which will be studied in detail from the point of view of the task of combating gas-dynamic phenomena (GDP) at depths above 1000 m.

This method differs from others by its high technological efficiency, does not involve the use of high-pressure fluid and can be compatible with some tunneling cycle operations.

Thus, the task of calculating the stress-strain state of the mass surrounding a mine working based on the finite element method (FEM) to determine the most stressed zones is the first component of the research provided in the papers [20]-[22].

The next comprehensive research stage is the experimental verification of the obtained data when modeling the state of adjacent rocks.

2. General provisions on coordination of the experimental-analytical research results

Based on a comprehensive analysis of the fields of SSS components, a significant decrease in the rock stress in the bottom-hole zone of the outburst-hazardous rock mass has been noted. It is practically impossible to verify these results by direct experimental determination of the current SSS components, especially in the conditions of constant tunneling face advance. Therefore, there is an obvious need to use indirect experimental methods to study the state of an adjacent rock mass and tendencies of change in the GDP manifestation intensity when using pre-drilled wells in mining technology under conditions of adjacent rock mass gas-dynamic activity.

Difficulties in determining the degree of correspondence between the results of analytical and experimental studies are inherent in the very nature of geomechanical processes operating in a gas-saturated coal-rock mass at great depths. Existing studies emphasize [23]-[26] the need to consider various interrelated factors, such as the two-phase state of the gas in free and sorbed form; at the same time, it is noted [23]-[25] that the sorbed gas phase is the determining factor causing gas-dynamic rock pressure manifestations when the mass equilibrium state is disturbed [25]. The general tectonic disturbance of the coal-bearing stratum is also considered to be an influential factor.

In this sense, there are many hypotheses about the mechanism of rock-gas outburst formations [27]-[29], and the consideration of rock pressure as the main cause of the GDP occurrence is only one hypothesis [30]. In the paper [31], even a statistical dependence between the seam outburst-hazard probability and the relative release of light substances has been obtained. However, most experts believe that a rock outburst occurs due to the release of energy from elastic deformations of a highly stressed rock mass [32]-[35]. There is an idea about such SSS factor for the coal-rock mass bottom-hole zone: high variability along the length of the limiting state area of the lithotypes ahead of the face, which periodically creates high outburst-hazardous gradients of stress components and, consequently, gas pressure drop. That is, there is a sufficiently deep connection between the probability of GDP and SSS manifestations in the bottom-hole zone of the mass, but if the FEM modeling technology of this connection does not cause problems, then the experimental determining of patterns is currently possible only by indirect methods and their indicators.

The problem also exists on the other side of safe mining operations in seams with increased gas-dynamic activity and it consists in the differences regulated by normative documents [36]-[41] and research [42]-[50]. The authors raising this issue [51] are convinced of the need to adjust the normative documents taking into account the developments [42]-[54].

In the direction of controlling the state of a coal-bearing mass, there are a number of mining geophysics methods [55], which have certain advantages in terms of averaging small-scale fluctuations of physical-mechanical properties of the mass and its texture. One of the most common indirect methods of mining geophysics is the vibroacoustic method, which involves studying the oscillatory rock mass response to the impact influence during the operation of stoping and tunneling equipment, as well as other artificial sources. Using appropriate equipment, technological acoustic signals are processed and analyzed relatively:

– predicting the GDP in stoping and tunneling faces, sudden coal-gas outbursts, rock bursts, sudden coal seam displacements, etc.;

– predicting geological disturbances ahead of an advancing face;

– determining the sizes of bearing pressure and de-stressing zones, as well as other SSS parameters near the bottom-hole zone of the rock mass;

– assessing the effectiveness of measures to prevent GDP, for example, hydraulic loosening of a coal seam or drilling pre-drilled wells.

Today, the most widespread methods for predicting the GDP are based on the parameters of acoustic signals, which are recorded by appropriate equipment, such as APSS1, AK-1 and AK-1M. It enables continuous assessment of the mass stress degree while sensing with acoustic signals of the studied zone. At the same time, there is information about the average level of reliability of the seismic-acoustic prediction of GDP about 60-70%, but this figure is being tried to increase [56] by developing more reliable methodologies for prediction.

Prediction of the rock mass gas dynamic activity during mine workings (mainly preparatory workings) is the most common in operational terms [57], [58]. This current prediction is complicated by existing diverse GDP manifestations and related hypotheses to substantiate the predominant role of one or another factor [57]. Even for the same phenomenon, different predictive methods and indicators have been developed.

Thus, during indirect experimental research, there are a number of indicators that reflect the state of the adjacent rock mass, and the main task is to reliably coordinate them with the analytical research parameters. When solving this problem, we obtain a fairly objective assessment of the mass bottom-hole zone state, both from analytical calculations and from experimental measurements.

The following provisions of the principles of coordination of the experimental and analytical research results are substantiated based on the acoustic signal parameters.

Firstly, it is well known that the rock state, close to elastic, is characterized by an increased acoustic signal response energy, since it is absorbed mainly by the mass zones with inelastic deformations.

That is, the less widespread the inelastic deformation zones, the higher the signal energy. On the other hand, the predominantly elastic state of the mass surrounding the mine working, located at a great depth, indicates its significant stress with significant concentrations of components σ_y, σ_x, σ_z and σ, determined by analytical research (FEM modeling). Thus, it is possible to substantiate a certain relationship between increased concentrations of SSS components and the acoustic signal energy W: a higher value of W corresponds to increased concentrations of SSS components, and their degree of stress can be characterized by an integral indicator well-known in rock mechanics – stress intensity σ. In this sense, if to trace the change patterns (along the length of mine working or pre-drilled well) of the W and σ parameters, then a certain commonality in their tendencies can be revealed.

Particular attention should be paid to studying patterns $W(z)$ and $\sigma(z)$ in pre-drilled wells: they are drilled up to 7 units along the cross-sectional mine working plane. This makes it possible to compare the experiment with modeling even in the mine working section plane yx. Also, the data of seismic-acoustic studies in pre-drilled wells provide information on the sizes of stress zones of different concentration levels in order to compare them with similar parameters determined during FEM modeling.

Of course, the first provision uses indirect indicators to assess the degree of coordination between experimental and analytical researches, but if one accumulates several such indirect evidence of the reliability (or lack of it) of the obtained results, then this will be a fairly objective analysis when exploring the rock mass behavior.

The second provision for coordinating analytical and experimental researches is the joint study of the change patterns (along the length of the mine working or pre-drilled wells) of the additional load coefficient (experiment), stress component curves (modeling), and the adjacent mass texture with corresponding mechanical characteristics. The additional load coefficient contains data on the formation of the unstable rock zone, which by its weight exceeds the initial virgin mass pressure. In these well length areas, the stress intensity σ significantly exceeds the strength properties of the lithotypes – a large coal dust volume is formed – weakening and loosening of coal contributes to increased methane release. The additional load coefficient K_l along the well length z usually changes in anti-phase to acoustic signal response energy W. Consequently, a comparison of dependences $K_l(z)$ and $\sigma(z)$, considering the strength properties of lithotypes in the area with the coordinate z, can also be an indirect evidence of the reliability degree of the FEM modeling results.

Using available methodologies to study the coal-bearing mass gas-dynamic activity, as a rule, the outburst-hazard coefficient $K_{o\text{-}h}$, equal to the ratio of the amplitudes of high-frequency and low-frequency components of the vibration spectra, is determined.

The third provision is an attempt to coordinate the initial gas release velocity v_g with the presence of hazardous stress concentrations in the rock mass bottom-hole zone. Mine working length areas are classified as hazardous if the measured initial velocity v_g (in l/min) is equal to or exceeds the critical value for the given mining-geological conditions of conducting the mine working.

The fourth provision for coordinating the analytical and experimental research results is to find a relationship between the sudden coal displacement process and the rock pressure parameters.

The last of the provisions used is the coordination of the distribution fields of the adjacent rock mass SSS components (modeling) using FEM with the degree of outburst-hazard of sandstones, determined experimentally.

The outburst-hazard of sandstones is predicted on the basis of the sample analysis in accordance with the requirements [36]-[39], [42], [59]-[61]. At the same time, drilling core wells is not always possible [42], [60], [62], so other methods are used to predict the risk of outbursts of sandstones [43], [45], [63]-[66].

As a result of substantiating the basic provisions to coordinate experimental and analytical researches, it is possible to assert that indirect experimental indicators of the rock mass state surrounding the tunneling face have a certain relationship with the spatial distribution peculiarities of its SSS components. Their sufficient quantity makes it possible to assess the degree of adequacy and reliability of the FEM modeling results.

3. Peculiarities of the preliminary experimental research into the GDP manifestations during the construction of mine workings

Based on the stated general provisions, the GDP manifestations are studied by measuring indirect indicators in the process of conducting conveyor drift of the 2nd northern longwall face of block No. 11 using preliminary drilled de-stressing wells.

According to the principles of de-stressing the bottom-hole zone of the rock mass surrounding the conveyor drift, 5 wells are preliminary drilled step by step in the central part of the coal seam according to the scheme shown in Figure 1; this scheme has been developed taking into account the exit of the buried parts of the peripheral wells beyond the design mine working contour to reduce the load-bearing pressure in the border rocks. Drilling of wells in soft coal is characterized by increased process rate and more intense outgassing of the bottom-hole part of the mass.

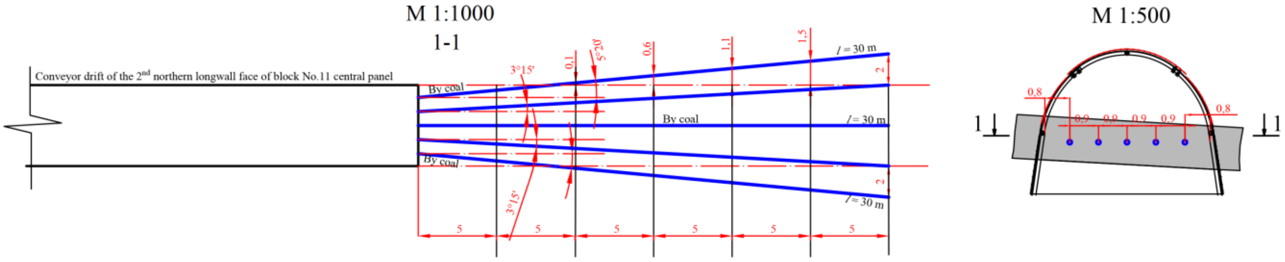


Figure 1. Scheme for drilling pre-drilled wells in the conveyor drift face of the 2nd northern longwall face of block No. 11

During the drilling each well, seismic-acoustic control is carried out and the initial gas release velocity is measured using normative methodologies. Information on the initial gas release velocity v_g and anti-outburst measures is constantly systematized, and for clarity, Figure 2 shows an example for one of the mine working areas.

To assess the specificity of gas release along the length of each well, the drilling process is describied with simultaneous indication of coal dust yield, accidental "clamping" of drilling tools and the overall coal weakening degree. The length of drilling the pre-drilled wells is 30 m and the analysis of the change in the situation during the drilling process makes it possible to draw some conclusions.

Firstly, the statistics of gas release at different areas of the conveyor drift proves a lower value at the first stage of drilling wells 5-15 m long; further, the deeper the well, the predominantly more gas is released. Secondly, with a still short well length, the coal dust yield is small and it gradually increases when the well length is more than 5-10 m. This phenomenon is more actively observed in the peripheral wells, and in the central wells – a small coal dust yield is observed along the well length of up to 15-25 m.

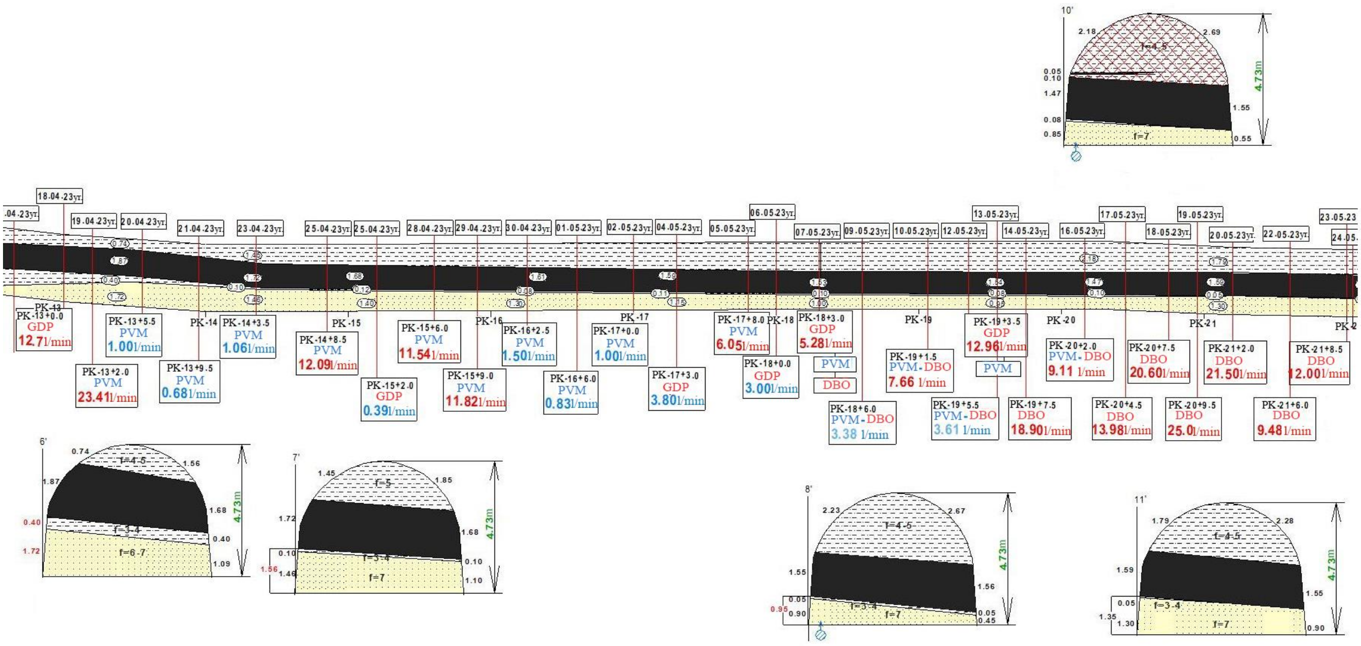


Figure 2. Example of visualization of measurements of the initial gas release velocity vg and the application of anti-outburst measures along the mine working length

Thirdly, as the coal dust yield begins to increase, so the so-called "clamping" of drilling tools periodically occurs, which somewhat complicates the drilling process.

The above-mentioned experimentally recorded three factors of peculiarities of the gas-dynamic activity manifestations of the rock mass surrounding the tunneling face along the route of drilling the pre-drilled wells can be explained in terms of the mechanism of bottom-hole rock deformations. An attempt to form such a representation is based on well-known principles of rock mechanics [67]-[69].

The relationship between the tendencies in the growing total gas release volumes V_g along the length of pre-drilled wells and the SSS anomaly parameters of the rock mass bottom-hole zone has the following underlying basis. The most weakened bottom-hole mass part, especially the coal seam, releases an increased gas volume, but this zone is limited by the action of maximum rock pressure anomalies. On the other hand, further drilling of wells reduces the degree of coal seam weakening, but increases the area of gas release surfaces in direct proportion to the length of wells. These two gas release factors counteract each other and obviously the second factor prevails over the first. This is facilitated by the natural coal fracturing: at a depth of more than 1000 m, large vertical and horizontal stresses are formed, contributing to certain coal deformations and intensifying methane drainage from numerous fractures; that is, gas release, although somewhat slower, continues, and the growing area of well surfaces (during their drilling) contributes to an increase in the gas release volume near the tunneling face.

As a result of the research, in our opinion, the depth of drilling the pre-drilled wells should be limited to 15 m. In this case, the actual rock pressure will contribute to destressing of the overstressed bottom-hole part of the mass by strengthening some of its zones, which limits the probability of the GDP occurrence during mining operations.

4. GDP prediction results according to normative methodologies

In the process of conducting conveyor drift of the 2nd northern longwall face of block No. 11, the parameters of the seismic-acoustic signal and the initial gas release velocity v_g were recorded and studied according to the current normative methodologies. Since normative methodologies provide for the determination of indirect indicators, the assessment of the GDP threat degree has only certain reliability: in general, there were no clear tendencies in changes in seismic-acoustic control indicators or the initial gas release velocity along the length of the pre-drilled wells and along the mine working route. But at the same time, there was a change in the mine working location depth and the coal-bearing mass texture parameters. There was also noted a discrepancy between the GDP threat degree according to seismic-acoustic control data and the methodology for measuring the initial gas release velocity.

In our opinion, the normative methodologies should be necessarily implemented operationally during mine workings, but the results should be treated critically, given other observations during drilling the pre-drilled wells and existing measures to prevent GDP. This general conclusion can be explained by specific examples of measuring indirect gas dynamic activity indicators of rocks adjacent to mine working.

In the already given example (Fig. 2), it is possible to see a certain stochasticity in the indicators for measuring the initial gas release velocity v_g along the mine working length. It should be noted here that when conducting mine working, the depth of its location changes somewhat, but more significantly – the texture of the roof and bottom rocks of the coal seam and its thickness; the mine working location coordinates relative to the coal seam also fluctuate. However, no consistent tendencies in the influence of the above factors on the indicator v_g have been identified.

Based on the length of pre-drilled wells, the tendency for increasing gas release volumes, coal dust yield, frequency of drilling tool "clamping" has already been revealed and explained. This constant pattern is confirmed in other mine working areas. A similar picture of the absence of consistent tendencies is observed when performing acoustic control using APSS-1 equipment. To substantiate this statement, fragments of observations (Table 1) and conclusions (Table 2) on the risk level of GDP manifestations are given.

Table 1. An example of systematization of seismoacoustic signal parameters along the mine working length (conveyor drift of the 2nd northern longwall face of block No. 11)

No.	Date	Time	Picket	Phon	Interval	F_{max}, Hz	f_n, Hz	f_n', Hz	f_v, Hz	f_v', Hz	A_n	A_v	K	E
1	24.06.23	04:40:42	PK30+6.0	195.88	18	140	140	140	140	140	7.98	5.78	0.72	1939
2	24.06.23	14:06:14	PK30+6.5	195.88	17	180	40	140	300	200	5.74	5.42	0.94	1999
3	24.06.23	14:58:09	PK30+7.0	195.88	19	200	20	80	320	220	5.44	5.71	1.05	2654
4	24.06.23	15:30:13	PK30+7.5	195.88	17	200	40	120	340	300	5.23	5.90	1.13	880
5	24.06.23	16:32:16	PK30+8.0	195.88	18	140	40	140	140	140	6.85	5.08	0.74	813
…	….	…	…	…	…	…	…	…	…	…	….	…	…	…
…	….	…	…	…	…	…	…	…	…	…	….	…	…	…
100	09.07.23	04:55:56	PK35+6.0	126.89	13	160	140	160	160	160	6.59	5.44	0.82	2768
Average value						281	148	245	338	298	5.40	5.86	1.22	2070
Minimum values						140	20	40	140	140	3.46	4.11	0/58	770
Maximum values						500	440	440	580	540	7.98	7.04	2.01	3745
Mean square deviation						142	116	135	196	153	1.49	0.88	0.50	686

When analyzing the tables, there was no consistent dependence of indirect indicators on changes in the mine working location depth, its position relative to the coal seam, and variations in the roof and bottom rock texture.

A consistent tendency of acoustic signal variation has been revealed along the length of the wells, acting irrespective of the mine working site and the location coordinates of the wells (Figs. 3-6). The above fragments clearly indicate reduced acoustic signal energy in less deep well areas and a further increase in this parameter in more distant areas. These tendencies can be associated with the rock pressure anomaly zone acting in the bottom-hole area of the mine working: here, high anomalies in the distribution of SSS components contribute to intensive stratification and weakening of the adjacent mass, in which the acoustic signal is actively absorbed due to cavities, fractures and stressed deformations of the mass. On the contrary, the mass continuity with its predominantly elastic deformations is partially preserved in the remote well areas – the acoustic signal passes through with less energy loss.

The length of the wells, where the reduced acoustic signal energy is detected, ranges from 12-15 m to 22-25 m; lower distance is observed in predominantly central wells, while medium and high distances – in peripheral wells. That is, in relation to the total gas release volume, there is a very opposite distance variation tendency depending on the growth of indirect GDP manifestation indicators.

The general conclusion from the experimental research is that it is most expedient to drill pre-drilled wells up to 12-15 m long, where the weakened bottom-hole rocks have lower stress and freer gas drainage, which reduces the probability of the GDP occurrence. Additional conclusion is that due to the extreme stochasticity of fluctuations in experimental gas-dynamic activity indicators of the rocks, the focus should be on the FEM modeling results of the bottom-hole mass state, based on which it is expedient to determine the rational parameters for the location of de-stressing pre-drilled wells.

5. Modeling of the mass state near the tunneling face of the in-seam working

The study of the bottom-hole mass state in order to substantiate the parameters of anti-outburst measures concerns all preparatory workings (field and in-seam), which are constructed at a depth of more than 1000 m in rocks with increased gas dynamic activity. There are obvious differences in the in-seam working texture relative to the occurrence parameters and mechanical properties of the adjacent lithotypes. Therefore, it is necessary to calculate and analyze the SSS of the in-seam working using a specific example of the 2nd northern conveyor drift of block No. 11 central panel.

5.1. Substantiation and development of a geomechanical model for a conveyor drift

Regarding the first stage of substantiating the model, the following should be noted. The model shape is taken as a rectangular parallelepiped, which is very common in the practice of modeling geomechanical processes and is recommended by numerous experts [70]-[73]. The model dimensions in height – coordinate $y = 40$ m and in width – coordinate $x = 35.5$ m. In terms of the model thickness coordinate z, we consider it expedient to increase it to 60 m for the following reasons.

Table 2. An example of conclusions on the risk level of GDP manifestations (2nd northern conveyor drift of block No. 11 central panel)

No.	Date	Mine working	Picket	Process	Start	End	Downtime	Energy	Result
1	01.07.23	2nd northern conveyor drift of block No. 11 central panel	PK32+8.5	Drilling	13:47:14	20:50:39		1750	Safe mining depth – one cycle
2	02.07.23				01:20:07	04:48:41		1192	
3	02.07.23				10:56:09	13:12:47		1260	
4	02.07.23				10:57:01	15:03:23		1799	
5	02.07.23				11:01:26	11:22:51		4118	
6	02.07.23				15:19:43	19:46:06		1794	
7	02.07.23				21:20:28	00:15:59		1631	
8	03.07.23		PK32+9.0	Prediction	05:49:11	06:19:52	54:10:13	2775	Dangerous situation! Implement control measures
9	03.07.23		PK32+9.5		06:25:23	07:23:59	0:36:12	2659	
10	03.07.23		PK33+0.0		11:53:32	12:22:37	5:28:09	2611	
11	03.07.23		PK33+0.5		12:27:04	13:04:29	0:33:32	2329	
12	03.07.23		PK33+1.0		13:09:58	16:26:54	0:42:54	1976	
13	03.07.23		PK33+1.5		16:31:38	18:01:17	3:21:40	2504	
14	03.07.23		PK33+2.0		19:06:27	20:59:20	2:34:49	2448	
15	03.07.23		PK33+2.5		21:21:59	22:12:40	2:15:32	2394	
16	03.07.23		PK33+3.0		22:34:25	06:57:35	1:12:26	2015	
17	04.07.23		PK33+3.5		07:13:02	08:27:52	8:38:37	2005	
18	04.07.23		PK33+4.0		09:09:50	10:06:53	1:56:48	902	
19	04.07.23		PK33+4.5		10:20:50	14:27:24	1:11:00	2123	
20	04.07.23		PK33+5.0		15:04:29	16:11:39	4:43:39	2552	
21	04.07.23		PK33+5.5		16:15:17	17:00:10	1:10:48	3135	
22	04.07.23		PK33+6.0		17:25:03	19:45:05	1:09:46	2508	
23	04.07.23		PK33+6.5		22:15:17	22:49:59	4:50:14	2260	
24	04.07.23		PK33+7.0		22:55:11	23:21:51	0:39:54	1253	
25	04.07.23		PK33+7.5		23:28:34	23:59:17	0:33:23	1962	
26	05.07.23		PK33+8.0		00:07:25	00:51:22	0:38:51	2759	
27	05.07.23		PK33+8.5		06:30:47	16:14:02	6:23:22	2419	
28	05.07.23		PK33+9.0		16:26:07	17:16:33	9:55:20	2356	
29	05.07.23		PK33+9.5		17:31:54	18:39:16	1:05:47	2439	
30	05.07.23		PK34+0.0		19:31:38	20:02:20	1:59:44	2402	
31	05.07.23		PK34+0.5		22:34:42	23:12:34	3:03:04	3156	
No.	Date	Mine working	Picket	Process	Start	End	Downtime	Energy	Result
32	06.07.23	2nd northern conveyor drift of block No. 11 central panel	PK34+1.0	Prediction	04:47:58	05:19:14	6:13:16	3718	Dangerous situation! Implement control measures
33	06.07.23		PK34+1.5		05:30:49	07:15:40	0:42:51	1880	
34	06.07.23		PK34+2.0		14:36:01	15:06:09	9:05:12	3359	
35	06.07.23		PK34+2.5		15:22:18	15:51:38	0:46:17	1973	
36	06.07.23		PK34+3.0		16:11:07	16:44:06	0:48:49	1026	
37	06.07.23		PK34+3.5		18:22:25	18:51:46	2:11:18	3745	
38	06.07.23		PK34+4.0		20:44:20	22:39:41	2:21:55	1972	
39	06.07.23		PK34+4.5		23:06:03	01:0102	2:21:43	2146	
40	07.07.23		PK34+5.0		02:30:22	02:57:05	3:24:19	2239	
41	07.07.23		PK34+5.5		03:14:24	03:50:19	0:44:02	1888	Dangerous! Reserve zone! Implement control measures
42	07.07.23		PK34+6.0		04:07:33	04:46:54	0:53:09	771	Dangerous! Reserve zone! Implement control measures
43	07.07.23		PK34+6.5		04:58:38	07:31:18	0:51:05	1894	Safe mining depth – one cycle
44	07.07.23		PK34+7.0		12:34:13	13:11:56	7:36:35	2779	Dangerous situation! Implement control measures
45	07.07.23		PK34+7.5		13:26:48	14:55:59	0:52:35	1637	
46	07.07.23		PK34+8.0		15:38:58	19:52:14	2:12:10	2290	
47	07.07.23		PK34+8.5		19:58:36	20:46:03	4:19:38	1440	
48	07.07.23		PK34+9.0		22:41:43	23:10:15	2:43:07	2120	
49	07.07.23		PK34+9.5		23:19:56	23:53:22	0:38:13	1607	

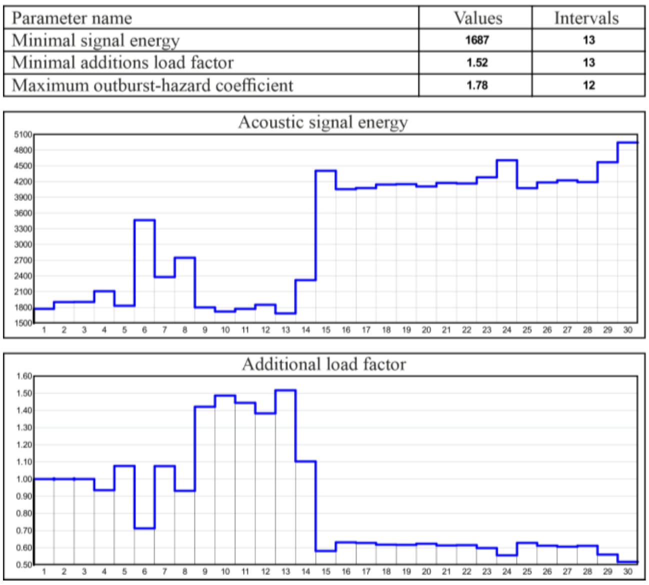


Figure 3. Tendencies of changes in acoustic signal parameters along the length of well No. 5 on PK25+6.2 (2nd northern conveyor drift of block No. 11 central panel)

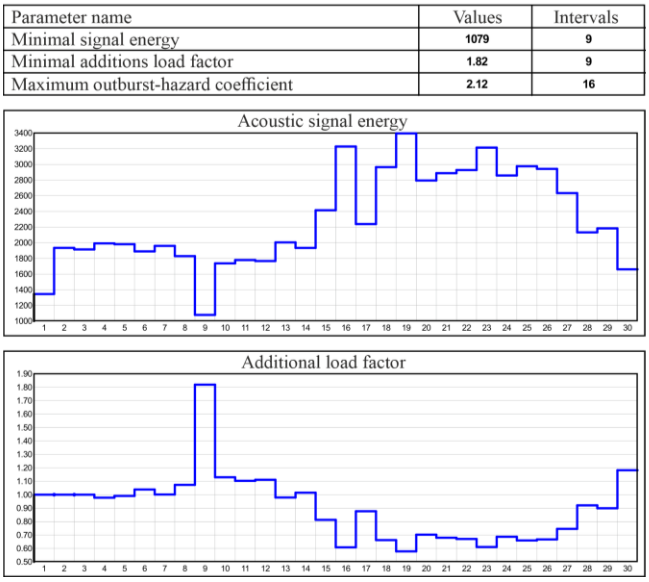


Figure 4. Tendencies of changes in acoustic signal parameters along the length of well No. 5 on PK27+6.0 (2nd northern conveyor drift of block No. 11 central panel)

On the one hand, in practice, pre-drilled wells 30 m long are drilled in the conveyor drift. From the point of view of model adequacy, it is appropriate to reflect its entire length plus another 10 m (along the mine working route) to represent some SSS disturbances at the well ends. On the other hand, according to available geomechanical studies, a more yielding coal seam (low deformation modulus) contributes to the displacement of SSS components along the disturbance coordinate z deep along the mine working route [69], [74]-[80]. To reflect this difference, it became necessary to increase the model size along the coordinate z as shown in Figure 7.

The second stage of constructing a conveyor drift geomechanical model involves representation of the rock mass texture based on unchanged mechanical properties of its lithotypes. The thickness and mechanical properties of the model lithotypes are given in Table 3.

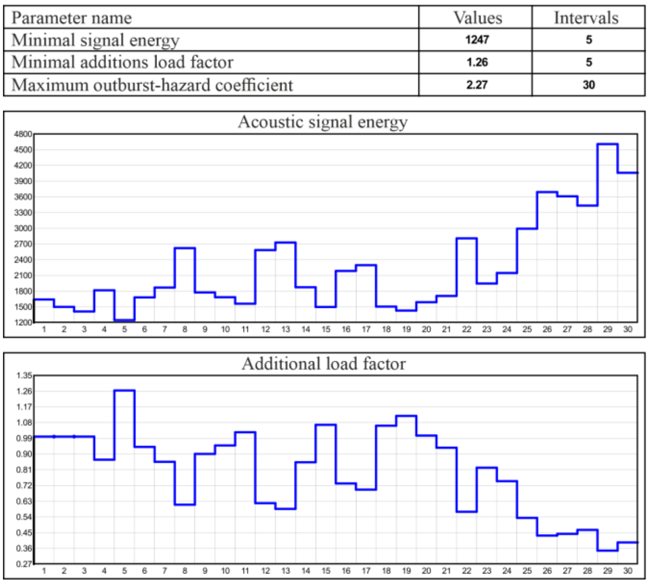


Figure 5. Tendencies of changes in acoustic signal parameters along the length of well No. 1 on PK27+6.0 (2nd northern conveyor drift of block No. 11 central panel)

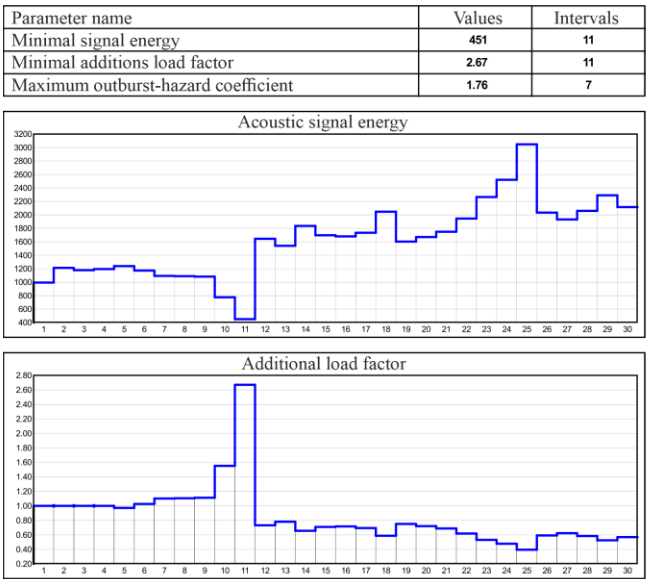


Figure 6. Tendencies of changes in acoustic signal parameters along the length of well No. 3 on PK32+8.5 (2nd northern conveyor drift of block No. 11 central panel)

Table 3. Parameters of texture and mechanical properties of lithotypes surrounding the conveyor drift

No.	Lithotypes	Thickness, m	Compressive strength, MPa	Elasticity modulus, MPa	Tensile strength, MPa
1	Sandstone	18.2	65	$3.5 \cdot 10^4$	9.1
2	Siltstone	5.6	47	$1.5 \cdot 10^4$	3.9
3	Coal seam	1.5	12,5	$0.4 \cdot 10^4$	1.0
4	Siltstone	0.5	47	$1.5 \cdot 10^4$	3.9
5	Sandstone	12.4	72	$4.0 \cdot 10^4$	8.0
6	Siltstone	0.9	46	$1.5 \cdot 10^4$	5.3
7	Sandstone	9.8	76	$4.0 \cdot 10^4$	8.0

The third stage involves substantiating the boundary conditions of the model load on its boundaries along the planes *xz*, *yx* and *yz* (Fig. 7). Geometric parameters of mine working and pre-drilled wells are considered in the well length of l_w = 30 m.

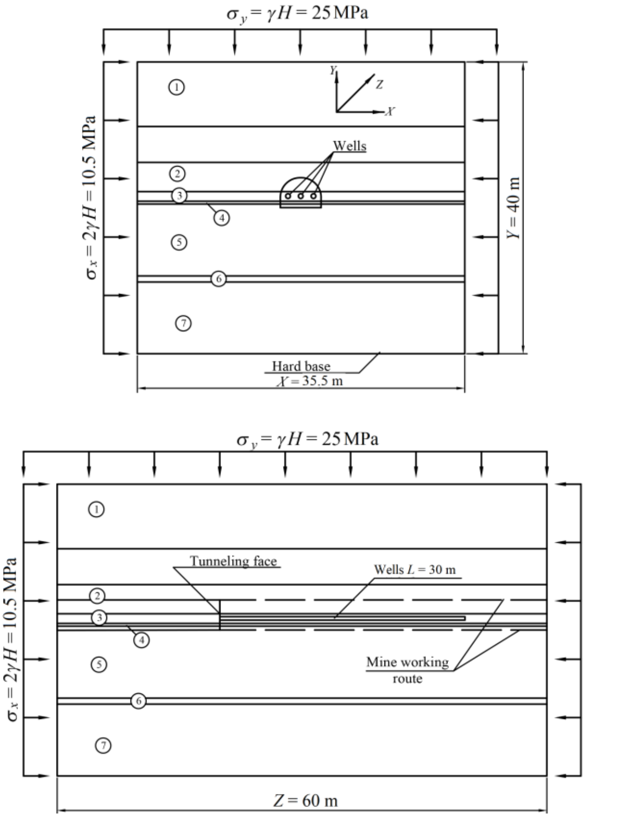


Figure 7. Geomechanical model for block No. 11 2nd northern longwall face conveyor drift

Another difference concerns the number n of wells in the mine working cross-section; two options are modeled here: $n = 3$ for objective assessment compared to field working; $n = 5$ to adequately reflect the actual technology for constructing a conveyor drift.

5.2. Vertical stress field differences

Differences in the bottom-hole mass SSS (along the mine working construction route and in its cross-section) are determined based on the main stress components: vertical σ_y, horizontal σ_x and σ_z, as well as stress intensity σ. The search for differences is performed in two directions: the first is the difference in the bottom-hole mass SSS of in-seam and field workings; the second is the influence of the number of pre-drilled wells ($n = 3$ or $n = 5$) on the SSS of the mass surrounding the in-seam working. A generalization of the differences obtained will be useful in developing appropriate recommendations on safe mine working construction in conditions of gas-dynamic activity of adjacent rocks at depths of over 1000 m.

Here and further, the distribution of stress components from the tunneling face and deep into the mass along the route of mine workings is studied. Methodologically, visualization of isolines σ_y is performed as follows (Fig. 8):

– isolines σ_y when comparing the corresponding curves relative to field and in-seam workings are located on the right side of the figure;

– isolines σ_y representing the influence of the number of pre-drilled wells are shown on the left side of the Figure.

A comparative analysis of the curves σ_y has revealed the following differences.

Regarding the differences in the propagation of concentrations σ_y in the bottom-hole mass surrounding the in-seam working, there is a general very stable tendency to increase the distance (from the mine working) of influence of any concentration σ_y (Fig. 8b): for example, it is possible to argue about the expansion of the area of influence of the following concentrations σ_y:

– K_y = 1.24-1.36 by 19.6% in the roof, 42-47% – in the sides and 12.4% – in the bottom;

– K_y = 1.60-1.92 by 18.3% in the roof, 42-44% – in the sides and 28.3% – in the bottom;

– concentration of the K_y = 2.0-2.6 level has not been observed at all in the in-seam working border rocks;

– the highest tensile stresses σ_y in the in-seam working bottom have also reduced their propagation by 33-56%.

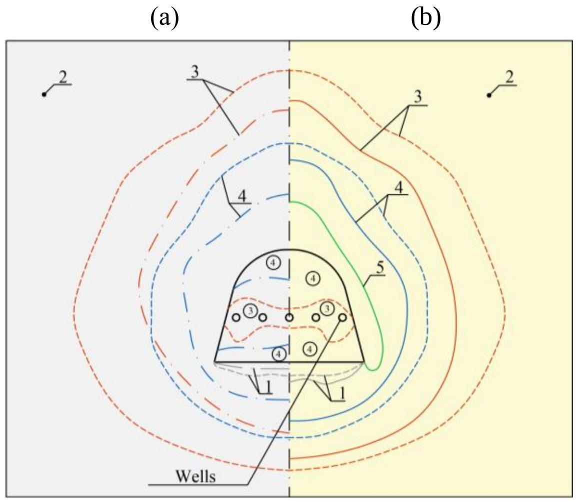


Figure 8. Vertical stress isolines σ_y in the cross-section of mine workings: (a) comparison of the influence of the number n of wells relative to in-seam working: — — $n = 3$, – · – $n = 5$; (b) comparison of the field (——) and in-seam (— —) workings at $n = 3$; 1 – σ_y = +(4 – 5) MPa; 2 – $\sigma_y = \gamma H \approx$ -25 MPa ($K_y \approx 1.0$); 3 – σ_y = -(31-34) MPa (K_y = 1.24-1.36); 4 – σ_y = -(40-48) MPa (K_y = 1.60-1.92); 5 – σ_y = -(50-65) MPa (K_y = 2.0-2.6)

Regarding the changes in the curve σ_y within the mine working cross-section plane, a general drop in the level of compressive stress concentrations should be noted.

The analysis of the curves σ_y proves significant influence of the number n of pre-drilled wells (Fig. 8a); here, the general tendency is noted for decreasing concentration σ_y propagation when the number n of wells increases from 3 to 5:

– at K_y = 1.24-1.36, the propagation of σ_y reduces by 29% in the roof, by 62-104% – in the sides and by 43% – in the bottom;

– at K_y = 1.60-1.92 by 86% – in the roof, by 61-129% – in the sides and by 88% – in the bottom;

– concentration of the K_y = 2.0-2.6 level has not been observed in both options;

– the highest tensile stresses σ_y have also reduced their propagation in the bottom by 80%.

In the middle of the mine working contour there is an expansion of the zone of acting low concentrations of K_y = 1.24-1.36 by 130%.

Thus, two groups of differences in vertical stress σ_y distribution curves have been revealed: the tendency to expand the zone of acting concentrations K_y of different levels from 15-20% to 40-50% for in-seam working compared to field working; the tendency to decrease the zone of acting concentration K_y by 60-120% when the number n of pre-drilled wells increases from 3 to 5.

In terms of the geomechanical processes acting around mine workings, the indicated tendencies are explained as follows. Firstly, the location of the coal seam within the adjacent rock mass causes a more intense deformation of the roof and bottom rocks in the coal seam due to its lower deformation characteristics. This contributes to the development of deformations (roof and bottom) to areas of the adjacent mass more distant from the face. Secondly, the increase in the number of pre-drilled wells contributes to a more yielding mode of the coal seam resistivity, which prevents the occurrence of high stress concentrations.

The formulated conclusions and explanations are confirmed by the analysis of vertical stress propagation curves σ_y in the longitudinal direction of the mine working route (Fig. 9).

(a)

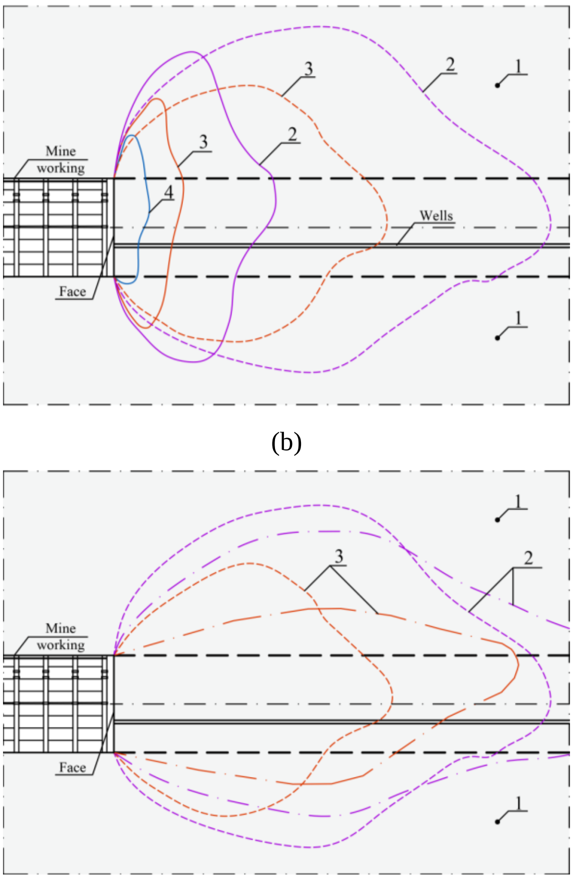


Figure 9. Vertical stress isolines σ_y in the longitudinal section of mine workings: (a) comparison of the field (——) and in-seam (— —) workings at n = 3; (b) comparison of the influence of the number n of wells relative to in-seam working: — — n = 3, – · – n = 5; 1 – $\sigma_y = \gamma H$ = -25 MPa (K_y = 1.0); 2 – σ_y = -(31-34) MPa (K_y = 1.24-1.36); 3 – σ_y = -(40-48) MPa (K_y = 1.60-1.92); 4 – σ_y =-(50-65) MPa (K_y = 2.0-2.6)

A comparison of the distribution curves $\sigma_y(z)$ relative to field and in-seam workings indicates the presence of two tendencies (Fig. 9a). Firstly, relatively lower concentrations of K_y propagate along the coordinate z much deeper along the in-seam working route: K_y = 1.24-1.36 – by 2.68 times; K_y = 1.60-1.92 – by 3.82 times. Secondly, there are no increased concentrations of K_y for in-seam working; for example, a concentration of K_y = 2.0-2.6 is completely absent. The explanation for this fact, which has been known for a long time, is as follows: a less hard coal seam (as compared to sandstone or siltstone) has the property of moving rock pressure concentrations from the face deeper into the mass, as already mentioned earlier.

A comparison of the tendency of the influence of the number n of pre-drilled wells (Fig. 9b) has also already been provided and is fully consistent with the classical principles of rock mechanics. As the number of pre-drilled wells increases, the coal seam becomes more yielding: concentrations of K_y flatten, become lower in value (resulting in lower propagation distances from the mine working contour), but act over a more extended section of the mine working route. For example, when comparing options n = 3 and n = 5, the propagation length increases K_y = 1.24-1.36 by 21%, and K_y = 1.60-1.92 – by 44%. The revealed tendencies, in our opinion, should be taken into account when substantiating the parameters for drilling pre-drilled wells for effective de-stressing of the rock mass bottom-hole zone, which in a certain way limits the probabi-lity of the GDP manifestations.

5.3. Horizontal stress field differences

The SSS analysis proves a significant difference in the horizontal stress distribution curves σ_x (Fig. 10) in in-seam working compared to field working, as well as the influence of the number n of pre-drilled wells on the change in the distribution parameters σ_x in the mine working cross-section. General tendencies of influence of these factors have a certain similarity with the vertical stress curves σ_y, but some differences have also been noted.

(a) (b)

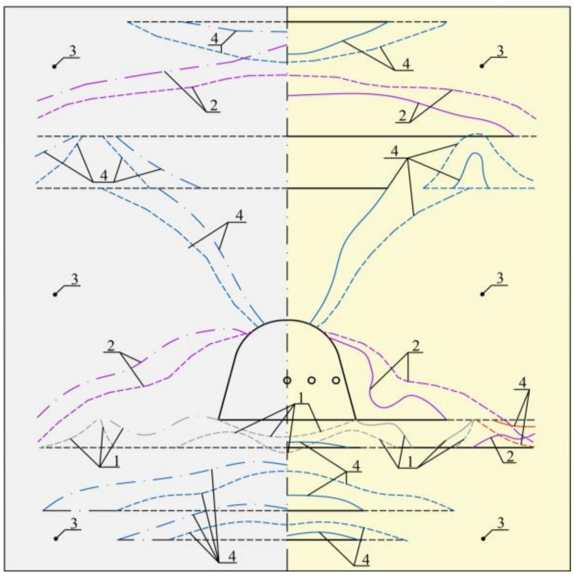


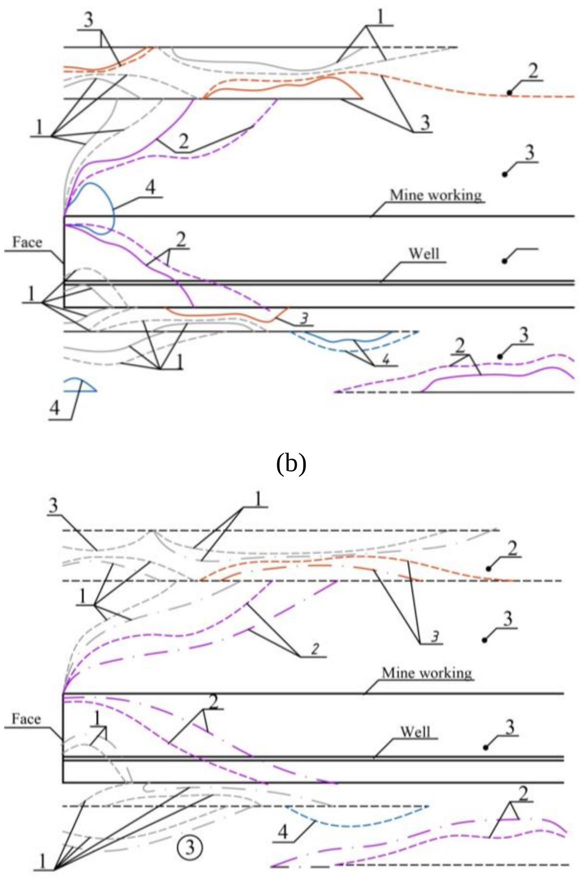
Figure 10. Horizontal stress isolines σ_x in the cross-section of mine workings: (a) comparison of the influence of the number n of wells relative to in-seam working: — — n = 3, – · – n = 5; (b) comparison of the field (——) and in-seam (— —) workings at n = 3; 1 – σ_x = +(3-5) MPa; 2 – $\sigma_x \approx 0$ MPa ($K_x \approx 0$); 3 – $\sigma_x \approx \lambda\gamma H$ = -(9-12) MPa ($K_x \approx 1.0$); 4 – σ_x = -(19-30) MPa (K_x = 1.8-2.8)

The similarity of tendencies is in the fact that for in-seam working, the penetration zones of isolines σ_x predominantly increase, reflecting both lower and higher values. For example (Fig. 10b), de-stressing zones with an almost zero value of σ_x expand to 20-50% in the roof, to 40-90% in the mine working sides; compressive stress σ_x concentrations of K_x = 1.8-2.8 level will also increase their propagation up to 50-70% in the roof, up to 40-70% – in the sides and up to 40-120% – in the mine working bottom. This, in our opinion, is due to a significant decrease in deformation properties of coal and an increase in the bending deformations of the seam roof and bottom rocks, at which zones of de-stressing and compressive stress concentrations extend to more distant adjacent mass areas. Similar tendencies have been observed for the influence of the number *n* of de-stressing wells during the in-seam working construction (Fig. 10a), but they act mainly in de-stressing zones.

For example, isolines of $K_x \approx 0$ expand (with an increase of *n* from 3 to 5) to 40-50% in the roof and to 30-50% in the mine working sides. Opposite tendencies in limiting the propagation zones are observed for isolines of compressive stress concentrations σ_x. For example, for K_x = 1.8-2.8, there is a reduction in propagation zones (with an increase of *n* from 3 to 5) to 50-80% in the roof, to 33-70% in the sides, while in the mine working bottom, on the contrary, there is an expansion of the isoline propagation zones K_x = 1.8-2.8 up to 40-90%.

Horizontal stresses σ_z have the following tendencies of change in the direction of the longitudinal axis of the mine working along the coordinate *z* (Fig. 11).

(a)



(b)

Figure 11. *Horizontal stress isolines σ_z in the longitudinal section of mine workings: (a) comparison of the field (——) and in-seam (— —) workings at n = 3; (b) comparison of the influence of the number n of wells relative to in-seam working: — — n = 3,– · – n = 5; 1 – σ_z = -(1-2) MPa (K_z = 0.09-0.19); 2 – σ_z = -(7-9) MPa (K_z = 0.65-0.84); 3 – σ_z = -(13-17) MPa (K_z = 1.21-1.59); 4 – σ_z = -(20-28) MPa (K_z = 1.87-2.62)*

A consistent tendency of a general nature has been revealed, consisting in the expansion of the zones of acting both lower and higher compressive stresses σ_z (Fig. 11a). For example, zones of almost complete de-stressing (K_z = 0.09-0.19) expand for in-seam working (compared to field working) by 50-80% in the roof, by 40-60% in the sides and by 35-45% in the mine working bottom. The concentration of K_z = 1.21-1.59 level propagate more (up to 20-60%) in the roof in the zone closest to the face, and at a distance of over 16-17 m, a relatively uniform field σ_z with a small compressive stress concentration is set. The same is observed in the sides and bottom of the mine working. But, if in the sides an almost uniform field σ_z is set at a distance of more than 7-8 m from the tunneling face, then in the seam bottom there are still small disturbances at a distance of up to 20-22 m: these are the zones of de-stressing (K_z = 0.65-0.84) and compressive stress concentration (K_z = 1.87-2.62) – both of them have a tendency to increase in size for in-seam working compared to field working. It is also worth noting the disappearance of increased concentration zones K_z = 1.87-2.62 in local bottom-hole areas near the mine working contour. The latter is possible if the lithotypes are not hard enough inside the mine working contour (for example, a coal seam). Then, according to the canons of bearing pressure formation near any face, a less hard lithotype favours the reduction of stress concentrations. At the same time, the reduced stress values extend to the areas of the mine working route that are more distant from the tunneling face.

Mostly similar tendencies are observed when analyzing the influence of the number *n* of de-stressing wells on the horizontal stress field σ_z in the rock mass surrounding the in-seam working (Fig. 11b). The overall expansion (at *n* = 5) of de-stressing zones is 20-60%, while the concentration zones σ_z of the K_z = 1.21-1.59 level either disappear altogether or decrease to 30%. That is, the influence of the number *n* of de-stressing wells on the curves σ_z is somewhat similar to changes in the curve σ_x and can also be substantiated by a decrease in the coal seam hardness when the number of wells increases.

5.4. Horizontal stress field differences

The field σ differences are shown on the isolines of Figure 12. The influence of the type of mine working (field or in-seam) has tendencies that are similar to other SSS components (Fig. 12b) – regardless of the level of acting stresses σ, there is a widespread expansion of their propagation zones for in-seam working. For example, for a concentration of K_σ = 2.0-3.0, the height of propagation into the roof increases to 30%, in the sides the zones expand to 40%, and in the bottom they deepen to 35%; a more significant concentration σ of the K_σ = 3.5-4.5 level has the following expansion of the zone of action: up to 70% in the roof, up to 35% in the sides and up to 30% in the bottom of the mine working. The de-stressing zone σ of the K_σ = 0.42-0.56 level also deepens into the bottom to 60%. The given examples indicate the consistent tendency, and the explanation for this fact has already been given earlier – the reduced coal seam hardness compared to other lithotypes.

An increased number *n* of de-stressing pre-drilled wells also favours the reduction of the coal seam hardness, but previous tendencies were recorded only in the mine working bottom (Fig. 12a), where the zone of acting K_σ = 0.42-0.56 deepened to 80%. Other concentrations σ have the opposite change tendencies.

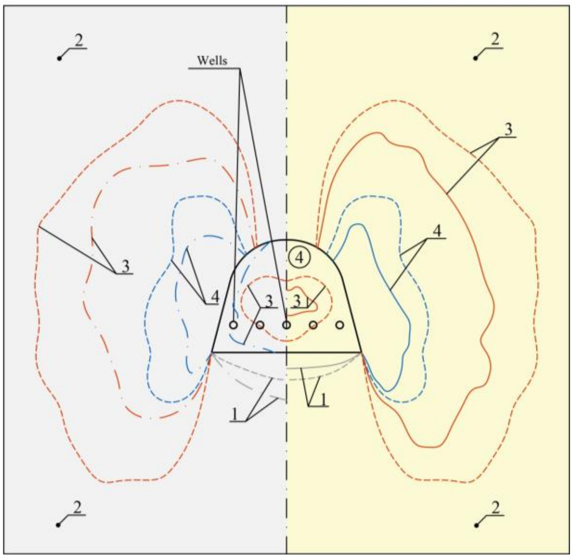


Figure 12. Horizontal stress isolines σ in the cross-section of mine workings: (a) comparison of the influence of the number n of wells relative to in-seam working: — — n = 3, – · – n = 5; (b) comparison of the field (——) and in-seam (— —) workings at n = 3; 1 – σ = 6-8 MPa (Kσ = 0.42-0.56); 2 – σ = 13-16 MPa (Kσ ≈ 1.0); 3 – σ = 30-45 MPa (Kσ = 2.0-3.0); 4 – σ = 50-65 MPa (Kσ = 3.5-4.5)

For example, for K_σ = 2.0-3.0 there is a reduction in propagation of up to 85% in the roof, up to 30% in the sides and up to 50% in the bottom. With concentration of K_σ = 3.5-4.5, a similar tendency occurs – almost eliminating the propagation into the mine working roof and reducing the zone of action to 60% in the sides and up to 70% in the bottom. The reason for such a phenomenon we see in the predominant action of mass de-stressing processes over stress concentration formation processes relative to the free deformation of the rocks in the roof and bottom of the coal seam of reduced hardness.

Many aspects given above are confirmed when considering changes in the stress intensity propagation in the longitudinal mine working direction (Fig. 13). Thus, the stress intensity σ concentration propagation along the mine working route deep into the mass is noted for in-seam working in comparison with field working.

For example, the propagation of K_σ = 2.0-3.0 concentrations increases by 50 –80%, and of K_σ = 3.5-4.5 concentrations – up to 75%. It is also worth noting the displacement along the mine working route of the maximum distances of the concentration σ propagation into its roof and bottom. While for the harder lithotypes (field working) these coordinates are z = 1.9-3.4 m for different K_σ levels, then for in-seam working they have increased to 4.7-7.0 m (Fig. 13a).

The increased n reduces the already small coal seam hardness, and here the pattern of growth in the propagation coordinates z of stress intensity concentrations σ is completely preserved (Fig. 13b): by 12% for K_σ = 2.0-3.0 and by 49% for K_σ = 3.5-4.5. Also, the coordinate z of the maximum propagation into the roof and bottom of the corresponding concentrations σ moves slightly (by 17-33%) deeper into the mine working route, but the maximum propagation distances decrease when the number n of de-stressing wells increases. Thus, at a certain stage of reduction of the coal seam hardness, the opposite tendency is observed – a decrease in the propagation distances of the stress intensity concentrations σ.

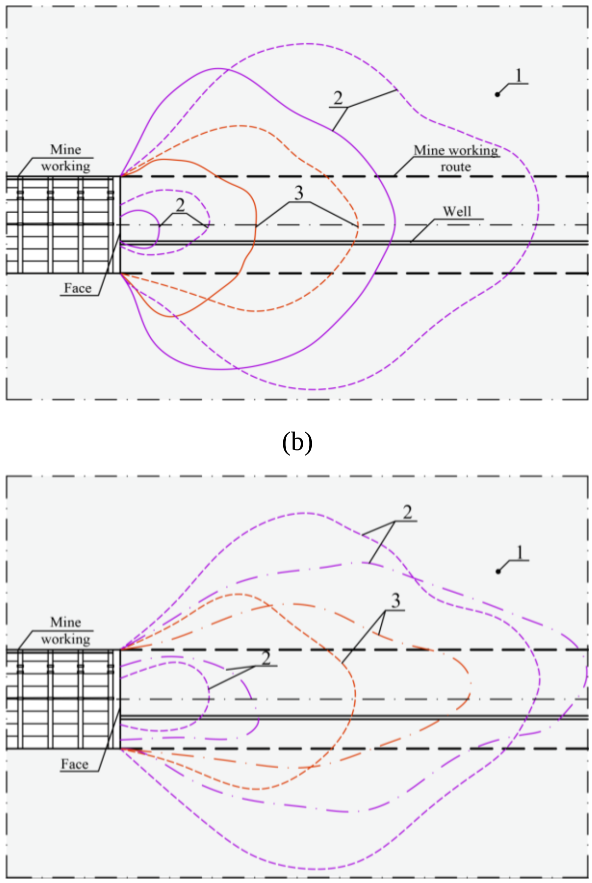


Figure 13. Stress intensity isolines σ in the longitudinal section of mine workings: (a) comparison of the field (——) and in-seam (— —) workings at n = 3; (b) comparison of the influence of the number n of wells relative to in-seam working: — — n = 3; – · – n = 5; 1 – σ = 13-16 MPa (Kσ ≈ 1.0); 2 – σ =30-45 MPa (Kσ = 2.0-3.0); 3 – σ = 50-65 MPa (Kσ = 3.5 – 4.5)

Our explanation for the set result is as follows. Obviously, there are two opposite patterns in the formation of the parameters for SSS disturbances in the rock mass around the tunneling face: the first well-known one is the propagation of stress concentrations with a decrease in the coal seam hardness; the second – under certain conditions, the continued decrease in the coal seam hardness entails a general decrease in stress concentrations due to the acting factor of the occurrence of a supposedly damping interlayer in the adjacent mass texture. Therefore, the tendency of the influence of the coal seam hardness is directed depending on which pattern "prevails".

Determining the propagation patterns for the rock mass SSS disturbances near the tunneling face is embodied in their use for the creation of a calculation method and recommendations for the selection of rational parameters for the location of de-stressing pre-drilled wells. As a result of implementation, two purposes have been achieved: firstly, substantiation of the effectiveness of the use of tunnelling machines to conduct mine workings in partially weakened (due to the use of rock pressure anomalies) rock mass; secondly, the reduced probability of the GDP occurrence during the construction of mine workings is also conditioned by the controlled rock mass weakening.

6. Conclusions

1. General provisions for objective coordination of the experimental-analytical research results have been substantiated. It has been methodically proven that the indirect experimental indicators of the rock mass state around the tunneling face have a certain connection with the distribution peculiarities of its SSS components, and a large volume of measurements and a sufficient number of indirect indicators make it possible to conduct an objective assessment of the degree of adequacy and reliability of the FEM modeling results.

2. A large amount of information made it possible to determine the tendencies in changes (in the process of drilling) of gas release, coal dust yield and periodic "clamping" of drilling tools; according to their analysis, the well length of up to 10-15 m is recommended for efficient and safe de-stressing of the rock mass surrounding the tunneling face; this length of wells is entirely consistent with the length of propagation of rock pressure disturbances along the mine working route.

3. Based on the current normative documents, the recorded parameters of the seismic-acoustic signal and the initial gas release rate have been studied.

4. It is most expedient to drill de-stressing pre-drilled wells up to 12-15 m long, in which the bottom-hole rocks have partially reduced stress and freer gas drainage, thus reducing the corresponding probability of the GDP occurrence.

5. The parameters of the new geomechanical model have been substantiated, taking into account the actual conditions of drilling pre-drilled wells and the adjacent mass texture. The implementation of this task allows an objective and adequate approach to the analysis of the peculiarities of bottom-hole mass behavior around field and in-seam workings. This, on the one hand, ensures the expansion of the research object in terms of mechanical conditions and, on the other hand, the validity of comparison between analytical and experimental studies.

6. Comparative analysis of stress component propagation patterns in field and in-seam workings has revealed the following consistent tendencies of change.

Four main tendencies have been identified with respect to vertical stresses σ_y:

– pattern of expansion of concentration K_y zones of different levels (from 15-20% to 40-50%) for in-seam working compared to field working;

– the tendency to reduce by 60-120% the zones of action of any K_y concentrations when the number of wells increases from 3 to 5;

– the disappearance of concentration $K_y = 2.0$-2.6 of the maximum level;

– expansion of propagation along the route of mine workings of reduced concentrations ($K_y \leq 1.92$) up to 2.7-3.8 times.

Horizontal stresses σ_x and σ_z have similar tendencies of predominant expansion of the zones of acting disturbances (up to 20-90%) for in-seam working compared to field working. The influence of the number of de-stressing pre-drilled wells has ambiguous tendencies to expand the zone of acting de-stressing and reduction of the zone of acting compressive stress concentration. This is also explained by the reduced coal seam hardness as a lithotype, as such, and under the condition of an increase in wells that simultaneously perform de-stressing functions.

Stress intensity σ concentrations have a significant dependence of their propagation on the degree of hardness of the lithotypes that constitute the rock mass surrounding the tunneling face. The propagation into the roof, sides, bottom and along the mine working route can vary in the range of 30-80% depending on the type of mine working (field or in-seam) and the number of de-stressing pre-drilled wells in the coal seam.

7. Significant dependence of propagation parameters for SSS component concentrations on the degree of hardness of the lithotypes constituting the rock mass surrounding the tunneling face has been identified. A geomechanical explanation is given for two tendencies in changes in the propagation distances of rock pressure anomalies, which are fully consistent with existing ideas about the formation of SSS disturbances near tunneling or stoping faces. The importance of new knowledge is in its use to create a calculation method and recommendations for choosing rational parameters for the location of de-stressing pre-drilled wells, pursuing two goals simultaneously: partial weakening of the rock mass surrounding the tunneling face to exclude hazardous drill-and-blast method of mine working construction in conditions of gas-dynamic activity of the host rocks; reducing the probability of the GDP occurrence through controlled weakening of adjacent rocks, thus reducing their degree of tension.

Author contributions

Conceptualization: VB; Data curation: IK; Formal analysis: IK; Funding acquisition: VB; Investigation: VK, VC, OH, RS, IV; Methodology: VB, IK; Project administration: VB, IK; Resources: OH, RS; Software: VK, VC, IV; Supervision: VB, OH; Validation: VK, VC, OH; Visualization: RS, IV; Writing – original draft: RS, IV; Writing – review & editing: VK, VC. All authors have read and agreed to the published version of the manuscript.

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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.

References

[1] Sobolev, V.V., Chernay, A.V., Zberovskiy, V.V., Polyashov, A.S., & Fillipov, A.O. (2014). *Fizicheskaya mekhanika vybrosoopasnykh ugley*. Zaporizhzhia, Ukraina: Pryvoz Prynt, 304 s.

[2] Black, D.J. (2019). Review of coal and gas outburst in Australian underground coal mines. *International Journal of Mining Science and Technology*, *29*(6), 815-824. https://doi.org/10.1016/j.ijmst.2019.01.007

[3] Keneti, A., & Sainsbury, B.A. (2018). Review of published rockburst events and their contributing factors. *Engineering Geology*, *246*, 361-373. https://doi.org/10.1016/j.enggeo.2018.10.005

[4] Ptáček, J. (2017). Rockburst in Ostrava-Karvina coalfield. *Procedia Engineering*, *191*, 1144-1151. https://doi.org/10.1016/j.proeng.2017.05.289

[5] Bondarenko, V., Salieiev, I., Kovalevska, I., Chervatiuk, V., Malashkevych, D., Shyshov, M., & Chernyak, V. (2023). A new concept for complex mining of mineral raw material resources from DTEK coal mines based on sustainable development and ESG strategy. *Mining of Mineral Deposits*, *17*(1), 1-16. https://doi.org/10.33271/mining17.01.001

[6] Simser, B.P. (2019). Rockburst management in Canadian hard rock mines. *Journal of Rock Mechanics and Geotechnical Engineering*, *11*(5), 1036-1043. https://doi.org/10.1016/j.jrmge.2019.07.005

[7] Fernandez-Diaz, J.J., Gonzalez-Nicieza, C., Alvarez-Fernandez, M.I., & Lopez-Gayarre, F. (2013). Analysis of gas-dynamic phenomenon in underground coal mines in the central basin of Asturias (Spain). *Engineering Failure Analysis*, *34*, 464-477. https://doi.org/10.1016/j.engfailanal.2013.07.027

[8] Wasilewski, S. (2020). Gas-dynamic phenomena caused by rock mass tremors and rock bursts. *International Journal of Mining Science and Technology*, *30*(3), 413-420. https://doi.org/10.1016/j.ijmst.2020.03.012

[9] Dubinski, J., Stec, K., & Bukowska, M. (2019). Geomechanical and tectonophysical conditions of mining-induced seismicity in the Upper Silesian Coal Basin in Poland: A case study. *Archives of Mining Sciences*, *64*(1), 163-180. https://doi.org/10.24425/ams.2019.126278

[10] Zhulay, Y., Zberovskiy, V., Angelovskiy, A., & Chugunkov, I. (2012). Hydrodynamic cavitation in energy-saving technological processes of mining sector. *Geomechanical Processes During Underground Mining – Proceedings of the School of Underground Mining*, 61-65. https://doi.org/10.1201/b13157-11

[11] Ahaiev, R., Prytula, D., Kliuiev, E., Cabana, E., & Kabakova, L. (2020). The determination of the influence degree of mining-geological and mining-technical factors on the safety of the degassing system. *E3S Web of Conferences*, *168*, 00040 https://doi.org/10.1051/e3sconf/202016800040

[12] Bondarenko, V.I., & Sai, K.S. (2018). Process pattern of heterogeneous gas hydrate deposits dissociation. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, *2*, 21-28. https://doi.org/10.29202/nvngu/2018-2/4

[13] Kovalevska, I., Symanovych, G., & Fomychov, V. (2013). Research of stress-strain state of cracked coal-containing massif near-the-working area using finite elements technique. *Annual Scientific-Technical Collection – Mining of Mineral Deposits 2013*, 159-163. https://doi.org/10.1201/b16354-27

[14] Griadushchiy, Y., Korz, P., Koval, O., Bondarenko, V., & Dychkovskiy, R. (2007). Advanced experience and direction of mining of thin coal seams in Ukraine. *Technical, Technological and Economical Aspects of Thin-Seams Coal Mining, International Mining Forum, 2007*, 2-7. https://doi.org/10.1201/noe0415436700.ch1

[15] Zhang, W., Ma, N., Ma, J., Li, C., & Ren, J. (2020). Mechanism of rock burst revealed by numerical simulation and energy calculation. *Shock and Vibration*, 1-15. https://doi.org/10.1155/2020/8862849

[16] Ratov, B.T., Fedorov, B.V., Syzdykov, A.Kh., Zakenov, S.T., & Sudakov, A.K. (2021). The main directions of modernization of rock-destroying tools for drilling solid mineral resources. *21st International Multidisciplinary Scientific GeoConference SGEM 2021. Section Exploration & Mining*, 503-514. https://doi.org/10.5593/sgem2021/1.1/s03.062

[17] Zhang, W., Mu, C., Xu, D., & Li, Z. (2021). Energy action mechanism of coal and gas outburst induced by rockburst. *Shock and Vibration*, 1-14. https://doi.org/10.1155/2021/5553914

[18] Bondarenko, V., Salieiev, I., Symanovych, H., Kovalevska I., & Shyshov, M. (2023). 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. *Inżynieria Mineralna*, *1*(51), 23-32. https://doi.org/10.29227/IM-2023-01-03

[19] Bondarenko, V., Cherniak, V., Cawood, F., & Chervatiuk, V. (2017). Technological safety of sustainable development of coal enterprises. *Mining of Mineral Deposits*, *11*(2), 1-11. https://doi.org/10.15407/mining11.02.001

[20] Pivnyak, G., Bondarenko, V., Kovalevs'ka, I., & Illiashov, M. (2013). *Mining of mineral deposits*. London, United Kingdom: CRC Press, Taylor & Francis Group, 372 p. https://doi.org/ 10.1201/b16354

[21] Simanovich, G., Serdiuk, V., Fomichov, I.A., & Bondarenko, V. (2007). Research of rock stresses and deformations around mining workings. *Technical, Technological and Economical Aspects of Thin-Seams Coal Mining*, 47-56. https://doi.org/10.1201/noe0415436700.ch6

[22] Pivnyak, G., Bondarenko, V., Kovalevs'ka, I., & Illiashov, M. (2012). *Geomechanical processes during underground mining*. London, United Kingdom: CRC Press, Taylor & Francis Group, Book. 238 p. https://doi.org/10.1201/b13157

[23] Saranchuk, V.I., Ayruni, A.T., & Kovalyov, K.Ye. (1988). *Nadmolekulyarnaya organizatsiya, struktura i svoystva uglya*. Kyiv, Ukraina: Naukova dumka, 190 s.

[24] Alekseev, A.D., & Surgay, N.S. (1994). *Prognoz i upravlenie sostoyaniem gornogo massiva*. Kyiv, Ukraina: Naukova dumka, 200 s.

[25] Mineev, S.P., Prusova, A.A., & Kornilov, M.G. (2007). *Aktivatsiya desorbtsii metana v ugol'nykh plastakh*. Dnipropetrovsk, Ukraina: Veber, 252 s.

[26] Voloshin, N.Ye. (1985). *Vnezapnye vybrosy i sposoby bor'by s nimi v ugol'nykh shakhtakh*. Kyiv, Ukraina: Tekhnika, 127 s.

[27] Nikolin, V.I., Lysikov, B.A., & Tkach, V.Ya. (1972). *Prognoz vybrosoopasnosti ugol'nykh plastov*. Donetsk, Ukraina: Donbas, 126 s.

[28] Stepanovich, G.Ya., Nikolin, V.I., & Lysikov, B.A. (1970). *Gazodinamicheskie yavleniya pri podgotovke glubokikh gorizontov*. Donetsk, Ukraina: Donbas, 110 s.

[29] Nikolin, V.I., Lysikov, B.A., & Yarembash, I.F. (1968). *Vybrosoopasnye porody bol'shikh glubin*. Donetsk, Ukraina: Donbas, 80 s.

[30] Zborshchik, M.I., Osokin, V.V., & Sokolov, N.M. (1984). *Predotvrashchenie gazodinamicheskikh yavleniy v ugol'nykh shakhtakh*. Kyiv, Ukraina: Tekhnika, 148 s.

[31] Kolesov, O.A., Nikolin, V.I., Stepanovich, G.Ya., & Tkach, V.Ya. (1971). Regional'nyy prognoz vybrosoopasnosti ugol'nykh plastov Donetskogo basseyna. *Ugol' Ukrainy*, *5*, 42-44.

[32] Zorin, A.N., Dolinina, N.N., & Kolesnikov, V.G. (1981). *Mekhanika upravleniya geterogennym uprugo-nasledstvennym gornym massivom*. Kyiv, Ukraina: Naukova dumka, 284 s.

[33] Zabigaylo, V.Ye., & Nikolin, V.I. (1990). *Vliyanie katageneza gornykh porod i metamorfizma ugley na ikh vybrosoopasnost'*. Kyiv, Ukraina: Naukova dumka, 168 s.

[34] Ol'khovichenko, A.Ye., & Sirota, O.Ts. (1969). K voprosu vliyaniya ostatochnykh tektonicheskikh napryazheniy na vozniknovenie vnezapnykh vybrosov uglya i gaza. *Voprosy Inzhenernoy Geologii pri Proektirovanii Stroitel'stva i Ekspluatatsii Podzemnykh Sooruzheniy*, *1*, 64-68.

[35] Ahaiev, R., Prytula, D., Kliuiev, E., Cabana, E.,& Kabakova, L. (2020). The determination of the influence degree of mining-geological and mining-technical factors on the safety of the degassing system. *E3S Web of Conferences*, *168*, 00040. https://doi.org/10.1051/e3sconf/202016800040

[36] NPAOP 10.0-1.01-10. (2015). *Pravyla bezpeky u vuhilnykh shakhtakh*. Kharkiv, Ukraine: Fort, 248 s.

[37] SOU-P 10.1.00174088.011:2005. (2005). *Pravyla vedennia hirnychykh robit na plastakh, skhylnykh do hazodynamichnykh iavyshch*. Kyiv, Ukraina: Minvuhleprom Ukrainy.

[38] SOU-P 05.1.00174088.033:2012. (2013). *Prognoz i predotvrashchenie vybrosov peschanikov na glubokikh shakhtakh*. Kyiv, Ukraina: Minenerhovuhillia Ukrainy.

[39] SOU-P 10.1.00174088.017:2009. (2009). *Pravila peresecheniya gornymi vyrabotkami zon geologicheskikh narusheniy na plastakh, sklonnykh k vnezapnym vybrosam uglya i gaza*. Kyiv, Ukraina: Minvuhleprom Ukrainy.

[40] SOU-P 10.1.00174088.029:2011. (2011). *Pravila otneseniya ugol'nykh plastov k kategoriyam vybrosoopasnosti.* Kyiv, Ukraina: Minenerhovuhillia Ukrainy.

[41] SOU-P 10.1.00174088.031:2011. (2011). *Kontrol' za provedeniem meropriyatiy i tekhnologicheskikh protsessov po parametram akusticheskogo signala pri raskrytii sklonnykh k GDYa ugol'nykh plastov*. Kyiv, Ukraina: Minenerhovuhillia Ukrainy.

[42] Minieiev, S., Vasyliev, L., Trokhymets, M., Maltseva, V., Vialushkin, Y., & Moskalova, T. (2022). Heading set of equipment for underground development galleries drivage in rocks prone to gas-dynamic phenomena. *IOP Conference Series: Earth and Environmental Science*, *970*(1), 012044. https://doi.org/10.1088/1755-1315/970/1/012044

[43] Mineev, S.P., Rubinskiy, A.A., Vitushko, O.V., & Radchenko, A.V. (2010). *Gornye raboty v slozhnykh usloviyakh na vybrosoopasnykh ugol'nykh plastakh*. Donetsk, Ukraina: Skhidnyi vydavnychyi dim, 604 s.

[44] Koptikov, V.P., Bokiy, B.V., Mineev, S.P., Yuzhanin, I.A., & Nikiforov, A.V. (2016). *Sovershenstvovanie sposobov i sredstv bezopasnoy razrabotki ugol'nykh plastov, sklonnykh k gazodinamicheskim yavleniyam*. Donetsk, Ukraina: Promin, 480 s.

[45] Mineev, S.P., & Rubinskiy, A.A. (2007). *Provedenie vyrabotok prokhodcheskimi kombaynami po vybrosoopasnym ugol'nym plastam i porodam*. Dnipropetrovsk, Ukraina: Dnipro, 384 s.

[46] Mineev, S.P., Il'yushenko, A.V., & Vostretsov, N.A. (2018). *Vskrytie vybrosoopasnykh ugol'nykh plastov prokhodcheskimi kombaynami*. Dnipro-Kyiv, Ukraina: Khalikov R.Kh., 136 s.

[47] Mineev, S., Filatieva, E., Oleinichenko, A., & Toderas, M. (2021). On the relationship between gas emission from undermined coal-bearing stratum and the intensity of coal seam mining. *E3S Web of Conferences*, *280*, 08017. https://doi.org/10.1051/e3sconf/202128008017

[48] Mineev, S.P., Prusova, A.A, & Kornilov, M.G. (2007). *Aktivatsiya desorbtsii metana v ugol'nykh plastakh*. Dnipropetrovsk, Ukraina: Veber, 252 s.

[49] Zhou, A., Hu, J., Wang, K., & Du, C. (2023). Analysis of fault orientation and gas migration characteristics in front of coal mining face: Implications for coal-gas outbursts. *Process Safety and Environmental Protection*, *177*, 232-245. https://doi.org/10.1016/j.psep.2023.07.011

[50] Mineev, S.P., Potapenko, A.A. Mkhatvari, T.Ya., Nikiforov, A.V., Kuzyara, S.V., & Timofeev, E.I. (2013). *Povyshenie effektivnosti gidrorykhleniya vybrosoopasnykh ugol'nykh plastov*. Donetsk, Ukraine: Skhidnyi vydavnychyi dim, 216 s.

[51] Minieiev, S.P., & Kostrytsia, O.O. (2021). Issues of adjustment of normative documents on safe carrying out of workings by the tunneling combine on outburst-hazardous sandstone or near it at mines of Ukraine. *Journal of Donetsk National Technical University*, *1*(6)-*2*(7), 111-122. https://doi.org/10.31474/2415-7902-2021-1(6)-2(7)-111-122

[52] Trokhymets, M.Ya., Maltseva, V.Ye., & Vialushkin, Ye.O. (2020). *Sposib provedennia pidhotovchoi vyrobky po hazonosnomu vykydonebezpechnomu vuhilnomu plastu prokhidnytskym kombainom*. Patent No. 122179, Ukraina.

[53] Minieiev, S.P., Iliushchenko, A.V., & Vostretsov, M.O. (2020). *Sposib provedennia vyrobok kombainom u vykydonebezpechnykh plastakh vuhillia ta hirskykh porid*. Patent No. 140378, Ukraina.

[54] Bulat, A.F., Mineev, S.P., & Prusova, A.A. (2016). Generating methane adsorption under relaxation of molecular structure of coal. *Journal of Mining Science*, *52*, 70-77. https://doi.org/10.1134/S1062739116010149

[55] Baysarov, L.V., Il'yashov, M.A., & Demchenko, A.I. (2005). *Geomekhanika i tekhnologiya podderzhaniya povtorno ispol'zuemykh gornykh vyrabotok*. Dnipropetrovsk, Ukraine: Lira LTD, 240 s.

[56] Klymenko, D.V. (2018). *Zakonomirnosti proiaviv i seismoakustychnyi prohnoz hazodynamichnykh iavyshch pry vidpratsiuvanni vuhilnykh plastiv*. PhD Thesis. Dnipro, Ukraine: NTU "DP".

[57] NPAOP 10.0-5.28-87. (1987). *Instruktsiya po prognozu i podderzhaniyu vnezapnykh proryvov metana iz pochvy gornykh vyrabotok*. Kyiv, Ukraine: Minvuhleprom URSR.

[58] Agafonov, A.V. (1998). *Sposoby i sredstva obespecheniya bezopasnosti provedeniya podgotovitel'nykh vyrabotok po vybrosoopasnym plastam*. Donetsk, Ukraine: Donbas, 235 s.

[59] Yanzhula, O.S. (2020). *Obhruntuvannia parametriv vedennia ochysnykh robit poblyzu heolohichnykh porushen, skhylnykh do raptovykh vydilen metanu*. PhD Thesis. Dnipro, Ukraine: IHTM NAN Ukrainy.

[60] Poturaev, V.N., Zorin, A.N., & Zabigaylo, V.N. (1986). *Prognoz i predotvrashchenie vybrosov porod i gaza*. Kyiv, Ukraine: Naukova dumka, 160 s.

[61] Vasilkovskyi, V., Minieiev, S., & Kaluhina, N. (2019). Bonding energy and methane amount at the open surface of metamorphic coal. *E3S Web of Conferences*, *109*, 00108. https://doi.org/10.1051/e3sconf/201910900108

[62] Baranov, V.A. (2000). *Strukturnye preobrazovaniya peschanikov Donbassa i prognoz ikh vybrosoopasnosti*. PhD Thesis. Dnipropetrovsk, Ukraine: IHTM NAN Ukrainy.

[63] Bezruchko, K.A. (2015). Opyt primeneniya metoda lokal'nogo prognoza vybrosoopasnosti peschanikov na shakhtakh Donbassa. *Ugol' Ukrainy*, *12*, 42-44.

[64] Zorin, A.N., Kolesnikov, V.G., Mineev, S.P., Prusova, A.A., & Kovtun, Ye.D. (1986). *Upravlenie sostoyaniem gornogo massiva*. Kyiv, Ukraine: Naukova dumka, 212 s.

[65] Korol', V.I., & Skobenko, A.V. (2013). *Akusticheskiy sposob prognoza gazodinamicheskikh yavleniy v ugol'nykh shakhtakh*. Dnipropetrovsk, Ukraine: NHU, 182 s.

[66] *Rukovodstvo po primeneniyu na shakhtakh Donbassa akusticheskikh sposobov kontrolya sostoyaniya prizaboynoy chasti vybrosoopasnogo plasta*. (1996). Makiivka, Ukraina: MakNDI.

[67] Bondarenko V., Kovalevska, I. Symanovych, G., Sotskov, V., & Barabash, M. (2018). Geomechanics of interference between the operation modes of mine working support elements at their loading. *Mining Science*, *25*, 219-235. https://doi.org/10.5277/msc182515

[68] Vinogradov, V.V. (1989). *Geomekhanika upravleniya sostoyaniem massiva vblizi gornykh vyrabotok*. Kyiv, Ukraine: Naukova dumka, 192 s.

[69] Bondarenko, V., Kovalevska, I., Husiev, O., Snihur, V., & Salieiev, I. (2019). Concept of workings reuse with application of resource-saving bolting systems. *E3S Web of Conferences*, *133*, 02001. https://doi.org/10.1051/e3sconf/201913302001

[70] Bondarenko, V., Kovalevs'ka, I., & Ganushevych, K. (2014). *Progressive technologies of coal, coalbed methane, and ores mining*. London, United Kingdom: CRC Press, Taylor & Francis Group, Book. 523 p. https://doi.org/10.1201/b17547

[71] Sdvizhkova, Ye.A., Babets, D.V., & Smirnov, A.V. (2014). Support loading of assembly chamber in terms of Western Donbas plough longwall. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, *5*, 26-32.

[72] Shashenko, A., Gapieiev, S., & Solodyankin, A. (2009). Numerical simulation of the elastic-plastic state of rock mass around horizontal workings. *Archives of Mining Sciences*, *54*(2), 341-348.

[73] Smoliński, A., Malashkevych, D., Petlovanyi, M., Rysbekov, K., Lozynskyi, V., & Sai, K. (2022). Research into impact of leaving waste rocks in the mined-out space on the geomechanical state of the rock mass surrounding the longwall face. *Energies*, *15*(24), 9522. https://doi.org/10.3390/en15249522

[74] Bondarenko, V., Kovalevska, I., Symanovych, H., Barabash, M., & Snihur, V. (2018). Assessment of parting rock weak zones under the joint and downward mining of coal seams. *E3S Web of Conferences*, *66*, 03001. https://doi.org/10.1051/e3sconf/20186603001

[75] Kovalevs'ka, I., Fomychov, V., Illiashov, M., & Chervatuk, V. (2012). The formation of the finite-element model of the system "undermined massif-support of stope". *Geomechanical Processes During Underground Mining*, 73-80. https://doi.org/10.1201/b13157-13

[76] Pivnyak, G.G., Pilov, P.I., Bondarenko, V.I., Surgai, N.S., & Tulub, S.B. (2005). Development of coal industry: The part of the power strategy in the Ukraine. *Gornyi Zhurnal*, *5*, 14-17.

[77] Bondarenko, V.I., Samusya, V.I., & Smolanov, S.N. (2005). Mobile lifting units for wrecking works in pit shafts. *Gornyi Zhurnal*, *5*, 99-100.

[78] Prykhodko, V., Ulanova, N., Haidai, O., & Klymenko, D. (2018). Mathematical modeling of tight roof periodical falling. *E3S Web of Conferences*, *60*, 00020. https://doi.org/10.1051/e3sconf/20186000020

[79] Chudyk, I.I., Femiak, Ya.M., Orynchak, M.I., Sudakov, A.K., & Riznychuk, A.I. (2021). New methods of preventing crumbling and collapse of the borehole walls. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, *4*, 17-22. https://doi.org/10.33271/nvngu/2021-4/017

[80] Maksymovych, O., Solyar, T., Sudakov, A., Nazar, I., & Polishchuk, M. (2021). Determination of stress concentration near the holes under dynamic loadings. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, *3*, 19-24. https://doi.org/10.33271/nvngu/20213/019

Методичні принципи експериментально-аналітичних досліджень впливу випереджаючих свердловин на інтенсивність проявів газодинамічних явищ

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Мета. Обгрунтування загальних положень щодо узгодження результатів експериментальних та аналітичних досліджень впливу випереджаючих свердловин на інтенсивність проявів газодинамічних явищ (на прикладі гірничо-геологічних умов явищ ШУ "Покровське", Україна.

Методика. При проведенні досліджень застосовувався комплексний метод, який складається з непрямих експериментальних методів досліджень стану прилеглого гірського масиву і тенденцій.

Результати. Доведено, що непрямі експериментальні показники стану гірського масиву навколо прохідницького вибою мають зв'язок з особливостями розподілу компонент його напружено-деформованого стану. На базі цих досліджень встановлено довжину свердловин до 10-15 м для ефективного й безпечного розвантаження гірського масиву. Достовірність експериментальних досліджень доведено проведенням обчислювальних експериментів, за допомогою яких встановлено залежність параметрів розповсюдження концентрацій компонент напружено-деформованого стану від ступеня жорсткості літотипів та надано геомеханічне обгрунтування тенденціям розповсюдження аномалій гірського тиску біля прохідницьких та очисних вибоїв. Отримані нові знання є основою для створення методу розрахунку раціональних параметрів розташування випереджаючих розвантажувальних свердловин.

Наукова новизна. Зроблено об'єктивну оцінку ступеня адекватності та достовірності результатів проведення обчислювального експерименту за умов використання нової геомеханічної моделі з шахтними дослідженнями параметрів сейсмоакустичного сигналу та початкової швидкості газовиділення. Виявлено основні тенденції розповсюдження вертикальних σ_y, горизонтальних σ_x і σ_z та інтенсивності напружень. Отримані результати з вивчення привибійного масиву спрямовано на обгрунтування параметрів противикидних заходів усіх підготовчих виробок.

Практична значимість. Проведені дослідження впроваджуються у створення методу розрахунку та рекомендацій щодо вибору раціональних параметрів розташування випереджаючих розвантажувальних свердловин з метою знеміцнення гірського масиву навколо прохідницького вибою та зниження ймовірності виникнення газодинамічних явищ за рахунок керованого знеміцнення прилеглих порід.

Ключові слова: *шахта, газодинамічні явища, випереджаючі свердловини, напружено-деформований стан, польова і пластова виробки*

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