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JUSTIFICATION OF THE PARAMETERS FOR SAFE BLASTING OF FLOOR ROCKS IN THE ROADWAY DRIVEN THROUGH THE HAZARDOUS BY OUTBURSTS SANDSTONES

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ОБГРУНТУВАННЯ ПАРАМЕТРІВ БЕЗПЕЧНОЇ ПІДРИВКИ ПОРІД ГРУНТУ ВИРОБКИ, ЯКУ ПРОВОДЯТЬ ПО ВИКИДОНЕБЕЗПЕЧНИМ ПІЩАНИКАМ

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ОБОСНОВАНИЕ ПАРАМЕТРОВ БЕЗОПАСНОЙ ПОДРЫВКИ ПОРОД ПОЧВЫ ВЫРАБОТКИ, ПРОВОДИМОЙ ПО ВЫБРОСООПАСНЫМ ПЕСЧАНИКАМ

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Abstract. In this article, the authors provide the substantiation of the parameters for safe floor rocks ripping by drilling-and-blasting technique in the roadway driven through the hazardous by outburst sandstones by way of forming an unloaded (nonhazardous by outburst) zone from the side of previously driven roadway.

The nomogram of numerical values of stresses is given for the conditions of the Pokrovskoe Mine, 1st northern belt road, panel No. 11. From the given calculations, radius of the unloaded nonhazardous by outburst zone in the vertical and horizontal planes around the driven experimental roadway of the 1st northern belt road, panel No. 11, was obtained with accounting anisotropy, depth of mining operations and rate of deformation.

The analysis of the material presented in the article allows to conclude that the unloading effect of the driven roadway predetermines the safety of mining operations conducted in the hazardous by outburst sandstone, and drilling-and-blasting operations within the calculated protected zone can be performed as in the nonhazardous by outburst zone. In this research, regularities of the unloading effect of the roadways were established, and dependences were obtained to determine boundaries of the unloading zones in specific mining and geological conditions, which should be determined for each concrete roadway to perform the blasting operations.

The presented justifications come to the fact that drilling-and-blasting operations used for ripping hazardous by outburst rocks in the roadway floor are carried out in the already unloaded (i.e. nonhazardous by outburst) zone, which is created from the same, previously driven, roadway. That is, it follows that drilling-and-blasting operations will be carried out in sandstone with no outburst hazard. This makes it possible to perform the drilling-and-blasting operations without making the forecast of the mine outburst hazard and without introducing the shock blasting mode, which, in turns, cut the time and labor costs and lead to significant savings of material and technical means.

A further research is needed for establishing dependence between the size of the formed unloaded (nonhazardous by outburst) zone around the working roadway in sandstone and depth of mining operations, section of the roadway and time passed since the roadway was driven.

Keywords: roadway, ripping, hazardous by outburst sandstone, drilling-and-blasting operations, safety.

Formulation of the problem. When conducting mining operations in coal mines, it is often necessary to rip rocks in the roadway floor with the help of the drilling-and-blasting operations (the DBO).

The main technological solutions for ripping the roadways floor are well developed and widely tested [1, 2]. However, when the floor rocks should be ripped with the help of the drilling-and-blasting operations conducted in the hazardous by outburst sandstones, a number of problems occur, technological solutions for which in terms of the work safety have not been developed yet [3, 4]. In particular, the requirements of regulatory documents [3 - 6] stipulate that blasting operations in the shock blasting mode (the SB mode) conducted in hazardous by outburst sandstones and near them should be carried out on the basis of forecast of the sandstone outburst hazard made by way of drilling core holes, which presents significant technical and technological difficulties for the existing mine faces.

Considering the above, the authors believe that substantiation of the parameters and development of safe method for conducting drilling-and-blasting operations for ripping the floor rocks in the roadway driven through the hazardous by outburst sandstones or near them, by way of formation of an unloaded zone in the site of the blasting operations, is the question of the day for the coal industry.

Purpose of the article. To substantiate the parameters for the safe ripping of roadway floor rocks by the drilling-and-blasting operations in the hazardous by outburst sandstones by forming an unloaded (nonhazardous by outburst) zone, which is created from the previously driven roadway.

Main material. As it is known, in the process of the mine roadway drivage, the redistribution of stresses and deformation of rocks occur around the roadway, the rate and nature of which depends on the combined conditions of many interdependent factors. It should also be noted that, on the one hand, the rocks surrounding the roadway feature a limited bearing capacity, that is their ability to resist an increase in stresses, and, on the other hand, they can be deformed without breaking their discontinuity only within the limited ranges. Therefore, a consequence of the new stress - the deformed state of the rock mass created after the roadway has been formed - can be destruction processes associated with a partial or complete loss of bearing capacity of surrounding rocks and formation of cracks [1, 2, 7, 8, 9].

In this case, areas with complete (ruined) destruction of rocks are formed around the roadway, which can cover a part of the contour or the entire contour of the roadway. The process of transition from the limiting state to the above-limiting state is developed with time, since strength characteristics of the rocks decrease under the influence of long-term application of load [2, 10].

Depending on specific features of deformation of various rocks above the ultimate strength, mechanical processes associated with destruction can be realized in the form of plastic flow or brittle fracture. In plastic rocks, formation of limiting equilibrium can proceed without such noticeable destruction and manifest itself in the form of a plastic flow without breaking the continuity. In this case, in a certain range of deformations, no significant change in mechanical characteristics occurs. Many scientists emphasize in their works that, in principle, unloading effect is typical for the roadways of any configuration. At the same time, studies in this field indicate a change in the gas-dynamic state of the hazardous by outburst seams and rocks being under the influence of the driven roadways; as well as their degassing effect is observed.

Formation of unloading area (zone of low stresses) around the roadway is a consequence of deformation processes occurred in the space outside the roadway contour. According to the laws of geomechanics, these deformation processes are conditioned by a combination of factors, of which of primary importance are: depth of mining operations; geometric parameters of the roadway cross-section; mining, geological and technical conditions for mining operations; physical and technical properties of rocks containing the roadway (strength, deformation, rheological property, etc.). The unloading effect of the driven roadway can be explained by zone of stress drop formed in the rock mass around the roadway contour. The use of the unloading effect of the working roadway predetermines the safe conducting of works near the hazardous by outburst sandstone and excludes self-development of its gas-dynamic activity [2, 4, 7 - 9].

Formation of zone of low stressed around the roadway, which makes it possible to use its unloading effect, is caused by formation of a vast area of the above-limiting state of rocks with partial or complete loss of their bearing capacity. In relation to the conditions of the Donbass coal mines, the following criterion is most used for assessing depth H, where not anchored roadway transits to the category of unstable [1, 2, 8 - 11]:

$$H > \frac{\kappa\sigma_{сж}}{\gamma} = \frac{0,24\sigma_{сж}}{\gamma} \quad (1)$$

where $\sigma_{сж}$ - is ultimate compression strength of rocks, MPa; γ - is volumetric weight of rocks, MN/m^3.

For the most common conditions of Donbass, at $\kappa = 0.25$, $\sigma_{сж} = 10f$, MPa and γ=0.025 MN/m^3, we have

$$H \geq 100f \quad (2)$$

where f - is coefficient of rock hardness by the scale of prof. M.M. Protodyakonov.

When mining operations are carried out at the depths corresponding to condition (2), the behavior of rocks around the roadway is most fully described by a general model of the rock mass elastoplastic deformation, which is based on the phenomenon of medium loosening and takes into account the influence of characteristics of behavior of the rocks in above-limiting state on the deformation process. Among the detailed developed models, the most acceptable for engineering calculations is the geomechanical model, which should be accepted as the basic one. Let’s reproduce the defining dependences for the total radial σ_r and tangential σ_θ stresses in the region of the above-limiting state [8, 12]:

$$\sigma_r = pr^{2\lambda} + \frac{A\xi + (\beta+1)\sigma_{сж}}{2\lambda(\beta+1)}\left(\frac{r^{2\lambda}}{r_p^{2\lambda}} - 1\right) + \frac{A\xi}{(\beta+1)(\beta+1+2\lambda)}\left(\frac{r_n^{\beta+1}}{r^{\beta+1}} - \frac{r_n^{\beta+1} r^{2\lambda}}{r_p^{\beta+1+2\lambda}}\right); \quad (3)$$

$$\sigma_\theta = (2\lambda+1)\sigma_r + \sigma_{сж} - \frac{A\xi}{(\beta+1)}\left(\frac{r_n^{\beta+1}}{r^{\beta+1}} - 1\right), \quad (4)$$

where p - is reaction of support, MPa; r - is current working radius, m; $\lambda = \sin g/(1-\sin g)$ – is parameter depended on the angle of internal friction of rocks; $A = \frac{3}{2}\frac{2\lambda\gamma H + \sigma_{сж}}{1+\lambda}$ - is stress determinant, MPa; ξ - is ratio of the modulus of deformations in above-limiting state to the modulus of deformations in the pre-limiting state; β - is coefficient of transverse deformation for above-limiting state; r_n - is radius of the region of above-limiting state determined by the expression [8-11]

$$r_n = \left\{\frac{1}{2}\left[\frac{A\xi}{(\beta+1)(\beta+1+2\lambda)}\left(\varphi^{\beta+1+2\lambda} - 1\right) - \frac{A\xi + \sigma_{сж}(\beta+1)}{2\lambda(\beta+1)}\left(\varphi^{2\lambda} - 1\right) + \gamma H - \frac{A}{3}\right]\right\}^{\frac{1}{2\lambda}}, \quad (5)$$

where r_p - is radius of zone of ruined destruction set by the relation [8]

$$r_p = \frac{r_n}{\varphi}\frac{r_n}{\left[1 + \frac{\sigma^n_{сж}(\beta+1)}{\xi A}\right]}. \quad (6)$$

According to the accepted model of deformation, values of $\sigma_{сж}$ and $\sigma\sigma^n_{сж}$ included in the expressions (3) ÷ (6) cannot exceed, by their absolute value, the level of geostatic stresses and, therefore, for the boundary conditions of the rock transition to the above-limiting state at a fixed strength, in accordance with the condition (2), the lithological difference can be taken within the range

$$\sigma_{сж} = \sigma^n_{сж} = \gamma H \quad (7)$$

In zone of ruined destruction, the reduced stresses are low and do not exceed their residual strength, which obviously excludes a possibility of any outburst hazard here [4]. Consequently, the formulation of the problem of determining the radius of an area with a safe level of stresses is possible only in zone of plastically deformed rocks. By introducing protection criterion developed by the All-Union Scientific Research Mine Surveying Institute (AUSRMSI) into the right side of the expression for the rectilinear envelope of Mohr's circles, we obtain

$$\sigma_\theta - (2\lambda + 1)\sigma_r = \gamma h, \tag{8}$$

where h - is the minimum depth of coal and gas outburst in the given mine formation, m.

By substituting expressions (3), (4) into (8) and by solving the equation of the current radius included in the expressions σ_θ and σ_r we obtain the defining dependence for the radius r_δ of zone with the safe level of stresses [11]

$$r_\delta = r_n \left[\frac{A\xi}{\gamma(H-h)(\beta+1) + A\xi} \right]^{\frac{1}{\beta+1}}. \tag{9}$$

Expression (9) is valid for the roadway with the unit radius when its length $l \to \infty$ and the time $t \to \infty$ passed from the moment of this roadway being driven. For specific mining conditions, the dependence for determining the roadway formation takes the following form

$$R_\delta = r_\delta \alpha K_{o.\partial.}^{1/2\lambda} K_t^{1/2}, \tag{10}$$

where α - is reduced (equivalent) radius of roadway, m; for the roadway with arched shape $\alpha = 0.6\sqrt{S}$, where S - is area of its cross-section in the rough, m^2; $K_{o.\partial}$ - is coefficient which takes into account the effect of zones of high rock pressure on the deformation process depending on the distance from the coal pillars and edge parts of adjacent seams; it is determined by the nomograms developed by the AUSRMSI [12]; K_t - is a coefficient that takes into account the degree of rocks deformation over time: in general, it can be determined in accordance with the recommendations.

The coefficient K_t is not a constant value, even for a certain lithological difference, and depends, first of all, on the depth of mining operations. Meanwhile, when comparing analytical data with the field data, it becomes necessary to use its fixed values. Due to the anisotropy and heterogeneity of physical and mechanical characteristics of the rocks composing the same lithological difference, value of this coefficient cannot be determined by calculation methods as they give a significant spread of parameters. Obviously, the most acceptable in this case are the results of mine experimental observations conducted in the mines of Donbass, according to which it deems possible to linearize, to a certain extent, a part of the B. Schwartz's deformation logarithmic curve based on the following values of the coefficient at depth of mining operations up to 1000 m: $K_t = 0.5$ - after 1 month; $K_t = 0.7 \div 0.8$ - after 3 - 4 months; $K_t = 1$ - after 180-200 days [8].

Here, it should be noted that the analytical method for determining radius of the safe zone is somewhat cumbersome and cannot be recommended for sufficiently quick practical calculations. For this purpose, let's consider the nature of the change in the reduced stresses in the partially loosen zone by using the equation of the rectilinear envelope of Mohr's circles $\sigma_{np} = \sigma_0 - (2\lambda + 1)\sigma_r$, the solution of which, with taking into account the previously accepted conditions for the transition of rocks to the above-limiting state, takes the form:

$$\sigma_{np} = \gamma H - \frac{A\xi}{\beta + 1}\left(\frac{r_n^{\beta+1}}{r^{\beta+1}}\right) - 1. \tag{11}$$

For the view of simplifying a general scheme of graphic reproduction of the nature of the reduced stresses changing in this zone, let's assume that level of the reduced stresses in the area of ruined destruction is equal to zero. In this case, only the interval r_n - r_p is subject to analysis. In order to ensure sufficient accuracy of the graphic constructions, a step of interval exploration $\Delta r = \frac{r_n - r_p}{n}$ is taken at $n = 4$.

The results of numerical values of the quantities acting in the stress zone, together with initial data for their calculation for the most typical lithological differences for the conditions of the Pokrovskoe Mine, can be presented as a first approximation in the form of nomograms shown in Figure 1. Their analysis indicates that size of the safe unloaded zone around the roadway increases with the change of the rock hardness and depth of the rock bedding and is determined by the safe level of geostatic stresses and their minimum value in zone of above-limiting deformation. With 1.2 decrease of the coefficient of transverse deformation of rocks in above-limiting state, zone of safe unloading decreases by 1.1 times at depth of more than 800 m. The established patterns show the need to determine the boundaries of the unloading zones for each specific case of conducting of mining operations. For their practical determination, it is necessary to use the established dependencies and the given nomograms.

The analysis of the above results showed that at a certain level of stresses depending on physical and mechanical properties of rocks, time and space, rather extensive areas of the rock mass are formed around the mine roadway with level of stresses lower than pressure of undisturbed rocks. Radius of zone with safe level of stresses can be determined by the nomograms (Fig. 1). Based on the above calculations and with taking into account all the influencing factors, radius of the unloaded nonhazardous by outburst zone around the 1st northern belt road of panel No. 11 is approximately equal to $r_\delta = 3.8$ m.

Let's further consider specifics of the rock mass deformation around the roadway with taking into account their anisotropy. It is known that rock mass manifests the properties of elastic and plastic anisotropy depending on geological conditions of their occurrence and pattern of their fracturing.

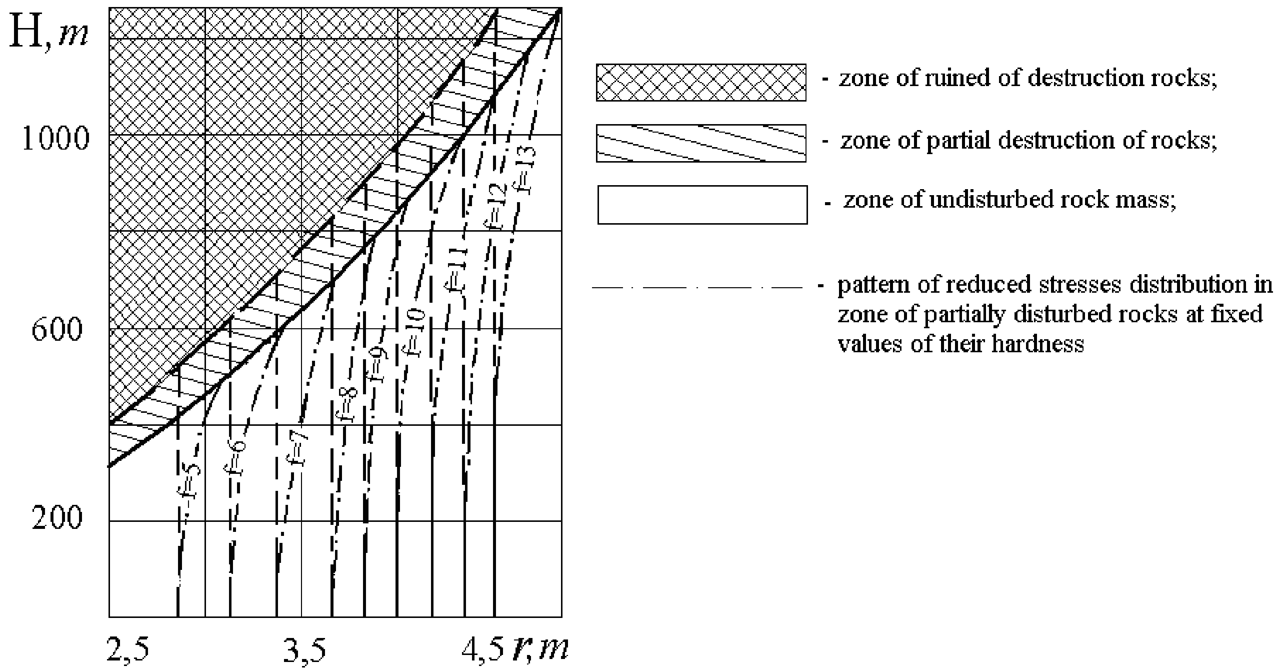


Figure 1 – The nomogram for determining radius of zone with safe level of stresses r_δ and pattern of distribution of reduced stresses σ_{np} in zone of partial loosened rocks in sandstones at $\beta = 6$, $\zeta = 4$ and $\rho = 38^o$

The tests of rock samples under uniaxial compression perpendicularly and parallel to their stratification show that their strength differs in these directions. The experimental data on determining strength and deformation characteristics of the rocks under their uniaxial compression and tension perpendicularly and parallel to their laminar bedding are shown in [8, 10, 12]. The anisotropy coefficient is equal to the ratio of the ultimate compression strength perpendicular to the laminar bedding to the ultimate compression strength parallel to the laminar bedding. Uniaxial compression strength depends on the direction of the rock laminar bedding relatively to the acting load [1, 8, 10]:

$$\sigma_{np} = \sigma_{np} \cdot (\Theta),$$

where Θ - is angle between the laminar bedding and the direction of the load effect.

It is known that displacement of rocks *K* is associated with the ultimate strength at uniaxial compression by the dependence [1, 2, 8, 11]:

$$K = (1 - \cdot sin\rho)\ \sigma_{np} \cdot (\Theta) / (2\ cos\rho),$$

where ρ - is angle of internal friction of the rock.

When calculating parameters of the rock plastic deformation in massifs with different ultimate compression strengths parallel and perpendicular to the laminar bedding, it is necessary to take into account an angle between the acting principal stresses and the directions of laminar bedding.

The solution of practical problems can be limited by two terms:

$$K = (1 -\cdot sin\rho)\ \sigma_{np}\cdot(\Theta) / (2\ cos\rho).$$

Let's denote the cohesion of rocks under compression perpendicular to the laminar bedding by K_1 and parallel to laminar bedding by K_2. Then, according to the equation, we have

$$K(0) = K(1+\delta) = K_1;$$

$$K(\pi/2) = K(1-\delta) = K_2.$$

Then it follows that:

$$K = (K_1 + K_2) / 2;$$

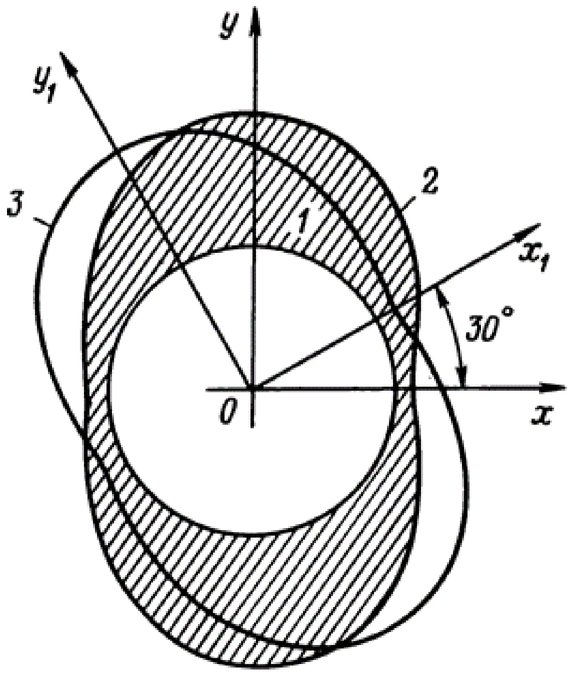
$$\delta = (K_1 - K_2) / (K_1+K_2).$$

In this way, the coefficients K and δ characterize the rate of average cohesion of rocks in the near-contour zone of the roadway and the scatter of the strength properties caused by anisotropy. Having determined the coefficients K and δ, it is possible to calculate analytically the shape and size of plastic deformation area around the roadway. In this research, shape and dimensions of the area of plastic deformations were determined experimentally for the conditions of Donbass on the basis of data received from the benchmark stations [1, 8].

The analysis of instrumental observations showed that rock contour of the roadway was shifted unevenly along the perimeter. In all areas, the greatest displacements were observed in the roadway floor. The stresses corresponded to these displacements were previously determined by simulation [1, 8 - 13] and are shown in Figure 2.

The analysis of displacements of the near-contour massif by depth benchmarks made it possible to determine shape and dimensions of zones with inelastic deformations for the conditions under consideration. The performed analysis shows that, due to plastic anisotropy, the area of plastic deformations turns out to be elongated in the vertical direction.

Observations in various mining and geological conditions showed that size of zone of ultimate deformations varied from 1 m to 10 m relatively to the roadway contour. Shape of the area of ultimate deformations primarily depends on the angle of rock inclination in the roadway driven through the rocks of the same type, the largest size of the ultimate deformation zone is elongated in the direction perpendicular to the laminar bedding. At the same time, in rocks of the Donetsk basin with ultimate strength under uniaxial compression σ_{np} = (32 - 60 MPa), at depths of 780 - 1000 m, size of the ultimate deformation zone reaches 7 - 9 m. From the above calculations, the resulted radius of the unloaded nonhazardous by outburst zone around the driven 1st northern belt road of panel No. 11 is r_δ = 3.8 m. And given that with an anisotropy coefficient δ = 0.28, the area of plastic deformations in the vertical plane is 1.35 times larger than in horizontal plane, then dimensions of the unloaded zone in the horizontal plane is r_δ = 2.8 m.



1 - area of ultimate deformations; 2 - contour of ultimate deformations in case of horizontal bedding of rocks; 3 - contour of ultimate deformations at inclined bedding of rocks

Figure 2 – Ultimate deformations around the roadway

Let's further analyze an effect of time on the degree of rock deformation. Analysis of the deformation rate of massif enclosing the roadway and the time of formation of unloading zone around the roadway shows that in case of sandstones, this process is practically ended within several months (up to one year).

Calculation methods cannot be used for determination with taking into account the anisotropy and heterogeneity of physical and mechanical characteristics of rocks composing the same lithological difference, as they give a significant spread of parameters. Obviously, the most acceptable in this case are the results of mine experimental observations conducted in the mines of Donbass, according to which it deems possible to linearize, to a certain extent, a part of the B. Schwartz's deformation logarithmic curve based on the following values of the coefficient at depth of mining operations up to 1000 m: K = 0, 5 in one month: K = 0.7 ÷ 0.8 in three to four months: K = 1 in six months.

With taking this factor into account, we find that the value of the quality of the unloaded nonhazardous by outburst zone around the driven roadway is r_δ = 1.9 m in 1 month , r_δ = 2.7 m in 3 months and r_δ = 3.8 m in 6 months after the roadway section was driven.

At the same time, some researchers note that with an increase of mining operations depth, the deformation rates can change depending on the properties of the host rocks and the mining and geological conditions of their bedding. With accounting the elements of idealization inherent in any geomechanical model, the use of these dependencies can be recommended mainly at the preliminary design stage. With the view of the above, in case of ripping the floor rocks by drilling-and-blasting operations and re-supporting the roadway at a shorter distance, final determination of the space-time ratio of the works should be done by the well-proven in practice experimental mining method without undertaking outburst-preventing measures.

It follows from the above that unloading effect of the driven roadway predetermines the safety of conduction of mining operations in hazardous by outburst sandstone, and drilling-and-blasting operations within the calculated protected zone can be performed as in the nonhazardous by outburst zone [4, 11]. In this research, the regularities of the unloading effect of roadways were established and dependences were obtained to determine the boundaries of the unloading zones in specific mining and geological conditions, which should be determined for each concrete roadway when performing the blasting operations.

The above justifications come to the fact that under certain conditions the DBO used for ripping hazardous by outburst sandstones can be carried out without making the forecast of the outburst hazard and without introducing the SB mode [11]. These recommendations are based on the fact that the DBO used for ripping the hazardous by outburst rocks in the roadway floor are carried out in the already unloaded (i.e. nonhazardous by outburst) zone, which is created from the same, previously driven, roadway. This effect was established earlier [14]. Therefore, it follows that DBO will be carried out in nonhazardous by outburst sandstone. This makes it possible to carry out the drilling-and-blasting operations without making the forecast of the mine outburst hazard and without introducing the SB mode.

The proposed safe parameters for blasting hazardous by outburst rocks in the roadway floor should be checked when driving an experimental roadway.

Such experimental roadway - the 1st northern belt road of panel No. 11 under the conditions of the Pokrovskoye Mine - was driven through the coal seam d_4, with rock-cutting with the roof and floor layer. The coal seam d_4 features a simple and complex structure (two coal units separated by the layer of siltstone), with total geological thickness of 1.45 - 1.70 m. Coal is black, semi-shiny, thin-banded, uneven fracture, of medium strength.

Siltstone with thickness of 2.55 - 6.40 m and sandstone with thickness of 9.70 - 18.65 m are bedded in the roof of the coal seam. Siltstone is dark gray, micaceous, horizontally- and wavy-layered due to fine-grained sandstone, with frequent lenses of coal at the end of the layer and with alluvial deposits of coalified detritus in layering, of medium strength. Sandstone is gray, fine-grained with medium-grained and coarse-grained bands, feldspar-quartz, on clay cement, with carbonaceous interlayers, fractured, sometimes micaceous, of medium strength.

The floor of the coal seam contains siltstone with a thickness of 0.45 - 0.80 m and sandstone with a thickness of 5.30 - 12.95 m. Siltstone is dark gray, not layered, micaceous, at the beginning of the layer is "curly" up to 0.20 m, with imprints of coalified stigmaria, prone to heaving, of medium strength. Sandstone is medium-grained, feldspar-quartz, on clay cement, gray, with interlayers of siltstone, with charred detritus along the layering, with small lenses and smears of coal, with inclusions of siderite buds and sandy shale, massive, dense, of medium strength.

According to the project, the 1st northern belt road of panel No. 11 was supported by the КШПУ-20.3 supports. Cross-section of the roadway in clear is 20.3 m^2, and 23.7 m^2 in the tunnel. Step of supports setting is 0.50 m. Depth of the excavation is 990 m. When this roadway was driven, the heaving of floor rocks occurred after a while, as well as deformation of roof beams on the frame support, which led to a significant decrease of the roadway cross-section. To bring the cross-section of the roadway to the design state, the workers of the Pokrovskoe Mine ripped the floor rocks with the help of drilling-and-blasting operations.

Having regard to the fact that sandstones at a depth of more than 600 m are related to hazardous by outburst, the IGTM of the NAS of Ukraine developed recommendations for the safe conducting of drilling-and-blasting operations used for ripping the floor rocks in the sandstone and near it in the 1st northern belt road of panel No. 11 [11].

The blasting operations for ripping the floor rocks were conducted in the experimental roadway according to the Blasting Pattern developed by the Pokrovskoe Mine jointly with the IGTM [4, 5, 15, 16]. Prior to perform the blasting operations, the following requirements of the Safety Regulations (SR) were included into the Blasting Pattern [4, 5, 17]:

- when conducting blasting operations, before each charging of shotholes and their explosion, and during the subsequent inspection of the face after the explosion, the master shot-firer must measure concentration of methane over the entire section of the face; when concentration of methane is 1%, blasting operations are prohibited;
- shelter for the master shot-firer should be ventilated with a fresh stream of air provided by general mine depression;
- the minimum depth of shotholes for blasting should be 0.6 m;
- in seams hazardous by gas and dust, rock dusting or irrigation of settled coal dust should be carried out before each explosion with blasting of adjoining rocks.

Below are the main parameters of drilling-and-blasting operations used for ripping the roadway floor (Fig. 3-6).

The main characteristics and parameters of the DBO in the experimental roadway – 1st belt road of panel No. 11 - are shown in Tables 1-5.

Table 1 – Parameters of shothole charges

Delay circuit for ЭДКЗ (ЭДКЗ - short-delay electric detonator)	0	2	3	4	5	6	7
Shothole №№	4 pieces	1-5	6-10	15-20	21-30	31-40	41-50
Charge mass, kg	0,15	0,6	0,6	0,6	0,6	0,6	0,6

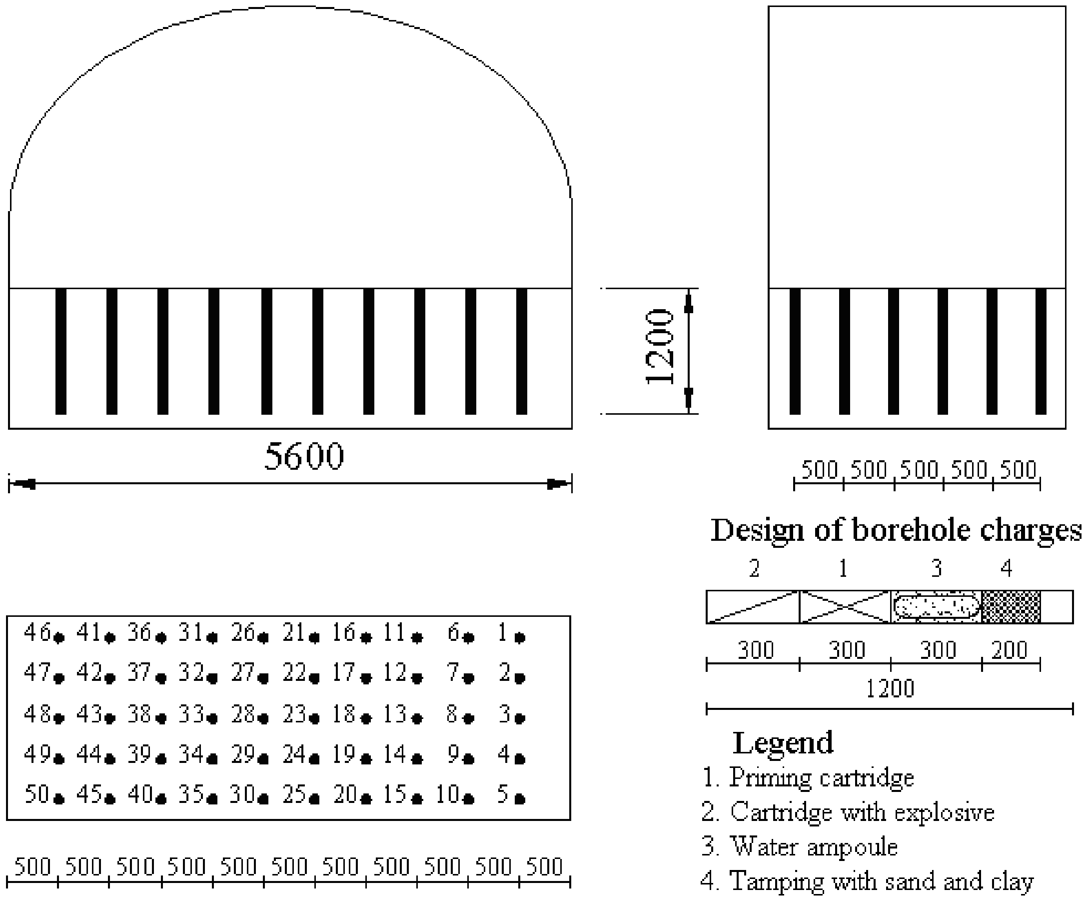


Figure 3 – Layout of shotholes and design of shothole charges

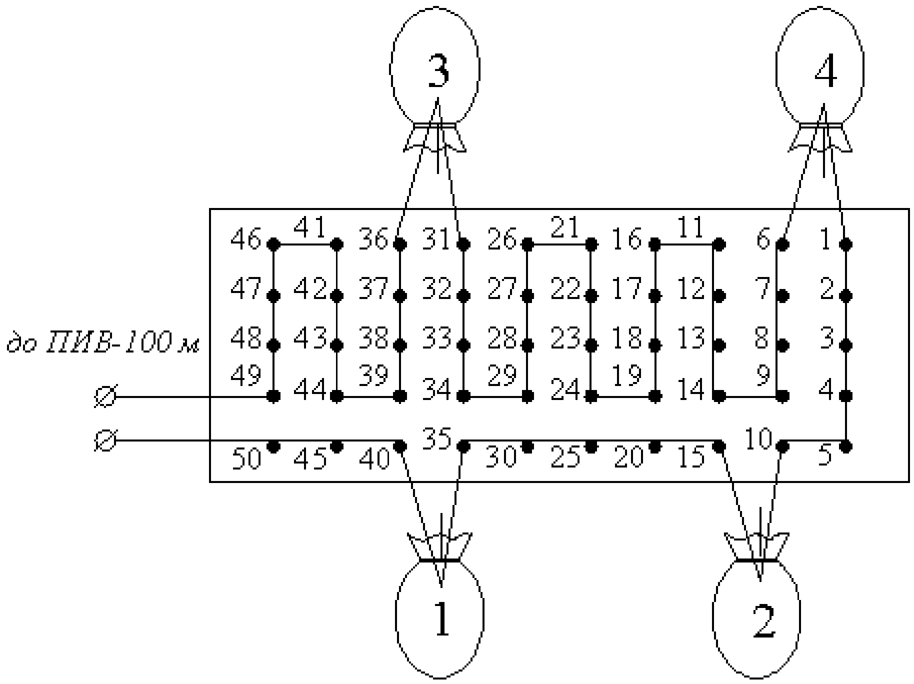


Figure 4 – Diagram of assembling of the explosive network

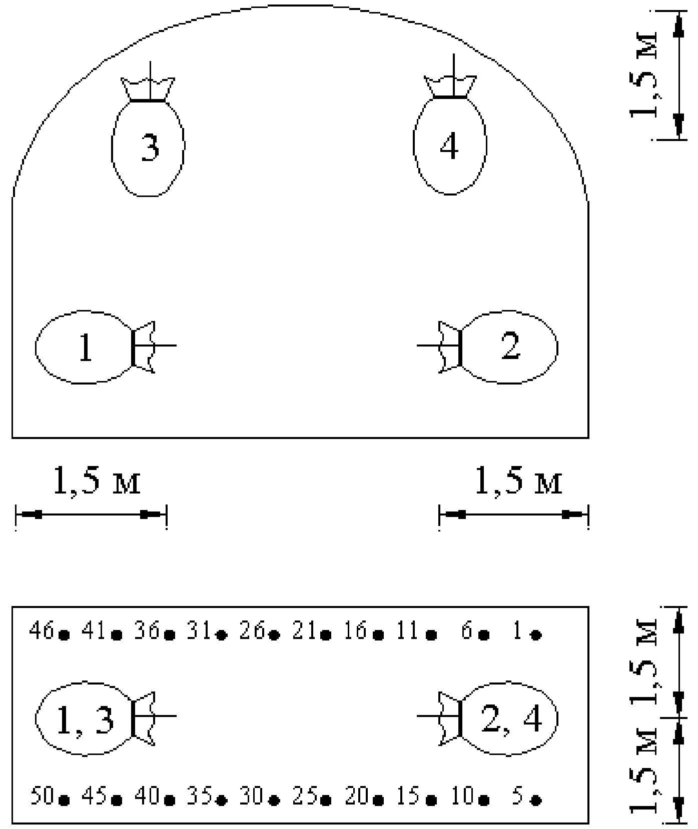
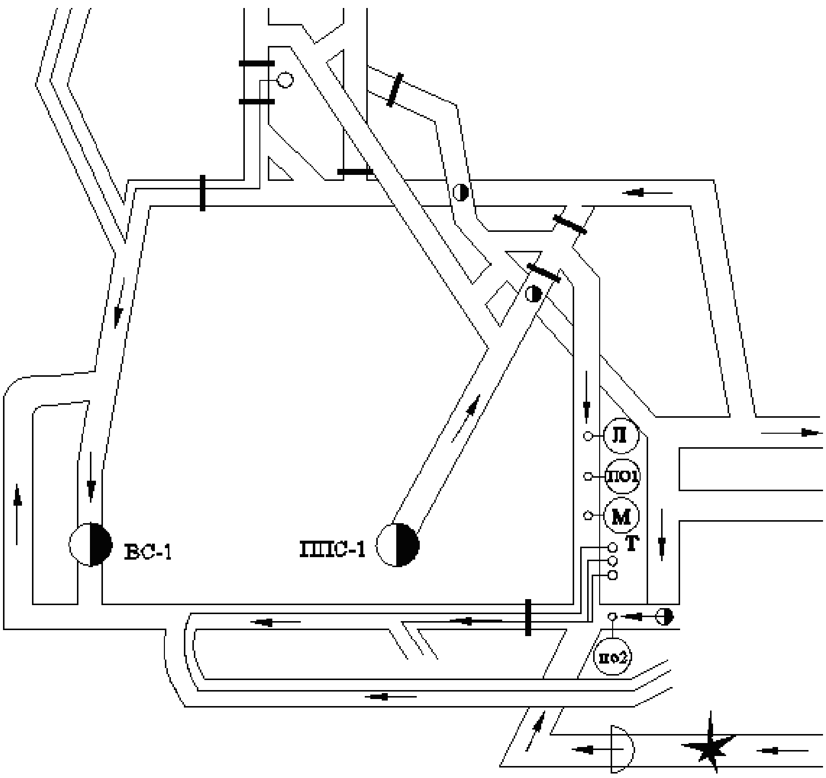


Figure 5 – Layout of containers with for the water spray curtain



ПО1 - points of security posts

ПО2 - points of security posts

Л - location of people

М - location of shelter for the master shot firer

- ventilation hole

- site for conducting the blasting operations

- shale barrier

- air jet

- blind jumper

T -telephone

Figure 6 – Scheme of ventilation of the face with location of security, shelter for the master-shot-firer and people

Table 2 – The main indicators of the Blasting Pattern

№№	Indicators	of measurement	Qty
1	Mine hazard by gas (dust)	-	Hazardous by sudden outbursts of coal, rocks and gas
2	Roadway hazardous by gas (dust)	-	hazardous
3	Rough cross-section of roadway	m^2	18,3
4	Strength factor by the Protodyakonov scale	-	6-7
5	Type of explosive used	-	Ammonite ГФ-5К
6	Shothole diameter	mm	41
7	Explosive consumption per cycle	kg	30,0
8	Consumption of electric detonator per cycle	pieces	50
9	Type of tamping used	-	water ampoule in combination with sand-clay plug
10	Consumption of water ampoules per cycle	pieces	55
11	Face advance per explosion: in coal in rock	 m m	 - 1,1
12	Duration of face aeration after explosion	min	20
13	Time appointed for blasting operations (start, end)	-	1 shift: 09.00 – 14.00 2 shift:15.00 – 20.00 3 shift:21.00 – 02.00 4 shift:03.00 – 08.00

Table 3 – Parameters of shothole charges

№№ of shotholes or shothole groups	Depth of shotholes, mm	Type of explosives	Mass of charge per each shothole (kg)	Angles of shothole inclination to the face plane in projection, degree		Type of ЭДКЗ and rate of their delay	Q-ty of electric detonators	Depth in inner tamping, m
				Horizontal	Vertical			
1-5	1,2	Ammonite ГФ-5К	0,6	90	90	ЭДКЗ-2 ПМ	5	0,5
6-10	1,2	Ammonite ГФ-5К	0,6	90	90	ЭДКЗ-3 ПМ	5	0,5
11-20	1,2	Ammonite ГФ-5К	0,6	90	90	ЭДКЗ-4 ПМ	10	0,5
21-30	1,2	Ammonite ГФ-5К	0,6	90	90	ЭДКЗ-5 ПМ	10	0,5
31-40	1,2	Ammonite ГФ-5К	0,6	90	90	ЭДКЗ-6 ПМ	10	0,5
41-50	1,2	Ammonite ГФ-5К	0,6	90	90	ЭДКЗ-7 ПМ	10	0,5

Table 4 – Parameters of water spray curtain

Methods of blasting	Water consumption in face		Qty of containers (pieces) with volume (l)		Type		Consumption		
							explosives		ЭДКЗ
	Specific, l/m^2	total, l	20	30	explosives	ЭДКЗ	Per one container, kg	Totally, kg	Totally, pieces
In one go	4	80	4	-	Metanil E 7H	ЭДК 3-ОП	0,15	0,6	4

Table 5 – Timing of blasting operations

№№	Name of the operation	Current time	Duration of operation, min.
1	Measuring of methane gas content, giving of sound signal, people should leave the danger zone, arranging the site security and prohibition signs.	23, 40	13
2	Charging of shotholes and assembling of explosive network	23, 53	44
3	Measuring of methane gas content after shotholes are charged, removal of equipment for shotholes charging away from the face.	00, 37	4
4	Master shot-firer going to the shelter, measuring of methane gas content in the shelter.	00, 41	8
5	Checking of the explosive network integrity, giving a combat signal and explosion the shotholes	00, 49	3
6	Airing of the face and executing the service order.	00, 52	20
7	Master shot-firer and mining master return to the face for checks.	01, 12	8
8	Inspecting of the face, reporting about the result to the mine dispatcher.	01, 20	4
9	Giving of sound signal "All Clear", turning of electricity on, admitting the workers to return to the face.	01, 24 / 01, 30	6

On the 03.03.2020, in 3rd shift, in the process of blasting operations for ripping the floor rocks in the 1st northern belt road of panel No. 11, timing of the blasting operations was performed, the data of which are given in Table 5. Experimental check carried out in the1st belt road in the Pokrovskoe Mine showed that the developed method is safe and effective.

The positive for the Pokrovskoe Mine result is that on the basis of these recommendations it is possible to use DBO for ripping the floor rocks without making the forecast of the mine outburst hazard and without introducing the SB mode, which, in turns, will cut the time and labor costs and lead to significant savings of material and technical means.

At the same time, it should be noted that it is necessary to conduct a research in the preparatory roadway to establish a dependence of the size of the unloaded (nonhazardous by outburst) zone around the roadway on the depth and section of the roadway and on the time passed since the roadway was driven.

It is necessary to conduct tests in stopes in order to determine at what distance and to what depth from the bottomhole the unloading occurs (in other words, a protected zone is created), as DBO are quite often performed in the face area of the seam.

Based on the foregoing, given that the DBO used for floor rock ripping should be carried out in an unloaded, nonhazardous by outburst zone created by the roadway itself, the Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine has prepared recommendations in which it considers it possible to rip the floor rocks in 1st northern belt road of panel No. 11 by drilling-and-blasting method in the mode established for the mines related to the super-category by gas with mandatory implementation of the following additional recommendations [11]:

- blasting and re-supporting works can be conducted only in such areas of roadway, which were driven not less than 6 months ago before the day of the blasting operations;
- before charging the shotholes during blasting operations in underground roadways, it is necessary to ventilate the face and to remove previously blasted rock mass, and people who are not involved into performing of blasting operations should leave the roadway;
- explosion of charges is prohibited if, at a distance of less than 20 m from the point of their laying, rock mass, trolleys or other objects are left which cover an area of more than 1/3 of the roadway cross section;
- length of the shotholes for blasting the rock floor should be not more than 1.50 m. The shotholes should not be deepened to more than 0.60 m below the line of the design (initial) contour of the roadway floor. The distance from the end rows of the shotholes to the roadway walls of the design section should be at least 0.40 m;
- the length of the shotholes for blasting operations used for re-supporting the roadway should be not more than 1.70 m, and the shotholes should not be deepened below the line of the design contour of the roadway;
- drilling-and-blasting operations should be performed in accordance with the requirements of the "Safety Rules for Handling Industrial Explosives";
- all workers should be provided with methane alarms connected with headlights, and should have oxygen self-rescuers with them;
- each worker and engineer should be familiarized with the signs warning of gas-dynamic phenomena by putting their signatures;
- when signs of gas-dynamic phenomena occur in the roadway, all works must be stopped, all workers must go out into a fresh stream of air to a safe place, electricity should be turned off and all the taken measures should be reported to the mine dispatcher. The resumption of work is possible only with the written permission of the chief engineer of the mine after inspection of the mine.

Conclusions. 1. The recommendations are developed, which allow ripping of floor rocks by drilling-and-blasting operations in the hazardous by outburst sandstone in the mode established for mines related to the super-category by gas.

2. It is established that drilling-and-blasting operations in hazardous by outburst sandstone are carried out in the already unloaded zone, i.e. in nonhazardous by outburst zone, which is created from the same roadway previously driven. This confirms the previously established pattern (scientific discovery [14]), which allows the working roadway to realize unloading around itself.

3. A further research is needed for establishing dependence between the size of the formed unloaded (nonhazardous by outburst) zone around the working roadway in sandstone and depth of mining operations, section of the roadway and time passed since the roadway was driven.

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Анотація. У статті виконано обґрунтування параметрів безпечного підривання порід підошви виробки, яка проходиться буропідривними роботами по викидонебезпечним пісковикам, шляхом утворення розвантаженої (невикидонебезпечної) зони, яка створюється від раніше пройденої виробки.

Для умов шахтоуправління «Покровське» 1-го північного конвеєрного штрека блока № 11 надана номограма чисельних значень напружень. З наведених розрахунків отримано радіус розвантаженої (невикидонебезпечної) зони в вертикальній та горизонтальній площинах навколо пройденої експериментальної виробки 1-го північного конвеєрного штрека блока №11, з урахуванням анізотропії, глибини ведення гірничих робіт і швидкості деформації.

Аналіз викладеного в статті матеріалу дозволяє зробити висновок, що розвантажуючий вплив пройденої виробки зумовлює безпечне ведення гірничих робіт по викидонебезпечним пісковикам, а буропідривні роботи в межах розрахованої захищеної зони дозволяють здійснювати як у невикидонебезпечній зоні. В наданій роботі встановлені закономірності розвантажуючої дії і отримані залежності для визначення меж зон розвантаження в конкретних гірничо-геологічних умовах, які необхідно визначати в кожній конкретній виробці при веденні вибухових робіт.

Наведені обґрунтування зводяться до того, що буровибухові роботи з підривання викидонебезпечних порід в підошві виробки здійснюється вже в розвантаженій (тобто невикидонебезпечній) зоні, яка створюється від раніше проведеної цієї ж виробки. Звідси випливає, що буровибухові роботи будуть здійснюватись вже в невикидонебезпечному пісковику. Це дає можливість проводити буровибухові роботи не виконуючи прогноз, і без введення режиму струсного підривання, що дозволить знизити витрати часу, трудомісткості і призводить до значної економії матеріально-технічних засобів.

Виявлена необхідність проведення надалі досліджень по встановленню залежності розміру утвореної розвантаженої (невикидонебезпечної) зони навколо проведеної виробки в пісковику від глибини ведення робіт, перерізу виробки та часу після проходки цієї виробки.

Ключові слова: виробка, підривання, викидонебезпечний пісковик, буропідривні роботи, небезпечність.

Аннотация. В статье выполнено обоснование параметров безопасного взрывания пород подошвы выработки, выполняемой буровзрывными работами по выбросоопасным песчаникам, путем образования разгруженной (невыбросоопасной) зоны, создаваемой от ранее пройденной выработки.

Для условий шахтоуправления "Покровское" 1-го северного конвейерного штрека блока №11 предоставлена номограмма численных значений напряжений. Из приведенных расчетов получен радиус разгруженной (невыбросоопасной) зоны в вертикальной и горизонтальной плоскостях вокруг пройденной экспериментальной выработки 1-го северного конвейерного штрека блока №11, с учетом анизотропии, глубины ведения горных работ и скорости деформации.

Анализ изложенного в статье материала позволяет заключить, что разгружающее влияние пройденной выработки обуславливает безопасное ведение горных работ по выбросоопасным песчаникам, а буровзрывные работы в пределах рассчитанной защищенной зоны позволяет осуществлять как в невыбросоопасной зоне. В данной работе установлены закономерности разгрузочного действия и получены зависимости для определения границ зон разгрузки в конкретных горно-геологических условиях, которые необходимо определять в каждой конкретной выработке при ведении взрывных работ.

Приведенные обоснования сводятся к тому, что буровзрывные работы по подрывке выбросоопасных пород в подошве выработки производятся уже в разгруженной (т.е. невыбросоопасной) зоне, создаваемой от ранее произведенной этой же выработки. Отсюда следует, что буровзрывные работы будут производиться уже в невыбросоопасном песчанике. Это позволяет проводить буровзрывные работы не выполняя прогноз и без введения режима сотрясения, что позволит снизить затраты времени, трудоемкости и приводит к значительной экономии материально-технических средств.

Выявлена необходимость проведения дальнейших исследований по установлению зависимости размера образовавшейся разгруженной (невыбросоопасной) зоны вокруг проводимой выработки в песчанике от глубины ведения работ, сечения выработки и времени после проходки этой выработки.

Ключевые слова: выработка, взрывание, выбросоопасный песчаник, буровзрывные работы, опасность

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