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DETERMINATION OF THE DISPLACEMENTS OF ROCK MASS NEARBY THE DISMANTLING CHAMBER UNDER EFFECT OF PLOW LONGWALL

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ВИЗНАЧЕННЯ ДЕФОРМАЦІЙ ПОРОДНОГО МАСИВУ В ОКОЛІ ДЕМОНТАЖНОЇ КАМЕРИ СТРУГОВОЇ ЛАВИ

Purpose. Determining the increase of rock displacements nearby a pre-constructed dismantling chamber while a plow longwall approaching. Additional goal is to develop a technique for estimating the pressure created by failed rocks at different stages of mining.

Methodology. Displacements around a pre-constructed dismantling chamber were studied in situ using tell-tale stations. Numerical simulation was carried out to determine the rock stress-strain state applying a plastic deformation model. The numerical procedure of strain accumulation was implemented at the sequential change of mined-out space while modeling. Areas of broken rocks (failure zones)were determined according to Hoek-Brown strength criterion. Numerical simulation was carried out concerning different geological conditions and excavation dimensions. The nonlinear estimation method combining with multiple regression and variance analysis were used to build general regularities.

Findings. The multi-variant calculations of stress-strain state change were carried out for different values of rock strength, coal seam thickness, mining depth and dismantling chamber size as well. The results were generalized for different geological conditions. The failure zone height and excavation contour displacements are represented as a function of factors mentioned above.

Originality. New regularities were obtained relatively the increase of rock displacements nearby a dismantling chamber. A failure zone spreading was shown depending on rock properties. Convenient techniques were developed to calculate constitutive geomechanical characteristics and provide an adequate support design for dismantling chamber under various mining and geological conditions.

Practical value. The set of formulas derived with regression method allows determining the main geomechanical characteristics and gives a simple technique to design the support of dismantling chamber. This is a background for developing the general standards related to dismantling chamber designing under Western Donbass geological conditions.

Keywords: *dismantling chamber, plow longwall, stress-strain state, failure criterion*

Introduction. Coal mining in Western Donbas is characterized by complex geological conditions. Thin coal seamsand ground control problems (intensive floor heaving and rock falls) cause significant problems for mining.

However, the challenge is to increase the coal production involving high technologies and speeding up mining operations.

Implementation of the first plow longwall GH 800 and shield complex DBT 65/130 in Ukraine creates the urgent task of timely preparing mine sites. This involves assembling and dismantling the plow equipment in the shortest time possible.

Assembling and dismantling the plow longwall are multifunctional and complex processes which are carried out in cramped conditions of underground excavations. Therefore, the special requirements of stability and technology operations are applied to special excavations named assembly chamber and dismantling one. After all, these underground excavations are exposed to the extreme load during mining.

Special attention has been paid to the stability of assembly chambers in [1].This paper is focused on the process of plow long wall dismantling.

Currently the dismantling of Ukrainian-made mining systems is performed according to the well-proven scheme. It is supposed that equipment is disassembled directly in longwall space. However, the DBT plow complex cannot be disassembled in such a way due to lack of working space. The alternative solution is to pre-construct an additional excavation (dismantling chamber) at the side of a panel where coal extracting will be finished.

The preliminary constructed chamber ensures safety as the preparation of equipment for removal is fulfilled under the support protection (Fig. 1). The dismantling chamber provides the necessary working space and reduces the time of equipment removing.

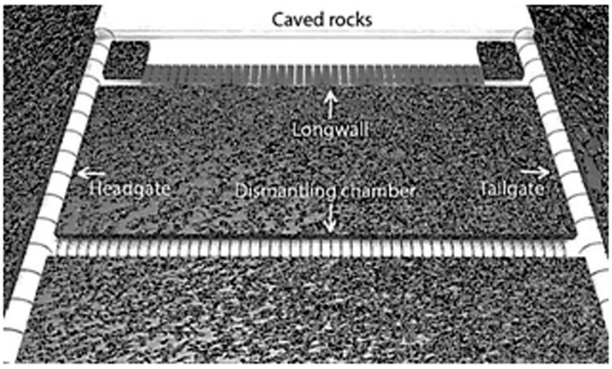


Fig. 1. Site preparation

Initially,the dismantling chamber is placed outside of the longwall influence. However, the coal face gradually approaches the chamber and it can be destroyed due to the rock pressure in front of moving longwall.

Lack of experience in dismantling chamber designing under conditions of West Donbas is a problem. There are no Ukrainian regulations evaluating the rock pressure affected by the support of longwall and pre-constructed dismantling chamber considering their mutual influence. Nowadays there are no complex analyses of visual observations and tool measurements in situ as well as numerical and physical simulation in terms of weak fractured rocks of Pavlohrad coal region. But these aspects are an important element to design the appropriate protective means and provide the stability of excavations.

A set of research stages is carried out to meet the goal. They are:

- numerical simulation of geomechanical processes in rock mass at continuous movement of longwall;
- definition of support type and parameters;
- instrumental monitoring of rock displacements near the dismantling chamber at various stages of longwall movement.

Since this is the first experience of pre-constructing the dismantling chamber in Western Donbas two types of cross-section were tested. The chamber was driven with a rectangular shape of a cross section (4.2 m wide and 3.0 m height) at the site from picket PK 0 till picket PK 12 + 5.6 m. Starting with PK 12 + 5.6 m the arched shape of the cross section was applied (Fig. 2). Setup of survey stations is shown in Fig. 2 as well. Deep reference marks (tell-tales) were installed to a depth of 7 m to determine rock displacements.

Visual observations. Five measuring points consisting of two tell-tale stations are installed in the dismantling chamber. The tell-tales are situated on the opposite sides in the same cross section at a distance of 1 m from the side surface of excavation. The standard factory-produced tell-tales are used as well as a custom devise developed at the NMU. The length of the hole for installation of the tell-tale is 7 m. Reference marks are set at a distance of 6, 5, 4, 3, 2, 1 and 0.5 m from the excavation contour. Installation of all the tell-tales has to be completed before the longwall approaches at the distance of 300–180 m (outside of longwall effect).

Each measuring point is additionally equipped with three contour reference marks. Two of them are installed in the excavation walls at the height of 1.8 and 2.0 m above the floor and one is located in the roof.

Observations consisting of 18 series have been done. Intervals between observations were 5–7 days. No significant changes in tell-tales metrics were fixed before longwall approaching up to 30 m. During the 5th observation series, when the distance between the longwall face and dismantling chamber decreased up to 30–25 m, a slight movement of the sensors (0.5–5.0 mm) was detected. According to the results of the 8-th and 10-th observation series the maximum displacement increased up to 10 and 17 mm respectively. The observations results are shown in Fig. 3.

Generalizing visual observations we can conclude that significant deformation of excavation contour occurs when the width of the coal pillar between the dismantling chamber and longwall face decreases up to 6.0 m. After that the geomechanical processes nearby the dismantling chamber becomes activated precipitously.

The rock mass behaviour is different at different distance from the excavation contour. The displacement of the points located at a distance of 0.5; 1.0; 2.0 and 3.0 m from the contour is rather predictable. The displacement of the excavation contour is 150 mm at the moment of the longwall and dismantling chamber conjugation. It increa-

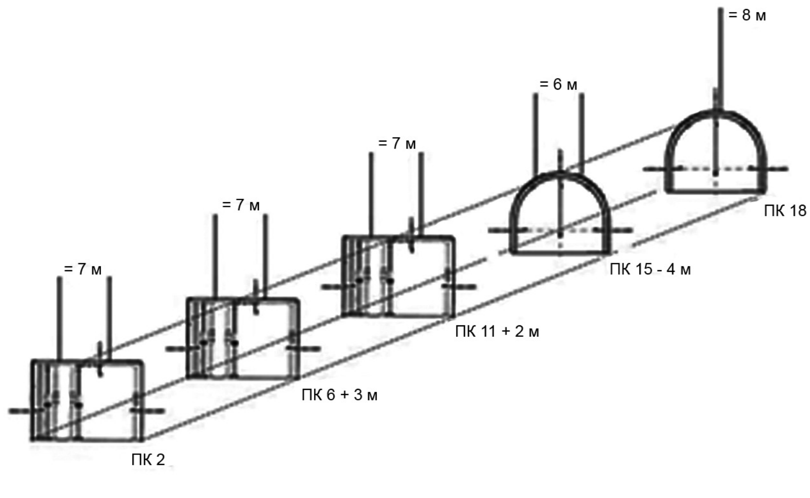


Fig. 2. The cross section of the dismantling chamber and location of survey stations

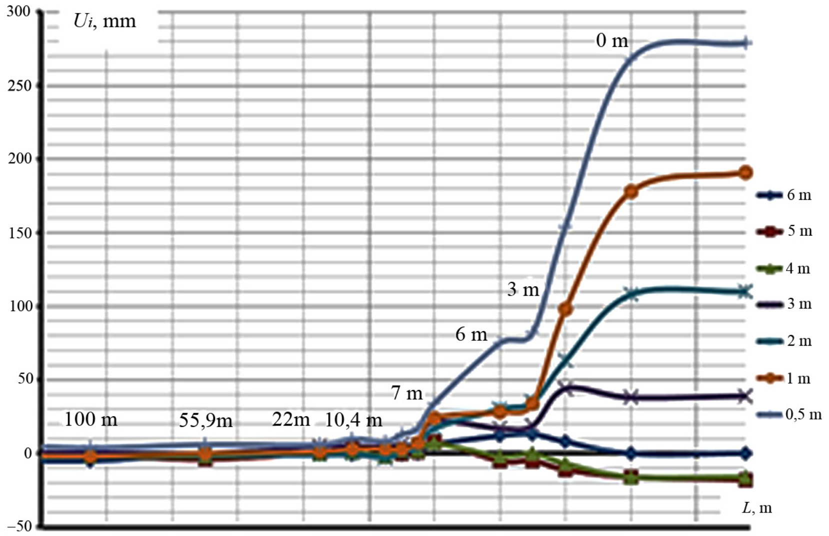


Fig. 3. The tell-tales displacement depending on the distance to longwall face

ses up to 280 mm in the process of the equipment dismantling. Then the displacements are damped.

The behaviour of the reference points located in the depth of the rock mass(a distance from the contour is 4.0, 5.0 and 6.0 m) does not match the logic of the physical model. There is a wrong impression that the rock mass displacement is reduced at the distance exceeding 3.0 m from excavation contour. Subsequent visual inspection of tell-tales showed that rocks nearby these sensors are extremely destroyed and the descriptiveness of these measurements is poor.

A change in the excavation cross-section indicates the quantification of the rock pressure. When the longwall face approaches the dismantling chamber at a distance of 10–6 m, the vertical and horizontal convergence increase extremely. The moment of the longwall face and dismantling chamber conjugation is marked by the following characteristics:

- the average height of the dismantling chamber cross-section has been kept in a range of 70–80 % in case of a rectangular shape of the cross section and 80–90 % in case of an arched shape of the cross section;
- the average cross-section width along the dismantling chamber for both type of cross section remained at a level of 75–85 %
- the floor heaving has been observed at a level of 0.4–0.5 m for rectangular shape of a cross section and 0.3–0.4 m for an arch done;
- significant destruction of rock mass is observed nearby the unsupported wall of the dismantling chamber with rectangular shape of a cross section.

The observations in situ are resulted in the following statements:

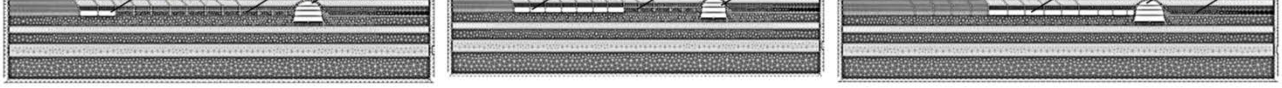
1. The influence of rock pressure in front of a moving longwall face causes the intensive displacements of the dismantling chamber contour (at a level of 30–40 %).

2. The impact of rock pressure becomes significant at longwall approaching the dismantling chamber at a distance of 15–10 m.

Numerical simulation of changing the rock stress-strain state at various stages of mining. The rock stress-strain state should be determined using one of the numerical methods. We apply the finite element method (FEM) proven in geomechanics problems in combination with the strength theory in the nonlinear formulation [2, 3].

The area investigated includes a coal face, a mined-out space, a site of caved rocks behind the mined-out space (a goaf) and a dismantling chamber (Fig. 4). The software Phase-2 developed by Rocscience laboratory is used.

The rock mass is modelled as a layered body with plastic properties. The infinite Hoek-Brown medium is applied. Different stages of longwalling are simulated by reducing a distance between the coal face and dismantling chamber. The strains and displacements calculated at a previous stage are taken into consideration at subsequent stage. Thus, the



a *b* *c*

Fig. 4. Design schemes at different distances between the longwall and dismantling chamber: 1 − dismantling chamber; 2 – coal seam; 3 – area of caved rocks (goaf); 4 − mined-out space; a – 20 m distance; b – 10 m distance; c – moment of conjugation

quasistatic process of longwall movement towards the preconstructed dismantling chamber is simulated.

The main reason to carry out the simulation is to locate the yielding area nearby the excavations and determine the displacement of excavation contour at each simulation stage. For this purpose a well-known empirical Hoek-Brown criterion is used as a condition of rock failure [4, 5]. To ensure the reliability of numerical simulation a special attention should be paid to the reliability of physical and mechanical rock properties. As we mentioned above, the rock mass under conditions of Western Donbas can be characterized as poor quality rocks. Rock mass inhomogeneity exists both at macro- and micro-levels.

The macro-level inhomogeneity can be observed in situ as the siltstone and mudstone in the roof and walls of excavation are heavy jointed. To consider the macro-level inhomogeneity we apply the generalized Hoek-Brown criterion developed especially for weak and fractured rocks. It involves the Geological Strength Index (GSI) [6,7] to estimate a degree of rock jointing and blocking. This index can be determined according to visual rock studying or using data base developed by Hoek and Brown. Based on GSI and developed formulas the numerical parameters of the generalized Hoek-Brown failure criterion can be determined. In such a way the rock texture and structure are taken into account during the simulation.

To use the generalized Hoek-Brown failure criterion at simulating the rock state around the dismantling chamber we define GSI for coal and rocks under conditions of 167-th plow longwall of *Stepnaya* mine on the basis of the data provided by the mine geological service (Table) and visual estimation of rocks during observations in situ. Based on this studying the GSI is taken equal to 50 which corresponds the 'very blocky' rock mass structure.

A uniaxial compressive strength of intact rock is one of parameters that the Hoek-Brown failure criterion involves. Actually this parameter is obtained by rock sample testing and processing the statistical results. The spread of specimen strength relatively an average value characterizes the micro-level inhomogeneity of rock mass. Decreasing the intact rock strength caused by the micro-level inhomogeneity should be considered with usage of a structural factor. It looks like

$$k_c = \frac{\sigma_m}{\overline{\sigma}_{ci}},$$

where σ_m is a compressive strength of real rock mass and $\overline{\sigma}_{ci}$ is an average compressive strength of the tested samples.

A technique to determine a structural factor has been developed by Shashenko & Sdvyzhkova [8] depending on the adopted statistical model of rock strength. The log-normal distribution of probabilities is the most appropriate model to describe the spread of rock strength under conditions of Donbas poor rocks. The structural factor based on the log-normal strength distribution looks like

$$k_c = \frac{\exp(t \cdot \sqrt{\ln(\eta^2 + 1)})}{\sqrt{\eta^2 + 1}}.$$

Here $t = \arg F(1-p)$ is an argument of normalized function of the normal law

$$F(t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{t} e^{-\frac{t^2}{2}} dt,$$

at its value is equal $1-p$; η is a variation of random values of rock sample compressive strength defined as

$$\eta = \frac{\sqrt{D(\sigma)}}{\overline{\sigma}_{ci}},$$

where $\sqrt{D(\sigma)}$ is a standard deviation of strength value.

Thus, introducing the structural factor based on the probability model we consider the micro-level inhomogeneity of rock mass. The rock mass compressive strength looks like $\sigma_m = \overline{\sigma}_{ci} \cdot k_c$

The Hoek-Brown constants and structural factor values as well as rock physical and mechanical properties are referred to the Table.

Simulation results. Simulations in terms of *Stepnaya* mine are carried out considering the initial stress field equals to 12 mPa. As a result, the displacements of rocks nearby the dismantling chamber are obtained depending on the distance from the longwall face (Fig. 5).

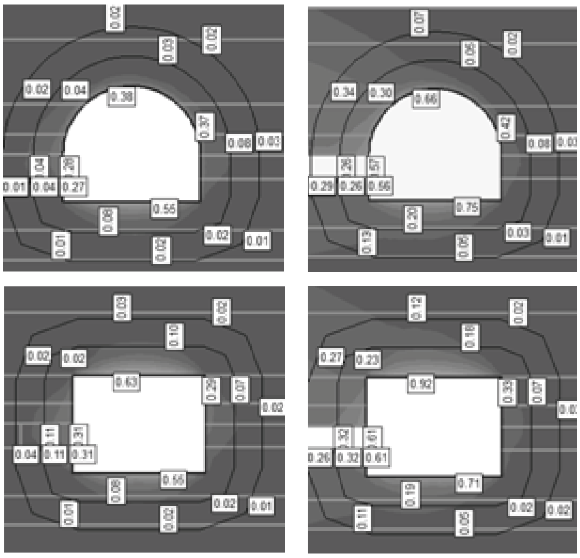
Rock displacements are studied directly on the contour of the dismantling chamber and at a distance of 1.0 and 2.0 m from the contour.

Due to the arch shape of the dismantling chamber the displacements in the roof are reduced up to 30–45 % in comparison with a rectangular form of cross-section.

Table

Physical and mechanical properties of the rocks

Characteristic	Argillite	Siltstone	Coal	Caved rocks
Young's modulus, MPa	3193.0	2981.7	11755.2	300.0
Poisson's ratio	0.3	0.3	0.3	0.3
Compressivestrengthof intactrock, MPa	32	43	37.5	7
Structural factor	0.5	0.45	0.6	-
Compressive strength reduced, MPa	16.0	20.0	22.5	7
Hoek-Brown parameter, m_b	1.17	1.13	2.66	0.98
Hoek-Brown parameter, a	0.51	0.51	0.5	0.51
Hoek-Brown parameter, s	0.001	0.001	0.016	0.0007



a b

Fig. 5. Displacement of rocks nearby the dismantling chamber: a – the distance between longwall face and chamber is 5 m; b – a moment of the longwall face and dismantling chamber conjugation

However, the displacement of the chamber contour at the moment of conjugation with longwall face is great in the roof (up to 0.63 m) and in the floor (up to 0.75 m) and walls (up to 0.6 m).

The special support should be developed to compensate such significant displacements. We can see that the simulation results are close to the observed in situ. Thus, we assume that the deformation model is calibrated and gives adequate results.

Besides modelling and analysis of displacements, it has been showed that mutual effect of coal face and dismantling chamber becomes significant when a distance between the longwall and chamber reduced up to 10–15 m. This is another confirmation of the fact that the calculation scheme and the sequence of the simulations are correct.

As indicated above, the definition of the yielding zone nearby the dismantling chamber is the next purpose of the simulation. The size of this zone determines the pressure on the support of the excavation. Because the adequacy of the model is proven, it can be assumed that the configuration of yielding zones is also consistent with reality.

The size of the yielding zone nearby the dismantling chamber as well as the rock displacement increases gradually and reaches its maximum at the moment of conjugation with the longwall face. The size of yielding zones increases in the roof above the mined out space, coal face and over dismantling chamber. These zones join together when the longwall approaches directly the wall of the chamber.

Within the yielding zone rocks have lost the cohesion between layers and a general part of rock mass. The weight of rocks within the yielding zone creates the load on the excavation support [9]. This concept is adopted in Ukrainian standards and regulations. Therefore, to locate the failure zones analysing the components of stress-strain state of rocks nearby the dismantling chamber and coal face is a challenge. The most important parameter is the height of the yielding zone. This parameter should be defined as normal to the layering. Its value can be used easily in engineering formulas for estimation of the pressure on the support.

The algorithm described above allows executing multiple calculations for various geological and mining conditions. The multivariate simulation enables to generate simple engineering formulas to determine the displacements of rocks nearby the dismantling chamber.

Multivariate simulation. Derivation of the general formulas for dismantling chamber design. The input parameters are:

- $\frac{B}{h}$ is a ratio of the width to the height of excavation;
- γH is a normal (vertical) component of the initial stress field;
- R_c is an average strength of the rock mass;
- m is a coal seam thickness.

To obtain the maximum displacements of dismantling chamber contour and the height of yielding zone as a function of input data the method of nonlinear estimation is used. It generalizes two methods: multiple regression and analysis of variance. Nonlinear estimation involves a preselecting type of the target functions of initial variables. It could be logarithmic, exponential, power, or any composition of elementary functions.

In general, all of the regression model can be written as a formula

$$y = F(x_1, x_2, ..., x_n).$$

The main issue of the nonlinear regression analysis is that the relationship between the target function and the initial variables exists, i.e. the dependent variable (function) is connected with a set of independent variables (arguments). Summarizing the results of the numerical simulation the model of exponential growth is used as one of the methods of nonlinear estimation. It looks like

$$y = a + \exp(b_0 + b_1 z_1 + b_2 z_2 + ... + b_m z_m),$$

where y is a target function; a, b_i are unknown coefficients; z_i are initial parameters.

To assess the adequacy of the model the Pearson's chi-squared test is used. If the value of chi-squared test statistic is significant, we reject the null hypothesis and accept the independent variables that affect significantly the target expression.

As a result of the regression analysis the following formulas are derived.

A maximum roof displacement of the dismantling chamber with an arched shape of a cross section could be defined by formula

$$U_{кр} = \exp\left(0.11\frac{B}{h} + 0.56\frac{\gamma H}{R_c} + 0.018 \cdot m - 0.23\right) - 0.8. \quad (1)$$

The visualization of this formula is shown on the Fig. 6.

A maximum floor displacement of the dismantling chamber with an arched shape of a cross section is

$$U_n = \exp\left(0.105\frac{B}{h} + 0.66\frac{\gamma H}{R_c} + 0.017 \cdot m - 0.225\right) - 0.8. \quad (2)$$

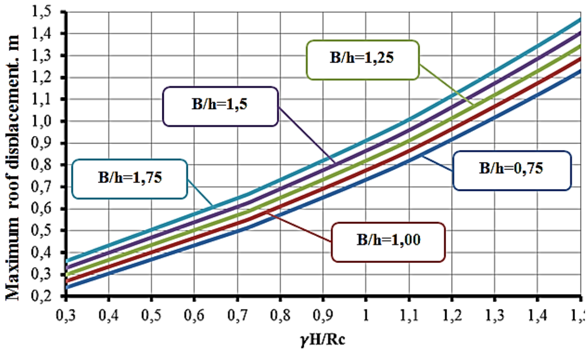


Fig. 6. Maximum roof displacement of the dismantling chamber with an arched shape of a cross section

A maximum displacement of the dismantling chamber wall adjoining with the coal face is

$$U_{бл} = \exp\left(0.1\frac{B}{h} + 0.28\frac{\gamma H}{R_c} + 0.002 \cdot m + 0.62\right) - 2. \quad (3)$$

A maximum displacement of the dismantling chamber wall bordering the intact rock is

$$U_{бц} = \exp\left(0.005\frac{B}{h} + \right.$$
$$\left. + 0.011\frac{\gamma H}{R_c} + 0.0001 \cdot m + 3.89\right) - 49.23. \quad (4)$$

For the dismantling chamber with a rectangular shape of a cross section the following formulas are derived.

A maximum roof displacement looks like

$$U_{кр} = \exp\left(0.17\frac{B}{h} + 0.65\frac{\gamma H}{R_c} + 0.12 \cdot m - 0.2\right) - 1.2.$$

The visualization of this formula is shown in Fig. 7.

A maximum floor displacement of the dismantling chamber with a rectangular shape of a cross section is

$$U_{п} = \exp\left(0.2\frac{B}{h} + 0.6\frac{\gamma H}{R_c} + 0.1 \cdot m - 0.1\right) - 1.21.$$

A maximum displacement of the dismantling chamber wall adjoining with the coal face is

$$U_{бл} = \exp\left(0.15\frac{B}{h} + 0.37\frac{\gamma H}{R_c} + 0.002 \cdot m + 0.52\right) - 2.05.$$

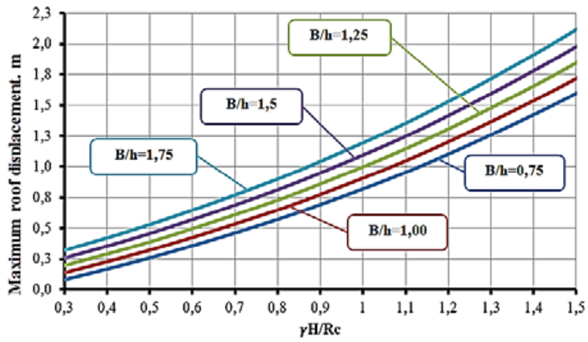


Fig. 7. Maximum roof displacement of the dismantling chamber with a rectangular shape of a cross section

A maximum displacement of the dismantling chamber wall bordering the intact rock is

$$U_{бц} = \exp\left(0.1\frac{B}{h} + 0.7\frac{\gamma H}{R_c} + 0.009 \cdot m - 1.35\right) - 0.25.$$

These values should be used for the dismantling chamber support design under different geological conditions.

The similar formulas are obtained to determine the height of a yielding zone:

- a rectangular shape of a cross section

$$h_p = 4.2\exp\left(0.5\frac{B}{h} + 0.6\frac{\gamma H}{R_c} + 0.2 \cdot m - 0.75\right) + 1.5;$$

- an arched shape of a cross section

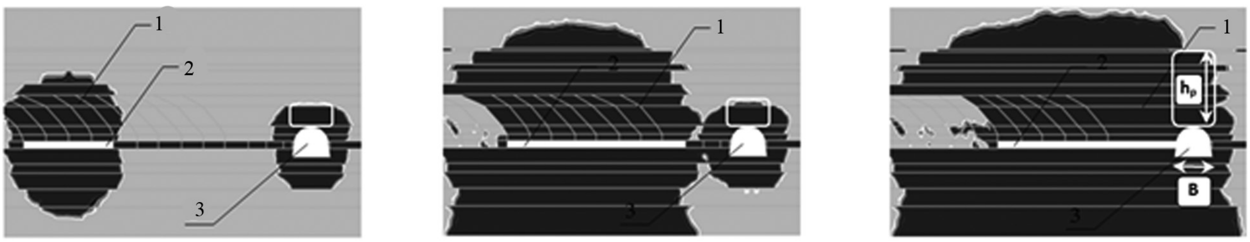
$$h_p = 4.2\exp\left(0.15\frac{B}{h} + 0.5\frac{\gamma H}{R_c} + 0.12 \cdot m - 0.01\right). \quad (5)$$

As indicated above, the weight of the rocks within the failure zone creates a load on the support according to the formula

$$P = \gamma \times S_m.$$

Where is the area of the yielding zone above the dismantling chamber; is a rock gravity.

The magnitude should be determined by a simple mathematical formula in engineering calculations. Despite the fact that the area of failure zone has an irregular shape, it can be approximately represented as a rectangle with a height h_p, and a base, equal to the width of excavation B (Fig. 8). Thus, some margin of safety is provided.



a *b* *c*

Fig. 8. Failure zone spreading: 1 – yielding zone; 2 – mined-out space; 3 – dismantling chamber; a – 10 m distance; b – 3 m distance; c – the moment of conjugation

Then the load on excavation support generated by failed rocks is approximately equal to

$$P = \gamma \cdot S = \gamma \cdot B \cdot h_p. \quad (6)$$

Using this approach the design of the dismantling chamber under condition of *Stepnaya* mine is created.

Engineering approach to the dismantling chamber design under condition of *Stepnaya* mine. The input data for calculation are:

- the depth of dismantling chamber is $H = 330$ m;
- the length of the longwall is 292 m.
- the area of chamber cross-section is $S = 15.5$ m^2;
- the width of dismantling chamber is $B = 5.2$ m;
- the height of the excavation is $h = 3.9$ m.

Hence, the excavation width – height ratio is $\frac{B}{h} = 1.57.$

The average compressive strength considering the structural factor is 17 MPa.

According to [10] a real depth of mining (H) should be increased while simulation to provide a safety margin.

Therefore, the design depth is, m

$$H_p = 1.5 \cdot 330 = 495.$$

Using this value we can calculate the normal component of the initial stress field, mPa.

$$\gamma H_p = 24.7 \cdot 495 = 12\,227 \text{ kN/m}^2 = 12.2\ .$$

Then the ratio of the vertical component of the initial stress field to the average rock strength should be determined

$$\frac{\gamma H}{R_c} = \frac{12.2}{17.0} = 0.72.$$

These parameters are used to calculate geomechanical characteristics of the dismantling chamber.

The height of the yielding zone above the dismantling chamber could be determined using (5), m

$$h_\partial = 4.2 e^{0.15 \cdot 1.57 + 0.5 \cdot 0.72 + 0.12 \cdot 0.85 - 0.01} = 8.35.$$

And then we can define the weight of the rocks within the failure zone, i.e. the support pressure (6), kN/m.

$$P_n = \gamma \cdot B \cdot h_p = 24.7 \cdot 5.2 \cdot 8.35 = 1072.$$

To ensure the stability of the dismantling chamber during the withdrawal of powered support shields throw the dismantling window the safety factor ($k_з$) should be taken into account, kN/m.

$$P_n = \gamma \cdot B \cdot h_p \cdot k_з = 24.7 \cdot 5.2 \cdot 8.35 \cdot 1.5 = 1608.$$

We can see that the support pressure is very high. It cannot be compensated by the installation of metal sets only. Obviously, the rock bolting is necessary. Taking into account the height of the yielding zone above the dismantling chamber an anchor system should be two-tier including the cable anchors with a length of at least 8 m.

The significant displacements of the dismantling chamber contour could confirm the necessity of roof bolting.

Using formulas (1–4) let us determine the values of displacements,

$$U_{кр} = \exp(0.11 \cdot 1.57 + 0.56 \cdot 0.72 + 0.018 \cdot 0.85 - 0.23) - 0.8 = 0.63;$$

$$U_{п} = \exp(0.105 \cdot 1.57 + 0.66 \cdot 0.72 + 0.017 \cdot 0.85 - 0.225) - 0.8 = 0.74;$$

$$U_{бл} = \exp(0.1 \cdot 1.57 + 0.28 \cdot 0.72 + 0.002 \cdot 0.85 + 0.62) - 2 = 0.77;$$

$$U_{бц} = \exp(0.005 \cdot 1.57 + 0.011 \cdot 0.72 + 0.0001 \cdot 0.85 + 3.89) - 49.23 = 0.44\ .$$

The value of total vertical displacement is,

$$U = U_{кр} + U_{п} = 0.63 + 0.74 = 1.37.$$

This value shows the need of roof bolting.

The maximum displacement of the dismantling chamber wall adjoining with the coal face ($U_{бл} = 0.77$ m) indicates the additional support necessity at this part of rock mass to provide the safety approaching of the longwall face.

The dismantling chamber wall adjoining with the coal face could be strengthened by installing the rail (8.0 m length) at the angle of 5–7° to the coal seam and 50° with respect to the excavation line to overlaps 4 sections of powered roof supports. Then the extremely fast reacting two-component injection resin "Bevedol-Bevedan" is pumped into strata to form a pore-free material. The distance between rails is 3.5–4.0 m.

Thus, to compensate the displacement of the roof the next support elements are necessary:

- 6 steel-polymer bolts with a length of 2.5 m installed between metal sets;
- 1 deep-level cable anchor ($L = 8.0$ m) installed between metal sets;
- 1 additional rail ($L = 8.0$ m) to the wall adjoining with the coal face (Fig. 9).

Conclusions.

1. A mutual effect of the coal face and the dismantling chamber becomes significant when distance between the longwall and chamber reduced up to 10–15 m.

2. Due to the arch shape of dismantling chamber the displacements in the roof are reduced up to 30–45 % in comparison with a rectangular form of cross-section. However, the displacements are significant at the moment of conjugation with longwall face. They increase up to 0.6–0.7 m in the roof and floor and walls of excavation.

3. The reliable estimation of rock stress-strain state at plow longwalling allowed designing an adequate support

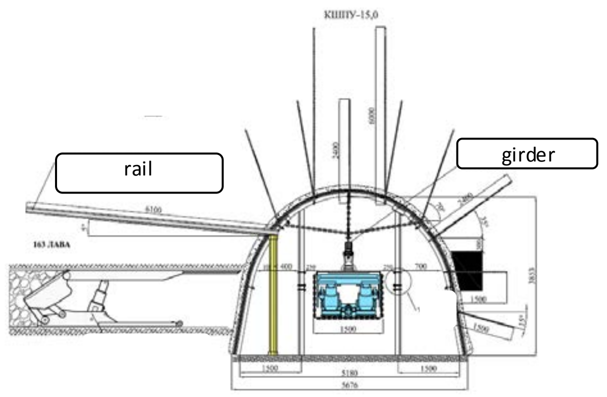


Fig. 9. Support scheme of the dismantling chamber

of pre-constructed chamber under conditions of *Stepnaya* mine and dismantling the plow equipment safely.

4. Just-in-time monitoring and compensation of deformations allowed keeping the excavation cross-section in the sufficient for operation form.

5. The failure zones around the mined-out space and pre-constructed chamber spreads depending distance between these both excavations.

6. The formulas are derived to calculate constitutive geomechanical characteristics and provide an adequate support design for the dismantling chamber under various mining and geological conditions. They form a background for developing the standards of dismantling chamber designing under conditions of Western Donbas.

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Мета. Встановлення закономірностей змінення переміщень контуру попередньо спорудженої демонтажної камери при наближенні вибою стругової лави, а також розробка інженерної методики визначення навантаження на кріплення демонтажної камери, враховуючи зростання гірського тиску.

Методика. Переміщення порід навколо камери демонтажу досліджуються в умовах шахти шляхом встановлення глибинних реперних станцій. Чисельний аналіз використано для визначення напружено-деформованого стану порід на основі пружно-пластичної моделі деформаційного середовища. Реалізується процедура накопичення деформацій за послідовного збільшення розмірів очисного простору. Зони руйнування визначаються за критерієм міцності Хока-Брауна. Чисельне моделювання виконане для низки гірничо-геологічних умов та розмірів виробки. Для побудови узагальнюючих залежностей використовується метод множинної регресії та дисперсійний аналіз.

Результати. Виконані багатоваріантні розрахунки напружено-деформованого стану навколо стругової лави та демонтажної камери для різних значень міцності порід, потужності вугільного пласта, глибини розробки та розмірів демонтажного штреку. Одержані результати були узагальнені для різноманітних гірничо-геологічних умов у вигляді залежностей висоти зон руйнування та переміщень контуру демонтажної камери від факторів, що перелічені вище.

Наукова новизна. Уперше встановлені залежності розвитку деформацій та формування зон руйнування в породному масиві навколо демонтажної камери в момент спряження з вибоєм стругової лави. Одержані розрахункові формули для визначення основних геомеханічних характеристик, що необхідні для вибору способу кріплення демонтажної камери в різноманітних гірничо-геологічних умовах.

Практична значимість. Сукупність формул для визначення основних геомеханічних характеристик складає інженерну методику встановлення навантаження на кріплення демонтажної камери, а також є основою типових матеріалів проектування демонтажних камер стругових лав в умовах Західного Донбасу.

Ключові слова: *демонтажна камера, стругова лава, напружено-деформований стан, критерій міцності.*

Цель. Установление закономерностей изменения перемещений контура предварительно сооруженной демонтажной камеры при приближении забоя струговой лавы, а также разработка инженерной методики определения нагрузки на крепь демонтажной камеры с учетом возрастания горного давления.

Методика. Перемещения пород вокруг демонтажной камеры исследуются путем установки глубинных реперных станций. Численный анализ выполнен для оценки напряженно-деформированного состояния пород на основе упругопластической модели деформационной среды. Реализуется процедура накопления деформаций при последовательном изменении размеров моделируемой полости. Зоны разрушения определяются по критерию прочности Хоека-Брауна. Численное моделирование выполнено для различных горно-геологических условий и размеров выработки. Для построения обобщающих зависимостей используется метод нелинейного оценивания, сочетающий множественную регрессию и дисперсионный анализ.

Результаты. Выполнены многовариантные расчеты напряженно-деформированного состояния области, содержащей струговую лаву и демонтажную камеру, для различных значений прочности пород, мощности угольного пласта, глубины разработки и размеров демонтажного штрека. Полученные результаты обобщены для различных горно-геологических условий в виде зависимостей высоты зон разрушения и перемещений контура демонтажной камеры от перечисленных выше факторов.

Научная новизна. Впервые установлены закономерности развития деформаций и формирования зон разрушения в породном массиве в окрестности демонтажной камеры в момент сопряжения с забоем струговой лавы. Получены расчетные формулы для определения основных геомеханических характеристик, необходимых для выбора способа крепления демонтажной камеры в различных горно-геологических условиях.

Практическая значимость. Совокупность формул для определения основных геомеханических характеристик составляет инженерную методику определения нагрузки на крепь демонтажной камеры, а также является основой типовых материалов проектирования демонтажных камер струговых лав в условиях Западного Донбасса.

Ключевые слова: *демонтажная камера, струговая лава, напряженно-деформированное состояние, критерий прочности*.

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GENERAL MOST PROBABLE POINT BASED APPROACH FOR RELIABILITY INDEX COMPUTATION

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УНІВЕРСАЛЬНИЙ ПІДХІД ДО РОЗРАХУНКУ КОЕФІЦІЄНТА НАДІЙНОСТІ, ЩО ГРУНТУЄТЬСЯ НА НАЙІМОВІРНІШИХ ЗНАЧЕННЯХ

Purpose. As for the reliability analysis of complex engineer problems, the nonlinearity and implicitness of the limit state functions always stand in the way. On one hand, the nonlinearity influences the convergence computation of some reliability problems when using most methods of reliability analysis. On the other hand, the implicitness means that information of the partial derivatives of the limit state function is impossible to obtain, which is necessary for most of the reliability methods. In order to overcome these difficulties, the paper presents a new general most probable point based (MPP-based) approach for computing the reliability.

Methodology. Within the framework of the proposed iterative algorithm, we presented new strategies for searching three types of the approximate MPPs by merely using the input and output information of the limit state function. In addition, the found MPPs can be used for updating the constructed response surface of the limit state function, which in its turn helps to find a more accurate MPP.

Findings. As illustrated by the examples, the proposed method provides excellent precision and convergence for the calculation results.

Originality. Three types of the approximate MPPs are firstly presented for updating the constructed response surface of the limit state function, whose input and output information is sufficient.

Practical value. The proposed method does not necessitate any requirements for the detailed format and complexity of the limit state functions, which is an advantage. Hence, it is especially applicable to the implicit case of complex engineer problems.

Keywords: *limit state function, most probable point, index computation*