Supporting a Mine Working with a Shelter in Various Mining and Geological Conditions

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http://doi.org/10.29227/IM-2023-01-05

Submission date: 22-02-2023 | Review date: 20-03-2023

Abstract

Shelters are used to protect miners from exposure to harmful gases and for the work of rescuers. Such shelters are built in a niche adjacent to the mine working. The purpose of this work is a numerical study of the stress state of a coal-rock massif with a mine working and a shelter, their stability in various mining and geological conditions and with various supporting schemes.
Numerical simulation of the stress state of a coal-rock massif with a mine working and a shelter was performed; their stability was studied in various mining and geological conditions and with various supporting schemes. It is shown that, over time, near-contour rocks are unloaded from rock pressure, and an area of increased difference of the stress tensor compo-nents expands around the mine working and the shelter. This leads to cracks formation of varying degrees of intensity. When the mine working with the shelter is driven at a shallow depth in hard rocks, the basic scheme, which consists mainly of metal frames and a reinforced concrete barrier, is sufficient for their supporting. If the host rocks are weaker, the stability of the mine working and the shelter is broken and it is necessary to strengthen their supporting with rock bolts. In the bolted area, the rocks are in triaxial compression conditions, a rock-bolts arch is formed above the mine working and the shelter, which pre-vents the displacement of the roof rocks into the mine working and increases its stability. With an increase in the depth of min-ing operations, the stability of the mine working decreases; the inelastic deformation zone in the mine walls grows; the load on the support increases. For the rock-bolts arch formed in the mine roof, supports are required in the walls of the mine working and the shelter. For this purpose, side rock bolts are installed. The use of an appropriate supporting scheme leads to a de-crease of the area of inelastic deformation zone by 2.5 times and the area of the zone unloaded from rock pressure by 2.6 times. Thus, such schemes for supporting the mine working and the shelter are selected, which ensure their stability in the con-sidered mining and geological conditions.

Keywords: *mine workings stability, mining safety, numerical simulation, rock deformation, shelters, supporting of mine workings*

1. Introduction

Coal mining is of paramount importance during the conduct of warfare, when the demand for energy carriers is increased and there is a constant threat to the country's energy infrastructure. Most mines in Ukraine develop gas-bearing coal seams, and host rocks also contain methane. In order to meet air sanitary standards in the mine workings, their ventilation and degassing of the coal-rock massif are used. Emergency power cuts lead to the shutdown of many technological processes, in particular, ventilation, degassing, mine hoisting. Under such conditions, methane accumulations and explosions of the methane-air mixture represent a significant danger to miners. Shelters are used to protect miners from lack of oxygen and exposure to harmful gases [1, 2]. Shelters are also necessary for the work of rescuers who must explore and take the victims out of the emergency area. Such shelters are built in a niche adjacent to the mine working [3, 4].

To ensure non-repair operation of the mine working and the shelter for a long time, as well as the tightness of the shelter, it is necessary to choose their supporting correctly [5, 6]. Therefore, the purpose of this work is a numerical study of the stress state of a coal-rock massif with a mine working and a shelter, their stability in various mining and geological conditions and with various supporting schemes.

2. Problem definition

Fig. 1 shows a typical design of a shelter adjacent to a mine working that is driven through a coal seam. Both the mine working and the shelter are supported with frames, the astel of the walls and the roof is reinforced concrete, the shelter is separated from the mine working by a concrete barrier 200 mm thick. The floor of the shelter is located 700 mm above the floor of the mine working.

Several variants for mining and geological conditions were considered in this work: the depth of the mine working construction is 400 m and 800 m, the host rock is hard sandstone and weak argillite. For these conditions, the effectiveness of the use of three supporting schemes was investigated:

- the 1st supporting scheme, basic (fig. 1);
- the 2nd supporting scheme, basic scheme + 7 steel rock bolts 2.4 m long with polymer fastening in the borehole in the mine roof + 2 of the same rock bolts in the shelter roof;
- the 3rd supporting scheme, basic scheme + 7 steel rock bolts 2.4 m long with polymer fastening in the borehole in the mine roof + 2 of the same rock bolts in the shelter roof + 2 plastic bolts 1.5 m long in the coal seam in the right wall of the mine working and in the left wall of the shelter.

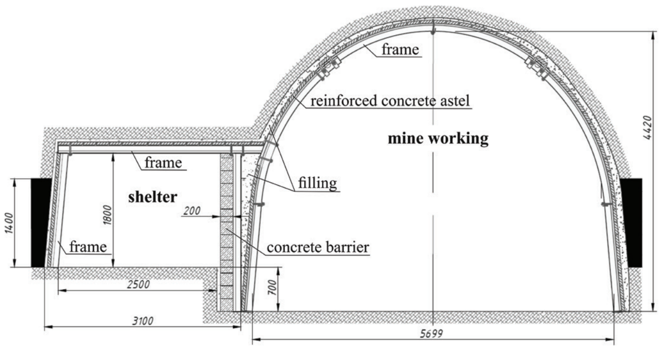

Fig. 1. The typical design of the shelter

Rys. 1. Typowy projekt schronu

Tab. 1. The properties of rocks and materials

Tab. 1. Właściwości skał i materiałów

Rocks and materials	Ultimate strength σ_c, MPa	Modulus of elasticity, E, GPa	Poisson's ratio, ν	Cohesion, C, MPa	Friction angle, φ, deg
Sandstone	42	13	0.36	11.2	34.0
Argillite	20	11	0.32	5.8	30.0
Coal	15	5	0.26	4.5	28.5
Steel	650	200	0.25	-	-
Concrete	40	20	0.2	11.5	30.0
Reinforced concrete	50	24	0.2	13.9	32.0
Backfilling	2	1.2	0.18	0.7	20.0

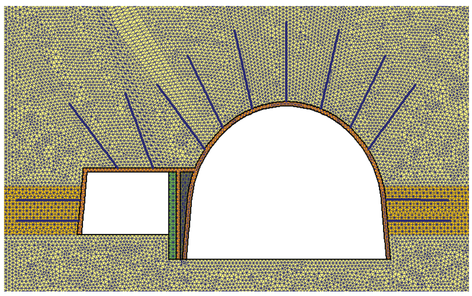

Fig. 2. The central fragment of the finite element mesh

Rys. 2. Centralny fragment siatki elementów skończonych

The properties of rocks and materials support that were used in the calculation are given in Tab. 1.

3. Methods

The process of rocks deformation is described by such equations [7, 8]:

$$c_g \frac{\partial u_i}{\partial t} = \sigma_{ij,j} + X_i(t) + P_i(t),$$

where c_g – the damping coefficient, kg/(m^3·s); u_i – displacements, m; t – time, s; $\sigma_{ij,j}$ – derivatives of the stress tensor components along x, y, Pa/m; $X_i(t)$ – projections of the external forces acting on the volume unit of a solid body, N/m^3.

The initial and boundary conditions for this task set are:

$$\sigma_{yy}\big|_{t=0} = \gamma H; \quad \sigma_{xx}\big|_{t=0} = \lambda\gamma H; \quad u_x\big|_{t=0} = 0; \quad u_y\big|_{t=0} = 0;$$

$$u_x\big|_{\Omega_1} = 0; \quad u_y\big|_{\Omega_2} = 0,$$

where λ – the side thrust coefficient; H – the mining depth, m; Ω_1 – vertical boundaries of the outer contour; Ω_2 – horizontal boundaries of the outer contour.

The problem is solved in an elastic-plastic formulation by the finite element method [9–11]. For the mathematical description of the process of rocks changeover into a disturbed state, the Mohr-Coulomb failure theory is applied [12, 13]. The rock bolts are simulated by the rod finite elements [14–16]. The central fragment of the finite element mesh with the mine working and the shelter, which are supported according to the 3rd scheme, is shown in Fig. 2.

Such geomechanical parameters as Q* characterizing the difference of the stress tensor components and P* characterizing a probable rock failure mode are applied to evaluate the stress state of rock [17]:

$$Q^* = \frac{\sigma_1 - \sigma_3}{\gamma H}; \qquad P^* = \frac{\sigma_3}{\gamma H},$$

where σ_1, σ_3 – maximum and minimum components of the principal stress tensor, Pa; γ – averaged weight of the overlying rocks, N/m^3.

4. Study of the stability of a mine working and a shelter, and their supporting in various mining and geological conditions

First, it was investigated whether the basic support shown in Fig. 1 ensures the stability of the mine working and the shelter at a relatively shallow depth of 400 m, if the host rock is sandstone or argillite. Figure 3 demonstrates the results of calculating of Q* parameter values and zones of inelastic de-

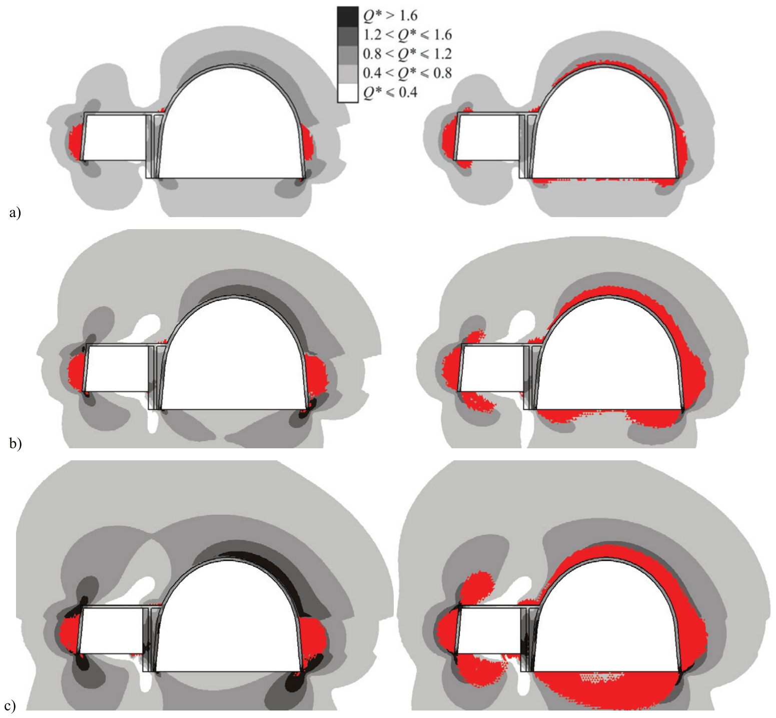

Fig. 3. Distributions of Q* parameter values and inelastic deformation zones (red color) in the rocks around the mine working and the shelter with the 1st supporting scheme, H = 400 m, host rock is sandstone (on the left side) and mudstone (on the right side) at the time points: a) t = 1 day; b) t = 3 days; c) t = 20 days

Rys. 3. Rozkłady wartości parametrów Q* i stref odkształceń niesprężystych (kolor czerwony) w skałach wokół wyrobiska i schronu przy pierwszym schemacie obudowy, H = 400 m, skałą macierzystą jest piaskowiec (po lewej stronie) oraz mułowiec (po prawej stronie) w punktach czasowych: a) t = 1 dzień; b) t = 3 dni; c) t = 20 dni

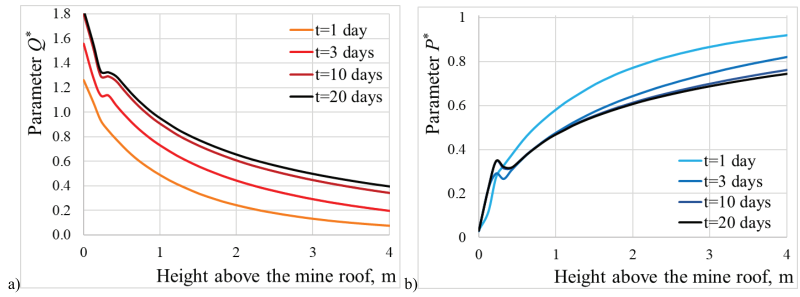

Fig. 4. Changes in the values of geomechanical parameters in the mine roof along the vertical axis passing through the center of the mine working at different points in time; the host rock is argillite; the 1st supporting scheme: a) Q* parameter; b) P* parameter

Rys. 4. Zmiany wartości parametrów geomechanicznych stropu kopalni wzdłuż pionowej osi przechodzącej przez środek kopalni pracującej w różnych punktach czasowych; skałą macierzystą jest argilit; pierwszy schemat wspomagający: a) parametr Q*; b) parametr P*

formations, which are shown in red, in the rocks and support at various points in time.

Mine working drivage leads to a redistribution of the stress field in the host rock (Fig. 3). Over time, the zone of increased difference of the stress tensor components (Q* parameter) expands around the mine working and the shelter. During one day, the zone, where Q* > 0.4, extends deep into the mine roof by 1.3 m and in 20 days it reaches 4.0 m (Fig. 4a). An increase of Q* parameter values leads to cracks formation with different degrees of intensity. If the values of this parameter decrease, the mine working becomes more stable. Q* parameter takes on large values in the mine roof, in the coal seam near the exposed surface and in the roof of the shelter, above its left wall (Fig. 3). P* parameter values, on the contrary, decrease with time because the near-contour rocks are gradually unloaded from rock pressure (Fig. 4b). On the mine working contour P* parameter values are equal to zero.

Zones of inelastic deformations arise if the ultimate strength of rock is exceeded and its destruction is possible [18]. In this case, we will assume that the mine working is unstable. It can be seen how the zone of inelastic deformations grows with time in the mine roof, composed of argillite, and the mine working loses its stability. In both cases, the weaker coal seam is fractured in the walls of the mine working and the shelter. However, it can be seen that the zone of inelastic deformations does not occur in the mine roof if it is composed of sandstone. Durable sandstone withstands such a load without fracture; the mine roof does not lose stability. The concrete barrier, which is part of the support structure located between the mine working and the shelter, deforms elastically under these conditions and performs its function of supporting the rock arch.

Therefore, in the case when the mine working with the shelter is driven at a shallow depth, in hard rocks, the basic

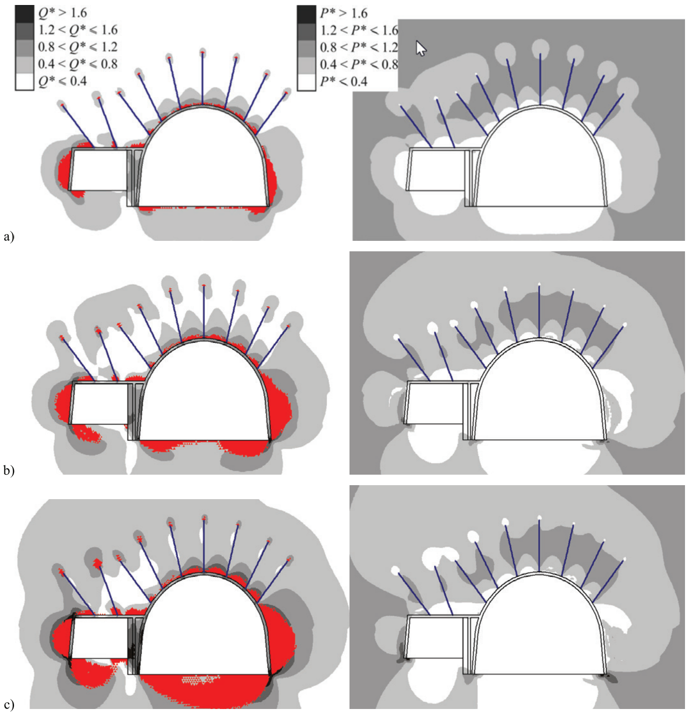

Fig. 5. Inelastic deformation zones (red color) and distributions of Q* parameter values (on the left side) and P* parameter values (on the right side); the 2nd supporting scheme; H = 400 m; host rock is argillite; at the time points: a) t = 1 day; b) t = 3 days; c) t = 20 days

Rys. 5. Strefy odkształceń niesprężystych (kolor czerwony) oraz rozkłady wartości parametrów Q* (po lewej stronie) i wartości parametrów P* (po prawej stronie); drugi program wsparcia; H = 400 m; skałą macierzystą jest argilit; w punktach czasowych: a) t = 1 dzień; b) t = 3 dni; c) t = 20 dni

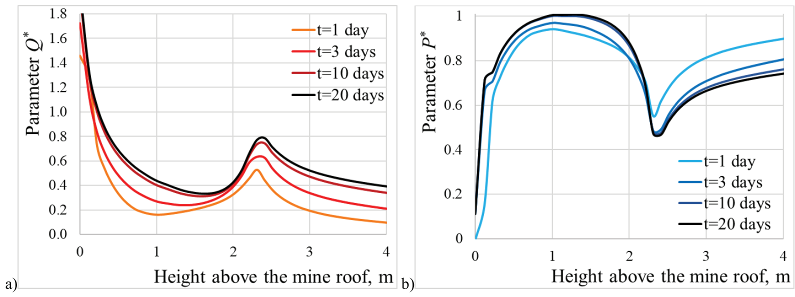

Fig. 6. Changes in the values of geomechanical parameters in the mine roof along the vertical axis passing through the center of the mine working at different points in time; the host rock is argillite; the 2nd supporting scheme: a) Q* parameter; b) P* parame-ter

Rys. 6. Zmiany wartości parametrów geomechanicznych stropu kopalni wzdłuż pionowej osi, przechodzącej przez środek kopalni pracującej w różnych punktach czasowych; skałą macierzystą jest argilit; drugi schemat wspomagający: a) parametr Q*; b) parametr P*

scheme is sufficient for their supporting. If the host rocks are weaker, it is necessary to strengthen the supporting of the mine working and the shelter.

Next, calculations are performed for the following conditions: H = 400 m; host rock is argillite; the 2nd supporting scheme is used. Figure 5 shows the calculation results.

If rock bolts are installed in the roof of the mine working and the shelter, the distribution of Q* parameter values changes. The difference of the stress tensor components is significantly reduced, the area of undisturbed rock zones where Q* < 0.4 increases. Areas where Q* > 0.8 are closely adjacent to the surface of the mine roof. The zone of inelastic deformations in the near-contour rocks of the mine roof practically disappears (Fig. 5, on the left side).

When the free surface is exposed during the mining excavation, the minimum component of the principal stress tensor decreases, which is shown by the P* parameter. An increase of the P* parameter value in a certain area of the rock massif will bring the state of this area closer to equal-component compression, and the probability of its fracture will decrease. Figure 5 (on the right side) shows that the rocks of the floor and walls of the mine working and the shelter are unloaded from rock pressure, here P* < 0.4. While above the working, in the bolted area, a zone was formed, where P* > 0.8.

Let us compare the graphs of geomechanical parameters in the cases of basic supporting and basic supporting with the addition of roof bolting, Fig. 4 and Fig. 6.

The length of the rock bolt is 2.4 m and the depth of its influence in the mine roof corresponds to this value. At a distance of 0–2.4 m, when installing rock bolts, Q* parameter values decrease by an average of 1.8 times, maximum by 3.1 times in the initial period of time at a depth of 1 m from the mine working contour (Fig. 6a). P* parameter values increase by an average of 1.9 times, with a maximum of 4.0 times in the near-contour zone.

Thus, in the bolted area, the rocks are in triaxial compression conditions with increased values of the minimum principal stress component [19]. Consequently, a rockbolts arch

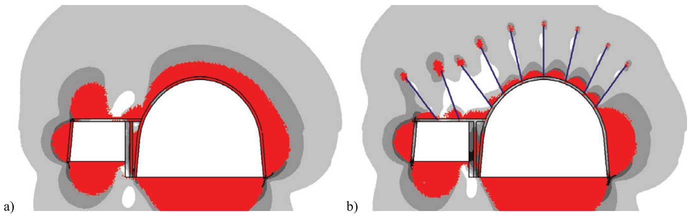

Fig. 7. Inelastic deformation zones (red color) and distributions of Q* parameter values; H = 800 m; host rock is argillite; t = 20 days: a) the 1st supporting scheme; b) the 2nd supporting scheme

Rys. 7. Strefy odkształceń niesprężystych (kolor czerwony) i rozkłady wartości parametrów Q*; H = 800 m; skałą macierzystą jest argilit; t = 20 dni: a) pierwszy schemat wsparcia; b) drugi schemat wsparcia

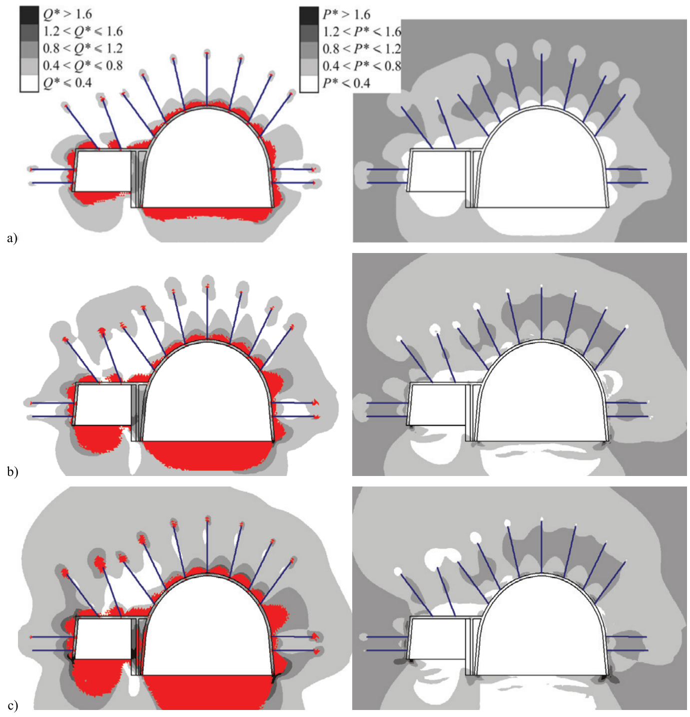

Fig. 8. Inelastic deformation zones (red color) and distributions of Q* parameter values (on the left side) and P* parameter values (on the right side); the 3rd supporting scheme; H = 800 m; host rock is argillite; at the time points: a) t = 1 day; b) t = 3 days; c) t = 20 days

Rys. 8. Strefy odkształceń niesprężystych (kolor czerwony) oraz rozkłady wartości parametrów Q* (po lewej stronie) i P* (po prawej stronie); trzeci program wspierający; wys. = 800 m; skałą macierzystą jest argilit; w punktach czasowych: a) t = 1 dzień; b) t = 3 dni; c) t = 20 dni

is formed above the mine working and the shelter, where the rocks are preserved in a natural, undisturbed state, and the rock bolts effectively interact with each other, preventing the displacement of the near-contour rocks into the mine working and increasing its stability [20].

With an increase in the depth of mining operations from 400 m to 800 m, the initial stress state of the rocks deteriorates and the mine working stability decreases, Fig. 7. It can be seen that distributions of the Q* parameter values for the same conditions at a depth of 400 m (Fig. 5c) and 800 m (Fig. 7b) are the same, since the Q* parameter is a relative value and does not depend on the depth H.

The area of the inelastic deformation zone increases by 68% around the mine working with basic supporting scheme and by 58% around the mine working with supporting according to the 2nd scheme. With increasing depth, the support structure located between the mine working and the shelter begins to experience limiting stresses. However, the durable reinforced concrete barrier, which is the main element of this structure, withstands high stresses and does not fracture. With the transition to a greater depth, the load on the anchor lining also increases. With increasing depth, the load on the roof bolting also increases. For the rock-bolts arch formed in the mine roof, supports are required in the walls of the mine working and the shelter. For this purpose, in the 3rd supporting scheme, it is provided to install side rock bolts in the coal seam.

Fig. 8 shows that with the installation of side rock bolts, the zone of inelastic deformations in the coal seam is significantly reduced; Q* parameter values decrease; P* parameter values in the bolted area in the walls of the mine working and the shelter increase to a value characterizing undisturbed rocks not unloaded from rock pressure. The coal seam is not fractured in the near-contour zone when using the 3rd supporting scheme. Thus, rockbolts supports for the rock-bolts arch, which is located in the mine roof, are formed in the walls of the mine working and the shelter.

It is possible to evaluate the change in the zone of inelastic deformations and the zone unloaded from rock pressure, the growth of which negatively affects the stability of mine workings, using the graphs shown in Fig. 9.

The inelastic deformation zone increases in size with time (Fig. 9a) and its growth is much slower if the 2nd or 3rd sup-

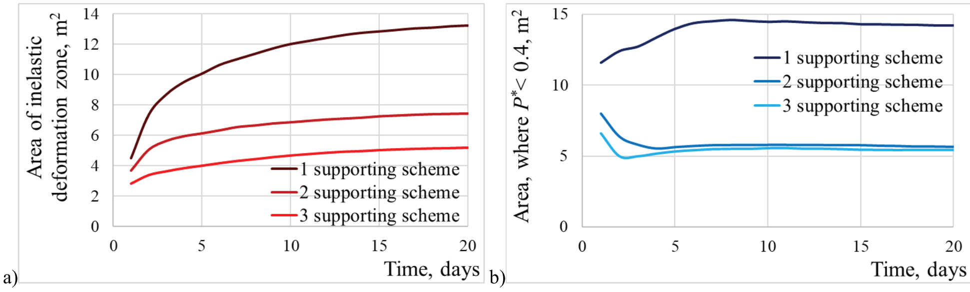

Fig. 9. Time change of the area of: a) the zone of inelastic deformations; b) the zone where P* < 0.4 in the roof and walls of the mine working and shelter, depending on the applied supporting scheme; the host rock is argillite; H = 800 m

Rys. 9. Zmiana czasowa obszaru: a) strefy odkształceń niesprężystych; b) strefa, w której P* < 0,4 w stropie i ścianach wyrobiska i schronu w zależności od zastosowanego systemu wsparcia; skałą macierzystą jest argilit; H = 800 m

porting scheme is used [21, 22]. Installation of rockbolts in the roof and walls of the mine working and the shelter reduces the area of the non-elastic deformation zone by 2.5 times.

The zone unloaded from rock pressure in the roof and walls practically does not change in size starting from the 6th day after the installation of the supporting, Fig. 9b. If the 3rd supporting scheme is applied, then the area of the zone where P* < 0.4 is reduced by 2.6 times.

5. Conclusions

Numerical simulation of the stress state of a coal-rock massif with a mine working and a shelter was performed; their stability was studied in various mining and geological conditions and with various supporting schemes.

It is shown that, over time, near-contour rocks are unloaded from rock pressure, and an area of increased difference of the stress tensor components expands around the mine working and the shelter. This leads to cracks formation with different degrees of intensity. When the mine working with the shelter is driven at a shallow depth in hard rocks, the basic scheme, which consists mainly of metal frames and a reinforced concrete barrier, is sufficient for their supporting. If the host rocks are weaker, the stability of the mine working and the shelter is broken and it is necessary to strengthen their supporting with rock bolts. In the bolted area, the rocks are in triaxial compression conditions, a rock-bolts arch is formed above the mine working and the shelter, which prevents the displacement of the roof rocks into the mine working and increases its stability.

With an increase in the depth of mining operations, the stability of the mine working decreases; the inelastic deformation zone in the mine walls grows; the load on the support increases. For the rock-bolts arch formed in the mine roof, supports are required in the walls of the mine working and the shelter. For this purpose, side rock bolts are installed. The use of an appropriate supporting scheme leads to a decrease in the area of the inelastic deformation zone by 2.5 times and the area of the zone unloaded from rock pressure by 2.6 times.

Thus, such schemes for supporting the mine working and the shelter are selected, which ensure their stability in the considered mining and geological conditions.

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Wspomaganie kopalni pracującej ze schronem w różnych warunkach górniczych i geologicznych

Schrony służą do ochrony górników przed narażeniem na szkodliwe gazy oraz do pracy ratowników. Schrony takie budowane są w niszy przylegającej do wyrobiska kopalnianego. Celem pracy jest numeryczne badanie stanu naprężeń masywu węglowo-skalnego z wyrobiskiem i osłoną, jego stateczności w różnych warunkach górniczo-geologicznych i przy różnych układach obudowy.
Wykonano symulację numeryczną stanu naprężeń masywu węglowo-skalnego z wyrobiskiem i schronem. Badano ich stabilność w różnych warunkach górniczych i geologicznych oraz przy różnych schematach podparcia. Pokazano, że w miarę upływu czasu skały przykonturowe odciążają się od naporu skał, a wokół wyrobiska i schronu rozszerza się obszar zwiększonej różnicy składowych tensora naprężeń. Prowadzi to do powstawania pęknięć o różnym stopniu intensywności. Gdy kopalnia współpracująca ze schronem jest prowadzona na płytkiej głębokości w twardych skałach, do ich podparcia wystarcza podstawowy schemat, składający się głównie z metalowych ram i bariery żelbetowej. Jeżeli skały macierzyste są słabsze, stabilność wyrobiska kopalnianego i osłony jest zerwana i konieczne jest wzmocnienie ich podparcia kotwami skalnymi. W rejonie kotwionym skały znajdują się w stanie trójosiowego ściskania, nad wyrobiskiem i schronem tworzy się łuk kotwowy, co zapobiega przemieszczaniu się skał stropowych do wyrobiska i zwiększa jego stateczność. Wraz ze wzrostem głębokości eksploatacji zmniejsza się stabilność wyrobiska górniczego, powiększa się strefa odkształceń niesprężystych w ścianach kopalni, obciążenie podpory wzrasta. Dla łuku kotwiowego formowanego w stropie kopalni wymagane są podpory w ścianach wyrobiska i schronu. W tym celu montowane są boczne kotwy skalne. Zastosowanie odpowiedniego schematu podparcia prowadzi do 2,5-krotnego zmniejszenia powierzchni strefy odkształceń niesprężystych oraz 2,6-krotnej powierzchni strefy odciążonej od parcia skał. W związku z tym dobierane są takie schematy obudowy wyrobiska i osłony, które zapewniają ich stabilność w rozważanych warunkach górniczo-geologicznych.

Słowa kluczowe: *stateczność wyrobisk górniczych, bezpieczeństwo górnicze, symulacje numeryczne, deformacje skał, osłony, obudowy wyrobisk górniczych*