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Rock bolt and frame support of mine workings with a compound cross-section: Collective refuge chambers for mine workers

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Abstract

Purpose is to study the influence of mining and geological conditions on the time-dependent stability of the collective refuge chamber for mine workers with the adjacent mine workings and develop support schemes for different conditions of construction of such mine workings.

Methods. Numerical modelling methods of the connected processes of elastoplastic deformation of gas-bearing rocks and gas filtration within the area disturbed during mining operations were used to study stability of mine workings with a compound cross-section, i.e. the collective refuge chambers and its adjacent extraction gallery. The model was based on fundamental principles of solid mechanics and filtration theory. The problem was solved using a finite element method.

Findings. A classification of the conditions for locating collective refuge chambers for mine workers according to the relative strength of the enclosing rocks was developed. Support schemes for the chamber and its adjacent mine working were elaborated. The schemes include basic support and provide for its strengthening with rock bolts located in the roof of the mine working and chamber, or in their walls. The compliance of these support schemes with the developed classification of location conditions was determined. A numerical study of the time-dependent stability of the chamber and its adjacent mine working, while applying the recommended support scheme, was performed. It is shown that the strengthening of rock bolting schemes reduces the multicomponent stress field and the area of the zone of inelastic deformations, forms a rock-bolt overlap in the roof of the mine workings and chambers, which helps increase their stability under the complicated mining and geological conditions.

Originality. Dependence of the changes within the area of a zone of inelastic deformations around the chamber with its adjacent mine working on the relative strength of the enclosing rocks was identified; time-dependent changes within the area of the zone of inelastic deformations, when using different support types, were specified.

Practical implications. Support schemes for collective rescue chambers for mine workers in terms of different construction conditions were developed along with the procedure of their selection for specific mining and geological conditions. The results of the study provide theoretical substantiation and scientific guidelines for the selection of supports for collective refuge chambers adjacent to the mine working.

Keywords: *rock bolt and frame support, relative rock strength, refuge chamber, time-dependent stability of mine workings, support schemes, numerical modelling*

1. Introduction

The most important task in underground mining is to support mine workings and maintain them in a safe operating condition throughout the entire period of use. Selecting supports for the mine workings with a compound cross-section is associated with specific difficulties, such as a large open roof span, significant redistribution of stress and deformation fields, additional load on the support, and roof caving [1]-[5]. Most often, the complexity of the mine working geometry is stipulated by the crossing or close location of two mine workings. For instance, it can be crossing of the main and branch tunnels [6], long-span branch bifurcated tunnels with complex 3D geometry [7], crossing of mine workings with various types of coal mine supports [3], [4], [8]-[11], a combination of longwall and an extraction gallery [12]-[17], and transport nodes in an underground mine [18].

Collective refuge chambers for mine workers can be located in a stable hole next to a mine working [19]; in this case, this underground object as a whole will also have compound cross-section. They are built on the exit routes of miners and protect them during accidents [20], [21] associated with the gas hazard in mine workings, fires, and explosions of methane-air mixture [22], [23].

The concept of safe refuge chambers, which were built in mine workings with the help of barricades, was first put forward more than a hundred years ago [24]. In the early 1970s, at the Gold Fields mine in South Africa, compressed air was pumped into the end of a working entry to provide a pressurized and fresh air shelter for a group of miners in the

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event of an underground fire. Since then, the use of chambers has become commonplace in metal mines in Canada and in coal mines in England [25]. In the United States of America, a special study was carried out, which recognized that the available refuge chambers could have a positive effect on the consequences of 12 of the 38 accidents studied; moreover, 83 of the 429 miners who were underground and injured in those 38 accidents could have been saved owing to the available refuge shelters [26]. In 2007, a law was adopted providing for the use of refuge shelters [25]. In practice, coal mines in the United States use rigid and inflatable shelter-chambers or stopping-type systems. In China, refuge chambers are also used to ensure safety of the personnel of underground mining enterprises. The proposed system of refuge chambers includes the following: a permanent chamber located near the main miners' exit from the level, temporary shelter chambers at the extraction sites, and rescue capsules that are installed directly near the workplace and can be moved along with the stoping front [21]. In the Dayangquan coal mine, China, a refuge chamber was built in an unused mine working [27], and in the Guilaizhuang gold mine in Shandong province, it was also located in a separate mine working [28]. All the chambers are lined with concrete and reinforced concrete with a layer of sealing material [28] with the addition of steel-polymer and rope bolt [21], [27]. They are built in single mine workings with a regular arched cross-section, and therefore their support is selected accor-ding to standard methods.

Numerous scientific studies in different countries of the world are devoted to the issue of underground object supports. Experienced specialists are improving the support of tunnels [29]-[31], mine workings [32]-[38], double mine workings [39] and refuge chambers [21], [27]. The studies propose the technologies of bearing-bolt supporting [32], full-stress anchoring [36], and a method of layer-by-layer grouting strengthening of mine working [33]. The mechanical behaviour of fully rock bolts in hydraulic tunnels was studied [29]. The effectiveness of various rock bolting schemes was analyzed, and a theoretical basis was developed to design safe and effective supports of mine workings [32], [34], [37], [38]. It is also identified that rock bolting is the most common for stabilizing underground structures in mines due to its substantiated reliability for rock strengthening [40]-[43].

Rock bolting as a part of continuous protective structures is also used to support underground collective refuge chambers for coal mine workers. Such a design is necessary for resistance to external force and temperature loads. In addition, it should have good gas tightness and the function of maintaining excess pressure in order to create a safe gas- and waterproof environment [19], [28]. Time and environment are also the factors influencing the stability and airtightness of support structures. During the service life, the load on the structural elements changes; the inherent defects of concrete structures continuously develop and expand until they finally damage the refuge chamber airtightness and become a channel for harmful gases, such as those found in the surrounding rock and atmosphere of mine workings [19], [28]. In addition, water and corrosive substances can penetrate into the concrete structure through cracks, which will accelerate the processes of chemical corrosion, carbonization, and corrosion of steel bars. In the long term, this will also affect the structure stability. Therefore, when selecting the support for underground refuge chambers and when performing numerical modelling of the operation of support structures under specific mining and geological conditions, it is very important to monitor the influence of time on changes in the stability of both the chamber and its support.

The analysis of regulatory documents of Ukraine regarding rock bolt [44] and frame-bolt [45] support of mine workings shows that its use is stipulated and regulated in permanent, development, assembling, and disassembling mine workings as well as at the connections of mine workings. The general technical requirements for stationary chambers-shelters [20] only note that the refuge chamber support must be non-combustible, selected basing on calculation of resistance to rock pressure, and ensure the required level of airtightness and repair-free maintenance of the chamber during operation.

Therefore, the analyzed data show that in underground mining, following refuge chambers are used: permanent (built in the rock mass) and temporary (mobile, requiring no solution of support problems). If the chamber is placed in a single mine working, separated from the others by an explosion-, gas- and fire-resistant stopping with a sealed door, its support is selected according to standard methods, taking into account the requirements to ensure airtightness. However, both the analyzed sources and available regulatory documents pay no attention to the selection of support for collective refuge chambers for the mine workers, located next to a mine working. Nevertheless, the design of such chambers has a number of features requiring additional attention:

– location next to an operating mine working, which increases the geometric dimensions of the underground object and complicates its cross-section geometry;

– limited internal space of the chamber, which complicates the support installation;

– necessity to ensure the chamber airtightness, which depends on the stability of the chamber and its adjacent mine working, as well as their support elements.

Therefore, the purpose of this work is to study the influence of mining and geological conditions, i.e. rock composition and location depth, on the time-dependent stability of the collective refuge chamber for mine workers with the adjacent mine workings and the development of support schemes for different conditions for constructing such mine workings. To achieve the goal, it is necessary to solve following problems:

1) to use numerical modelling methods to investigate influence of the depth of mining operations and strength of rocks, enclosing the mine working and refuge chamber, on their stability;

2) to develop a classification of the chamber location conditions according to the relative strength of enclosing rocks;

3) to elaborate the chamber support schemes for different conditions of chamber location;

4) to carry out a numerical study of the stress state of the enclosing rocks and time-dependent stability of the chamber and its adjacent mine working, if the recommended support scheme is applied.

2. Methodology

To solve the specified problem, numerical modelling of the connected processes of deformation of the rock mass and support elements, and gas filtration was performed. The availability of gas in the fracture-pore space of coal was taken into account, since coal seams in terms of Ukrainian coal mines usually have a high gas capacity, and neglecting the effect of gas on the stress field formation can lead to significant errors [46].

The stress state of the rock mass near the mine working and gas filtration within the disturbed area is described by the system of equations [47]-[49]:

$$c_g \frac{\partial u_i}{\partial t} = \sigma_{ij,j} + X_i(t) + P_i(t); \quad (1)$$

$$\frac{\partial p}{\partial t} = \frac{k_{tech}}{2\mu \cdot m}\left(\frac{\partial^2 p^2}{\partial x^2} + \frac{\partial^2 p^2}{\partial y^2}\right) + q(t), \quad (2)$$

where:

c_g – damping coefficient, kg/(s·m^3);

u_i – displacement, m;

t – time, s;

$\sigma_{ij,j}$ – derivatives from the components of main stress tensors along horizontal axis x and vertical axis y, Pa/m;

$X_i(t)$ – projection of the external forces affecting the rock volume unit, n/m^3;

$P_i(t)$ – projection of the forces stipulated by the gas pressure within the fracture-pore space, N/m^3;

p – gas pressure, Pa;

k_{tech} – filtration permeability caused by driving a mine working, m^2;

μ – gas viscosity, Pa·s;

m – rock porosity, %;

q – function of gas emission, which models methane desorption from the coal.

The k_{tech} permeability of rocks and concrete, depending on their stress state, is determined by the ratios obtained by the authors earlier [38], [47].

The initial and boundary conditions for this problem are as follows:

$$\sigma_{yy}\big|_{t=0} = \gamma H; \quad \sigma_{xx}\big|_{t=0} = \lambda\gamma H; \quad (3)$$

$$u_x\big|_{t=0} = 0; \quad u_y\big|_{t=0} = 0; \quad (4)$$

$$p\big|_{t=0} = p_0, \quad (5)$$

$$u_x\big|_{\Omega_1} = 0; \quad u_y\big|_{\Omega_2} = 0; \quad (6)$$

$$p\big|_{\Omega_3} = p_{at}; \quad p\big|_{\Omega 4} = p_{sh}; \quad p\big|_{\Omega_5} = p_0, \quad (7)$$

where:

γ – average weight of the above-lying rocks, N/m^3;

H – depth of mining operations, m;

λ – coefficient of lateral thrust;

u_x, u_y – components of the displacement vectors, m;

Ω_1 – vertical boundaries of the external contour;

Ω_2 – horizontal boundaries of the external contour;

p_0 – formation gas pressure, Pa;

Ω_3 – non-tight mine working contour;

p_{at} – atmospheric pressure, Pa;

Ω_4 – non-tight refuge chamber contour;

p_{sh} – pressure in the refuge chamber, Pa;

Ω_5 – time-varying boundaries of the filtration area.

The Coulomb-Mohr criterion [50], [51]is used for mathematical description of the process of rock transition into a disturbed state. Equations (1)-(2) with the initial and boundary Conditions (3)-(7) are solved with the help of a finite element method [52]-[54] involving the author's software developed to model connected processes of geomechanics and fluid filtration. Rock bolts are modelled by the rod finite elements; metal and concrete support elements are modelled by giving triangular finite elements the appropriate properties.

The stress field is analyzed with the help of geomechanical parameter Q^* characterizing the multicomponent nature of a stress field:

$$Q^* = \frac{\sigma_1 - \sigma_3}{\gamma H}, \quad (8)$$

where:

σ_1, σ_3 – maximum and minimum components of the main stress tensor, Pa.

The rock mass consists usually of numerous rock layers, which can differ significantly from each other in terms of their properties. Therefore, the average rock strength parameter R_c is used to compare geological conditions of the refuge chamber location. The R_c value is calculated within the area, which height depends on the calculated width B of the chamber and adjacent mine working, Figure 1:

$$B = B_s + B_r, \quad (9)$$

where:

B_s and B_r – actual width of the chamber and adjacent mine working in the driving, m.

The R_c value within the studied area with a height of at least 1.5 B to the roof and B to the floor is calculated by the Formula:

$$R_c = \frac{\sum_{i=1}^{N} R_{ci} m_{ci}}{\sum_{i=1}^{N} m_{ci}}, \quad (10)$$

where:

R_{ci} – compressive strength of separate rock layers, MPa;

m_{ci} – thickness of separate rock layers, m;

N – number of rock layers within the area under consideration, pcs.

While calculating, a typical design of the refuge chamber, adjacent to the mine working driven along the coal seam (Fig. 1), was considered [55]-[57]. However, the mine working and chamber are supported with frames; walls and roof are lined with reinforced concrete; the refuge chamber is separated from the mine working by a 200 mm thick concrete stopping. The chamber floor is located above the mine working floor.

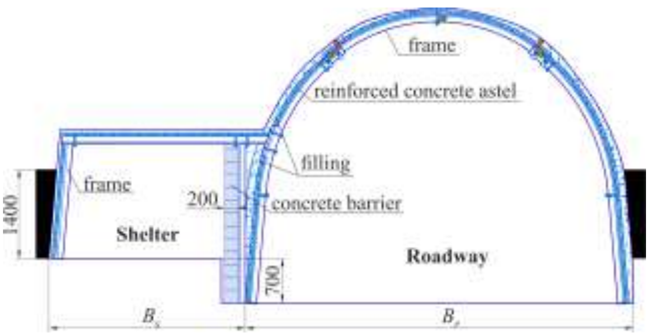

Figure 1. Typical design of a refuge chamber with a basic support

The stress state of rocks and support as well as zones of inelastic deformations were calculated for two variants of rock composition (Table 1) within the studied area with a height of at least 1.5 B to the roof and B to the floor with an average strength of R_c = 33.5 MPa and R_c = 20.6 MPa.

Table 1. Strength of rocks within the area under study

Variant	Rock	Ultimate strength σ_c, MPa	Thickness m, m	Average strength R_c, MPa
1	Sandstone	34.6	20.3	20.6
	Coal	17.3	1.4	
2	Argillite	20.8	20.3	33.5
	Coal	17.3	1.4	

The location of mine workings at the depths of H = 400 m, H = 800 m, and H = 1200 m was considered.

3. Results and discussion

3.1. Study of the stability of the refuge chamber and its adjacent mine working

To study the stability of both refuge chamber and its adjacent mine workings depending on the depth of mining operations and strength of the enclosing rocks, a stress field and a zone of inelastic deformations were calculated for the above conditions of the mine working location at different times. The results of calculating the time moment t = 20 days are shown in Figure 2. It is clearly visible that an area of increased multicomponent stress field (parameter Q^*) is formed around the mine working and the chamber. This parameter reaches the highest values in the mine working roof and in the chamber and mine working walls, where $Q^* > 1.2$. That leads to an increase in the intensity of the fracturing and breaking processes in rocks with a lower strength boundary.

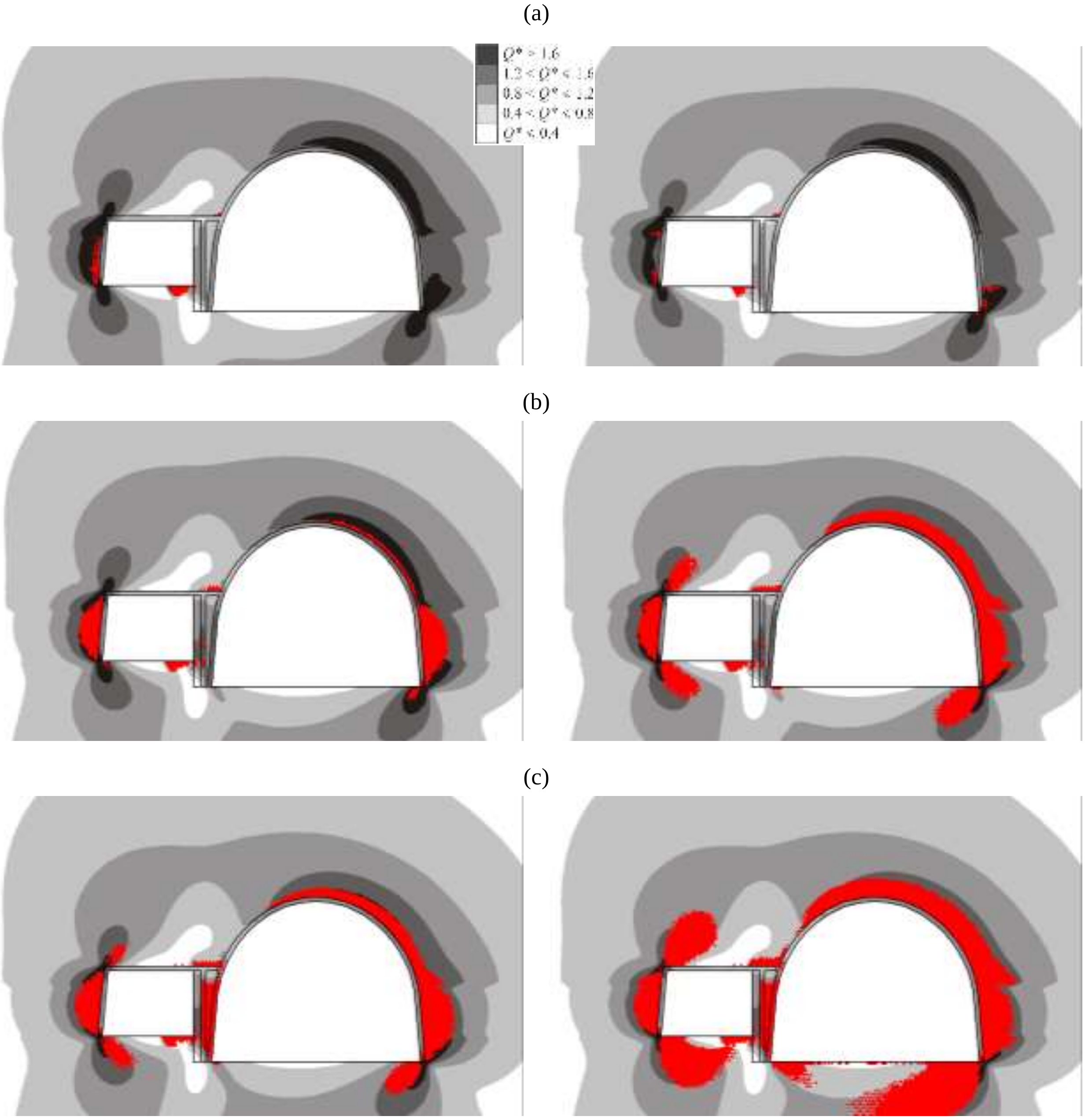

Figure 2. Zones of inelastic deformations, distributions of the Q* parameter values within the rocks with average strength R_c = 33.5 MPa (left) and Rc = 20.6 MPa (right) around the refuge chamber with the basic support: (a) H = 400 m; (b) H = 800 m; (c) H = 1200 m

Thus, stronger sandstone (Figs. 2b, c, left) can withstand loads increasing with depth with significantly less stability losses than a less strong argillite (Figs. 2b, c, right). The area of the zone of inelastic deformations within the rock area with R_c = 20.6 MPa exceeds the area of the same zone in rocks with R_c = 33.5 MPa by more than 2 times.

The depth of the underground structure location affects significantly the stability of mine workings and their support. If H = 400 m, the refuge chamber and its support are in a stable condition, the basic support ensures its safe operation (Fig. 2a). Along with the depth increase, in stronger rocks, the coal seam on the chamber and mine working walls is broken (Fig. 2b, left), which requires additional support with rock bolts. In case of less strong enclosing rocks, not only the coal seam in the walls is broken but also argillite in the mine working roof (Fig. 2b, right). Thus, it is necessary to take measures for its additional support with steel-polymer rock bolts. It is obvious that at a depth of H = 1200 m, the chamber and mine working support should be strengthened even more, taking into account both the strength of enclosing rocks and the depth of mining operations.

3.2. Schemes of the refuge chamber support for different conditions of its location

It is proposed to evaluate operating conditions of the refuge chamber by the value of relative rock strength index S_r, which considers negative influence of depth on the stability of underground structures and is calculated by the Formula:

$$S_r = \frac{R_c}{\gamma H}. \tag{11}$$

It is necessary to separate cases with the location of a weak coal seam in the chamber wall. A development workings, near which collective refuge chambers are constructed, are driven along the coal seams that are being worked out; and under conditions of most coal mines of Ukraine, coal has very low compressive strength and high gas capacity. Therefore, coal breaking is accompanied by methane release, and if the airtightness of the refuge chamber is broken, gas is likely to enter the chamber, which is dangerous for the people inside. To take into account the importance of reliable chamber wall support, introduce a parameter of the average strength of the chamber wall rocks $R_{c\,wall}$ calculated similarly to R_c but within the area limited by the refuge chamber height.

After calculating the stress fields and zones of inelastic deformations for various mining and geological conditions, graphs of changes within the area of zones of inelastic rock deformations in the roof and floor were drawn from the parameters R_c and $R_{c\,wall}$, Figure 3, illustrating the dependence of mine working stability on the relative strength of the enclosing rocks.

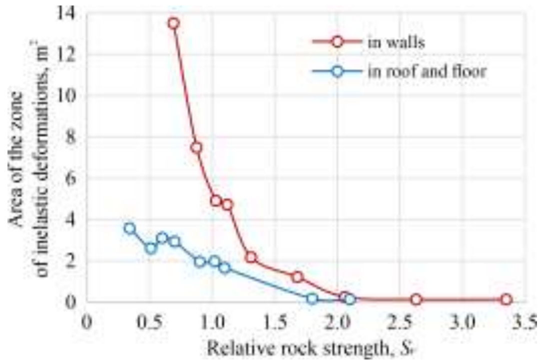

Figure 3. Area of the zones of inelastic deformation

When the results of mine observations and a series of numerical calculations with different rock composition and the depth of mine working location have been analyzed, we propose a classification of the operating conditions of the refuge chamber according to the relative strength of the rocks, with the selection of 3 types of conditions to construct the chamber, i.e.: non-complicated (S_r > 1.5), medium (1.0 < S_r ≤ 1.5), and complicated (S_r ≤ 1.0).

Within these types of conditions, conditions with weak ($S_{r\,wall}$ ≤ 1.5) and strong ($S_{r\,wall}$ > 1.5) lateral rocks are distinguished. Consequently, there are 6 main types of operating conditions of the refuge chamber. We suggest determining the support scheme that meets certain conditions according to Table 2 and Figure 4.

Therefore, the support scheme for the chamber with its adjacent mine working for specific mining and geological conditions is selected as follows:

– calculating the studied area dimensions;

– calculating the value of the average rock strength R_c according to Formula (10);

– calculating the relative rock strength S_r within the considered area and relative rock strength $R_{c\,wall}$ in the chamber and mine working walls according to Formula (11);

– defining the type of operating conditions of the refuge chamber according to Table 2;

– determining the support scheme that corresponds to these operating conditions, according to the Table 2 and Figure 4.

3.3. Chamber stability when using the recommended support scheme

Determine the support schemes for the refuge chamber under the mining and geological conditions discussed above while calculating R_c and $R_{c\,wall}$ for each case and using Table 2. The calculation results are given in Table 3.

We can see that the basic support is reliable both for the refuge chamber and the mine working at a relatively shallow depth, when H = 400 m.

Table 2. Support of the refuge chamber according to its construction conditions

Value of parameter S_r	Types of conditions	Support scheme
S_r > 1.5	Non-complicated	Scheme 1, basic (Scheme 1)
1,0 < S_r ≤ 1.5	Medium	Scheme 2, basic + rock bolting of the adjacent mine working (Scheme 2)
S_r ≤ 1.0	Complicated	Scheme 3, basic + rock bolting of the chamber and its adjacent mine working (Scheme 3)
$S_{r\,wall}$ ≤ 1.5	With weak wall rocks	Scheme 4, 5 or 6, with the addition of lateral rock bolts to schemes 1, 2 or 3 (Schemes 4-6)

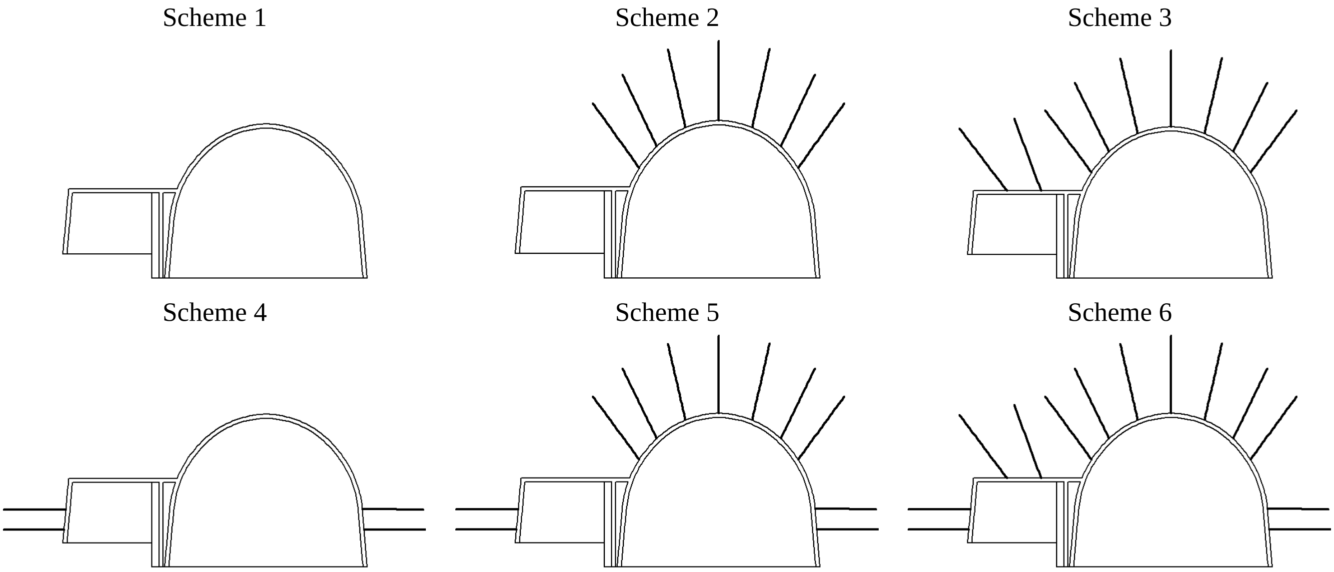

Figure 4. Schemes of the refuge chamber support

Table 3. Results of the calculations of relative strength of enclosing rocks

Depth H, m	Average rock strength R_c and $R_{c\ wall}$, MPa	Relative rock strength S_r and $S_{r\ wall}$	Category of conditions	Support scheme
400	33.5 / 21.14	3.35 / 2.1	Non-complicated	Scheme 1
400	20.6 / 18.08	2.06 / 1.8	Non-complicated	Scheme 1
800	33.5 / 21.14	1.68 / 1.1	Non-complicated with weak wall rocks	Scheme 4
800	20.6 / 18.08	1.03 /0.9	Medium with weak wall rocks	Scheme 5
1200	33.5 / 21.14	1.12 / 1.1	Medium with weak wall rocks	Scheme 5
1200	20.6 / 18.08	0.69 / 0.6	Complicated with weak wall rocks	Scheme 6

With the increasing depth, additional rock bolting is required, i.e. schemes No. 4-6 for various mining and geological conditions (Table 3). To verify the obtained results, the stress fields and zones of inelastic deformations were calculated for those cases where support of the chamber and its adjacent mine working needs strengthening (Fig. 5).

When rock bolts are installed, the distribution of the parameter Q^* value in the roof of the mine working and chamber changed. The multicomponent nature of the stress field decreased significantly; the area of rocks with well-developed fracturing, where $Q^* > 0.8$, decreased (Fig. 5). Within the rock bolted area, rock is under conditions close to triaxial compression with the increased values of the minimum component of the main stresses. A rock-bolt overlap is formed above the mine working and the chamber, where rock is preserved undisturbed, and the bolting prevents the contour mass displacement inside the mine working and chamber, increasing their stability.

It is also clearly seen that additional rock bolting results in the fact that the zone of inelastic deformations in all four cases has decreased significantly compared to Figure 2b and 2c. Moreover, in stronger rocks, its area decreased by 45% at H = 800 m (Fig. 5a) and by 28% at H = 1200 m (Fig. 5c); in less strong rocks – by 34% at H = 800 m (Fig. 5b) and by 28% at H = 1200 m (Fig. 5d). The zone of inelastic deformations within the chamber and mine working walls decreased by 3.7 times in case (a), in case (b) – by 3.2 times, in case (c) – by 2.1 times, and in case (d) – by 2.2 times (Fig. 5). It means that deformation of a very large volume of the contour rock, strengthened by rock bolting, occurs now in an elastic mode; and the underground compound-shape structure acquires a stable state.

Thus, to test the proposed approach, the relative strength of enclosing rocks was calculated in six different cases; the category of conditions for the chamber location was determined; a scheme of its support was selected; and a numerical study of the stress state of the enclosing rocks and stability of the chamber with its adjacent mine working, while applying the recommended support scheme, was performed. It is shown that support strengthening by rock bolting reduces the multicomponent nature of the stress field along with the area of the zone of inelastic deformations around the mine workings. The rock bolted-area rock is under conditions close to triaxial compression with the increased values of a minimum component of main stresses. A rock-bolt overlap is formed above the mine working and chamber, which increases stability of the chamber and its adjacent mine working under complicated mining and geological conditions.

The environment and mining operations affect significantly the underground structures. Therefore, in future, it is planned, firstly, to complement the research with a study of the stability of refuge chambers located next to the excavation gallery, which is stored for further reuse while stoping.

Secondly, to develop and improve the elaborated model, it is necessary to consider the effect of corrosion destruction of concrete and metal structural elements on the long-term stability and gas tightness of the refuge chamber. Such research will make it possible to improve support of mine workings of irregular cross-section under complicated mining and geological conditions.

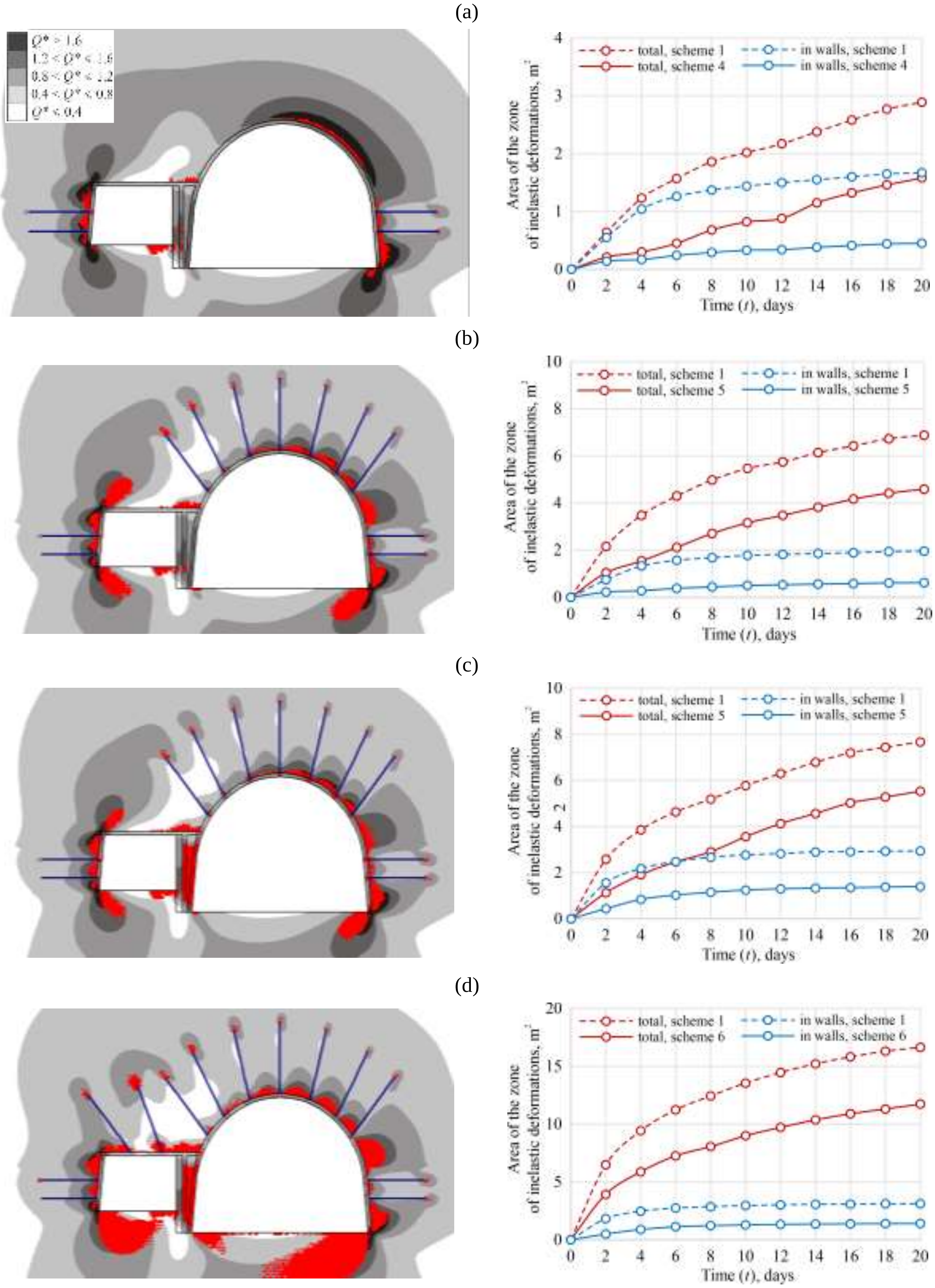

Figure 5. Zones of inelastic deformations, distributions of the values of Q^* parameter and graphs of changes within the area of the zone of inelastic deformations: (a) H = 800 m, R_c = 33.5 MPa, $R_{c\ wall}$ = 21.14 MPa; (b) H = 800 m, R_c = 20.6 MPa, $R_{c\ wall}$ = 18.08 MPa; (c) H = 1200 m, R_c = 33.5 MPa, $R_{c\ wall}$ = 21.14 MPa; (d) H = 1200 m, R_c = 20.6 MPa, $R_{c\ wall}$ = 18.08 MPa

4. Conclusions

This paper represents a numerical study of the stability of underground mine workings with a compound cross-section, i.e. the collective refuge chamber and its adjacent extraction gallery, under various mining and geological conditions, using different support schemes.

The influence of the depth of mining operations and the enclosing rock strength on the stability of rescue chambers with basic support (including frames, reinforced concrete lining of the sides and roof, and a concrete stopping between the chamber and its adjacent mine working) was analyzed. It is shown that at a relatively shallow depth, the basic support ensures chamber stability along with its safe operation. When depth is increasing and enclosing rocks become less strong, additional support with rock bolts is required.

A classification of chamber location conditions based on the relative strength of the enclosing rocks was developed. Based on the results of mine observations and a series of numerical calculations with varying rock composition and depth of mining operations, schemes for constructing refuge chambers and its adjacent mine workings for various location conditions were designed. The schemes include basic support and its strengthening with rock bolts located in the roof of mine working and the chamber or in their walls. The compliance of these support schemes with the developed classification of location conditions was determined.

To test the proposed approach, relative strength of the enclosing rocks was calculated in six different cases; the category of conditions to locate refuge chambers was determined; and its support scheme was selected. A numerical study of the stress state of the enclosing rocks and stability of the chamber and its adjacent mine working, when using the recommended support scheme, was performed. It is shown that the schemes, strengthened by rock bolting, reduce the multicomponent nature of the stress field and the area of the zone of inelastic deformations around the mine workings. The rock bolted-area rocks are under conditions close to triaxial compression with the increased values of the minimum component of main stresses. A rock-bolt overlap is formed above the mine working and refuge chamber, which increases the stability of the chamber and its adjacent mine working under complicated mining and geological conditions.

Author contributions

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

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Conflicts of interests

The authors declare no conflict of interest.

Data availability statement

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

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Анкерно-рамне кріплення виробок складного поперечного перерізу: камери колективного порятунку працівників шахти

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Мета. Дослідити вплив гірничо-геологічних умов на залежну від часу стійкість камери колективного порятунку працівників шахти з прилеглою гірничою виробкою і розробити схеми кріплення для різних умов спорудження таких виробок.

Методика. Для дослідження стійкості гірничих виробок складної форми поперечного перерізу, а саме камери колективного порятунку і прилеглого виїмкового штреку, використано методи чисельного моделювання зв'язаних процесів пружно-пластичного деформування газоносних порід і фільтрації газу в порушеній при веденні гірничих робіт області. Основу моделі складають фундаментальні положення механіки твердого тіла та теорії фільтрації. Задача розв'язана із застосуванням методу скінченних елементів.

Результати. Розроблено класифікацію умов розташування камери колективного порятунку працівників шахт за відносною міцністю вміщуючих порід. Розроблено схеми кріплення камери і прилеглої виробки. Ці схеми включають базове кріплення і передбачають його посилення анкерами, розташованими в покрівлі виробки і камери, або в їх боках. Визначено відповідність цих схем кріплення розробленій класифікації умов розташування. Виконано чисельне дослідження залежної від часу стійкості камери і прилеглої виробки у разі застосування рекомендованої схеми кріплення. Показано, що посилення схем кріплення анкерами зменшує різнокомпонентність поля напружень і площу зони непружних деформацій, формує у покрівлі виробки і камери породно-анкерне перекриття, яке підвищує їх стійкість в більш складних гірничо-геологічних умовах.

Наукова новизна. Встановлено залежності зміни площі зони непружних деформацій навколо камери з прилеглою виробкою від відносної міцності вміщуючих порід, а також зміни площі зони непружних деформацій у часі при застосуванні різних видів кріплення.

Практична значимість. Розроблено схеми кріплення камери колективного порятунку працівників шахти для різних умов спорудження і порядок їх вибору для конкретних гірничо-геологічних умов. Результати дослідження забезпечують теоретичне обґрунтування та наукові вказівки щодо вибору кріплення для камер колективного порятунку, прилеглих до гірничої виробки.

Ключові слова: *анкерно-рамне кріплення, відносна міцність порід, камера порятунку, стійкість гірничих виробок, схеми кріплення, чисельне моделювання*

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