Calculation of parameters of combined frame and roof bolting

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Abstract. The paper presents the method of calculation of the combined frame and roof bolting. Recommendations on providing joint operation of roof bolting with steel support frames are given. Graphs for determining standard rock movement, as well as for defining proof load on the yielding support, were developed.

1. Introduction

Efficiency enhancement of reinforcement and support of mine workings is one of the urgent tasks when conducting hollow mine working [1-3]. One of the possible ways of efficiency enhancement of reinforcement of mine workings is application of frame-roof bolting [4, 5, 8]. The conducted analysis of works [6, 7, 9, 10] are evidence of incomplete study of this problem. The existing constructions of linings and methods of their construction do not take into account to the full extent the potentialities inherent in frame-roof boltings.

Proceeding from this, the authors propose the method of calculation of parameters of a combined frame-roof bolting. The main initial data for calculation of parameters of the lining workings are [1-10]:

- estimated depth of placement of excavation;
- estimated resistance of rocks, accommodating production, to compression;
- standard material characteristics, flexibility and bearing capacity of the lining.

The estimated depth of placement of production of $H_p$ is determined by the formula:

$$H_p = H \cdot k,$$

where $H$ – the design depth of the placement of output, m;

$k$ – coefficient taking into account the difference of the stress state of the array compared to the stressful condition caused by the own weight of rocks to the surface and is assumed equal to 1 for normal geological conditions. The coefficient $k$ is taken according to experimental data results for areas of workings in zones of crustal movements and tectonic faults, and in their absence – is equal to 1.5.

The design resistance of rocks to compression $R_c$ is determined by the formula:

$$R_c = R \cdot k_c,$$
where \( R \) – the average value of resistance of rocks to uniaxial compression in the sample, which is determined by the test results of the samples, MPa;

\( k_c \) – coefficient taking into account additional disturbance of rock mass weakening surfaces without adhesion or with low connectivity (mirrors sliding, fractures, clay layers, etc.).

Values \( k_c \) are taken, depending on the tectonic disturbance of rocks in accordance with table 1.

Design resistance \( R_c \) of the rocks in case of prolonged flooding of the rocks in mines (flooding, water bypass, etc.) decreases for sandstones, siltstones and mudstones, respectively, by 20, 40 and 50 %.

The design resistance of rocks to compression \( R_c \), is determined by the contour of the cross section of development. It should be determined, taking into account all intersected by the production layers with a capacity of more than 0.5 m, lying from the contour of the cross section development in the roof at a distance of 1.5 \( B \); in the soil and sides – 1 \( B \), where \( B \) is the development width in the caverns.

### Table 1. The value of coefficient \( k_c \)

| Characteristics of disturbance of rocks in location of workings | \( k_c \) |
|---------------------------------------------------------------|--------|
| Beyond plicative violations with a radius over 300 m or beyond the influence of disjunctive violations at the distance from them equal to \( HN \) (\( N \) - normal amplitude of a violation, m). | 0.9 |
| In the zone of influence of plicative violations with the radius from 300 to 100 m or in the area of disjunctive disturbance at a distance from it, ranging from 4\( N \) to 1\( N \). | 0.6 |
| In disjunctive violation at a distance from it of less than 1\( N \), including the castles of tectonic dislocations and areas of intersections | 0.3 |

### 2. Materials and methods

For a series of adjacent layers, overlying along the contour of the cross section of a mine working, with variability \( R_c \) in the range to 30%, for the whole production, one should adopt a weighted average value of the calculated resistance of rocks to compression, defined by the formula

\[
R_c = \frac{R_{c1} \cdot m_1 \cdot R_{c2} \cdot m_2 + \ldots + R_{cn} \cdot m_n}{m_1 + m_2 + \ldots + m_n}
\]  

(3)

If one changes the calculated resistance of rocks to compression in the roof, in sides or in the soil of excavation more by more than 30%, \( R_c \) should be calculated according to the formula (3) separately by the elements of mine working (roof, sides, and soil). One area by the length of the production includes the one, in which values \( R_c \) in layers, with a capacity of more than 0.5 m, range within the limits up to 30 %. For this section, \( R_c \) is determined by the formula (3). If in the areas of mining, values of \( R_c \) are identified by more than 30 %, the value of \( R_c \) is taken by the lowest value \( R_c \) of the merged plots.

When using the roof bolting in combination with supporting linings, the bearing capacity of the combined system is determined as the sum of rebuffs on the circuit of mine working, included in the combination of anchoring and supporting lining,

\[
P_{k,kr} = P_a + P_{p,kr}
\]

(4)

where \( P_{k,kr} \) – load capacity of combined roof support, kN/m²;

\( P_a \) – back of roof bolting, kN/m²;

\( P_{p,kr} \) – bearing capacity of supporting lining, kN/m².
The magnitude of the displacements of the roof in the mine working must be compensated by a back anchoring and supporting linings. It is possible to set the value of displacements, attributable to roof bolting $U_a$, considering that its peak value should not be more than 300 mm. Then offset value $U_{p,k}$ that must be compensated by the supporting lining will be determined by the formula:

$$U_{p,k} = U - U_a,$$

where $U$ - total displacement of rocks, mm;

$U_a$ - the rock displacement, compensated by roof bolting, mm.

3. The study of the combined frame and roof bolting

Let us select the type and parameters of the frame yielding lining. The displacement of the roof rocks, soil or sides in horizontal and inclined mine workings, supported beyond the influence of the treatment works (respectively $U_{kr}$, $U_{ph}$, $U_b$), is calculated by the formulas

$$U_{kr} = U_{t,kr} \cdot k_a \cdot k_h \cdot k_a \cdot k_f,$$

where $U_{t,kr}$ - standard rock displacement, determined according to graphs in Fig. 1, depending on the size of the rocks and the depth of the location $H$ of the mine working;

$k_a$ - the coefficient of the effect of the angle of rocks bedding and penetration direction of the mine working relative to the stretch of rocks. It is determined by tables 2 and 3;

$k_f$ - the coefficient characterizing the influence of the rocks displacement. It is determined by table 2;

$k_h$ - the coefficient of the width effect of the mine working, the value of which is determined for the roof and soil by formula 7, and for sides – by 8.

$$k_h = 0.2(B - 1),$$

$$k_h = 0.2(h - 1),$$

where $B$, $h$ – respectively, the width and the height of the mine working in the excavation, m;

$k_B$ - the coefficient of influence of other mine workings; for single mine workings, $k_B = 1$ is used;

for coupling with the unilateral adjustment of generation $- k_B = 1.4$, for coupling with an adjacent mine workings $- k_B = 1.6$. 
Table 2. The values of coefficients $k_\alpha$ and $k_\theta$ (The direction of sink working is from $0^\circ$ to $40^\circ$)

| Direction of sink working | Coefficients $k_\alpha$ and $k_\theta$ at angles $\alpha$ of the bedding rocks |
|---------------------------|---------------------------------------------------------------------------------|
|                           | below $20^\circ$ | $30^\circ$ | $40^\circ$ |
| by course                 | $k_\alpha$ | $k_\theta$ | $k_\alpha$ | $k_\theta$ | $k_\alpha$ | $k_\theta$ |
| at an angle to course     | 1.00      | 0.35    | 0.95      | 0.55    | 0.80      | 0.80    |
| in the cross of course    | 0.85      | 0.45    | 0.80      | 0.65    | 0.65      | 0.90    |

Table 3. The values of the coefficients $k_\alpha$ and $k_\theta$ (The direction of sink working is from $50^\circ$ to $90^\circ$)

| Direction of working | Coefficients $k_\alpha$ and $k_\theta$ at angles $\alpha$ of bedding rocks $\alpha$ |
|----------------------|---------------------------------------------------------------------------------|
|                      | $50^\circ$ | $60^\circ$ | over $70^\circ$ |
| by course            | $k_\alpha$ | $k_\theta$ | $k_\alpha$ | $k_\theta$ | $k_\alpha$ | $k_\theta$ |
| at an angle to course| 0.15     | 1.20     | 0.60     | 1.70     | 0.60     | 2.25     |
| in the cross of course| 0.45    | 1.05    | 0.35    | 1.10    | 0.35    | 0.95    |

4. Conclusion
Estimated load $P$ per 1 m of mine working from the direction of the roof and soil is determined by formula 9:

$$P = P_N \cdot k_p \cdot k_{p_r} B,$$  \hspace{1cm} (9)
where $P^N$ - standard unit load, determined according to Figure 2, depending on the estimated displacements of rocks $U$ and the width of mine working in caverns $B$. In case of open lining, $P^H$ is determined by the displacements of the roof rocks; $B$ and $h$ - the width and the height of mine working, m; $k_n$ - the overload factor, taken for the access roadways by table 4; $k_{np}$ – the influence coefficient of the method of excavations. In a drilling and blasting method, $k_{np}$ is assumed to be 1, and in a combine one – using table 5.

![Figure 2. Graphs to determine standard load on yielding support.](image)

The type and parameters of metal yielding support are selected by the adopted width of the mine working, the area of its cross section, taking into account the conditions of the roof rocks. In case of solid roofs, lining with a flat (rectilinear lining) is preferable; in case of unstable roofs – beams of arch shape.

For the selected lining, the value of its resistance $N_i$ in the pliable mode is found, depending on the accepted tool joint. The density of frames mounting per 1 m of mine working length $n$ is given by (10):

$$n = \frac{P}{N_s}$$

The passport density of the frame mounting of the lining is taken by the nearest value of $n$ in the technological row: 0.8; 1.0; 1.25; 1.33; 1.43; 1.5; 1.62; 2.0; 2.25; 2.5; 2.67; 3.0. Metal lining is selected by the condition that its structural compliance exceeded the calculated anticipated displacements of roof rocks.

| Estimated displacement U, mm | $k_n$ |
|-----------------------------|------|
| Below 50                    | 1.40 |
| 50 – 200                    | 1.20 |
| 200 – 500                   | 1.15 |
| Over 500                    | 1.10 |
Table 5. Values of coefficient $k_{np}$

| The ratio of the depth to rock strength, $H/R_c$ | Below 16 | 16 – 20 | Over 20 |
|------------------------------------------------|----------|---------|---------|
| Value $k_{np}$                                | 0.6      | 0.8     | 1.0     |

Taking the permissible value of the displacement $U_a$ attributable to roof bolting (it is $30 – 40\%$ of the total displacements $U$, but not more than 300 mm), let us determine its parameters $P_a$ and $l_a$ according to the nomogram in Figure 2. Further, according to the formula (5), let us calculate the magnitude of displacements $U_{nk}$ falling to the frame yielding lining.

To ensure the joint operation, the roof bolting should be connected with frames of steel support. This can be accomplished by installation of additional longitudinal metallic holders, connected with the bolt shafts and frames of sustaining supports.

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