Determination of Room-and-Pillar system parameters for Transition to Greater Depths

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Abstract

With progress in depth, the most effective way to increase the field of application of room and pillar system is the transition to the combined support of the ore-concrete-ore or concrete-ore-concrete methods. With this arrangement, treatment of mine workings along the strike of the ore body enables the use of mobile equipment, which allows increasing performance indicators of stopping: performance of second working, labor of face worker, labor intensity.

Keywords: room-and-pillar system; performance indicators; productivity; mathematical model; labor intensity; efficiency

INTRODUCTION

A high rate of progress in depth is one of the main peculiarities of underground development of ore deposits. It is caused by fast depletion of mineral deposits, situated near soil surface, and, also, by increase in demand on the number of metals, especially strategic ones. In the number of foreign countries, which have advanced mining industry (Canada, India, the USA and etc.), production of the valuable ores is carried out on the depth more than 2-3 km (table 1).

As seen in the table 1, most of Russian and foreign mines prefer room-and-pillar system when switching to deeper mining. This system is one of the most economically efficient ones and simple in structure. Mineral mining with wide workings (6 – 15 m) provides friendly environment for labor productivity. The tendency of expanding application field of this system or attempts to retain this system during transitions to more complex subsurface conditions are understandable.

Table 1: Information about the number of deep mines.

<table>
<thead>
<tr>
<th>Country, company</th>
<th>Productivity, million, ton/year</th>
<th>Mining depth, m</th>
<th>Ore</th>
<th>System of mining</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA White Pine</td>
<td>3,0</td>
<td>1000</td>
<td>Copper</td>
<td>Room-and-pillar caving</td>
</tr>
<tr>
<td>Pierreport</td>
<td>0,5</td>
<td>800</td>
<td>Poly-metallic</td>
<td>Room-and-pillar system</td>
</tr>
<tr>
<td>Canada «Lockerby»</td>
<td>1,0</td>
<td>1200</td>
<td>Copper-nickel</td>
<td>Room-and-pillar, slicing-and-filling.</td>
</tr>
<tr>
<td>RSA DiilKaar</td>
<td>2,5</td>
<td>1200 – 2400</td>
<td>Gold bearing</td>
<td>Room-and-pillar and longwall systems</td>
</tr>
<tr>
<td>Norway Lekken-Gruber</td>
<td>0,3</td>
<td>1050</td>
<td>Copper-zinc</td>
<td>Room-and-pillar system</td>
</tr>
<tr>
<td>Poland Legnico-Gluhovskii-Lubinske</td>
<td>-</td>
<td>1000 – 600</td>
<td>Copper</td>
<td>Room-and-pillar system</td>
</tr>
<tr>
<td>Sweden «Laysvall»</td>
<td>2,7</td>
<td></td>
<td>Copper-zinc</td>
<td>Room-and-pillar system</td>
</tr>
</tbody>
</table>

Mining on the great depth demands specific approach in selecting mining system and technology; comprehensive studying of rock mass conditions and processes; developing of reliable methods of ground pressure control; and solution of the number of mine safety issues.

With progress in depth, prevention of dangerous consequences of ground pressure becomes relevant. Ground
pressure increases with mining depth, as well as rock bumps, which are the consequences of rock mass overstressed condition around mined-out area [1, 2, 3].

Rock bumps appear on the deep levels, where rock mass’ stresses are higher than break-down point of rock formations. They are followed by air blast and seismic effect. These effects are different in its scale and occur in relevant conditions, in second workings, as well as in development workings. Moreover, ventilation arrangement and dust prevention become significant issues in deep mines, due to the rise in rock masses’ temperature up to 40-65°C and considerable increase in air headings’ length. In some cases, wash boring as a way of dust allaying is not applicable in deep mines due to the high temperature of mine’s air or increase in humidity over the limits of human body.

More than 40% of bauxite is quarried using room-and-pillar system in North-Urals bauxite mines. However, employed methods of room-and-pillar system do not provide significant increase in productivity. Productivity of a face worker of room-and-pillar system in North-Urals bauxite mines is lower than in some CIS mines. In foreign countries room-and-pillar system is usually employed together with mobile drilling, loading, hauling and supporting equipment. That provides high values of performance indicators of second workings (Table 2).

### Table 2: Performance indicators of room-and-pillar system in Russian mines.

<table>
<thead>
<tr>
<th>Mine</th>
<th>$\delta$</th>
<th>$\omega$</th>
<th>$\gamma$</th>
<th>$\beta$</th>
<th>$\theta$</th>
<th>$\psi$</th>
<th>$\rho$</th>
<th>$\alpha$</th>
<th>$\omega$</th>
<th>$\beta$</th>
<th>$\theta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jezkazanskii</td>
<td>1.5-30</td>
<td>6-15</td>
<td>400-650</td>
<td>20</td>
<td>5-7</td>
<td>2-30</td>
<td>Usual</td>
<td>9-10</td>
<td>8-30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mirgalimaiskii</td>
<td>4-12</td>
<td>0-30</td>
<td>700-750</td>
<td>8</td>
<td>3-6</td>
<td>4-12</td>
<td>Mobile</td>
<td>20-22</td>
<td>10-25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kadamdzhaiskii</td>
<td>2-20</td>
<td>15-30</td>
<td>550-700</td>
<td>10-11</td>
<td>4</td>
<td>2-20</td>
<td>Usual</td>
<td>5</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ahtalskii</td>
<td>8-20</td>
<td>0-2</td>
<td>800</td>
<td>8-11</td>
<td>3-5</td>
<td>2-3</td>
<td>Mobile</td>
<td>5-6</td>
<td>10-20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vishnegorskii</td>
<td>2-12</td>
<td>15-40</td>
<td>600</td>
<td>6-8</td>
<td>2,5-8</td>
<td>2-10</td>
<td>Mobile</td>
<td>5-6</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>South-Urals bauxite mine</td>
<td>2-6</td>
<td>0-14</td>
<td>800</td>
<td>7-10</td>
<td>3,5-5</td>
<td>2-6</td>
<td>Mobile</td>
<td>6-7</td>
<td>11-12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>North-Urals bauxite mine</td>
<td>2-8</td>
<td>0-30</td>
<td>800</td>
<td>5-8</td>
<td>8-10</td>
<td>2-8</td>
<td>Usual</td>
<td>8-9</td>
<td>20-25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Productivity of a worker depends on the number of factors: deposit thickness, seam inclination, ore hardness, roof stability, presence of tectonic disturbances and etc. It is proposed to employ mobile equipment together with room-and-pillar system to increase labor productivity. It is necessary to determine optimal application parameters of different methods of room-and-pillar system on certain depths, because implementation of this system becomes harder with progress in depth.

One of the limiting parameters is intervening pillar’s width. There are a lot of methods to determine its value. However, one of the most reliable ways is method developed by Professor M.N. Cigalov [4], which determines bearing forces of the pillar:

$$\sigma = K_s K_a \frac{H(x + \delta) + \gamma \cdot h}{\sqrt{x}} \cdot \text{kgF/sm}^2$$

Where $K_s$ – assurance coefficient; $K_a$ – inclination coefficient; $\gamma$ – ore specific gravity, ton/m$^3$; $H$ – depth of ore body, m; $x$ and $\delta$ – width of a pillar and a room, m; $\gamma_0$ – backfilling material specific gravity, ton/m$^3$; $h$ – ore body thickness, m.

The equation, determining width of the pillar, is obtained after reconstruction of the formula with respect to $x$ and simplifying with Cardano formula:

$$x^3 \cdot \frac{\sigma}{\sqrt{h}} - x^2 \cdot (A + B)^2 - 2 \cdot x \cdot A \cdot B \cdot (A + B) - A^2 \cdot B^2 = 0$$

Where $A = K_s \cdot K_a \cdot \gamma \cdot H$; $B = K_s \cdot K_a \cdot \gamma_0 \cdot h$.

Obtain the equation: $a \cdot x^3 - b \cdot x^2 - c \cdot x - d = 0$

Change variables: $x = y + \frac{b}{3 \cdot a}$, where $y^3 + p \cdot y + q = 0$

Result after using Cardano formula:

$$y = 3 \left( -\frac{q}{2} + \sqrt{\frac{q^2}{4} + \frac{p^3}{27}} \right) + 3 \left( -\frac{q}{2} - \sqrt{\frac{q^2}{4} + \frac{p^3}{27}} \right)$$
Where \( p = \frac{b^2}{3a^2} + \frac{c}{a} \), and \( q = -\frac{2b}{27a^3} - \frac{c}{a^2} \).

After solving this system of equations, we will obtain pillar’s width \( x \) for variable mining depths, shown on the picture 1.

Empirical dependence is obtained on the base of least-squares fitting of the results. This dependence describes impact of ore body thickness and mining depth on the pillar’s width, and looks like:

\[
x = 0.184h^{1.292}H(0.34ln(h)+0.88)
\]

With this formula it becomes possible to determine pillar’s width by substituting only two parameters, which are critical with progress in depth and influence significantly on the sizes of intervening pillars. It is necessary to mention, that this formula is applicable only to North-Uralsk bauxite mine.

**Table 2:** Indexing of variable and relatively constant parameters

<table>
<thead>
<tr>
<th>№</th>
<th>Index</th>
<th>Notation</th>
<th>Parameters</th>
<th>Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>( P_{b3} )</td>
<td>Block capacity</td>
<td>ton/shift</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>( P_{z.r} )</td>
<td>Productivity of a face worker</td>
<td>ton/shift</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>( t_{b3.v} )</td>
<td>Time of block mining</td>
<td>shifts</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>( Q_{z3} )</td>
<td>Quantity of produces ore mass</td>
<td>ton</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>( N_{o} )</td>
<td>Number of rounds for mining of one room</td>
<td>units</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>( a_{axl} )</td>
<td>Bearable span of the outcropping</td>
<td>m</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>( t_{dp} )</td>
<td>Time of blast hole drilling</td>
<td>shifts</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>( t_{ap} )</td>
<td>Time of hole charging</td>
<td>shifts</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>( t_{m.k} )</td>
<td>Mucking time</td>
<td>shifts</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>( b_{3} )</td>
<td>Pillar’s width</td>
<td>m</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>( K_{cv} )</td>
<td>Contribution factor of the second working</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>( m )</td>
<td>Ore body thickness</td>
<td>m</td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>( L_{axl} )</td>
<td>Length of the second working</td>
<td>m</td>
</tr>
<tr>
<td>14</td>
<td></td>
<td>( K_{KH3} )</td>
<td>Heading advance per round to shotholes length ratio</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>( \sigma_{cm} )</td>
<td>Compressive resistance</td>
<td>MPa</td>
</tr>
<tr>
<td>16</td>
<td></td>
<td>( K_{z} )</td>
<td>Assurance coefficient</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td></td>
<td>( d_{l} )</td>
<td>Size of the formation joint block</td>
<td>m</td>
</tr>
<tr>
<td>18</td>
<td></td>
<td>( \gamma_{o} )</td>
<td>Ore mass density</td>
<td>ton/m(^3)</td>
</tr>
<tr>
<td>19</td>
<td></td>
<td>( \gamma_{z} )</td>
<td>Backfilling material density</td>
<td>ton/m(^3)</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>( K_{\alpha} )</td>
<td>Coefficient of the seam inclination influence</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td></td>
<td>( H )</td>
<td>Mining depth</td>
<td>m</td>
</tr>
<tr>
<td>22</td>
<td>( T_{\text{tmp}} )</td>
<td>Labor intensity of drilling</td>
<td>Man per shift</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>( T_{\text{tmp}} )</td>
<td>Labor intensity of charging</td>
<td>Man per shift</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>( T_{\text{tmp}} )</td>
<td>Labor intensity of transportation</td>
<td>Man per shift</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>( H_{\text{tmp}} )</td>
<td>Uniform time standards</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>( V_{\text{tmp}} )</td>
<td>Hole drilling footage</td>
<td>Per meter run</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>( V_{\text{tmp}} )</td>
<td>Mass of hole charging</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>( V_{\text{tmp}} )</td>
<td>Loading of ore mass</td>
<td>ton</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>( l_{\text{tmp}} )</td>
<td>Run of holes</td>
<td>m</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>( N_{\text{tmp}} )</td>
<td>Number of holes</td>
<td>units</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>( a )</td>
<td>Charge ratio</td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>( l_{\text{tmp}} )</td>
<td>Length of the advance per round</td>
<td>m</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>( S_{\text{tmp}} )</td>
<td>Cross sectional area of the second working</td>
<td>m²</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>( k )</td>
<td>Coefficient, which considers density of explosives</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>( \Delta )</td>
<td>Explosives density</td>
<td>g/sm³</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>( d_{\text{tmp}} )</td>
<td>Hole size</td>
<td>m</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>( q )</td>
<td>Specific consumption of explosives</td>
<td>kg/m³</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>( q_1 )</td>
<td>Explosives quantity disposable under standard conditions</td>
<td>kg/m³</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>( f_o )</td>
<td>Coefficient, which considers formation structure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>( m_o )</td>
<td>Coefficient, which considers cartridge size</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notice:
- □ Dependent variable
- ○ Independent variable
- △ Control variable (input data)

Variable data was set for each method of room-and-pillar system, considering second mining technology and subsurface conditions of the field. Four methods of room-and-pillar system were used in these calculations: barrier method, sill pillar method, combined support of the ore-concrete-ore method, combined support of the concrete-ore-concrete method.

Some of the constant values were taken from various sources. For example, compressive resistant value for barrier method of room-and-pillar system was taken as 102 MPa (based on the data of geological exploration of OJSC “North-Uralsk bauxite mine” fields). At the same time, compressive resistance value for sill pillar method of room-and-pillar system varied from 2 to 5 MPa. For combined support methods of room-and-pillar system this value fell within the limits of 20 to 50 MPa, the same as for concrete slab-lagging. Compressive resistant values for the last methods were taken from experimental data.

Moreover, control variable for all of the methods of room-and-pillar system was the width of the second working ranging within 2 to 20 m (considering bearable span of the second working). Control variable was used to determine an optimal value of the second working’s width and intervening pillar’s width.

Coefficient of the seam inclination influence:

\[
K_\alpha = \frac{\eta \cdot \sin \alpha}{\cos \beta \cdot \sin(\alpha - \beta)}
\]

Where \( \beta = \alpha - \arctg(\eta \cdot \tan \alpha) \);

\( \eta \) – horizontal stress coefficient, \( \eta = \frac{\mu}{1 - \mu} \)

1. Calculation algorithm for rooms and pillars technological parameters and performance indicators of room-and-pillar system’s methods

Calculation algorithm for performance indicators and parameters of room-and-pillar system considers following main analytical solutions:

- Value of the advance per round:

\[
l_{\text{yx}} = l_{\text{tmp}} \cdot K_{KHII} \cdot m
\]

Where \( l_{\text{tmp}} \) - hole run; \( l_{\text{tmp}} = 2.1 \) m; \( K_{KHII} \) – Heading advance per round to shot holes length ratio.

- Specific consumption of explosives:

\[
q = q_1 \cdot f_o \cdot V \cdot e \cdot m, \text{kg/m}^3
\]

Where \( q_1 \) – explosives quantity disposable under standard conditions, \( q_1 = 1 \); \( f_o \) – coefficient, which considers formation structure, \( f_o = 1.3 \); \( e \) – performance coefficient, \( e = 0.9 \); m –...
Coefficient, which considers cartridge size, $m=1$; $V$ – constraining factor:

$$V = \frac{3 \cdot l_{an}}{\sqrt{S_{an}}}$$

- Explosive quantity per explosion

$$Q_{ce} = q \cdot l_{an} \cdot S_{an}, \text{kg}$$

- Number of holes

$$N = \frac{1,27 \cdot q \cdot S_{an}}{d^2 \cdot \Delta \cdot a \cdot k}, \text{units}$$

Where $a$ – charge ratio, $a=0.7$; $\kappa$ – Coefficient, which considers explosive density, $\kappa=1.1$; $\Delta$ – explosive density, $\Delta=1.1, \text{g/sm}^3$.

- Workload per process:

  Drilling of holes: $V_{dyp} = l_{an} \cdot N_{an}, \text{meter run}$

  Charging of hole: $V_{zap} = V_{dyp} \cdot a, \text{kg}$

  Mucking: $V_{noz} = l_{yx} \cdot S_{an}, \text{m}^3$

- Labor intensity per process

  Drilling of holes: $T_{dyp} = V_{dyp} \cdot H_{qp}, \text{man per shift}$

Where $H_{qp}$ – time standards of Uniform Time Standards and Blasting Workings, man per shift

- Time per process:

  Drilling of holes: $t_{dyp} = \frac{T_{dyp}}{n \cdot K_{neq}}, \text{shift}$

Charging of hole: $t_{zap} = \frac{T_{zap}}{n \cdot K_{neq}}, \text{shift}$

Mucking: $t_{noz} = \frac{T_{noz}}{n \cdot K_{neq}}, \text{shift}$

- Second mining time:

  $t_{ow.a} = t_{dyp} + t_{zap} + t_{noz}, \text{shift}$

- Time of block mining:

  $t_{d3} = t_{ow.a} \cdot N_u, \text{shift}$

- Number of rounds for mining of one room

$$N_u = \frac{L_{uum}}{l_{yx}}$$

- Bearable span of the outcropping

$$a_{zam} = 2 \cdot d_1 \cdot \left( \frac{10 \cdot \sigma_{ce}}{K_{a} \cdot \gamma \cdot H} - 1 \right)$$

Where $d_1$ – horizontal dimension of the formation natural (joint) block, m; $\sigma_{ce}$ – compressive resistant of the ore mass, kg/sm$^2$; $H$ – mining depth, m; $\gamma$ – formation density, ton/m$^3$.

- Quantity of ore mass produced from the block:

$$Q_{d3} = m \cdot L_{uam} \cdot (a_{zam} + b_y), \gamma_p$$

Where $m$ – ore body thickness, m; $L_{uam}$ – length of a room, m; $\gamma_p$ – ore density, ton/m$^3$; $b_y$ – pillar width, $b_y = y + \frac{b}{3 \cdot a}$, where $a$, $b$ and $y$ – simplexes.

Therefore, block capacity is obtained:

$$P_{d3} = \frac{Q_{d3} \cdot K_{yx}}{t_{ow.e}}$$

Economic and mathematical model for calculation of performance indicators: block capacity, labor intensity, productivity of a face worker, – was composed based on this algorithm. In addition, program for implementation of this algorithm was developed.
Economic and mathematical model for calculation of performance indicators

1. \[ P_{ds} = \frac{Q_{ds} \cdot K_{yu}}{t_{ds}} \]

2. \[ t_{ds} = t_{o.cn} \cdot N_u \]

3. \[ Q_{ds} = m \cdot L_{sam} \cdot (b_y + a_{sam}) \]

4. \[ N_u = \frac{L_{sam}}{I_{yu}} \]

5. \[ t_{o.cn} = t_{6y} + t_{zsp} + t_{nsc} \]

6. \[ I_{yu} = I_{sam} \cdot K_{yu} \]

7. \[ a_{sam} = 2 \cdot d_l \cdot \left( \frac{10 \cdot \sigma_{csw}}{K_3 \cdot \gamma_p \cdot H} - 1 \right) \]

8. \[ b_y = y + \frac{b}{3 \cdot a} \]

9. \[ y = \sqrt{\frac{q}{2}} + \sqrt{\frac{q^2}{4} + \frac{p^3}{27}} + \sqrt{\frac{-q}{2} - \frac{q^2}{4} + \frac{p^3}{27}} \]

10. \[ a = \frac{\sigma_{csw}}{\sqrt{m}} \]

11. \[ b = K_2^2 \cdot K_3^2 \cdot (\gamma_p \cdot H + \gamma_3 \cdot m)^2 \]

12. \[ p = -\frac{b^2}{3 \cdot a^2} + \frac{c}{a} \]

13. \[ q = \frac{2 \cdot b^3}{27 \cdot a^3} - \frac{b \cdot c}{3 \cdot a^2} + \frac{d}{a} \]

14. \[ a = \frac{\sigma_{csw}}{\sqrt{m}} \]

15. \[ b = K_3^2 \cdot K_4 \cdot (\gamma_p \cdot H + \gamma_3 \cdot m)^2 \]

16. \[ c = K_3^4 \cdot K_4^2 \cdot (\gamma_p \cdot H)^2 \cdot (\gamma_3 \cdot m)^2 \]

17. \[ d = 2 \cdot a_{sam} \cdot K_1 \cdot K_3 \cdot (\gamma_p \cdot H + \gamma_3 \cdot m) \]
Continuation of block capacity calculations

Economic and mathematical model for calculation of face worker productivity

\[ P_{zp} = \frac{Q_{sl}}{(T_{бор} + T_{зар} + T_{поз})} \]
Continuation of block capacity calculations

21 \[ t_{mp} \]

34 \[ t_{mp} = t_{byp} + t_{sp} \]

35 \[ t_{byp} = \frac{T_{byp}}{n_{act} \cdot K_{nep}} \]

36 \[ t_{sp} = \frac{T_{sp}}{n_{act} \cdot K_{nep}} \]

37 \[ T_{sp} = V_{byp} \cdot H_{sp} \]

38 \[ T_{sp} = V_{sp} \cdot H_{sp} \]

39 \[ V_{byp} = \frac{b_s \cdot L_{sam} \cdot m}{L_{mp}^2} \]

40 \[ V_{sp} = \frac{b_s \cdot L_{sam} \cdot m}{L_{mp}^2} \]

41 \[ L_{mp} = \frac{N \cdot P}{K \cdot Q} \]

42 \[ Q = 20 \cdot \rho_n \cdot a_n \cdot a \cdot B \cdot \cos \left(\frac{\alpha}{2}\right) \]

43 \[ \theta = \frac{10 \cdot (a_n + C) \cdot (\cos \alpha + \sin \alpha \cdot \cot \beta)}{K_\alpha \cdot \sigma_g} \]

44 \[ C = \left( \frac{K_{cmp} \cdot \rho \cdot g \cdot H \cdot B}{100 \cdot \sigma_g} \cdot \cos \left(\frac{\alpha}{2} - 1\right) \cdot m \cdot \tan \left(\frac{90 - \varphi}{2}\right) \right) \]

45 \[ B = 1 + \frac{K_{cmp}^2 \cdot R}{2 \cdot K \cdot R + r} \]

46 \[ \varphi = \arctan \left(\frac{\sigma_m}{10}\right) \]

47 \[ R = \cos \left(\frac{\alpha}{2}\right) \sqrt{\frac{K \cdot m \cdot \rho \cdot g \cdot H}{0.35 \cdot \sigma_p}} \]
Calculations of performance indicators for each method of room-and-pillar system

Program for calculation of performance indicators for each method of room-and-pillar system with progress in depth was developed based on the mathematical model and the algorithm. Calculation results are presented on the pictures 2-5.

Extraction ratio is used as a main parameter of the produced ore quality. From the obtained results, it can be seen that the extraction ratio is decreasing with progress in depth; however, it still has a high value, around 70-80%.

Performance of a second working varies. On one hand, it decreases with use of combined support of the ore-concrete-ore method, the reasons for this are remaining of big sized pillars, and, consequently, big losses in minerals. On the other hand, it increases with use of combined support of the concrete-ore-concrete method. The reasons for this are little losses in minerals and high extraction ratio.

Labor intensity of second mining and productivity of a face worker (pictures 3 and 4) are decreasing as well. Labor intensity with the highest value is reached on the method of combined support of the concrete-ore-concrete; however, it has the highest productivity. The reason for this is high extraction ratio.

Accuracy of these data can be compared with the values of face worker productivity from other similar mines. Face worker productivity is one of the main parameters of mining, but only on shallowness (below 800 m). As seen on the picture 4, there is no significant difference, which indicates that the calculations were carried out right.

Based on this work [5], it was shown that:

1. Expansion of the application field of room-and-pillar system is possible due to the transition to combined support method
2. Most efficient method is combined support method
3. Most efficient way of implementation of room-and-pillar system is achieved by mining along the strike and shaping of second workings for mobile equipment

REFERENCES


