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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 ofsecond 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 laborproductivity. 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.

Country, company	Productivity, million,ton/year	Mining depth, m	Ore	System of mining
USA White Pine Pierrepont	 3,0 0,5	 1000 800	 Copper Poly-metallic	Room-and-pillar caving Room-and-pillar system
Canada «Lockerby» «Denison	1,0 –	1200 700 – 900	Copper-nickel Uranium ore	Room-and-pillar, slicing-and-filling. Room-and-pillar system.
RSA DiilKaar	 2,5	 1200 – 2400	 Gold bearing	 Room-and-pillarandlongwall systems
Norway Lekken-Gruber	 0,3	 1050	 Copper-zinc	 Room-and-pillar system
Poland Legnico-Gluhovskii Lubinskoe	 - -	 1000 600	 Copper Copper	 Room-and-pillar system Room-and-pillar system
Sweden «Laysvall»	 2,7		 Copper-zinc	 Room-and-pillar system

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' stressesare 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 40-65ºC 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-Uralsk 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-Uralsk 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.

Mine	dy thi ck	cli na tin	ng de pt	m s' wi	of pil lar	m s' he	Eq ui p m en	a fa ce w	Lo ss es,
Jezkazganskii	1,5-30	6-15	400-650	20	5-7	2-30	Usual	9-10	8-30
Mirgalimaiskii	4-12	0-30	700-750	8	3-6	4-12	Mobile	20-22	10-25
Kadamdzhaiskii	2-20	15-30	550-700	10-11	4	2-20	Usual	5	20
Ahtalskii	8-20	0-2	800	8-11	3-5	2-3	Mobile	5-6	10-20
Vishnegorskii	2-12	15-40	600	6-8	2,5-8	2-10	Mobile	5-6	12
South-Uralsk bauxite mine	2-6	0-14	800	7-10	3,5-5	2-6	Mobile	6-7	11-12
North-Uralsk bauxite mine	2-8	0-30	800	5-8	8-10	2-8	Usual	8-9	20-25

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:

$$\sigma = K_з K_\alpha \frac{\gamma H(x+в)+\gamma_o h}{x\sqrt{\frac{x}{h}}}, \text{ kgF/sm}^2$$

Where $K_з$ – assurance coefficient; K_α– inclination coefficient; γ – ore specific gravity, ton/m^3; H – depth of ore body, m; x and $в$ – width of a pillar and a room, m; γ_o– 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 $A = K_з \cdot K_\alpha \cdot \gamma \cdot H$; $B = K_з \cdot K_\alpha \cdot \gamma_o \cdot h$.

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:

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

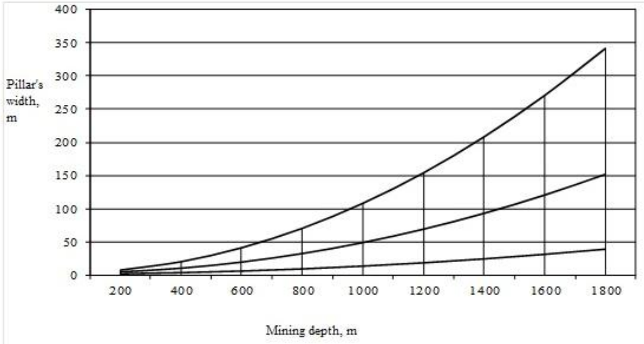
Where $p = -\frac{b^2}{3a^2} + \frac{c}{a}$, and $q = -\frac{2b^3}{27a^3} - \frac{c}{a}$.

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:

$$x = 0{,}184h^{1.292}H^{(0{,}34\ln(h)+0{,}88)}$$

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.



Pic. 1. Impact of mining depth on the pillar's width

Where 1,2 and 3 –ore body thickness of 15, 10 and 5 m respectively

SELECTION AND JUSTIFICATION OF INPUT DATA COMPOSITION

There are fundamental parameters, which help to determine performance indicators of room-and-pillar system. These parameters are the base of the method. Moreover, these parameters are the input data necessary for economic and mathematical modeling; they consist of variable and relatively constant values.

Table 2: Indexing of variable and relatively constant parameters

№	Index	Notation	Parameters	Dimension
1	□	$P_{бл}$	Block capacity	ton/shift
2	□	$P_{з.р.}$	Productivity of a face worker	ton/shift
3	□	$t_{оч.в}$	Time of block mining	shifts
4	□	$Q_{бл}$	Quantity of produces ore mass	ton
5	□	$N_{ц}$	Number of rounds for mining of one room	units
6	□	$a_{кам}$	Bearable span of the outcropping	m
7	□	$t_{бур}$	Time of blast hole drilling	shifts
8	□	$t_{зар}$	Time of hole charging	shifts
9	□	$t_{пог}$	Mucking time	shifts
10	□	$b_{ц}$	Pillar's width	m
11	△	$K_{уч}$	Contribution factor of the second working	
12	○	m	Ore body thickness	m
13	△	$L_{кам}$	Length of the second working	m
14	△	$K_{КИШ}$	Heading advance per round to shotholes length ratio	
15	○	$\sigma_{сж}$	Compressive resistance	MPa
16	△	$K_{з}$	Assurance coefficient	
17	○	d_1	Size of the formation joint block	m
18	△	$\gamma_{р}$	Ore mass density	ton/m^3
19	△	$\gamma_{з}$	Backfilling material density	ton/m^3
20	△	K_{α}	Coefficient of the seam inclination influence	
21	○	H	Mining depth	м

22	□	$T_{бур}$	Labor intensity of drilling	Man per shift
23	□	$T_{зар}$	Labor intensity of charging	Man per shift
24	□	$T_{пог}$	Labor intensity of transportation	Man per shift
25	△	$H_{вр}$	Uniform time standards	
26	□	$V_{бур}$	Hole drilling footage	Per meter run
27	□	$V_{зар}$	Mass of hole charging	kg
28	□	$V_{пог}$	Loading of ore mass	ton
29	△	$l_{шп}$	Run of holes	m
30	□	$N_{шп}$	Number of holes	units
31	△	a	Charge ratio	
32	□	$l_{ух}$	Length of the advance per round	m
33	□	$S_{кам}$	Cross sectional area of the second working	m^2
34	△	k	Coefficient, which considers density of explosives	
35	△	Δ	Explosives density	g/sm^3
36	△	$d_{шп}$	Hole size	m
37	□	q	Specific consumption of explosives	kg/m^3
38	△	q_1	Explosives quantity disposable under standard conditions	kg/m^3
39	△	f_o	Coefficient, which considers formation structure	
40	△	m_n	Coefficient, which considers cartridge size	

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 $\beta = \alpha - arctg(\eta \cdot tg\alpha)$;

η – 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:

$$l_{ух} = l_{шп} \cdot K_{КИШ}, \text{ m}$$

Where $l_{шп}$–hole run; $l_{шп}$=2,1 m; $K_{КИШ}$– 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:

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

■ Explosive quantity per explosion

$Q_{ee} = q \cdot l_{ш} \cdot S_{чер}$, kg

■ Number of holes

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

Where *a* – charge ratio, *a*=0,7; *κ* –Coefficient, which considers explosive density, *κ*=1,1; *Δ* –explosive density, *Δ*=1,1, g/sm^3.

■ Workload per process:

Drilling of holes: $V_{бур} = l_{шп} \cdot N_{шп}$, meter run

Charging of hole: $V_{зар} = V_{бур} \cdot a$, kg

Mucking: $V_{пог} = l_{ух} \cdot S_{кам}$, m^3

■ Labor intensity per process

Drilling of holes: $T_{бур} = V_{бур} \cdot H_{вр}$, man per shift

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

Charging of hole: $T_{зар} = V_{зар} \cdot H_{вр}$, man per shift

Mucking: $T_{пог} = V_{пог} \cdot H_{вр}$, man per shift

■ Time per process:

Drilling of holes: $t_{бур} = \frac{T_{бур}}{n \cdot K_{пер}}$, shift

Where *n* – number of people engaged with the process; $K_{пер}$– over-fulfillment coefficient

Charging of hole: $t_{зар} = \frac{T_{зар}}{n \cdot K_{пер}}$, shift

Mucking: $t_{пог} = \frac{T_{пог}}{n \cdot K_{пер}}$, shift

■ Second mining time:

$t_{оч.в} = t_{бур} + t_{зар} + t_{пог}$, shift

■ Time of block mining:

$t_{бл} = t_{оч.в.} \cdot N_{ц}$, shift

■ Number of rounds for mining of one room

$$N_{ц} = L_{кам} / l_{ух}$$

■ Bearable span of the outcropping

$$a_{кам} = 2 \cdot d_1 \cdot \left(\frac{10 \cdot \sigma_{сж}}{K_з \cdot \gamma \cdot H} - 1 \right)$$

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

■ Quantity of ore mass produced from the block:

$$Q_{бл} = m \cdot L_{кам} \cdot (a_{кам} + b_{ц}) \cdot \gamma_p$$

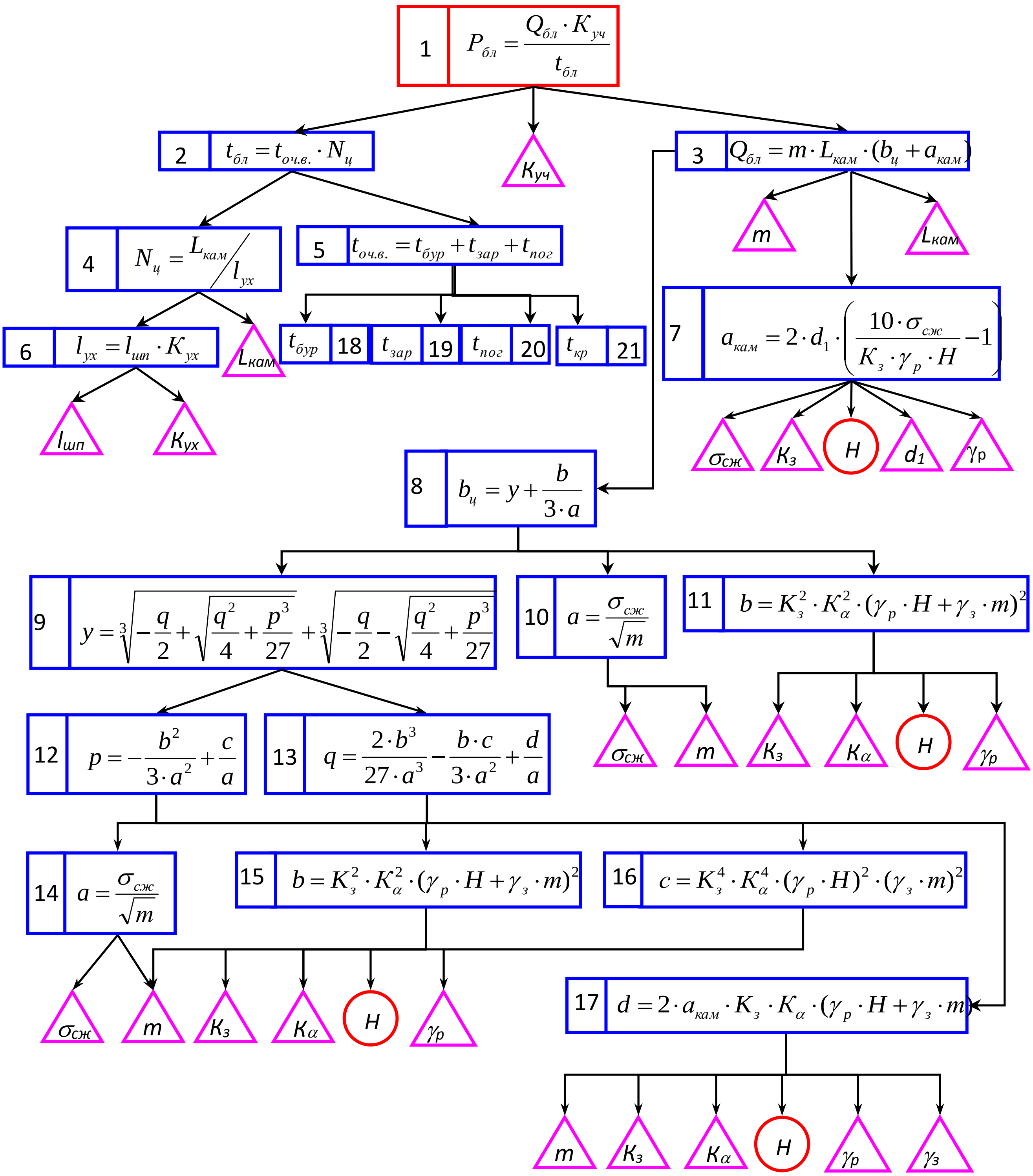
Where *m* – ore body thickness, m; $L_{кам}$ – length of a room, m; γ_p–ore density, ton/m^3; $b_{ц}$– pillar width, $b_{ц} = y + \frac{b}{3 \cdot a}$, where *a*, *b* and *y* – simplexes.

Therefore, block capacity is obtained:

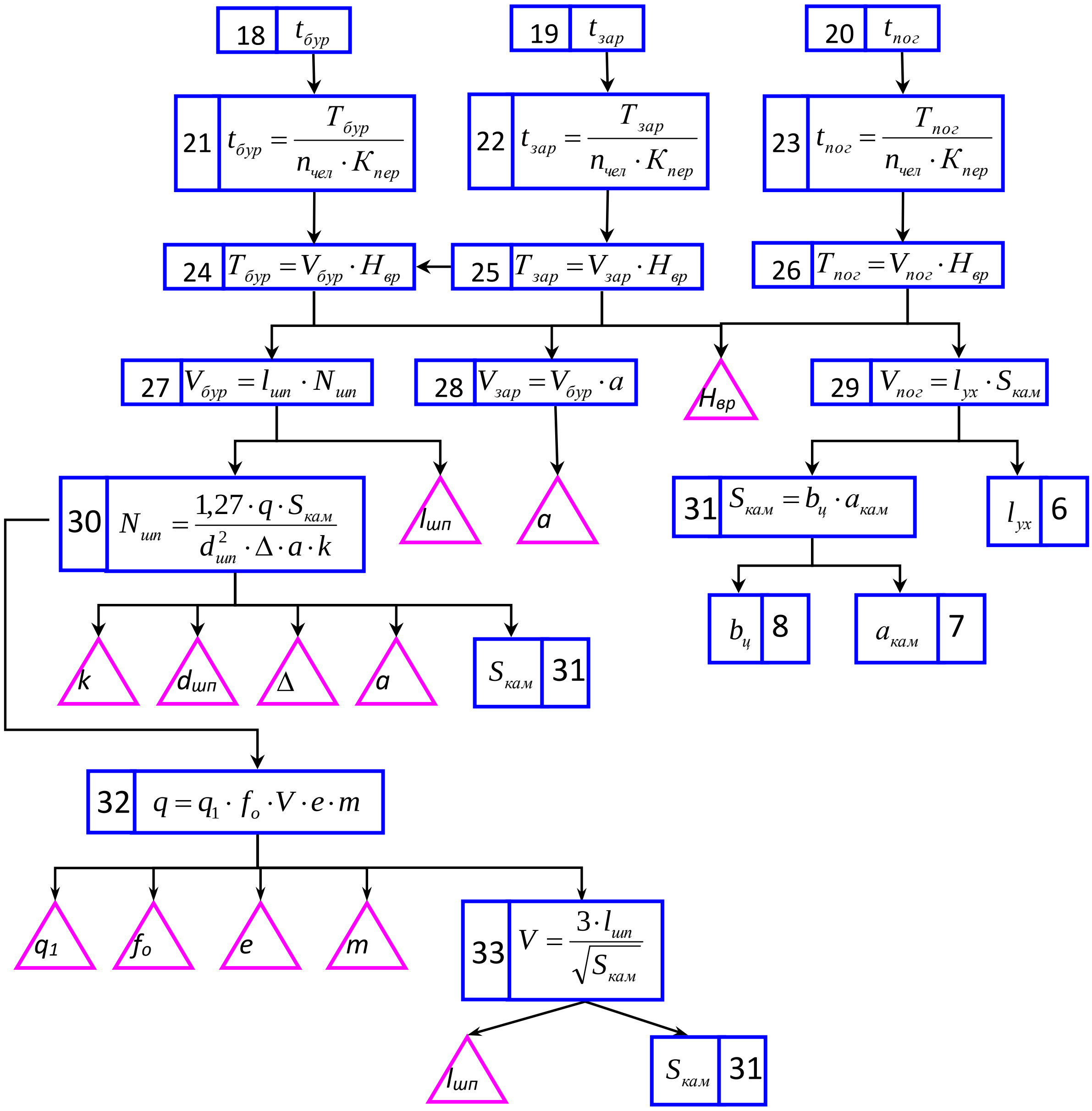
$$P_{бл} = \frac{Q_{бл} \cdot K_{уч}}{t_{оч.в.}}$$

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.

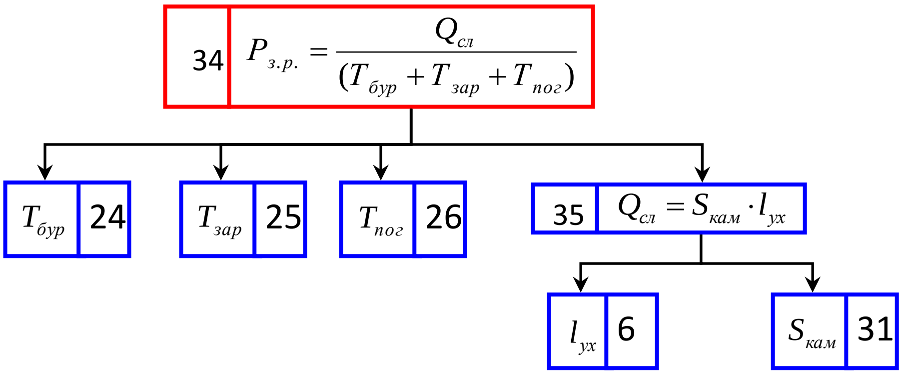
Economic and mathematical model for calculation of performance indicators



Continuation of block capacity calculations



Economic and mathematical model for calculation of face worker productivity



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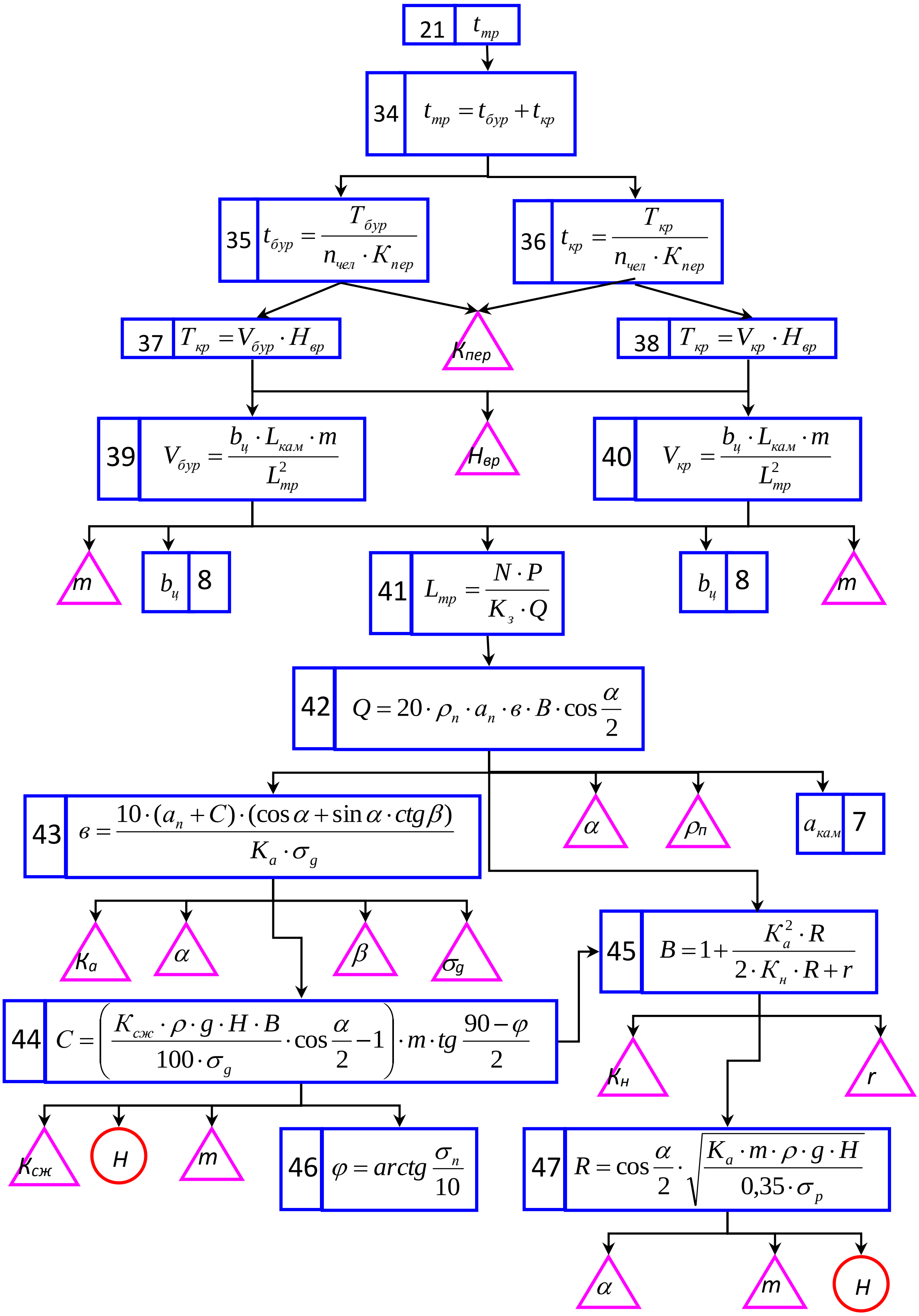
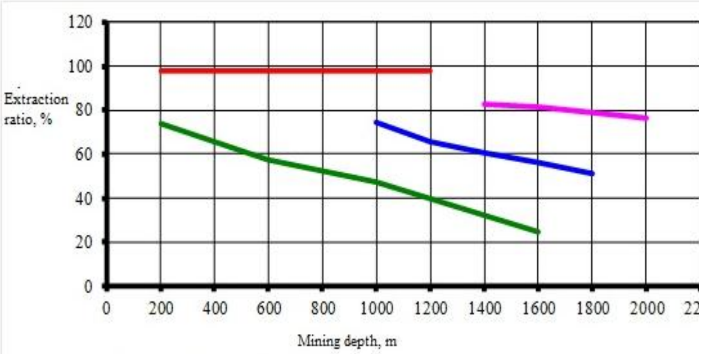
Continuation of block capacity calculations



Calculations of performance indicators for each method of room-and-pillar system

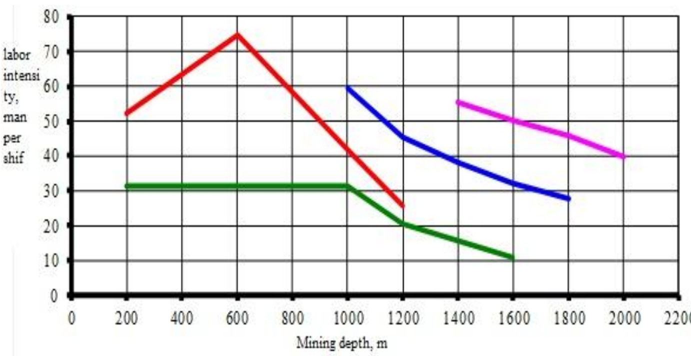
Program for calculation of performance indicators for each method of room-and-pillar system with progress in depth was developed based on the mathematical model and the algorithm. Calculation results are presented on the pictures 2-5.

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%.

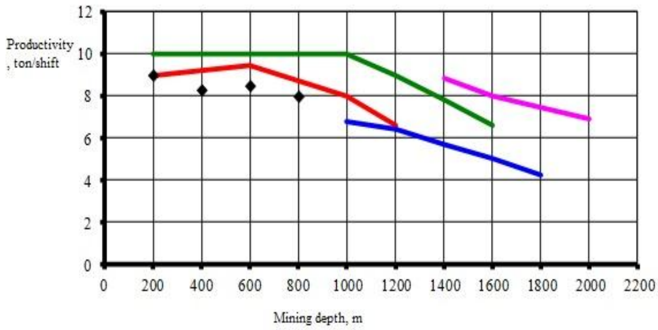


Pic. 2. Impact of the mining depth on the extraction ratio

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.

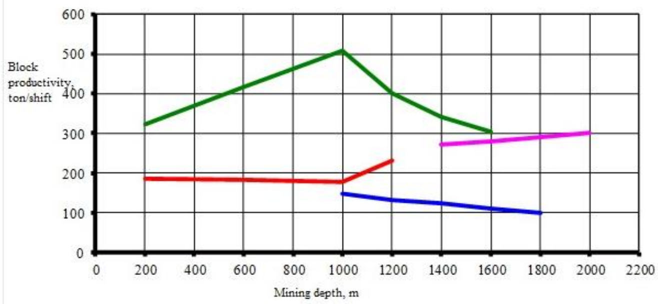


Pic. 3. Impact of the mining depth on the stope labor intensity



Pic.4. Impact of the mining depth on the productivity of a face worker

Performanceof 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.



Pic.5. Impact of the mining depth on the block productivity

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

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