Proportionality and Cyclicity of the Quarry Working Area Development

Alexei Selyukov[1,*], *Peter* Blištan[2], *Stanislav* Jacko[2], *Viliam* Bauer[2]

[1]T.F. Gorbachev Kuzbass State Technical University, Department of open pit mining, 650000 Kemerovo, 28 Vesennya st., Russian Federation
[2]Technical University of Kosice, 04200 Letná 9, Kosice, Slovak republic

Abstract. The mining science, unlike many other technical sciences, studies the processes that occur not in one place, but in moving faces. The primary task is to analyze the influence of the various factors defining the parameters of the quarry operational area and to define a possibility of mining operations' concentrating on the individual sections of the quarry, taking into account their further development downdip and in-depth. The intensity of their movement depends on the surface and on the excavating equipment capacity. The development of open pit mining area in time and space is subject to certain rules. Thus, the initiating works providing the access to the deposit should be ahead of the work on the preparation of excavation blocks, and the latter coal extraction. The intensity of the implementation of this works is also associated with certain patterns of the quarry working area development. The article describes the calculation method for determining the cyclical size of the working area, as a function of some key points: the time of working area development; its speed vector; the direction of the depth of mining and the quarry field area.

1 Introduction

Quarry working area expands from the initial size of the cut trench as well as mining works progress until the upper edge of the quarry reaches the final contours at the surface [1-3]. The development of the working area in depth continues until the mining works reach the final depth of the quarry. The working area of the quarry is a complex spatial surface, which configuration is getting changed with the quarry field development. The quarry working area consists of working sites and benches, permanent and cut trenches, internal dumps, sites under transshipment points, temporary stacks of rock mass, etc. The efficiency of the development of the quarry field and the quality of mined mineral are largely determined by the working area design and evolution in time and space, i.e. by adopted order of its initiation and development [4-6]. The formation of the working area of the quarry is carried out in accordance with certain rules and accepted criteria, and estimated by a number of indicators, such as the speed of the face movement, the speed of movement of the front of the bench or group of benches, the area of the working zone and the rate of its change, etc. [7-8]

* Corresponding author: sav.ormpi@kuzstu.ru

2 Materials and Methods

The work on the quarry field initiation should be developed in the space [9-11] with greater or equal intensity in relation to other works, and the stripping should be ahead of the mining work:

$$\frac{dB}{dt} \geq \frac{dP}{dt} \geq \frac{dO}{dt}, \tag{1}$$

where *B* - depth of stripping work, m;
P – the depth of preparation work, m;
O – the depth of the mineral extraction, m;
t – the duration of the work, years.

It is necessary to distinguish the two cases of mining operations – without a downdip and with a downdip. In the development of the working area of the quarry, each working bench with a horizontal movement in the process of working out must ahead of the underlying bench by a value of not less than the minimum width of the working platform, i.e.

$$B_{oi} \leq B_i + (V_i - V_{i+1})t, \tag{2}$$

where *Boi* – the minimum (calculated) width of the working platform (taking into account the slope) of the *i-th* bench at the beginning of the period, m;
Vi – the actual width of the working platform of the *i-th* bench at the beginning of the period;
t – the duration of the period, years;
V, Vi+1 – respectively, the speed of moving the *i-th* and the underlying (*i+1*) benches, m/year.

Sometimes the formula (2) is more convenient to use in another form to determine the possible speed of the underlying bench movement:

$$V_{i+1} \leq V_i + \frac{1}{t}(B_i - B_{oi}) \tag{3}$$

To define the equation (2) we consider the quarry working area (Fig. 1). As an example, consider the movement of the working benches shown in the graph *L = f(T)*, reflecting the change in time of the lower edge of the working benches. In the initial position, the working side is composed of 4 benches and, based on the need for placement of drilling and blasting equipment, communications, the shotpile of blasted rock, and ensuring the stability of the slopes of the benches, the working platforms must satisfy the condition:

$$B_i \geq B_{i\min} + h_{i+1} ctg\alpha_{i+1} \tag{4}$$

where $B_{i\ \min}$ – the minimum width of the working platform of the *i-th* bench, m;
α_{i+1} - the slope angle of the (*i+1*)*th* bench, degrees.

The movement of the bench 4 of a height *h4* (see Fig. 1) shows a polyline *OE4*, where the vertical sections have a length equal to the time of working out of one stope, and the horizontal sections have a length equal to the width of the stope. It can be replaced by a smooth curve (line *OE4*). The movement of the other benches is shown by solid lines *L3E3*, *L2E2*, *L1E1*. From Fig. 1 in the initial period (*T* = 0) we conclude:

$$\left.\begin{aligned} L_1 - L_2 = B_1 \geq B_{01}; \\ L_2 - L_3 = B_2 \geq B_{02}; \\ L_3 - L_4 = B_3 \geq B_{03}. \end{aligned}\right\} \tag{5}$$

After a time *t*:

$$\left.\begin{aligned}
L_4 &= v_4 t,\\
L_3 &= B_3 + v_3 t,\\
L_2 &= B_3 + B_2 + v_2 t,\\
L_1 &= B_3 + B_2 + B_1 + v_1 t.
\end{aligned}\right\} \quad (6)$$

Substituting the value L_1 from (5) into the expression (6), we obtain the basic equation (7).

$$\left.\begin{aligned}
B_{01} &\le B_1 + (v_1 - v_2)t;\\
B_{02} &\le B_2 + (v_2 - v_3)t;\\
B_{03} &\le B_3 + (v_3 - v_4)t;\\
&\cdots\cdots\cdots\cdots\\
B_{0i} &\le B_i + (v_i - v_{i+1})t.
\end{aligned}\right\} \quad (7)$$

3 Results and Discussion

Let us consider the process of quarrying in depth-and-time coordinates. As the quarry is deepening (Fig. 2A), its working side moves down and to the right, covering more and more benches.

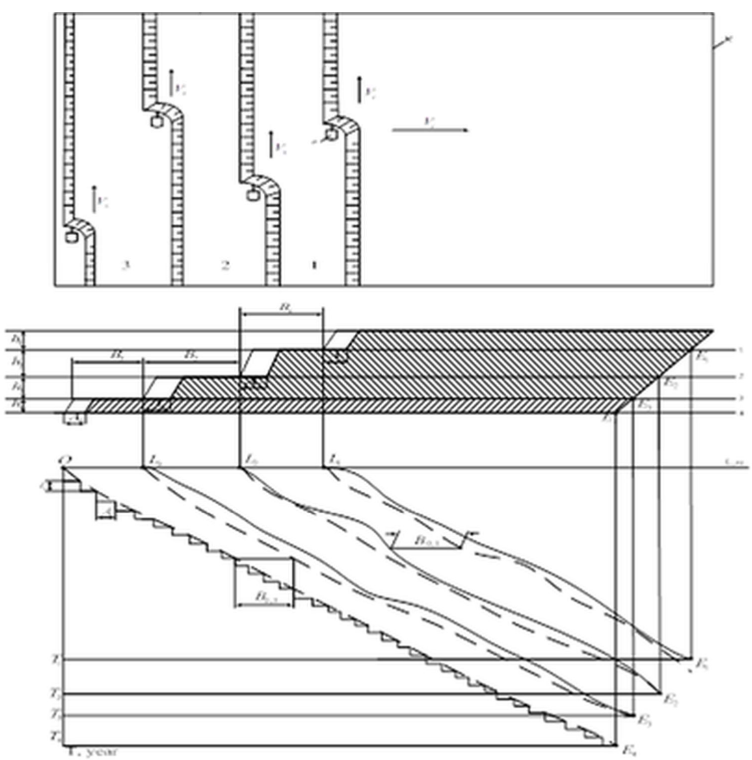

Fig. 1. Scheme of development of the working area of the quarry when working out the bench by longitudinal stopes (a) and the graph of the position of the lower edge of the bench L in time T (b). Note: 1, 2, 3, 4 – the horizons; K – the quarry contour; e – the excavator.

In the working area formation with the quarry downdip, each working bench with a horizontal movement goes ahead the underlying bench by a minimum (calculated) width of the working platform in the process of working out. When mining operations are moving in depth, the working platform of the minimum width should be preserved. on the lower working bench.

On each working bench and after its preparation, the working front moves to the right and consistently passes through points 1, 2, 3, etc., in which the possibility of stripping and preparation of the underlying bench is provided.

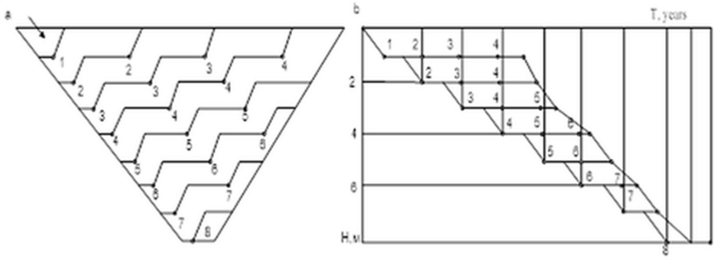

Fig. 2. Scheme of development of the working area of the quarry in the course of its deepening (a) and the schedule of change of depth of the quarry *H* in time *T* (b).

The development of works in time and space is shown on the graph $H = f(T)$. The benches work out is shown by horizontal lines, and the quarry's downdip – by inclined lines. Time of the coming of the work to the points 1, 2, 3, etc. is shown on Fig. 2b. If to draw the vertical lines from the lower points (see Fig. 2, dash-dotted lines), then all the same points on the upper benches should lie to the left of the vertical to ensure the calculated width of the working platforms, i.e. here the condition (7) is fulfilled. To identify the second condition associated with the quarry deepening, we consider the figure. 3.

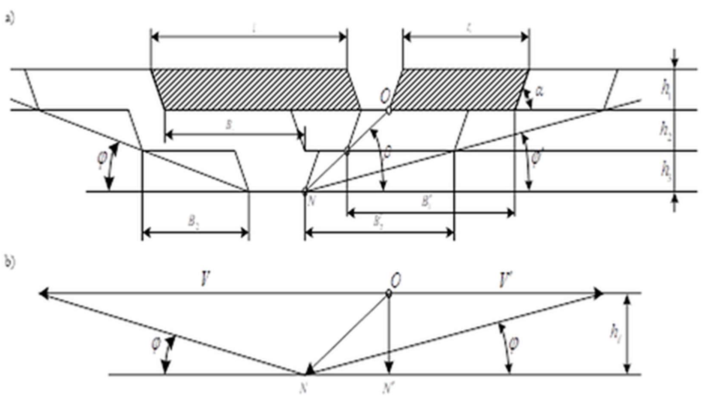

Fig. 3. The scheme of 2 benches mining (a) and the correlation between the velocity vectors of movement work bench and the quarry deepening speed (b).

To downdip into the second bench on the line (see Fig. 3A), it is necessary to move the front of the first bench to the left (in the direction of the downdip) by the value of *l1*, and to the right – by the value of l_1', and:

$$l_1 = h_2(ctg\varphi + ctg\beta) = B_1 + h_2 ctg\beta.$$

Since:

$$B_1 \geq B_{01} = B_{\min} + h_2 ctg\alpha_2,$$

So:

$$l_1 \geq B_{\min} + h_2(ctg\beta + ctg\alpha_2).$$

Similarly, we find the value of l_1', i.e:.

$$l_1' = h_2(ctg\varphi' - ctg\beta) = B_1' - h_2 ctg\beta.$$

Since:

$$B_1' \geq B_{01}' = B_{\min}' + h_2 ctg\alpha_2,$$

So:

$$l_1' \geq B_{\min}' + h_2(ctg\beta - ctg\alpha_2).$$

In common sights:

$$\left.\begin{aligned} l_i &= h_{i+1}(ctg\varphi + ctg\beta), \\ l_i' &= h_{i+1}(ctg\varphi' - ctg\beta) \end{aligned}\right\} \quad (8)$$

Or:

$$\left.\begin{aligned} l_i &\geq B_{\min} + h_{i+1}(ctg\alpha_{i+1} + ctg\beta), \\ l_i' &\geq B_{\min}' + h_{i+1}(ctg\alpha_{i+1} - ctg\beta). \end{aligned}\right\} \quad (9)$$

where *l1* – the necessary distance of moving the front of the *i-th* benche in the direction of the downdip for securing the opening (*i+1*)-th bench, m;
l_1' – the same for the opposite direction, m;
φ and *φ'* – the slope angles respectively of the left and right sides of the quarry, degrees;
β – the angle of the direction of the quarry deepening, degrees;
α i+1 – the slope angle of the bench(*i+1*), degrees;
Bmin, *Bmin*' – the minimum width of respectively the left and right working platforms, m.

Vectors of the quarry deepening speed and moving of benches in the horizontal direction have the form shown in Fig. 3b. The true speed of deepening is represented by the vector *ON*, but it is usually measured by its vertical projection *ON* = h_g. Then:

$$\left.\begin{aligned} V &\geq h_g(ctg\varphi + ctg\beta); \\ V' &\geq h_g(ctg\varphi' - ctg\beta), \end{aligned}\right\} \quad (10)$$

where *V* is the horizontal speed of moving the working bench in the direction of the downdip, m/year;
V' – the same for the opposite direction, m/year;
h_g – the vertical speed of quarry deepening, m / year.

Quarry mining, as well as most of the phenomena in nature, develop cyclically. Individual processes in their development pass certain stages, having a beginning and an end, and have been repeated when completed.

However, due to the fact that the spatial position of the working front of the quarry is constantly changing, each new cycle occurs in different conditions, and its parameters are deviated in one direction or another.

Cycles can be distinguished both in technological processes and in the formation of the working area of the quarry as a geometric object. In technological processes the cyclicity can be seen in the following:

• the cyclical nature of drilling rigs work;
• the repeatability of the well drilling, charging and blasting of certain portions of the rock mass; the resumption of the provision of blasted rocks;
• cyclic operation of excavator and other mining machines;
• repeatability of dump truck movements;
• constant renewal as the front of transport and other communications;
• cyclicity of operation of dump sites;

In the process of formation of the quarry working area appears:
• the cyclical nature of trenching;
• repeatability stope's movement within excavation block;
• repeatability of the stripping and preparation works on the new horizons; working out the new benches to the final contours of the quarry.

4 Conclusion

All production cycles are superimposed by organizational cycles. The presence of such a cycle makes it possible to study each process and, what is very important to predict the development of these processes in time and space. The presence of regularities associated with the proportionality and cyclicity in the mining operations development is of great importance and leads to the following important consequences:
• when working out the benches, it is necessary to carefully monitor the change in the width of the working platforms and the timely movement of the upper benches, since the narrowing of the platforms leads to a disturbance of the quarry work and to a decrease in its productivity;
• to maintain the quarry operability, it is necessary to constantly resume the volumes of the blasted rock mass, reserves of ready-to-excavate rock mass, the front of mining and stripping operations, etc.;
• defining the parameters of stripping and mining methods can be made only based on all the above-mentioned regularities.

References

1. O. Litvin, M. Tyulenev, S. Zhironkin, S. Prokopenko, Acta Montanistica Slovaca, **22:2**, 146-152 (2017)
2. M. Tyulenev, O. Litvin, M. Cehlár, S. Zhironkin, M. Gasanov, Acta Montanistica Slovaca, **22:3**, 296-302 (2017)
3. M. A. Tyulenev, S. A. Zhironkin, O. I. Litvin, E. A. Tyuleneva, O. V. Zhironkina, S. O. Markov, Geotechnical and Geological Engineering, **35:5**, 2065-2077 (2017)
4. M. Tyulenev, S. Zhironkin, E. Tyuleneva, A. Abay, S. Anyona, M. Hellmer, Coal International, **265:3**, 30-34 (2017)
5. M. Tyulenev, O. Litvin, M. Cehlár, S. Zhironkin, M. Gasanov, Acta Montanistica Slovaca, **22:3**, 296-302 (2017)
6. D. Hrehová, M. Cehlár, R. Rybár, N. Mitterpachová, 12th International Multidisciplinary Scientific GeoConference and EXPO - Modern Management of Mine Producing, Geology and Environmental Protection, SGEM 2012, **1**, 675-682 (2012)
7. N. Demirel, O. Gölbası, Minerals, **6:2**, 51 (2016)
8. N. Demirel, S. Frimpong, International Journal of Mining, Reclamation and Environment, **23:1**, 4-20 (2009)
9. A. V. Selyukov, Taishan Academic Forum - Project on Mine Disaster Prevention and Control, **1**, 156-160 (2014)
10. A. V. Selyukov, Journal of Mining Science, **51:5**, 879-887 (2015)
11. A. V. Selyukov, Bulletin of the Tomsk Polytechnic University, Geo Assets Engineering, **326:12**, 60-71 (2015)