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Quality control of drilling operations for efficiency upgrading of creation of separation plane by lineage drilling



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Abstract

The factors defining quality of lineage drilling are considered. Techniques of determination of blast-holes deviation are developed. On the basis of these techniques application, the empirical dependences for prediction of blast-holes deviation depending on overlap zone size are obtained and the optimum values of parameters, which identify the volumes of lineage drilling for specific technological parameters, are determined.

Keywords: DRILLING, ROCK EXCAVATION, LINEAGE DRILLING, BLAST-HOLES DEVIATION, QUALITY CONTROL, DIMENSION STONE, MINING TECHNOLOGY

Drilling of blast-holes is widely applied at pits of building and dimension stone [1]. The lineage drilling is quite widely applied in global practice in order to prepare the mined rock for extraction [2, 3]. Drilling of crack is applied for creation of separation plane in primary monolith [4, 5]. Maximum efficien-

cy of cracks drilling is achieved on block pits with the small cutting depth and homogeneous constitution of rocks [6]. As a rule, drilling is carried out in the end face of primary monolith. Moreover, drilling of open-pit is often used when construction of cross-over tracks and trenches [6, 7]. It should be noted that

high-quality drilling operations require considering of a large amount of natural and technology factors [7]. Therefore, the study of the factors defining quality of lineage drilling for the purpose of further development of technique of quality control of process of crack formation is relevant scientific and applied task.

It should be noted that sufficiently small attention is paid to research of drilling of blast-holes. Previously in paper [6], the problem of influence of deviations of blast-holes and their diameter on mineral losses was studied. In papers [4, 7, 8, 9], technological aspects of application of blast-holes drilling for production of decorative stone blocks were investigated.

When drilling of blast-holes line, there can be deviations due to the following reasons: cracks, stress condition of massif, inaccuracy of drill-press installation, side play due to physical wear or constructive shortcomings of certain units of the drilling rig and influence of surface irregularities where the machine is installed on the accuracy of its installation.

In the process of study of lineage drilling, determination of influence of blast-holes overlap zone (Figure 1) on their deviation from design position should be considered as the least studied and the most relevant problem.

With research objective of influence of blast-holes overlap zone, drilling of 7 series of 3 m in depth blast-holes with a diameter of 40 mm with overlap of 5, 10, 15, 20, 25, 30 and 35 mm in the Osnykovskoe occurrence by Perfora Rombo TC drilling rig was carried out. In each series 5 shots were used. Deviation of blast-holes was measured by photogrammetric method according to the technique proved in papers [10-13] after separation of monolith by traces of blast-holes in the massif.

Dependence of an angular deviation of the blast-hole, by which deviation from vertical position in the plane of crack parallel axis is meant, on length of overlap zone of the next blast-holes is characterized by correlation coefficient 0.87 and is described

analytically by polynomial of the second order of the following form:

$$\beta = 0,8681 + 0,1025 \cdot l_{ov} - 0,0012 \cdot l_{ov}^2 \quad (1)$$

where l_{ov} - length of overlap zone of the neighbor blast-holes, mm.

Graphic dependence of an angular deviation of the blast-hole on length of overlap zone of the neighbor blast-holes is presented in Figure 2.

It should be noted that the blast-hole deviation from design value is possible in two inter-perpendicular vertical planes. It is the most difficult to evaluate the blast-hole deviation in the plane, which is perpendicular to the direction of crack formation (Figure 3).

For this purpose, the possibility of implementation of several variants of blast-holes deviation determination in the plane, which is perpendicular to the direction of crack formation in course of lineage drilling, has been considered. These variants are the following: photogrammetric, laser scanning and also by means of curvimeter and mining compass.

Possibility of use of photogrammetric method for determination of deviation parameters is very limited due to some hindrances, and also is characterized by big convergent angles that will lead to the low accuracy of the results.

Use of laser scanning would make it possible to evaluate blast-holes deviations and their spatial position the most precisely and effectively, but the high cost of this equipment does not allow it to be used in the research. Therefore, after the analysis of possible variants of determination of blast-hole deviation, the technique with the use of curvimeter (Scale Master II is recommended in research KU-A) and mining compass has been suggested. The curvimeter was used for measurement of arc length of blast part, which is directly involved in crack formation of (it is length of arcs AB and BC respectively in Figure 3). The necessity of determination of EF distance, which characterizes a linear deviation of blast-holes in the plane,



Figure 1. The crack at the moment of overlap of blast-holes diameters

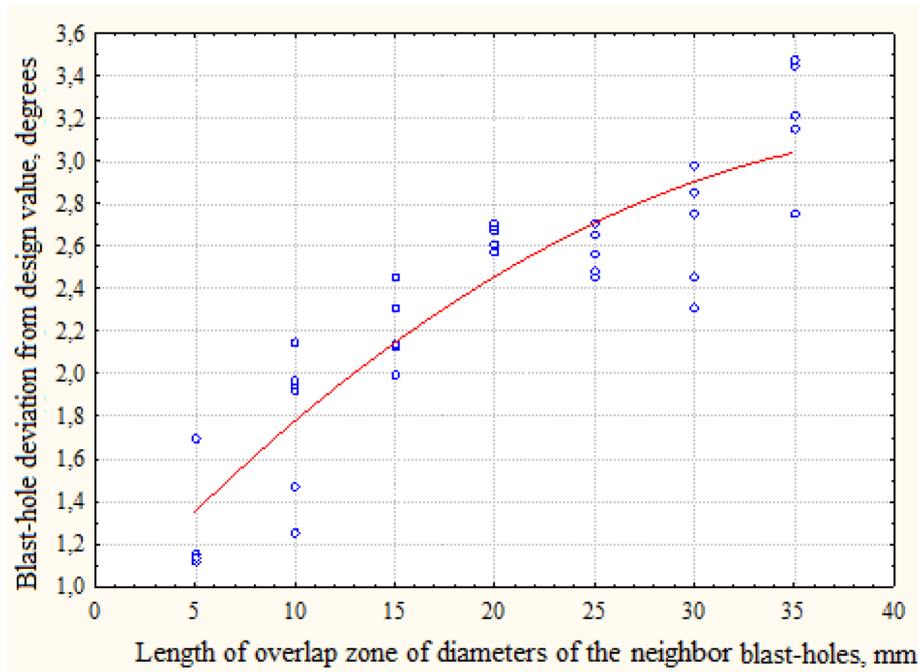


Figure 2. Dependence of blast-holes deviation on length of overlap zone of the neighbor blast-holes

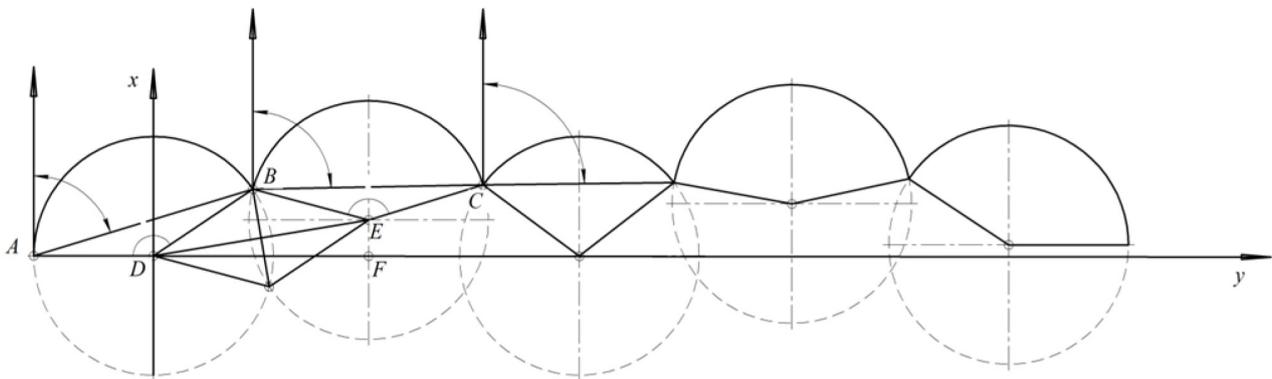


Figure 3. The schematic diagram of blast-holes deviation in the plane, which is perpendicular to the direction of crack formation in the process of lineage drilling

which is perpendicular to the direction of crack formation in course of lineage drilling, is obvious. For georeferencing, the measurement of azimuths of the chord connecting the beginning and the end of blast-hole part that forms a crack is carried out (they are AB and BC directions respectively in Figure 3). The technique of azimuths measurement of blast-holes chords is similar to a technique of azimuths measurement of natural cracks. Considering that blast-holes are crossed, we can make system of the equations of the following form:

$$\begin{cases} (x_B - x_D)^2 + (y_B - y_D)^2 = R^2 \\ (x_B - x_E)^2 + (y_B - y_E)^2 = R^2 \end{cases} \quad (2)$$

Let us take D as the initial point of the coordinates, thus, considering that $x_D = 0, y_D = 0$, the system of equations (2) will be of the form:

$$\begin{cases} x_B^2 + y_B^2 = R^2 \\ (x_B - x_E)^2 + (y_B - y_E)^2 = R^2 \end{cases} \quad (3)$$

Let us consider that the distance between blast-holes centers l_{cen} is known and corresponds to the designed values taking into account the accepted values of overlapped blast-holes, in this case, $y_E = y_D + l_{cen} = l_{cen}$ and the system (3) will be of the form:

$$\begin{cases} x_B^2 + y_B^2 = R^2 \\ (x_B - x_E)^2 + (y_B - l_{cen})^2 = R^2 \end{cases} \quad (4)$$

As a result of substitution, we obtain:

$$x_B^2 + y_B^2 = x_B^2 - 2x_B x_E + x_E^2 + y_B^2 - 2y_B l_{cen} + l_{cen}^2 \quad (5)$$

After simplification, the expression (5) will be of the following form:

$$x_E^2 - 2x_B x_E - 2y_B l_{cen} + l_{cen}^2 = 0 \quad (6)$$

The equation (6) for a variable x_E will have the following solution:

$$x_E = x_B \pm \sqrt{x_B^2 - (l_{cen}^2 - 2y_B l_{cen})} \quad (7)$$

In according to Figure 3, coordinate B can be found from the following expressions:

$$\begin{aligned} x_B &= x_D + DB \cdot \cos \alpha_{DB} \\ y_B &= y_D + DB \cdot \sin \alpha_{DB} \end{aligned} \quad (8)$$

It is obvious that $DB = R$ (Figure 3), where R - blast-hole radius, m.

Grid azimuth is $\alpha_{DB} = \alpha_{AB} - \angle ABD$. The value α_{AB} is accepted as equal to azimuth, measured by mining compass (correction to magnetic inducement will be neglected). ABD corner from triangle ABD (Figure 3) can be determined from the following expression:

$$\angle ABD = \arcsin \frac{AD \sin \angle ADB}{AB} \quad (9)$$

It is obvious that $AD = R$ (Figure 3). Considering that AB is chord, segment chord length according to [14] will be as follows:

$$AB = 2R \sin\left(\frac{1}{2} \angle ADB\right) \quad (10)$$

After substitution of (10) into (9) we obtain:

$$\angle ABD = \arcsin \frac{R \sin \angle ADB}{2R \sin\left(\frac{1}{2} \angle ADB\right)} = \arcsin\left(2 \cos\left(\frac{1}{2} \angle ADB\right)\right) \quad (11)$$

$$\begin{aligned} l_e &= R \cdot \cos\left(\alpha_{AB} - \arcsin\left(2 \cos\left(\frac{\pi \cdot R}{180 \cdot L_c \cdot 2}\right)\right)\right) \pm \\ &\pm \sqrt{\left(x_D + R \cdot \cos\left(\alpha_{AB} - \arcsin\left(2 \cos\left(\frac{\pi \cdot R}{180 \cdot L_c \cdot 2}\right)\right)\right)\right)^2 - \left(l_{cen}^2 - 2l_{cen}(y_D + R \cdot \sin\left(\alpha_{AB} - \arcsin\left(2 \cos\left(\frac{\pi \cdot R}{180 \cdot L_c \cdot 2}\right)\right)\right)\right)} \end{aligned} \quad (18)$$

where R - blast-hole radius, m;

α_{AB} - azimuth of the chord connecting the beginning and the end of blast-hole part, which forms crack, degrees;

L_c - length of arc of blast-hole part, which is directly involved in crack formation, m;

x_D, y_D - coordinates of the center of the previous blast-hole, m.

Researches of dependence of blast-holes deviation in the crack plan perpendicular to the direction of formation and length of overlap zone of the neighbor blast-holes (Figure 4) have been conducted. The statistical analysis of the obtained results has revealed rather close correlation connection between these

According to [14], corner of a segment is equal to

$$\angle ADB = \frac{\pi \cdot R}{180 \cdot L_c} \quad (12)$$

where R - blast-hole radius, m;

L_c - length of arc of blast-hole part, which is directly involved in formation of a crack; it is measured by curvimeter, m.

Considering (12), the equation (11) will be of the form:

$$\angle ABD = \arcsin\left(2 \cos\left(\frac{\pi \cdot R}{180 \cdot L_c \cdot 2}\right)\right) \quad (13)$$

After substitution, we obtain:

$$\alpha_{DB} = \alpha_{AB} - \arcsin\left(2 \cos\left(\frac{\pi \cdot R}{180 \cdot L_c \cdot 2}\right)\right) \quad (14)$$

Thus, taking into account (14) expression (8) will be described by the following equations:

$$\begin{aligned} x_B &= x_D + R \cdot \cos\left(\alpha_{AB} - \arcsin\left(2 \cos\left(\frac{\pi \cdot R}{180 \cdot L_c \cdot 2}\right)\right)\right) \\ y_B &= y_D + R \cdot \sin\left(\alpha_{AB} - \arcsin\left(2 \cos\left(\frac{\pi \cdot R}{180 \cdot L_c \cdot 2}\right)\right)\right) \end{aligned} \quad (15)$$

As a result of substitutions and transformations, we obtain the resultant expression for determination of center coordinate of the next blast-hole:

$$l_e = x_E - x_D \quad (17)$$

In this case:

results; it is characterized by correlation coefficient 0.667. Analytically, this dependence can be described by polynomial of the second level:

$$l_{cr} = 3,1002 + 0,4748 \cdot l_{ov} - 0,0042 \cdot l_{ov}^2 \quad (19)$$

where l_{ov} - length of overlap zone of the neighbor blast-holes, mm.

Therefore, generally the increase in blast-hole length caused by its deviation from a design position can be evaluated by means of the following expression:

$$\Delta L_{bh} = \frac{H_{dr}}{\cos \beta} + \sqrt{H_{dr}^2 + 0,001 \cdot l_{cr}^2} - 2 \cdot H_{dr} \quad (20)$$

where H_{dr} - design depth of drilling without possible deviations, m;

β - angular deviation of the blast-hole, degrees;

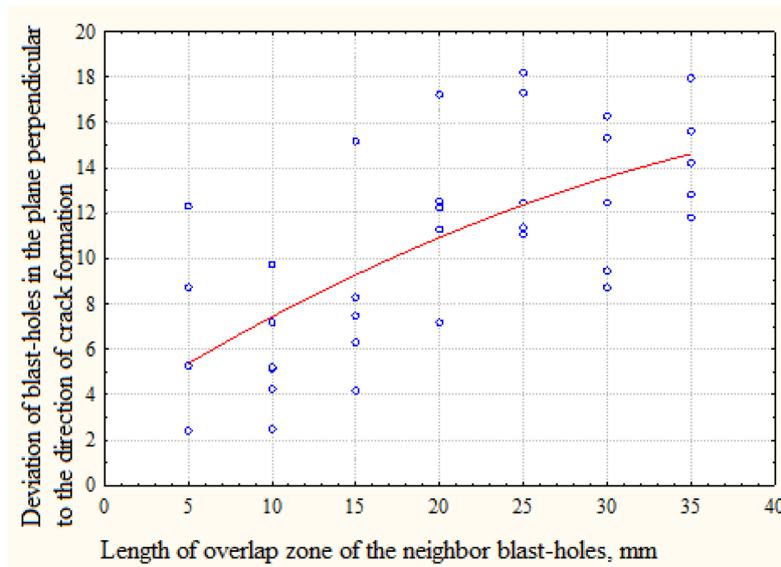


Figure 4. Dependence of blast-holes deviation in the plane perpendicular to the direction of crack formation on the length of blast-holes overlap zone

l_{cr} - deviations of blast-holes in the plane perpendicular to the direction of crack formation and length of overlap zone of the neighbor blast-holes, mm.

After substitution (1) and (19) in expression (20) we obtain:

$$\Delta L_{bh} = \frac{H_{dr}}{\cos(0,8681+0,1025 \cdot l_{ov}-0,0012 \cdot l_{ov}^2)} + \sqrt{H_{dr}^2 + (0,001 \cdot (3,1002+0,4748 \cdot l_{ov}-0,0042 \cdot l_{ov}^2))^2} - 2 \cdot H_{dr} \quad (21)$$

It is possible to evaluate the dependence of blast-hole deviation on depth of drilling and length of blast-hole overlap zone on the basis of the analysis of the three-dimensional diagram (Figure 5).

The analysis of dependence of blast-hole deviation on depth of drilling and length of blast-hole overlap zone has shown that this size is increased

intensively with increase in depth of drilling and less significant with growth of length of blast-hole overlap zone. The most essential indicator, which determines the efficiency of continuous drilling is the volume of drilling operations, which is reasonable to be determined from the following expression:

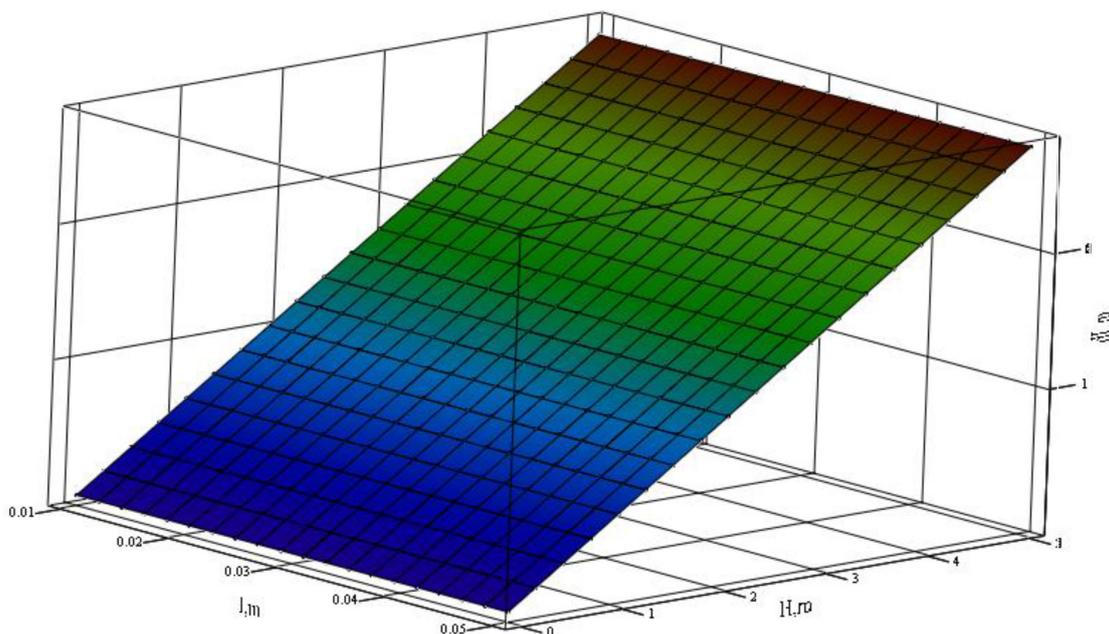


Figure 5. Dependence of blast-hole deviation on depth of drilling and length of blast-hole overlap zone

$$\Delta V_b = \frac{L_m \cdot \Delta L_{bh}}{(d - l_{ov})} \quad (22)$$

Where L_m - length of blast-holes line in a monolith, m;

ΔL_{bh} - design depth of drilling without possible deviations, m;

l_{ov} - length of blast-hole overlap zone, m;

d - blast-hole diameter, m.

It is reasonable to select the optimum values of parameters, which determine drilling volume according to the results of solution of the following system of the equations:

$$\begin{cases} \frac{\partial V_b}{\partial L} = 0 \\ \frac{\partial V_b}{\partial d} = 0 \\ \frac{\partial V_b}{\partial l_{ov}} = 0 \\ \frac{\partial V_b}{\partial(\Delta L_{bh})} = 0 \end{cases} \quad (23)$$

And taking into account expression (22), the system of the equations can be presented in the following form:

$$\begin{cases} \frac{\partial V_b}{\partial L} = 0 \\ \frac{\partial V_b}{\partial d} = 0 \\ \frac{\partial V_b}{\partial l_{ov}} = 0 \\ \frac{\partial V_b}{\partial H} = 0 \end{cases} \quad (24)$$

Change of volumes of drilling for various combinations of technological parameters at the accepted constant values $L_m = 5$ m and $d = 0.04$ m is presented in Figure 6.

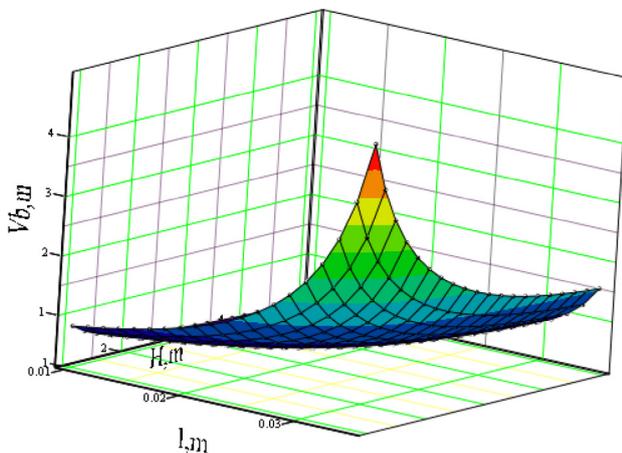


Figure 6. Dependence of volumes of drilling on drilling depth and length of blast-hole overlap zone

The solution of equation system under the conditions of Osnykovskoe occurrence in case of $L_m = 5$ m; $H_{dr} = 3$ m; $d = 0.04$ m has allowed determination of optimum value of length of the neighbor blast-holes $l_{ov} = 0.025$ m overlap zone.

As a result of researches, the methods of determination of angular deviation and blast-hole deviation in the plane, which is perpendicular to the direction of blast-hole crack formation, have been developed. On the basis of use of the developed methods, the influence of size of neighbor blast-holes overlap zone on blast-hole deviation from design value has been determined, empirical dependences for their forecasting have been obtained and optimum values of parameters, which identify drilling volume for specific conditions of the Osnykovskoe occurrence, have been determined.

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