Calculation Methodology Of Blasting And Explosion Operations' Parameters For Construction Of Horizontal And Inclined Excavations

Georgij Sergeevich Kurchin

Siberian Federal University
Russia, 660025, Krasnoyarsk, Krasnoyarskiy Rabochiy Avenue, 95

Sergej Antonovich Vokhmin

Siberian Federal University
Russia, 660025, Krasnoyarsk, Krasnoyarskiy Rabochiy Avenue, 95

Alexander Konstantinovich Kirsanov

Siberian Federal University
Russia, 660025, Krasnoyarsk, Krasnoyarskiy Rabochiy Avenue, 95

Andrey Olegovich Shigin

Siberian Federal University
Russia, 660025, Krasnoyarsk, Krasnoyarskiy Rabochiy Avenue, 95

Anna Aleksandrovna Shigina

Siberian Federal University
Russia, 660025, Krasnoyarsk, Vuzovsky Lane, 3

Abstract
Calculation methods for blasting and explosion operations is a topical issue in mining industry as they allow to improve characteristics of excavation works and safety of explosion operations. The paper presents a novel methodology for calculations for blasting and explosion operations and design of parameters of prismatic gain. That methodology comprises various specifics of rock geology and mining engineering during works in horizontal and vertical excavations. The feature of the presented methodology is that the calculation is based not on definition of specific consumption of explosives, but on accurate definition of radii of rock massif destruction zone in a case of explosion of an elongated charge. The study contains designed parameters of structures of gain blastholes. The proposed engineering solution allows to increase efficiency of explosion operations by decreasing of explosions' consumption, reducing drilling works and decreasing throwout of rocks after explosion. The proposed methodology had passed large scale industrial testing at mines of arctic branch of Norilsk Nickel ltd., which resulted in increase of quality of aforementioned parameters of explosions.

Keywords: calculation methodology, crumple zone, fracturing zone, blasting and explosion operations, straight gain, explosion.

1. Introduction
1.1 The Problem
Economic development of mining industry at the present time required large mining companies to expand and use large-scale methods of mining. Underground excavation method is often preferred among other methods for development of minerals' deposits.

Construction of new and reconstruction of existing mines requires large volume of excavation works, which length can reach tens of kilometers for only one project.

For effective destruction of rock massif in a case of underground development of minerals a technology of blasting and explosion operations (BEO) is used all around the world. According to leading specialists in mining industry blasting destruction of rocks in the near future will become a sole basis for the most part of mining technologies. Improvement of BEO is one of the directions, which allows to increase efficiency of excavation operations. BEO largely influence actual sizes and quality of an excavation's outline, as well as all further processes, which are related with advancing and production of minerals. In this regard, requirements to BEO for horizontal and inclined excavations had increased from points of view of necessary breakdown of rocks after explosion and quality of its crashing, high stability of excavations and design conformity of their outlines.

Despite the great attention given to studies of BEO, so far there is no universal algorithm for calculation of BEO parameters. Currently, most of the existing methods for

calculation of BEW parameters implement empirical equations, which prioritize definition of specific consumption of explosive substances (ES) (Pokrovski, 1977; Porcevski, 2005; Drukovani, *et al.,* 1976; Borisov, 1988; Kutuzov, *et al.,* 1974; Roginski, 1993).

A disadvantage of that approach is the fact that used coefficients have a very wide range changes and their accepted values greatly depend on qualification and intuition of a specialist carrying out calculations. As a result BEO parameters are accepted on a basis of average values, which has a negative influence on efficiency of BEO.

Thus, development of a new methodology for calculation of BEO parameters seems a topical problem.

1.2 Review of existing methodologies

BEO allow not only to break out rocks from a frontal part of an excavation, which is clearly visible, but also cause an internal effect, which can lead to undesired damage that, in turn, often lead to increased expenses for excavation operations and safety problems for personnel.

Nowadays, in order to decrease undesired internal damage and predict those damage during BEO many methodologies are developed, which are based on definition of rock massif destruction zones' parameters of during explosion of ES charge. Successful development of that methodology requires definition of key parameters, which influence modeling of explosion process. Better understanding of interaction of various processes during explosion of elongated ES charge achieved in the last decades allowed researchers to significantly improve such methodological approaches. For example, in a case of explosion of elongated ES charge in rock massif different researchers specify 2-3 main distinguished destruction zones. (Kutuzov, & Andrievski, 2002; Szuladzinski, 1993; Djordjevic, 1999; Mosinets, & Gorbacheva, 1972; Rakishev, 2010):

1. crumple zone (crushing, compression, impact zone, zone of fine fragmentation);
2. fracturing zone (zone of radial cracks);
3. zone of elastic deformation (seismic zone).

For convenience in further parts of the paper those zones will be referred as crumple zone, fracturing zone and zone of elastic deformations. Those zones differ in sizes and represent stages of cracking of rock around an exploding blasthole.

Review of the current status of BEW indicates that in the past decades a large volume of studies was carried out, which were aimed at improvement and development of new methodologies for calculation of BEW parameters. However, so far there is no joint methodology of calculation, which comprises all factors and explains mechanism of fracturing around an explosive charge and the process of rock destruction itself.

There are various methods for estimation of destruction degree for rock massif around an elongated cylindrical charge (Szuladzinski, 1993; Djordjevic, 1999; Mosinets, & Gorbacheva, 1972; Rakishev, 2010). Those approaches ofter imply explosion action in ideal detonation media, and evaluation of reliability of effects, which are calculated using those methodologies, of destruction zones on rock massif

seems quite complicated. In the following section there are brief explanations of the aforementioned methodologies.

1.2.1 Methodology of Szuladzinski (**Szuladzinski, 1993**)

Foreign researchers started to pay big attention to creation of methodology for definition of rock massif destruction zones quite long ago.

One of the first researchers, who proposed his own equation for definition of crumple zone radius was G. Szuladzinski (Szuladzinski, 1993):

$$R_{cr} = \sqrt{\frac{2r_0^2 p_0 Q_{EF}}{F_C'}} \text{, mm} \qquad (1)$$

where
r_0 – radius of a blasthole, mm;
p_0 – density of ES, kg/mm^3;
Q_{EF} – effective energy of ES;
F'_C – rock's compressive strength, Pa.

1.2.2 Methodology of Djordjevic (**Djordjevic, 1999**)

N. Djordjevic (Djordjevic, 1999) proposed to calculate radius of crumple zone using the following equation:

$$R_{cr} = \frac{r_0}{\sqrt{\frac{24T}{Pb}}} \text{, mm} \qquad (2)$$

where
r_0 – radius of a blasthole, mm;
T – rock's tensile strength, Pa;
P_b – pressure in blasthole, which is calculated using the equation:

$$P_b = \frac{P_{CJ}}{2} \text{, Pa} \qquad (3)$$

where
P_{CJ} – velocity of detonation, m/s, which is calculation using the equation:

$$P_{CJ} = \frac{p_0 D_{CJ}^2}{4} \qquad (4)$$

1.2.3 Methodology of Mosinets and Gorbacheva (**Mosinets, & Gorbacheva, 1972**)

Russian researchers are also developing methodologies based on definition of rock massif destruction zones. One of the first were Mosinets V.N. and Gorbacheva N.P. (Mosinets, & Gorbacheva, 1972), who proposed equation for radii of the three destruction zones.

crumple zone radius was proposed to calculate as follows:

$$R_{cr} = \sqrt{\frac{C_T}{C_L}} \cdot \sqrt[3]{q} \text{, m} \qquad (5)$$

fracturing zone radius:

$$R_{fr} = \sqrt{\frac{C_L}{C_T}} \cdot \sqrt[3]{q} \text{, m} \qquad (6)$$

radius of zone of elastic deformation:

$$R_e = \frac{\sqrt{C_L}}{10} \cdot \sqrt[3]{q} \text{ , m} \qquad (7)$$

where

C_L – speed of propagation of longitudinal waves in a massif, m/s;

C_T – speed of propagation of transversal waves in a massif, m/s;

q – weight of charge in TNT equivalent, kg.

1.2.4 Methodology of Rakishev (Rakishev, 2010)

B.R. Rakishev in his work (Rakishev, 2010) proposed the following method of calculations of destruction zone parameters:

crumple zone radius in monolithic rocks in camouflet stage is calculated using the equation:

$$R_{cr} = r_{\lim} \cdot \left(\frac{\rho_0 C^2}{5 \cdot \sigma_c} \right)^{\frac{1}{2}} \text{ , m,} \qquad (8)$$

where r_{lim} – limiting radius of explosion cavity, which is defined as follows:

$$\overline{r_{\lim}} = \left(\frac{P_S}{P_C} \right)^{1/4} , \qquad (9)$$

where P_s and P_c – starting pressure of detonation products and strength characteristic of media under conditions of strong explosion, respectively.

$$P_S = \frac{1}{8} \rho_{ES} D^2 \qquad (10)$$

$$P_C = \sigma_c \cdot \left(\frac{\rho_0 \cdot c^2}{\sigma_c} \right)^{1/4} \qquad (11)$$

where

ρ_0 – density of rock;

c – speed of sound in rock;

ν – Poisson ratio;

σ_C – compressive strength of rock;

σ_t – tensile strength of rock;

ρ_{ES} – density of ES charge;

D – velocity of detonation of ES.

Radius of fracturing zones is calculated using the following equation:

$$R_{fr} = R_{cr} \cdot \frac{\nu}{1+\nu} \cdot \frac{\sigma_c}{\sigma_t} \text{ , m.} \qquad (12)$$

Brief review of the aforementioned methodologies allows to conclude that the problem of development of methodology for calculation of BEO parameters was studied for long time, and various scientists proposed their own approaches to a solution. Some of the proposed methodologies are practically applied, but, as it was mentioned before, all of them consider specific cases and work in specific conditions, as a result there is still no joint methodology, which considers all factors influencing effective carrying out of BEO.

2. Methodology

2.1 The proposed methodology

The proposed methodology is based on definition of radii of zones of crumple and fracturing according to "new theory of destruction of rocks by means of elongated ES charges", which was developed by B.N. Kutuzov and A.P. Andrievski (Kutuzov and Andrievski, 2002).

Now, it is established that during explosion of elongated cylindric charge of ES two main zones are formed in a massif: crumple zone and fracturing zone (Kutuzov, 1983) (Fig. 1).
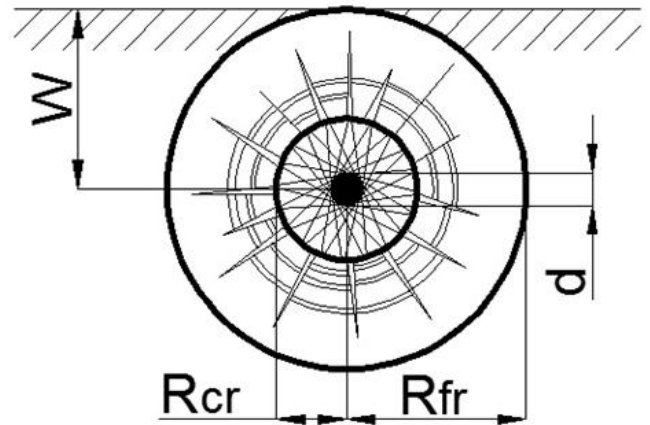
d – blasthole diameter; R_{cr} – crumple zone radius; R_{fr} – fracturing zone radius; W – line of least resistance

Figure 1 – Scheme of formation of crumple zone radius and fracturing zone radius

2.2 Calculation of main zones

The proposed methodology for definition of BEO parameters is based on reliable definition of radii of those two zones; it implies the following course of calculations:

Depending on rock geology and rock engineering characteristics main parameters are defined:

Radius of crumple zone is calculated using the equation (Kutuzov, & Andrievski, 2002):

$$R_{cr} = d \sqrt{\frac{\rho \cdot D^2}{8 \cdot f \cdot 10^7}} \text{ , m} \qquad (13)$$

where

d – blasthole diameter, m;

ρ – density of ES in charge, kg/m³;

D – detonation velocity of used ES, m/s;

f – strength coefficient of rocks according to scale of M.M. Protod'yakonov.

Radius of fracturing zone is calculated using the equation (Kutuzov, & Andrievski, 2002):

$$R_{fr} = 0.2102 \cdot d \cdot \rho^{0.75} \cdot D^{1.5} \cdot \sigma_{comp}^{-0.25} \cdot \tau_{shear}^{-0.5} \cdot K_S^{-0.5} \quad , \quad \text{m} \qquad (14)$$

where

σ_{comp} – compression strength of rocks, Pa;

τ_{shear} – shear strength , (for the major part of rocks τshear do not exceed 20 MPa. Approximately, τshear is equal to (0.1-0.02) σcomp Pa (Kutuzov, 2007);
K_S – structural weakening coefficient.

Structural weakening coefficient, according to the studies (SNiP, 1978), can be defined using the following equation:

$$K_S = 0.64 \cdot L_C - 0.115 \cdot L_C{}^2 + 0.086 \qquad (15)$$

where L_c – distance between cracks (for $L_c>2.5$ structural weakening coefficient is accepted as 1.0).

Line of least resistance is calculated as follows (Kutuzov, & Andrievski, 2002):

$$W = R_{fr} \cdot \cos(0.5 \cdot \alpha) \text{, m} \qquad (16)$$

where α – minimal angle of a formed explosion funnel α=60°.

However, in the aforementioned equation detonation velocity is accepted according to average values, which decreases accuracy of calculation of BEO parameters. Let's discuss relationships of detonation velocity, diameter of a charged blasthole and density of charging from the point of view of optimization of those parameters.
Results of studied of foreign researchers (Bhandari, 1997; Lowrie, 2002; Hartman, 1992) on detonation capacity of industrial ES it was established that there detonation characteristics are directly connected with diameter of charged blasthole and density of ES. Fig. 2 shows relationships, which were established by foreign researchers for ES based on saltpeter and ammonia.
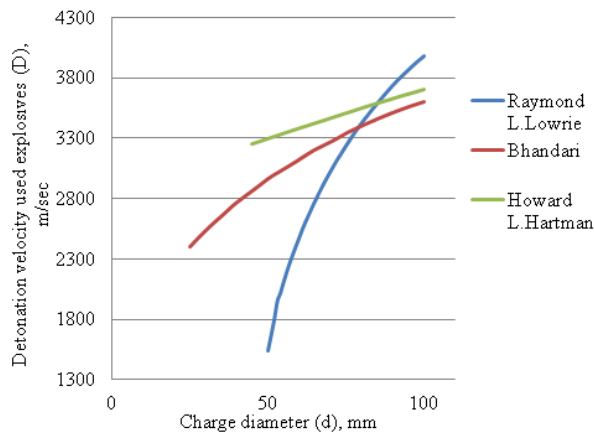
Figure 2 – Relationship between charge diameter (d) and detonation velocity (D)

Studied of S.A. Kalyakin and K.N. Labinski (Kalyakin, & Labinski, 2009) allowed to establish that detonation velocity of ES based on saltpeter and ammonia is affected not only by a blasthole diameter, but also by density of charging. Figure 3 shows relationships obtained taking into account data from the study of Kalyakin and Labinski (Kalyakin, & Labinski, 2009).
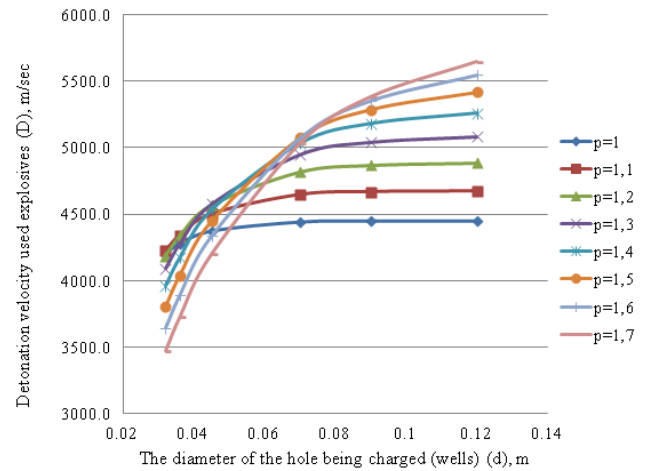
Figure 3 – Relationship of diameter of a charged blasthole and detonation velocity taking into account density of charging

Calculation of detonation velocity of ES based on saltpeter and ammonia taking into account diameter of a charge and density of ES is carried out using the equation (Vohmin, *et al.*, 2014):

$$D = (11.794 \cdot \rho - 7080) \cdot d^{0.00057p-0.46} \text{, m/s} \qquad (17)$$
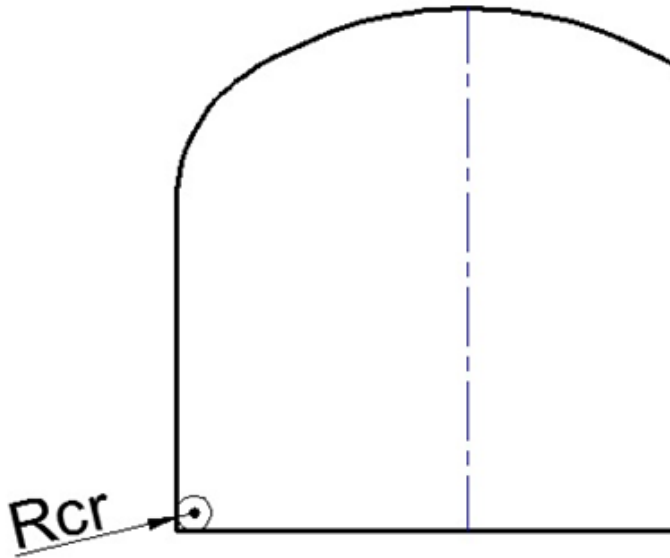
By inserting of the equation (17) for definition of detonation velocity for ES based on saltpeter and ammonia into equations (13) and (14) obtaining equation for radii of crumpling zone and fracturing zone (Vohmin, *et al.*, 2014):

$$R_{cr} = d \sqrt{\frac{\rho \cdot ((11.794 \cdot \rho - 7080) \cdot d^{0.00057\rho-0.46})^2}{8 \cdot f \cdot 10^7}} \text{, m} \qquad (18)$$

$$R_{fr} = 0.2102 \cdot d \cdot \rho^{0.75} \cdot ((11.794 \cdot \rho - 7080) \cdot d^{0.00057\rho-0.46})^{1.5} \cdot \sigma_{comp}^{-0.25} \cdot \tau_{shear}^{-0.5} \cdot K_S^{-0.5} \text{, m} \qquad (19)$$

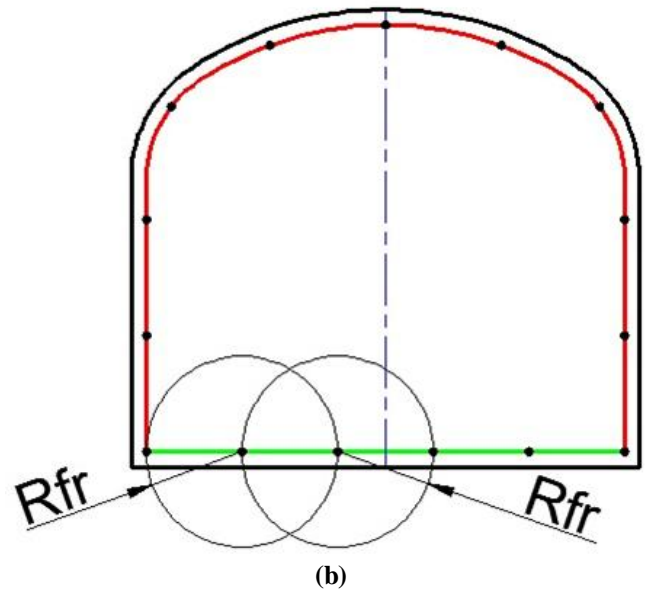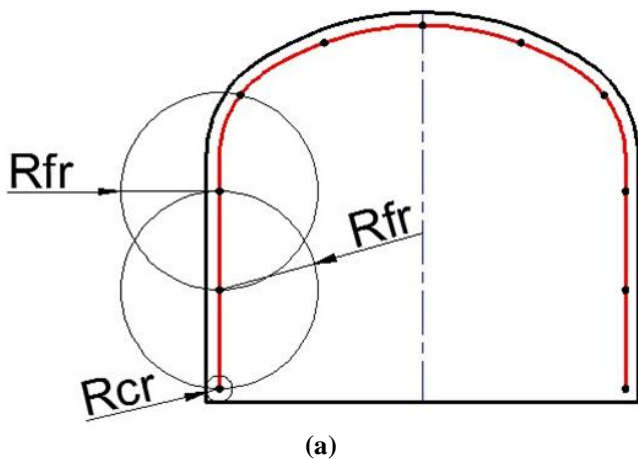### 2.3 Graphical representation of BEO passport
Creation of a graphical representation of frontal projection of BEO passport begins from placement of outlining blastholes. For that, at distance R_{cr} from an excavation's outline a point for a first blasthole is defined (Fig. 4).

Figure 4 – Location of a first blasthole

(b)

Figure 5 – Layout of outlining blastholes: a) Layout of outlining blastholes; b) Layout of outlining blastholes on ground considering different types of ES

After that, a distance R_{cr} from a design outline along a whole perimeter of an excavation other outlining blastholes are placed. Distance between outlining blastholes is defined using value of fracturing zone R_{fr} (Fig. 5a). If face is charged with different ES, R_{fr} is defined separately for each type of ES (Fig. 5b).
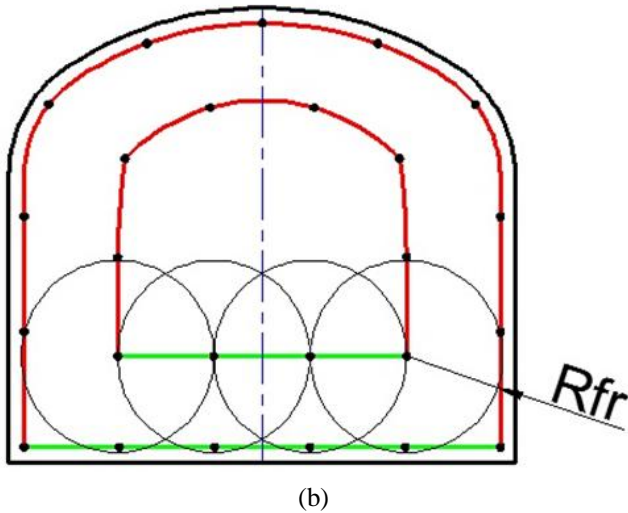
If number of blastholes after their placement is not integer, its value is rounded to the nearest integer value and distance between blastholes is calculated again in way that distances between outlining blastholes working in the same conditions were equal. Change of distance as compared with a calculated parameter must not exceed ±10%.

Distance between outlining and first row of auxiliary blastholes is defined by value of the line of least resistance (LLR) (Fig. 6). Distance between auxiliary blastholes in horizontal plane is equal to a value of a zone R_{fr} (Fig. 6b).

(a)

(a)

(b)
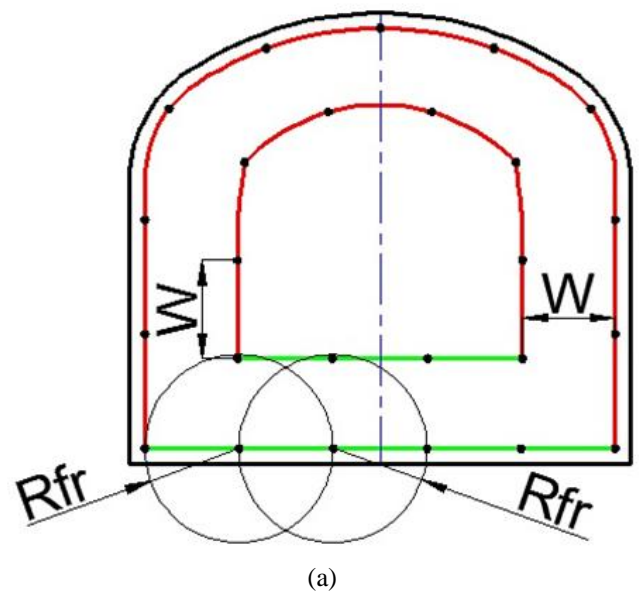
Figure 6 – Layout of first raw of auxiliary blastholes: a) Layout of first raw of auxiliary blastholes; b) Layout of first raw of auxiliary blastholes on ground considering different types of ES

If number of blastholes during their placement is not integer, its value is also rounded to the nearest integer value and distance between blastholes is calculated again in way that distances between were equal. Change of distance as compared with a calculated parameter must not exceed ±10% Taking into account those parameters location of outlining and auxiliary blastholes along a whole cross-section of an excavation is defined.

2.4 Calculation of parameters of explosion gain

Formation of gain cavity is a quite important element in blasting. In working faces with open surface in order to achieve high coefficient of blasthole use (CBU), in a case of BEO technology application, it is necessary to create a second open surface. That function is carried out by gain blastholes.

Practice of mining operations at foreign and Russian mines demonstrated that the most effective gains, which allow to achieve necessary SBU and required speed of excavation are straight gains together with compensation boreholes (which are not charged). It is related with the fact that application of that kind of gains is the most effective in a case of drilling using self-propelled drills (SPD) for depth of more than 2 m.

Number of compensation of boreholes and gain blastholes depends at rock geology conditions and area of cross-section of an excavation. The most widely used diameters of compensation boreholes: 76 mm and 102 mm, at that, their number changes from 1 to 4 pcs. In some cases 3 to 6 compensation boreholes are used, and, generally, their diameter is the same as of blastholes.

It worth mentioning that for blasthole charges faults and incomplete detonation with further inflammation and burning out of not detonated charges (Stankyuvich, *et al.*, 1959). Such incomplete explosions can lead to formation of so-called "glasses". That effect, to a certain point, can be explained by close location of blastholes and consequent damage of adjacent charges, which are initiated with a delay.

For creation of methodology for calculation of parameters and structure of straight prismatic gain we analyzed studies of leading specialists, who are carrying out studies in a field of optimal parameters of BEO. As a result, we established relationships, which allow to defined optimal parameters of a straight prismatic gain with compensating boreholes with high accuracy.

The proposed methodology for definition of parameters of a straight explosion gain is based on the following procedure.

1.   Because a destructed massif at a moment of explosion has only one open surface, first, number of compensation boreholes in a gain is defined, which is aimed at creation of an additional free surface and partial transition of explosion energy to that free zone. On a basis of analysis of operation practices of mines of "Norilsk nickel" ltd. arctic branch and results of some industrial experiments, which were carried out by the authors, it was established that optimal number of compensating boreholes can be defined by means of the following equation (Vohmin, *et al.*, 2014; Vohmin, *et al.*, 2015):

$$N_0 = \frac{0.5 \cdot l_0 - 0.2 \cdot d_0 \cdot l_0^2 + 1.3}{d_0 \cdot 0.087} \text{, pcs.,} \qquad (20)$$

where

l_0 – depth of compensation boreholes, m;
d_0 – diameter of compensation boreholes, m.

2.   For that type of explosion gain the key factor, which defines its usability, is selection of optimal distance between blastholes and compensation boreholes.

Results of industrial experiments allowed to make a conclusion that distance between empty boreholes of a gain must be defined by means of the equation (Vohmin, *et al.*, 2014; Vohmin, *et al.*, 2015):

$$h = d_0 + d - \frac{\pi \cdot d^2}{12 \cdot d_0} \text{, m} \qquad (21)$$

Optimal distance between a compensation borehole and a blasthole is (2÷3)d₀ (Taranov, 1976).

3.   Total number of a gain's boreholes and blastholes, which are situated at a working face's plane can be found as follows (Vohmin, *et al.*, 2014; Vohmin, *et al.*, 2015):

$$N_{gain} = \frac{0.04 \cdot S \cdot k_v}{\pi \cdot R_{cr}^2} \text{, pcs.,} \qquad (22)$$

where
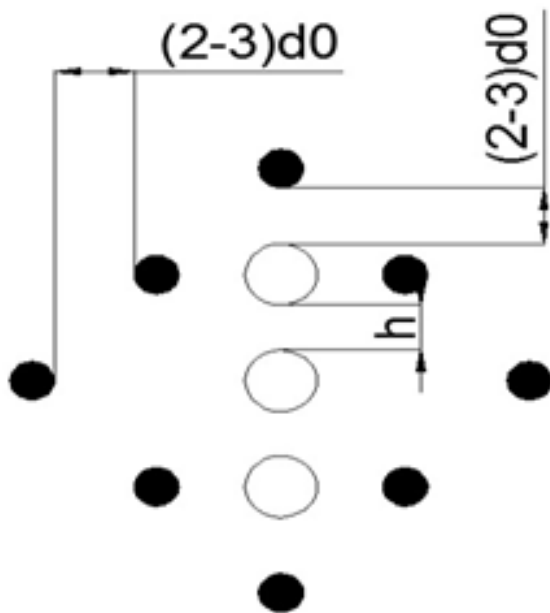
S – cross-section area, m²;
k_v – coefficient of rock ductility.

Depth of a gain's boreholes depends on capabilities of production equipment and, generally, equal to length of bar. Depth of outlining and auxiliary blastholes is lower than a gain's ones for 5-15%. Figure 7 shows scheme of straight prismatic gain created using the proposed equations.

Figure 7 – Scheme of straight prismatic gain created using the proposed equations

If charges of auxiliary blastholes are not enough and there are zones, which can be unaffected, a second raw of auxiliary blastholes is placed at R_{fr} distance (Fig. 8). In a case of small cross-section auxiliary blastholes can be absent.
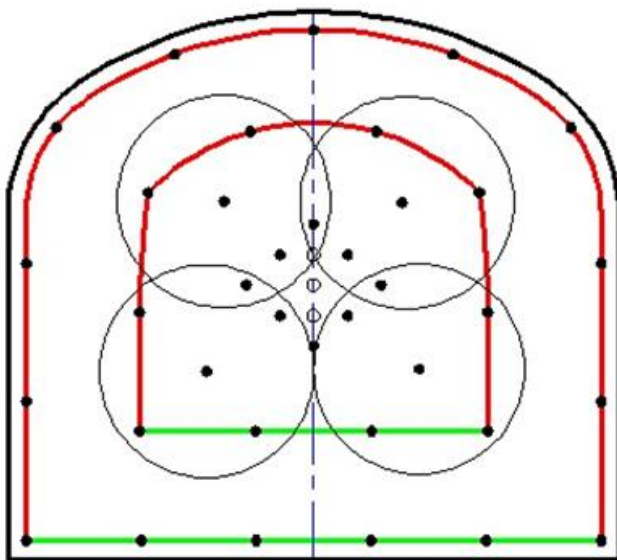
Figure 8 – Layout of second raw of auxiliary blastholes

2.5 Design of blastholes' charge structure

Calculation of structure of blasthole charge is carried out according to the following procedure:

Length of charge in a blasthole is calculated according tot he following equation (Vohmin, *et al.*, 2014; Vohmin, *et al.*, 2015):

$$L_{ch} = l_{bl} - 0.5W - l_{tamp} - l_{pec}, \text{m} \qquad (23)$$

where
l_{bl} – length of blasthole, m;
l_{tamp} – tamping length, m;
l_{pec} – length of prime explosive charge, m.

Possibility for charging with pneumatic charging device in 0.5 kg, 1.0 kg and 2.0 kg portions is checked.

Weight of charge in one blasthole is defined using the following equation (Vohmin, *et al.*, 2014; Vohmin, *et al.*, 2015):

$$Q_{ch} = \frac{L_{ch} \cdot \pi \cdot d^2 \cdot \rho}{4}, \text{kg.} \qquad (24)$$

After that structure of ES charge is defined. Example of that kind of structure is presented in Fig. 9.
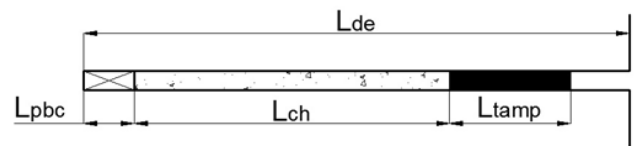
Figure 9 – Scheme of ES charge structure

3. Results and discussion

On a basis of the aforementioned methodology the authors developed passports of BEO and carried out experimental explosions at mines of "Norilsk nickel" ltd. arctic branch.

Experimental industrial trials at "Skalistaya" mine were carried out from 16 September 2013 to 23 November 2013. On a basis of source data main parameters of destruction zones of a rock massif were calculated (Table 1), that data was used for a graphical representation of BEO passport (Fig. 10).

Source data for the passport: blasthole diameter – 48 mm, used drilling equipment – SPD of Boomer M2D type, strength of rocks according to scale of professor M.M. Protod'yakonov f=14 with average level of inconsistency, cross-section of excavation – 16.83 m[2]; used ES: Granulit AZ and Ammonit #6 ZhV; type of gain – straight (with drilling of 3 boreholes of 76 mm diameter); method of charging: for cartridge ES – manual, for granulated ES – by means of pneumatic charging devices.

Table 1 – Characteristics of main parameters of zone of controlled crushing

Name of parameter	Designation	Unit	Value Granulit AZ	Value Ammonit 6 ZhV
Crumpling zone radius	R_{cr}	m	0.155	0.125
Fracturing zone radius	R_{fr}	m	0.94	0.92
Line of least resistance	W	m	0.81	0.8

In the graphical representation the following symbols are used:

− offset from borders of excavation – 150 mm (Fig. 10a);
− distance between outlining blastholes, charged with granulit AZ – for top – 900 mm, for sides – 900 mm (Fig. 10b);
− distance between outlining blastholes, charged with Ammonit 6 ZhV – for bottom – 925 mm (Fig. 10a);
− distance between outlining and first raw of auxiliary blastholes – 900 mm (for bottom) and 800 mm – for top and sides of excavation (Fig. 10b);
− distance between auxiliary blastholes – 800 mm (Fig. 10b).

(a)

(b)

(c)

(d)
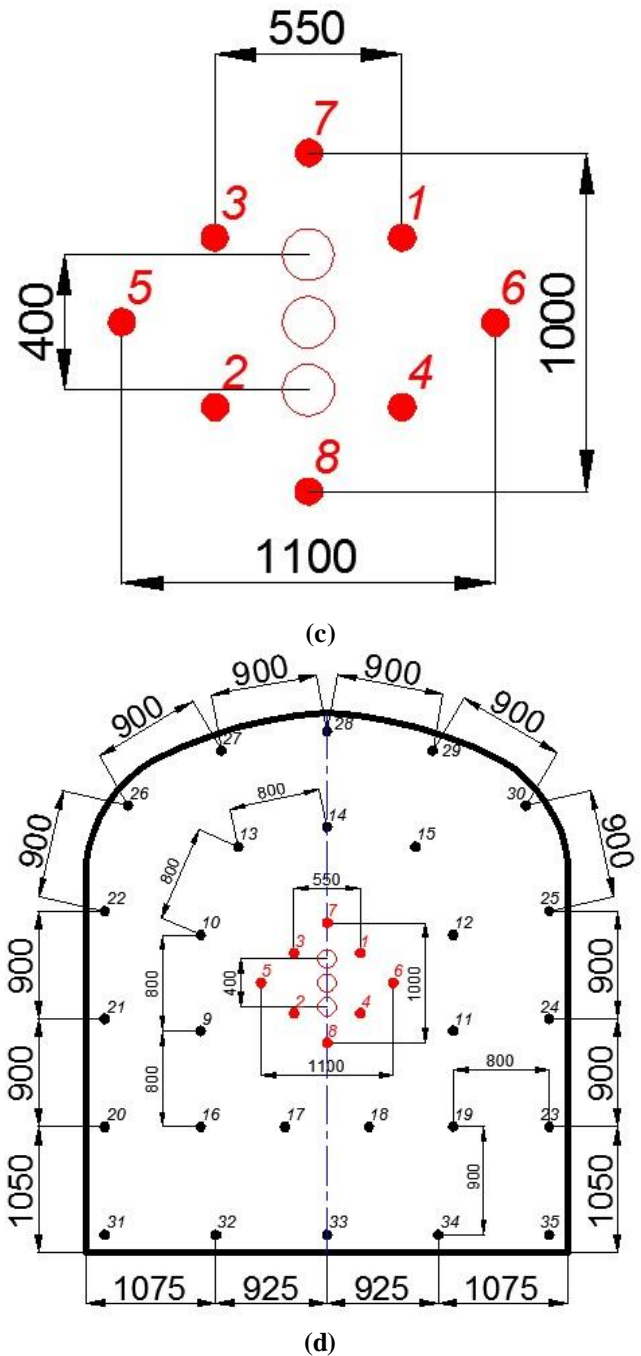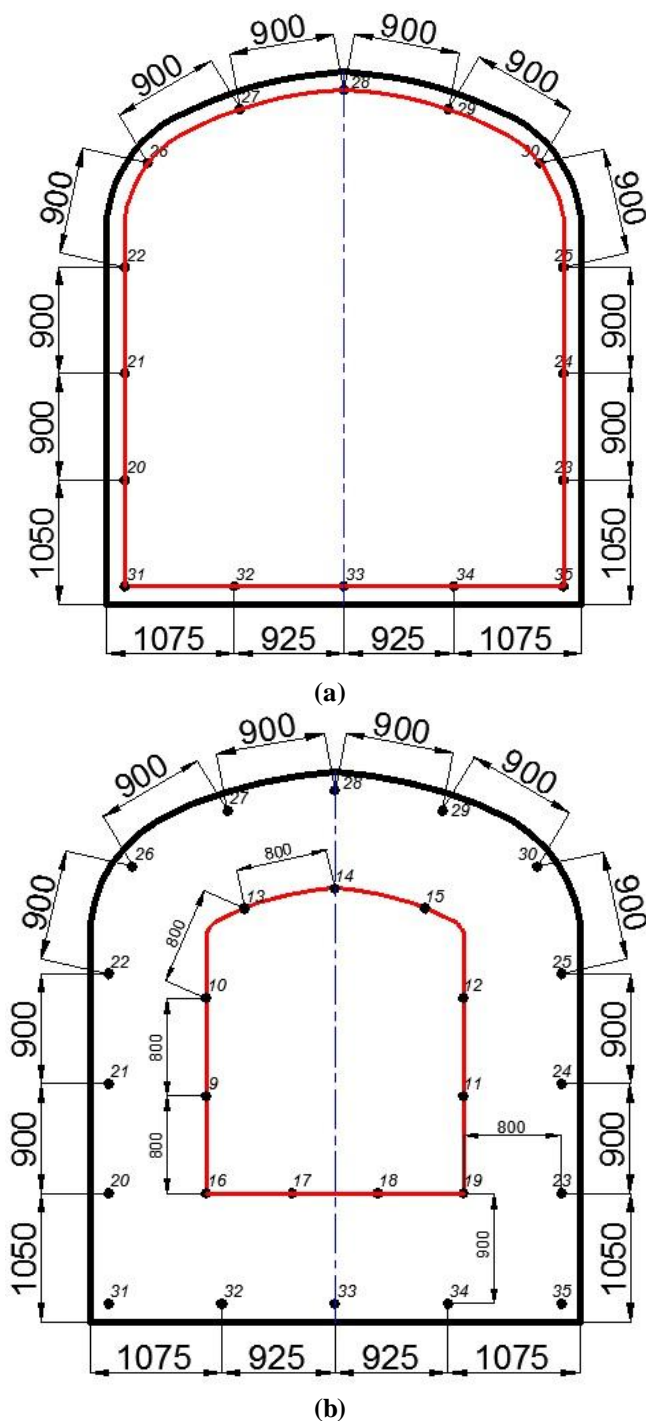
Figure 10 – Passport of BEO developed according to the proposed methodology: a) Layout of outlining blastholes; b) Layout of first raw of auxiliary blastholes: c) Layout of compensation boreholes and blastholes of gain; d) Final layout of blastholes and boreholes of working face

Table 2, for comparison, presents parameters of existing passport of BEO and passport of BEO developed using the new methodology for "Skalistaya" mine of "Komsomol'sky" mining facility.

Table 2 – Main parameters of BEO passports

Parameter	Existing BEO passport of mine	BEO passport developed using the proposed methodology	Difference
Total number of blastholes, pcs.	40	35	**-5**
Total number of gain blastholes, pcs.	8	8	**0**
Total number of auxiliary blastholes, pcs.	14	11	**-3**
Number of outlining blastholes, pcs.	18	16	**-2**
Consumption of ES, kg: Granulit AZ Ammonit #6ZhV Total consumption	80.0 10.0 90.0	64.0 16.25 80.25	**-16.0 +6.25 -9.75**
Volume of drilling, drill running meter	116.1	89.1	**-27.0**
Actual CBU	0.9	0.95	**+5%**

Comparison of those parameters makes it clear that with increase of CBU to 0.95 total volume of drilling decreased for 27 drill running meters, as well as consumption of ES for 9.75 kg. Evaluation of explosions' quality, which were made using experimental BEO passports showed that cross-section of an excavation meets design requirements and rock massif is crushed according to required parameters; Expected economic effect related with implementation of the proposed methodology of calculation of BEO parameters is estimated as 285997 rubles per 100 m of excavation.

4. Conclusion

As conclusion, it can be stated that work for definition of reasonable parameters of BEO is complicated by the fact that it is necessary to take into account various rock geology and rock engineering condition during construction of excavations. The developed methodology must be advantageous from points of view of effective use of resources, safety and economical parameters of mining facility.

The proposed methodology for calculation of BEO parameters considers main rock geology and rock engineering factors, which influence efficiency of BEO during construction of excavations. The methodology past trials at 8 underground mining facilities of "Norilsk nickel" ltd. arctic branch and demonstrated high efficiency, which was proved by decrease of consumption of ES and volume of drilling works.

The next stage of the presented study is development of methodology for vertical excavations and special software for faster and accurate creation of BEO passport at mining facilities.

References

1. Pokrovski, N. (1977). *Construction technology for underground facilities and mines. Part 1. Construction technology for horizontal excavations and tunnels. 6th edition.* Moscow: Nedra.
2. Porzevski, A. (2005). *Underground mining. Textbook in 4 parts, parts 1 and 2.* Moscow: MSRU.
3. Drukovani, M., Dubnov, L., Mideli, E., Ivanov, K., Il'in, V. (1976). *Drilling-and-blasting operations handbook.* Moscow: Nedra.
4. Borisov, S. (1988). Mining: Textbook for professional schools. Moscow: Nedra.
5. Kutuzov, B., Valuhin, Yu., Davidov, S., et al. (1974). *Planning of blasting operations.* Moscow: Nedra.
6. Poginski, V. (1993). *Technology, economical characteristics and management of mining operations in hard rocks.* Moscow: Nedra.
7. Kutuzov, B., & Andrievski, A. (2002). *New theory and new technologies for destruction of rocks by elongated explosive charges.* Novosibirsk: Nauka.
8. Szuladzinski, G. (1993). Response of rock medium to explosive borehole pressure. *Proceedings of the Fourth International Symposium on Rock Fragmentation by Blasting-Fragblast-4, Vienna, Austria,* 17-23.
9. Djordjevic, N. (1999). Two-component of blast fragmentation. *Proceedings of the Sixth International Symposium on Rock Fragmentation by Blasting-Fragblast 1999, South African Institute of Mining and Metallurgy, Johannesburg, South Africa,* 213-219.
10. Mosinets, V., & Gorbacheva, N. (1972). A seismological method of determining the parameters of the zones of deformation of rock by blasting. *Soviet Mining Science, 8*(6), 640-647.
11. Rakishev, B. (2010). Definition of sizes of destruction zones in a rock massif in a case of borehole crushing explosive charge. *Explosion engineering, 103-60,* 53-65.
12. Kutuzov, B. (1983). *Industrial explosive operation planning.* Moscow: Nedra.
13. Kutuzov, B. (2007). *Methodology of explosive operation. Part 1. Destruction of rocks by means of explosion.* Moscow: Mining literature.

14. *SNiP III-11-77. Underground mining.* (1978). Moscow: Stroiizdat of Gosstroy of USSR.

15. Bhandari, S. (1997). *Engineering rock blasting operations.* Rotterdam.

16. Lowrie, R. (2002). *Mining Reference Handbook.* Society for Mining, Metallurgy, and Exploration, Inc.

17. Hartman, H. (1992). *SME Mining Engineering Handbook. 2nd Edition, Volume 1.*

18. Kalyakin, S., & Labinski, K. (2009). *Bulleting of KSPU named after Michail Ostrogradski, 6*, 159-163.

19. Vohmin, S., Kurchin, G., Kirsanov, A., & Deryagin, P. (2014). Calculation methodology of blasting and explosion operations' parameters for horizontal and inclined excavations. *Bulletin of Magnitogorsk state technological university named after G.I. Nosov, 4*(48), 5-9.

20. Stanyukovich, K., Baum, F., & Shehter, B. (1959). *Physics of explosion.*

21. Vohmin, S., Kurchin, G., Kirsanov, A., & Gribanova, D. (2015). Design of a straight prismatic gain's structure. *Contemporary problems in science and education, 1.*

22. Taranov, P., & Gudz', A. (1976). *Destruction of rocks by means of explosion. Textbook. 3rd edition, expanded and corrected.* Moscow: Nedra.