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SOLVING THE ISSUE OF REGULATING THE GRANULOMETRIC COMPOSITION OF SHATTERED ROCK MASS DEPENDING ON THE QUALITY OF LOCKING EXPLOSION PRODUCTS IN THE EXPLOSION CAVITY

Dmitriy Moldovan, Vladimir Chernobai and Vladimir Kovalevskyi
Blasting Works Dept, the Saint-Petersburg Mining University, 199106, St. Petersburg, Russia

ABSTRACT

This paper is focused on the issue of regulating the fractional composition of shattered rock mass for further technological processes of building stone production. A new design of the charge has been proposed, namely, replacing old tampings with new technological devices. Along with the new tampings, a method has been developed for increasing the duration of explosion products influence on the rock mass due to changes in the design of the charge. Experiments made in a quarry in the Leningrad region, prove the possibility of using this design for forming geometrical parameters of collapse and fractional composition. Thus, the use of new charge designs allowed improving quality of shattering, namely, increasing the yield of average pieces of standard fraction, therefore, optimizing performance of the mining company in all production cycles.

Keywords: blasting, blast-hole tamping, particle size distribution, collapsing of the rock mass.

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1. INTRODUCTION

Today, the practice of developing building materials quarries shows that correct resolving of the issues of preparing the rock mass for blasting operations (particle size distribution) largely determines the productivity of the technological processes. The use of modern handling machinery and mobile crushing and screening installations impose strict requirements to the quality of raw materials [1].

During mass explosions, the following requirements should be met [2]:

- high-quality crushing of the rock mass (specified particle composition of the blasted rock mass);
- bench-toe reaming;
- minimal disruption of integrity of the peripheral part of the rock mass;
- forming a compact pile of broken rock mass;
- protection of nearby objects from seismic effects of the explosion [3], the effects of shock air wave (SAW) and scattering chunks of the rock.

To identify the most important parameters, the change of which has the most significant effect on drilling and blasting operations (DAB) in rock and aggregates quarries, the results of experimental studies were studied, which formed the basis of the ranking parameters.

After summarizing the results of studying [4] the influence of drilling and blasting parameters on the lumpiness of the blasted rock mass, the joint influence of the same parameters on the yield of out-of-size particles and the quality of the particle composition of the blasted rock mass, and on the parameters of its chattering was studied.

The ranking results [5] show that the yield of oversized particles and the lumpiness of the rock mass are mostly influenced by the following parameters: W - resistance at the toe, m; a - the distance between wells, m; d - hole diameter, mm; - method of blasting, q - specific consumption of explosives, kg/^{3}.

It should be noted that an important role in improving the quality of preparation for blasting operations rock mass is played by the design of the charge. The use of tamping, creating air spaces, combination of the structure of the explosive charge column with various properties allows changing the amount of the obtained energy of the explosive for rock fragmentation, therefore, opens the possibility to control the process of destruction.

The laboratory experiments performed by Zharikov I. F. [6] with oscillography of mass velocity of medium mass have shown that during an explosion of a charge with initiation at two points, the curve of mass velocity has two additional pressure waves' speed peaks propagating outside the frontal area. Due to these additional waves, the duration of compression wave increased by 30-40%, thus increasing the time of rock mass exposure, and increasing the quality of the product.

Any rock mass has certain jointing:

- induced, caused by the human activities;
- natural, whereby the cracks are formed by tectonic processes (unloading tectonic cracks), the gravity pressure of the overlying rock, in particular, the cracks are caused by cleavage, weathering, and leaching.

As a result, any rock may be considered a heterogeneous and anisotropic medium with a certain structure. This fact may be explained by the influence of the systems of cracks on the physico-mechanical properties [7-9].

The high density of dislocations, the presence of mechanical stress on the crystal eventually result in the emergence of flat gaps – cracks, resulting in decreasing the crystal energy, i.e. cracks play the role of "unloading" elements (unloading cracks) [10].

Studies [11, 12] of the gas-dynamic processes in the borehole and loading of its walls with explosions of charges of various designs were performed according to the program that uses the method of numerical simulation of the two-dimensional non-stationary problem. The solution considered the detonational and gas-dynamic processes of products escaping through the wellhead, and, based on these calculations, parameters of the flow were determined: shock wave, wave, and dynamic loads on the walls of the borehole.

To assess the explosive action of the rock mass, one can use numerical simulation of the longitudinal wave interaction propagating in an elastic medium [13].

The physical ideas about the mechanism of rocks shattering by the explosion energy, contained in these hypotheses, and the theoretical insights derived on their basis were the basis for creating the methods of controlling the action of the explosion on the rock mass [14, 15] in the conditions of mining engineering.

Works [16, 17] note advisability of using direct or inverse initiation, depending on ratio $\frac{D}{c}$, where D is the speed of detonation, m/s; and c is the speed of the stress wave in the rock, m/s.

Studying the effect of the direction of explosive charges detonation on the parameters of the stress waves resulted in the following conclusions:

- the maximum resulting stress near the free surface was observed in case of reverse initiation, and the minimum resulting stress – in case of direct initiation;
- in case of counter-initiation of the neighboring charges, the maximum duration of the pulse and its effective parts was achieved;
- in rock with hardness f = 4÷6, it was appropriate to use the scheme with counter-initiation of charges.

The results of works [18] show that in case of reverse initiation, the stress field is distributed more uniformly throughout the height of the ledge, which ensures simultaneous arrival of the wave to both naked surfaces of the ledge and, consequently, results in more intense rock crushing, compared to initiation from the top.

It is known [19] that tamping has significant impact on improving the blasting efficiency in rock shattering.

Tamping quality, and, consequently, its practical purpose, largely depends of the quality of the material. Main requirements to the material of tamping are the ease of handling and low cost.

Currently, based on the physico-mechanical properties that the tampings should have, their ability to resist gaseous products of detonation (PD), tampings of plastic materials (clay, sandy-clay), fine-grained (sand, slag, rock cuttings) and coarse (gravel, gravel and sand mixture) are used.

2. PROBLEM-SOLVING METHODS

Currently, thanks to the research of experts in the field of rock shattering by explosion, including terraced blasting with the use of the method of borehole charges, both the mechanism of rock shattering by explosion, and the factors that determine the result of the shattering have been commonly understood. This resulted in creating the methods and techniques of calculation, which, based on the existing classifications of rock by various physical-mechanical and physical-technical characteristics, as well as by the properties and energy characteristics of industrial explosive materials, parameters of the shattered rock mass, allowed calculating the drilling and blasting parameters in various conditions, ensuring the specified quality of rock shattering [20, 21].

To improve the quality of rock shattering, in is necessary to increase the duration of PD impact on the shattered medium. The maximum transfer of energy to the shattered rock mass may be achieved by their locking in the well for the required period. Delays in the escape of gaseous products of the explosion may be ensured by using various types of tampings. Traditional tampings made of sand or rock cuttings are most common. However, the time of locking that such tampings can ensure is not always sufficient for the maximum possible transfer of PD energy of the shattered rock mass. To lock explosion products in a well for longer time, tampings of special design should be used.

To determine the speed of movement of a tamping made of various materials with regard to the compressibility of its layers, studies were performed with the use of the electromagnetic method of displacement measurement [22]. To eliminate the influence of environment discontinuity and explosion products escaping through cracks, experimental explosions were made in a mortar made of special non-magnetic steel. 2 g of ammonite 6GW were charged into the 10 mm diameter and 130 mm long channel of the mortar. The magnetic induction sensors were placed in the tamping at the distance of 20, 55, 80 mm from the mouth. The sensor was a 9 mm long copper wire with the diameter of 0.2 mm, extended through a hole in a plate (10×9×4 mm^3) made of fabric-based laminate perpendicular to the lines of the magnetic field. Magnetic induction in the center of the 10 cm wide gap amounted to $19.8 \cdot 10^6$ T with the 3% uniformity. During explosion of the explosive charge, the sensor was involved into movement simultaneously with the tamping. The electromotive force (EMF) induced at the ends of the conductor during the motion was recorded with an electronic oscilloscope. The tamping was made of dry clay, sand, and a mixture of crushed granite of 2-3, 1-3, 4-6 mm fractions with sand.

The main goal to be achieved by using the tamping is to increase the duration of impact of expanding gaseous products of the explosion on the shattered rock mass and making the most of their energy.

A traditional well tamping made of crushed rock and sand does not provide any significant increase in the time of locking, as it is extracted from the well under the action of PD.

2.1. The proposed method of solving the problem

To increase the time of the delaying escape of explosion products from the explosion cavity, a locking gas-dynamic tamping (LGDT) developed at the St. Petersburg State Mining Institute (Figure 1) was used. The parameters of the LGDT were calculated according to method [23].

The diameter of the inlet hole is equal to the diameter of the explosive cavity of the charge. The profile of a supersonic diffuser is defined by the following parameters at the input [24]:

$$P_H = \frac{\rho_{BB} D^2}{2(k+1)}; \tag{1}$$

P_H is the pressure of detonation products, ρ_{BB} is the density of explosives, D is the detonation speed, k is the isentropic coefficient (in the initial period of the explosion k=3).

To calculate the length of the tapered section of the diffuser, relative speed $M = c/a$ is introduced (Mach number); c – is the current speed (U_H), a – is the local sound speed.

The check for dimensionless speeds at the exit is made using the correlation [3]:

$$M^2 = \frac{1}{1+k} \cdot \frac{\lambda^2}{1 - \frac{k-1}{k+1} \cdot \lambda^2}. \tag{2}$$

Replacing a polyline by a smooth curve forms the inner profile of the diffuser from input to critical, after which the speed is subsonic (Figure 1).

3. RESULTS

The measurements were made in the quarries with building stone deposits in the Leningrad region. The object for the experiment was the ledge at the second level. The charged units were in close proximity - thus, physical and geological parameters were the same. Then one unit was charged according to the standard scheme used in the enterprise, and the other one - using LGDT.

More detailed information about charged units is shown in Table 1.

Blasting works were performed with the use of standard explosives used at the facility (granulotole and grammonite 79/21), the specific consumption of which amounted to 0.97 kg/^{3}. The scheme of initiation in both cases was the same, diagonal-wedge.

Table 1 Main characteristics of experimental blocks

	14 unit	**15 unit**
Design volume, m^3	7,000	7,300
Number of wells, PCs	90	97
Diameter of wells, mm	115	115
Wells network, a×c, m	3×3	3×3
In the first row a, m	2.5	2.5
Value of excessive drilling, m	1.5	1.5
Depth of wells, m	9.0-9.5	9.0-10.5
Horizon, m	+18	+18
Tamping	standard	LGDT

After the explosion, shattering of the rock mass was assessed by width and height. Figures 2a, 2b show shattered units.

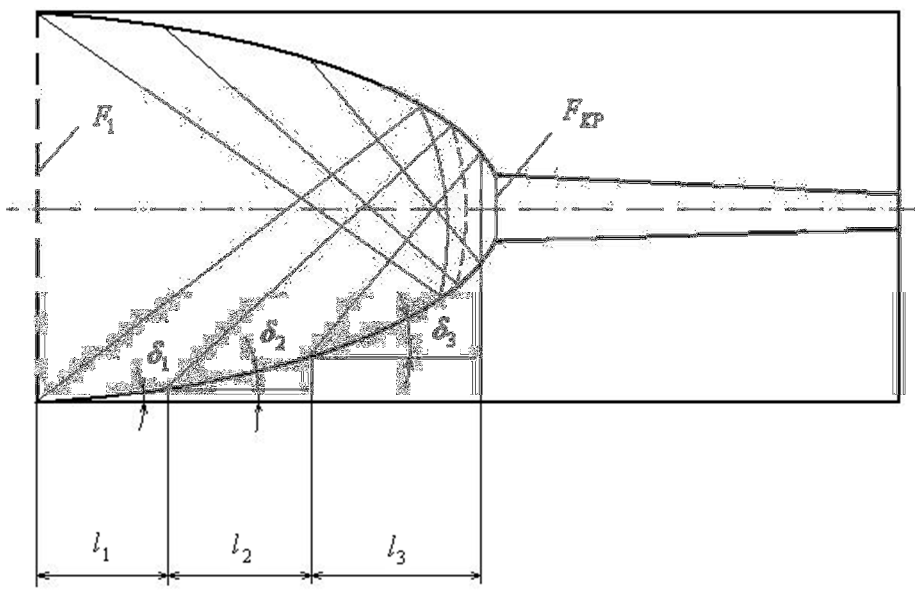

Figure 1 The scheme of calculating the geometric parameters of a tamping.

l_1, l_2, l_3 are the lengths of individual elements of the braking surface; δ_1, δ_2, δ_3 are the flow angles of these elements; F_1, F_{KP} are the cross-sectional areas at the inlet and the outlet of the product

a **b**

Figure 2 Rock mass chattering (a - with the use of LGDT, b - with the use of standard charging scheme)

Further, based on method [25] (Figure 3), let's calculate the parameters of rock mass shattering after the explosion.

Initial speed of the rock mass chipped off by the well charge can be determined by the following formula:

$$V = K\sqrt[3]{\left(\frac{Q}{W^3}\right)^2}, \tag{3}$$

Where Q is the weight of the charge in the well, kg; K = 12 is the ratio for rocky mass; W is the line of least resistance.

On the quarry face, the center of gravity of the shipped off rock mass lies at the height equal to half the height of the face. The angle of throwing α=0°. At low speed of throwing, the air resistance may be neglected.

The maximum distance of throwing the chipped off rock mass on the face (further referred to as the maximum distance of throwing) is determined by the formula:

$$L_1 = V\sqrt{\frac{H}{g}} + 0.5W. \tag{4}$$

The explosion of a well charge (and the overall number of wells) chips off the volume with the cross section, as per Figure 3, in the shape of parallelogram ABCD. The cross-sectional shape of the collapse in our model is composed of five geometric shapes: rectangle 2 and four triangles 1, 3, 4 and 5.

Collapse length:

$$L = L_1 + 0.25W + (n-1)W. \tag{5}$$

To determine the collapse height, it is necessary to find the total area of the collapse figure according to the model of the collapse cross section, and equate it to the area ABCD with regard to the coefficient of rock loosening during explosion. By using the appropriate schemes and conversions, we get:

$$B_1 = \frac{1.13L - 0.63L_2}{ctg\beta} - \sqrt{\left(\frac{1.13L - 0.63L_2}{ctg\beta}\right)^2 - \frac{1.4HWn}{0,5ctg\beta}}. \tag{6}$$

Here B_1 is the height of rectangle 2 in the model of the collapse cross-section.

The height of rectangles 4 and 5 in the model of the collapse cross-section:

$$B_2 = 0.25B_1. \tag{7}$$

The maximum height of the collapse:

$$B = 1.25B_1 . \quad (8)$$

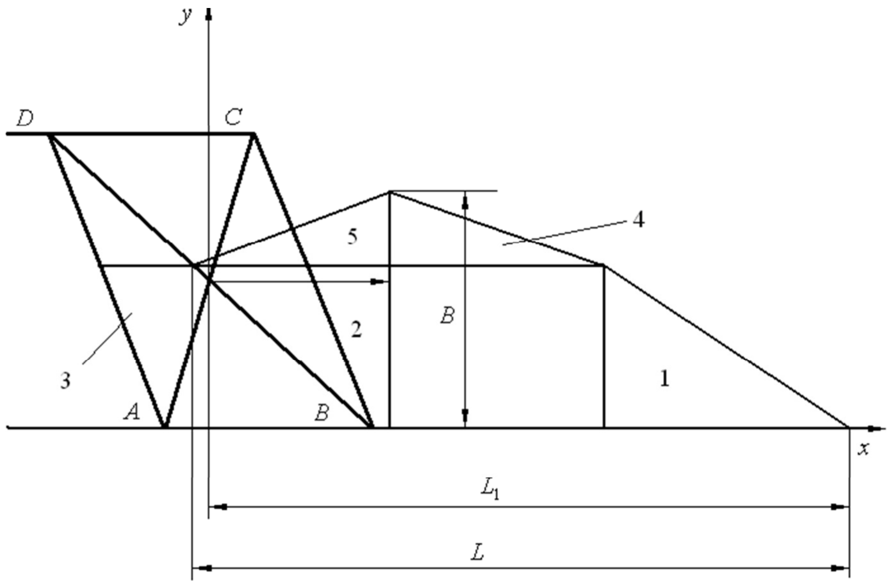

Figure 3 The model of the chipped-off rock mass collapse cross section

ABCD is the chipped-off unit; L is the length of the collapse; L_1 is the maximum distance of fragments throwing; B is the height of the collapse; 1, 2, 3, 4, 5 are the geometric shapes combined into the collapse

Comparative analysis of the theoretical data with the data obtained in the quarry is shown in Table 2.

Table 2 Theoretical and experimental results of studying the parameters of rock mass collapse

	Theoretical calculation of the collapse parameters	**Parameters of the collapse with the use of LGDT**
Height, m	6.5	6
Width, m	23.5	30

4. DISCUSSION

The papers devoted to the influence of technological drilling and blasting parameters (specific flow, charge design, charge diameter, etc.) are experimental and state the quantitative relationship described by the corresponding empirical correlations that have no relation to the fundamental physical studies in the area of rock shattering.

Few papers have been devoted to the pattern of environment loading during the use of charges of various design, the knowledge of which allows assessing efficiency of rock shattering.

Interesting from the scientific and practical points of view is the study of the mechanism of transferring the energy of explosion to the environment in case of using well charges of various design in combination with gas-dynamic tampings, and substantiating efficiency of their use.

The tasks of the previous research in this area did not include such an important issue as assessing the charge design effect on the gas-dynamic state of the explosion products in the charge chamber, which ultimately determined the parameters of the rock mass dynamic loading and destruction.

In this area, the following research is required:

1. influence of the charge design and other DAB parameters on rock mass shattering and collapse formation;
2. influence of DAB parameters on the economic efficiency of mass explosions in building material quarries.

5. CONCLUSION

The theoretical and practical data showed that with the use of LGDT, the height of collapse decreased by 8% and the width increased by 27.5%.

The results of industrial tests of the developed charge designs with gas-dynamic tamping showed an increased share of the explosion useful energy used for rock shattering, which allowed to reduce the yield of the out-of-size fractions about 2 times, and to improve the quality of shattering by 15-20% (the average size of a blasted rock piece decreased from 250 to 220 mm).

The use of gas dynamic tampings allows to ensure specified geometrical parameters of the rock mass collapse for the efficient use of front end loaders in building materials quarries.

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