Elaboration of the Charge Constructions of Explosives for the Structure of Facing Stone

Sergo Khomeriki¹, Edgar Mataradze¹, Nikoloz Chikhradze¹,², Marine Losaberidze¹,², Davit Khomeriki¹, Grigol Shatberashvili ¹,²
¹GrigolTsulukidze Mining Institute, 7, Mindeli St., Tbilisi, 0186, Georgia
²Georgian Technical University, 0175, Tbilisi, Georgia
khomeriki_sergo@yahoo.com

Abstract. Increased demand for high-strength facing material caused the enhancement of the volume of explosives use in modern technologies of blocks production. The volume of broken rocks and crushing quality depends on the rock characteristics and on the properties of the explosive, in particular on its brisance and serviceability. Therefore, the correct selection of the explosive for the specific massif is of a considerable practical importance. For efficient mining of facing materials by explosion method the solving of such problems as determination of the method of blasthole drilling as well as of the regime and charge values, selection of the explosive, blastholes distribution in the face and their order is necessary. This paper focuses on technical solutions for conservation of rock natural structure in the blocks of facing material, mined by the use of the explosives. It has been established that the efficient solving of mentioned problem is attained by reducing of shock pulse duration. In such conditions the rigidity of crystalline lattice increases in high pressure area. As a result, the hazard if crack formation in structural unites and the increases of natural cracks are excluded. Short-time action of explosion pulse is possible only by linear charges of the explosives, characterized by high detonation velocity which detonate by the velocity of 7-7.5 km/sec and are characterized by very small critical diameter.

1. Introduction
Increased demand for high-strength facing material caused the enhancement of the volume of explosives use in modern technologies of blocks production. Mining of the minerals by means of the explosion energy implies their removal from the massif and crushing to the fragments of such size which provides the uninterrupted loading of the broken mass, their transportation and further processing. The volume of the rock, broken by explosion, and its crushing degree depends on the rock characteristics and on the properties of the explosives, in particular, on its brisance and serviceability. Therefore, the correct selection of the explosive for specific massif is of a considerable practical interest.

The velocity of explosion reaction determines the nature of the explosives action by which they are divided into two groups of:

- brisant action or fractured explosives and,
- high-explosive action or throwing explosives.

At present the countries, manufacturing the blocks of the natural stone, are concentrated on the elaboration of the explosives of so-called saving (softened) brisance. But the effort of the use of the explosives of new type, characterized by law brisance, caused the prolongation of the action of explosion pulse on the rock which, in some cases, caused the development of natural defects-cracks in the marketable product. Of course this fact adversely effects on the efficiency of the industrial process.
2. The technology

The essence of the proposed technology involves the short-time action of the explosion of the convinent and simultaneously initiated small charges of the powerful explosives on the rock whereby the initial pressure on the front of the refracted wave doesn’t exceed the stone ultimate strength at dynamic compression and the total value of the tangential components of the converging waves of the stresses provides the breakaway of the monolith by the plane of the location of the contouring blastholes [1]. Hereafter the mentioned technology was improved in a certain degree in the work [2]. Short-time action of the explosion pulse, causing the reduction of the probability for generation of the dislocations in the stone as well as the increase of the existing cracks, is attained by the use of the charges of the explosives, detonating by the velocity of 7-7.5 km/sec and characterized by quite small critical diameter [3]. The sections of the detonating cord (DC), equipped by the charge of the TEN (Penthrite) with a linear mass of 12gr/m, represent the same ones. At the cord diameter of 25-45 mm and at the diameter of the TEN’s charge of 2.5mm the coefficient of the blasthole charging varies from 0.003 to 0.04. As a result, the initial pressure on the front of the refracted wave in the rocks of the average strength and higher comprises 185-400 MPa [4]. In this case the maximum quasi-static pressure of the gases on the blasthole walls doesn’t exceed 30 MPa and their energy is mainly spent on the relocation of the chipped part of the massif to the mined-out space. According to the technological regulation the rock over splitting by each plane of the charge location is carried out separately. As a result, the number of the explosives, required for manufacturing of one block, varies in the range of $I = 1 \pm 6$ depending on the mining and geological conditions. The multiple actions of relatively weak explosive loads on the same block generate the conditions for developing of the irreversible deformations, causing the reduction of the plate inlet at the definite conditions [5, 6]. The researches of the rock resistibility to the multiple explosive loads [5, 7] allowed to establish that this hazard is completely excluded if the parameters of the blasthole drilling (table 1) fulfil the condition:

$$\sum_{i=1}^{6} \frac{N_i n_i}{N_0 0.25 d_o} \left( \frac{d_o}{d} \right)^{1.6} \leq 1,$$  \quad (1)

where: $N_i$ – multiplicity of imposition of explosive loads on the block, $N_0$ – rock resistibility index to multiple explosive loads (table 1); $n_i$ – number of the sections of DC in the linear charge; $d_o = 25$ mm – standard diameter of the blasthole; $d$ – selected diameter of the blasthole, mm.

At simultaneous explosion of the series of linear charges of the explosives in the boundless area, in the plane of their location the summation of compressing and stretching stresses, coincident in direction, takes place determining the formation of the splitting magisterial crack in the mentioned plane.

Let us consider the development of the magisterial crack as the process with a clearly expressed boundary of the change of the sequential stages, coincident with the moment of the convergence of the stress waves in the points $\frac{a}{2}$, where $a$ is a distance between the adjacent charges.

At the initial stage of the explosion development each charge of the explosive operates in the automatic mode and exerts the quasi-static pressure ($P_o$) on the massif. At the use of the sections of DC as the linear charges, this pressure exceeds the rock ultimate strength at static compression by a factor of 2-7. As a result, in the plane near the blasthole the radical cracks are formed. In the paper [11] the procedure for calculation of the initial parameters of the shock waves, refracted in the rock, is given and in [12] – the peculiarity of their variation with the distance.

In table 2 the values of the initial pressures in the refracted wave and the radiuses of crack formation zone near the blast hole at various combinations: “charge-rock” are presented.
Table 1. Parameters of blasthole drilling at directed splitting of the rocks.

| Rock                     | Rock resistibility index to multiple explosive loads | Number of DC sections in linear charge (charge specific energy, kJ/m) | Distance between the charges (m) at blasthole diameter d, mm |
|--------------------------|-----------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|
| Marbled limestone        | 11-12                                        | 1(68)                                                       | 0.32 0.29 0.26 0.24 0.22                                   |
|                          |                                              | 2(136)                                                      | 0.46 0.41 0.37 0.33 0.31                                   |
| Marbled dense limestone  | 13-14                                        | 1(68)                                                       | 0.28 0.25 0.23 0.20 0.19                                   |
| and marble               |                                              | 2(136)                                                      | 0.39 0.35 0.32 0.29 0.27                                   |
| Coarse-grained           | 15-16                                        | 1(68)                                                       | 0.24 0.22 0.20 0.18 0.17                                   |
| Teschenite               |                                              | 2(136)                                                      | 0.34 0.31 0.28 0.25 0.23                                   |
| Granite                  | 17-18                                        | 1(68)                                                       | 0.22 0.19 0.18 0.16 0.15                                   |
|                          |                                              | 2(136)                                                      | 0.30 0.27 0.25 0.22 0.21                                   |
| Fine-grained granite,    | 19-20                                        | 1(68)                                                       | 0.19 0.18 0.16 0.14 0.13                                   |
| dense granite            |                                              | 2(136)                                                      | 0.27 0.25 0.22 0.20 0.19                                   |
| Tuff, basalt             | 21-22                                        | 1(68)                                                       | 0.18 0.16 0.14 0.13 0.12                                   |
|                          |                                              | 2(136)                                                      | 0.25 0.22 0.20 0.18 0.17                                   |
| Andesite                 | 23-24                                        | 1(68)                                                       | 0.16 0.15 0.13 0.12 0.11                                   |
|                          |                                              | 2(136)                                                      | 0.23 0.21 0.19 0.17 0.16                                   |

Table 2. Dependence of the radius (R) of crack formation zone near blasthole on initial pressure in the front of refracted wave (P₀).

| Construction of explosives charge | Blasthole diameter d, mm | Andesite | Basalt | Marbled limestone | Teschenite |
|-----------------------------------|--------------------------|----------|--------|------------------|------------|
|                                   | P₀, MP₀, R, mm           | P₀, MP₀, R, mm | P₀, MP₀, R, mm | P₀, MP₀, R, mm | P₀, MP₀, R, mm |
| Single sections of                | 25                       | 273      | 10     | 279              | 10         | 280            | 10             |
| DC in radial air                  | 32                       | 226      | 10     | 234              | 10         | 240            | 10             |
| gap                               | 44                       | 187      | 5      | 189              | 5          | 200            | 5              |
| Double sections of                | 25                       | 390      | 25     | 396              | 15         | 410            | 20             |
| DC in radial air                  | 32                       | 320      | 20     | 333              | 15         | 340            | 15             |
| gap                               | 44                       | 265      | 10     | 270              | 10         | 280            | 15             |
| Hydroexplosion of single sections of | 25                       | 546      | 40     | 576              | 40         | 590            | 80             |
| DC                                | 44                       | 499      | 40     | 450              | 25         | 450            | 50             |

The radiuses of the crack formation zones were determined by indirect method by testing of the rock plates of 50x50x50mm dimension on salt resistance.

Existence of the radial cracks of small length near the blasthole at the beginning of the further stage of directed fracture of the rocks, characterized by interaction of the charges of the explosive, allows the considerable reduction of the value of the stretching efforts, required for the formation of the magisterial crack of the splitting in the plane of the charge location.

Calculations of the summarized tangential stresses, determined by the explosion of two adjacent charges (Σ σ₁) for a distance of r₂ (table 3) have shown that at the stage of the charges interaction the minimal values of the indexes of the efficiency of dynamic splitting correspond to the definite length of the radial cracks: \( \frac{\Sigma \sigma_1^*}{\sigma_0} \), where \( \sigma_0 \) is a rock ultimate strength at static stretching (figure 1).
Table 3. Indexes of the efficiency of the rock dynamic splitting at various constructions of explosives charges.

| Construction of explosives charge | Blasthole diameter $d$, mm | Andesite $\sigma_{st}$, MPa | Basalt $\sigma_{st}$, MPa | Marbled limestone $\sigma_{st}$, MPa | Teschenite $\sigma_{st}$, MPa |
|----------------------------------|-----------------------------|-----------------------------|---------------------------|-----------------------------------|-----------------------------|
| Single sections of DC in radial air gap | 25                          | 1.05                        | 1.68                      | 0.69                              | 0.49                        |
|                                   | 32                          | 0.95                        | 1.34                      | 0.60                              | 0.34                        |
|                                   | 44                          | 1.22                        | 1.89                      | 0.70                              | 0.25                        |
| Double sections of DC in radial air gap | 25                          | 0.74                        | 0.80                      | 0.42                              | 0.57                        |
|                                   | 32                          | 0.71                        | 0.75                      | 0.37                              | 0.47                        |
| Hydroexplosion of single sections of DC | 25                          | 1.71                        | 1.26                      | 0.61                              | 0.65                        |
|                                   | 32                          | 1.56                        | 0.80                      | 0.66                              | 0.60                        |

It is evident from figure 1 that the maximum magnitudes of extreme values of the efficiency index of the rock dynamic splitting are characterized for viscous extrusive rocks - andesite and basalt ($\sigma_p=0.75$), the minimum ones – for brittle teschenite ($\sigma_p=0.3$), and intermediate values – for metamorphic rocks – for marbled limestone in this case ($\sigma_p=0.4$). These results testify that the existence of the radial cracks of small length near the blasthole significantly reduces the rock strength at static stretching [3].

In figure 2 the graphs of the dependence of extreme distance between the charges from the radius of the crack formation zone near the blasthole are presented.

With increase in the radius of crack formation zone near the blasthole the distance between the charges enhances only to definite limit. In this case the limiting length of the radial cracks, after which the distance between the charges is practically unchanged, is in the range from 15 mm to 25 mm for all types of the rocks.

Thus performed researches have shown that at the explosion of linear charges in boundless area the preference must be given to such constructions of the charges at which the length of technogenic
cracks near the blasthole is no more than 20 mm from the viewpoint of provision of qualitative contouring of the rock massif. Single sections of DC in the blastholes of 25-32 mm diameter are the same as applied to the mining of the blocks of decorative stone from the medium-strength rocks ($\sigma_{\text{com}} \leq 100\text{MPa}$) and double sections of DC in the blastholes of 32-40 mm at directed splitting of strong rocks.

In both versions the air radial gap is provided between the sections of DC. Because of increased hazard of the explosion harmful action on the stone structure the use of hydro explosion of DC in technological process of the blocks mining is impermissible.

At variation of boundary conditions, for example, at charge explosion in the immediate vicinity of lateral free surface, under the effect of the stress wave, refracted from this surface, the crack of splitting is shifted in relation to the plane of charge location. This fact considerably impairs the quality of rock contouring.

For visualization of the process of hard media splitting at various boundary conditions the laboratory experiments were carried out on destruction of the samples of Plexiglas (acrylic plastic) by simultaneous explosion of two charges involving the sections of DC located in the through holes of 5.5 mm diameter. In the first experiment the coefficient of charges approaching (ratio of the distance between charges $a$ to the distance to the lateral free surface $W$), $m = 0.6$, and in other case $m = 1.5$ at the same distance ($a = 55$ mm) between the charges.

In figure 3 the graphs of the dependence of optimal distance between charges (at which an average linear deflection of real contour of splitting from design one didn’t exceed 50 mm, in accordance with the requirement of GOST 9497 – 84) from their moving away from lateral free surface are presented.

It is seen from figure 3 that the decrease of $W$ causes the significant shrinkage of the distance between the charges. In this case, the maximum values of the parameter $a_0$ correspond to its values at the explosion of the same charges in boundless medium for every type of the rocks. The analysis of experimental data also testifies that the rock qualitative splitting at simultaneous explosion of a series of linear charges near lateral free surface is attained at coefficient of the charges approaching of $m \geq 0.85$ which may be considered as a characteristic for boundary conditions of smooth explosion.

On the basis above-mentioned at the values $m \leq \frac{a_0}{W} \leq 0.85$ (where $a_0$, optimal distance between the charges at the explosion in boundless medium) the use of such constructions of the charges is advisable, the explosion of which determines the relatively small values of initial pressure on the front of refracted wave (table 1). Single sections of DC are the same as applied to the explosive method of block mining in the blastholes of diameter of 42-44 mm with radial air gap. At the use of recommended constructions of the charges, the width of the zone of stone discontinuity by radial cracks is totally fitted in the thickness of the block slab layer providing their reasonable high quality.
Figure 3. Dependence of optimal distance between charges ($a_0$) on their moving away from lateral free surface ($W$): 1 – marbled limestone; 2 – teschenite; 3 – basalt, tuff; 4 – andesite

Efficiency of the explosive technology for mining of the blocks essentially depends on the accuracy of location of the blastholes in the plane of desired splitting and on severe maintenance of the distance between them. By the data of [8] a withdrawal of the blast hole line from predetermined direction by 2.5 degrees increases the block losses to 20% and the blast hole incline sideways to the massif or of the block by the same angle causes the increase of the losses to 28%. The blasthole drilling by manual perforator doesn’t provide the high accuracy of the block contouring. Therefore, the technology provides the use of the plants of the point drilling of the blastholes, allowing the maximum approaching of the form of separated blocks to rectangular parallelepiped.

In the G. Tsulukidze Mining Institute the plant of the point drilling – LDE – 2 was elaborated which is profitably distinguished from the foreign analogues by the light-weight of the construction. Its mass comprises 175 kg only in contrary to 600 kg of similar plants. This advantage has substantially simplified the mounting and levelling of the plant in the face.

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