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Efficiency of blasting of rocks with complex structure by multicharges in non-metallic pits

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Abstract
Results of industrial tests on grounding of rational parameters of drilling-and-blasting operations with the application of new methods of complex structural rocks blasting are presented. Methods of the account and evaluation of

massif structure for adjustment of explosion parameters, and also new designs of boreholes multicharges of various cross-sectional shapes are suggested. The evaluation of efficiency of the suggested methods of rocks blasting in non-metallic pits is carried out and recommendations on their application are provided.

Key words: BOREHOLE, EXPLOSION, BOREHOLE MULTICHARGE, SHOULDER SURFACE, JOINTING

The problem of intensity increase of rocks crushing with the use of blast energy of explosive material is relevant for the experts dealing with failure of rocky formations. The solution of this problem is inseparably associated with increase in explosion energy transformed to destructed part of the massif. It is known that the considerable part of explosion energy is expended in the zone, which is directly adjacent to charge cavity (usually 2-3 radiuses of a charge) where the medium is overgrinded that leads to losses of minerals in pits of non-metallic construction materials.

The reduction of fine fractional yield can be achieved due to both reduction of the contact area of borehole charge of explosive material (EM) with the destructed rocks, and creating of conditions providing reduction of explosion dynamic impact on charge cavity surface [1].

Thus, during failure of rocks, it is possible to increase the useful effect of explosion by various means, in particular, by regulation of value of specific energy of EM due to use of constructions of borehole charges of different configuration.

It should be noted that in case of explosion control, it is necessary to consider that the tensile strength of rocks is approximately 10 times less than compressive strength of rocks. As the energy capacity of the solid media destruction is proportional to a square of their strength in case of a specific loading, energy capacity of solid media destruction by tensile stresses is 100 times less than energy capacity of destruction in case of compression stresses. From this, it follows that the increase in a role of tensile stresses in solid media destruction by explosion can be reached when using of extended charges of variable diameter and various cross-sectional shapes.

There are some methods of extended charge formation of different configuration of both its length and cross-section [2-5].

In particular, it is:

– creation of expanded sections, which diameter is bigger than diameter of initial cavity, in the drilled cylindrical cavities;

– putting of EM in boreholes with polyethylene sheaths of variable section;

– placement of continuous column of EM in shape of cone or charge with stepwise decreasing diameter to the mouth of borehole in charging cavities;

– layout of hollow figures from inert materials in charge cavities;

– creation of charges of variable diameter with different configuration of cross section.

The above-mentioned constructions of extended borehole charges make it possible to create the multidirectional and multigradient field of stresses in the massif and at the same time, to reduce the dynamic impact of explosion on surface of charge cavity, due to reduction of the direct contact area of EM with rocks.

The **purpose** of research is evaluation of efficiency of blasting of massif with complex structure in non-metallic pits with use of new constructions of borehole charges.

For grounding of rational parameters of explosive failure of the rocks with complex structure (granites developed in pits of PrJSC “Ukragrovzryvprom”), the industrial tests of the new blasting methods [6-7] based on change of design features of a charge were carried out.

The rocks in pit are gray intensely water-flooded compact-grained granites with red inclusions of strength of f =12-16 grades on scale of the prof. M. M. Protodyakonov. Level of flowing waters in pits reaches 1.0-2.0 m in case of massif average water content of 15-20%.

The nature of failure of rocks of complex structure is affected by their microstructure – orientation of microcracks and anisotropy of physical mechanical properties of rock-forming minerals, as well as massif macrostructure – spatial position of different morphology cracks partitioning the exploded unit. Therefore, in case of selection of parameters of drilling-and-blasting operations (the specific consumption of EM, geometry of layout of boreholes and blasting), such features of micro- and macrostructure should be considered. It will allow obtaining of uniform rocks breaking in case of the minimum yield of fine fractions, which are losses of minerals in course of crushed stone production.

In this regard, the comprehensive data on nature massif jointing in the destructed unit of granite massif considerably simplifies calculation of rational parameters of drilling-and-blasting operation.

In order to determine the main characteristics of fracture pattern of granite massif within mining lease of pit of "Zvirky" of Uman Quarries Management using the method explained in paper [8], the stereophotographic work of horizons free faces, which were selected for industrial tests of the developed method of blasting of rocks with complex structure (unit 46, mount. – 42 m).

The separate photography of the same object (part of shoulder) was conducted from two camera angles using digital camera for obtaining of stereo pair in the experimental area along the face line. The statia rod was used for scaling of stereograms.

The stereo pair is oriented in case if the angle θ at the vertex of dihedral angle formed by the direction of photography rays and the spatial position of camera angles are known. In this case, in the stereomodel investigated by means of a stereoscope, it is possible to determine the basic characteristics of the natural macrocracks partitioning the massif, i.e. elements of their formation (angle of slope and its azimuth), and also intensity (number of the cracks in 1 m of face length).

Processing of deciphered stereo pairs was maintained with use of standard programs of image processing "Fotoshop" and "CorelDraw 11". In this case, the vertical and horizontal macrocracks, which can be seen in the picture, are usually represented in the form of lines of various thickness with the subsequent projection to the statia rod for determination of cracks density.

After data processing, the distribution parameters of cracks systems in the pit "Zvirky" were obtained. They are shown in Table 1.

In order to determine the cracks influence on nature of explosive breaking of anisotropic massif along the face line, the blast-holes were drilled and exploded (diameter is 36-43 mm, depth is 1.0-1.5 m, EM – stick powder ammonite No 6 liquid hydrogen). According to the specified sizes of big *a* and small *b* axes of breaking bell-hole caused by explosion of charge of EM and its orientation in parts of the world, coefficients of massif anisotropy were calculated according to expression K =a/b, which is equal to 1.14 on average. With use of data of anisotropy coefficient, the nomogram (Figure 1) was developed. Due to this nomogram, the parameters of borehole pattern of valid passport of DBO in the experimental field of the unit (the borehole pattern is equal to 4.5×5.5 m instead of 5×5 m) were corrected. Its long side coincides with the direction of maximum values of vector of explosion energy flow in the destructed massif $\vec{F}_{\max}$.

Table 1. The characteristic of the main joints systems in the pit "Zvirky"

Name of joints (Kloos nomenclature)	Coefficient of jointing, m	Distances between walls of joint, mm	Distance between separate joints, m	Width of zone of the higher jointing, m	Distances between centers of zones, m
Longitudinal joints of compression – S-joints	3-5	0,01 -0,1	0,1-2,0	40-50	45-60
Transversal joints –*Q*- joints	1-2	1,0-3,0	1,0-5,0	50-50	60-70
Horizontal joints of unloading –L-joints	3-5	0,05-0,1	0,5-1,0	zones of higher jointing are absent	—

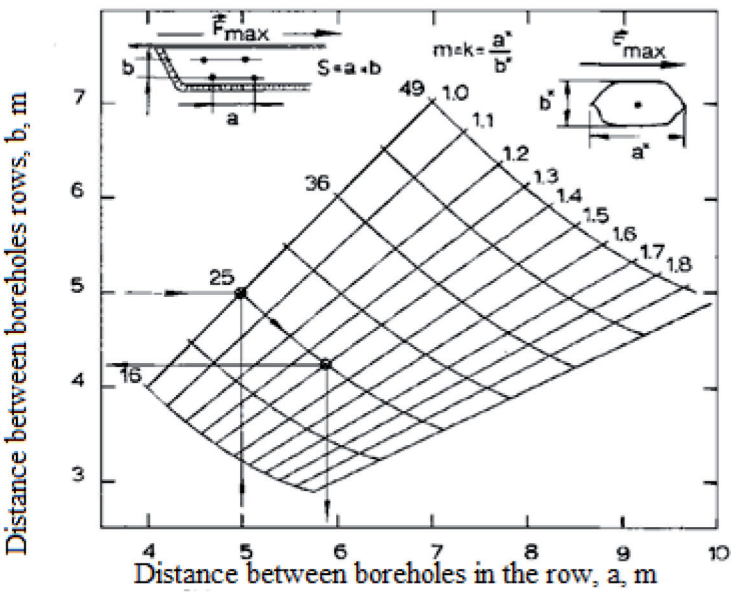


Figure 1. The nomogram for correction of boreholes considering anisotropy coefficient

According to the changed parameters of borehole pattern (a = 5.5 m – distance between boreholes in the row and b = 4.5 m – distance between rows of boreholes), and also considering revealed zones of higher jointing (focused orthogonally to the face line) in one of experimental units, the boreholes of diameter of 105 mm and depth of 14.5 m with the subdrill of 1.5 m were drilled according to valid passport of DBO in the massif in the shoulder of 13.0 m high.

The diagram of the experimental unit is shown in Figure 2.

After drilling-off, the boreholes were charged. The borehole multicharges were formed in the test area according to approved standard passport of DBO for mass explosion for the unit. For this purpose, 2.0-2.4 m were left for tamping in the borehole, and another part of borehole was divided into two equal sections. The mixed explosion of trotyl (hydrocarbon gas + granulated ammonium nitrate in a proportion 65/35) or emulsion EM such as Anemix were placed in the lower part of the borehole, the booster explosive of two trotyl blocks T-400 connected by wave guide with plain detonator by non-electric system of initiation "Impuls" or "PRIMA-ERA" was installed.

After that, the top part was filled with conversion explosive material (charge section is DKRP-4 with plastid) and the top booster explosive was installed. The space between walls of borehole and section DKRP-4 was filled up with mixed EM – trotyl (hydrocarbon gas + ammonium nitrate). The mouth of borehole was encapsulated by tamping of stone screening dust (fraction of 3-5 mm).

The charges were formed in the experimental area considering the areas of higher jointing (on the one hand, considering the direction of local cracks in the block massif, and on the other hand, direction of extended zones of higher jointing). For the first option, the multicharges of variable section were formed in the boreholes of the massif with the local jointing, and charges of various cross-sectional shapes were formed in the area with extended zones of higher jointing.

Formation of charges of variable section in the boreholes was carried out by installation of the spherical cavities (spheres) connected in a chain by means of binder in the lower section of explosive column. The spherical cavities diameter is $0.8D_{bor.}$, where: $D_{bor.}$ – borehole diameter. The distance between spherical cavities was accepted as equal to active part of length of a cumulative charge [6]

$$H_{lim.} \geq \ell_{c.ch.} \geq 2d_{sph.\ cav},$$

where $d_{sph.\ cav.} = 0.5d_{ch.}$ – diameter of spherical cavity; $\ell_{c.ch.}$ – length of cumulative charge.

Charges of variable diameter with spherical cavities are formed in zones of monolithic block rocks, and charges of continuous structure are formed in jointing zones. The lower section of charge was filled with the mixed explosion of trotyl (hydrocarbon gas + granulated ammonium nitrate in a proportion 65/35) or emulsion EM such as Anemix; the top section was filled with conversion EM – DKRP-4 with plastid, and the top booster was installed. The space between walls of borehole and section DKRP-4 was filled up with mixed EM – trotyl (hydrocarbon gas + ammonium nitrate) or pyroxylin powder.

The multicharges in boreholes were formed in zones of higher jointing in the experimental area. It is extended borehole charges with various cross-sectional shapes.

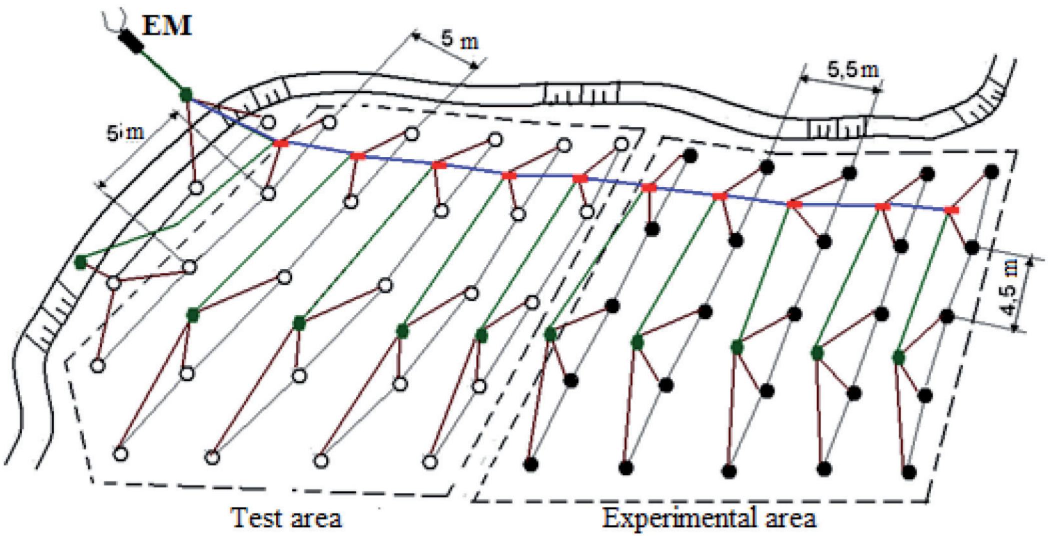


Figure 2. The diagram of placement of boreholes and charges commutation in pit shoulders of "Zvirky", unit 46, mount. – 42.0 m

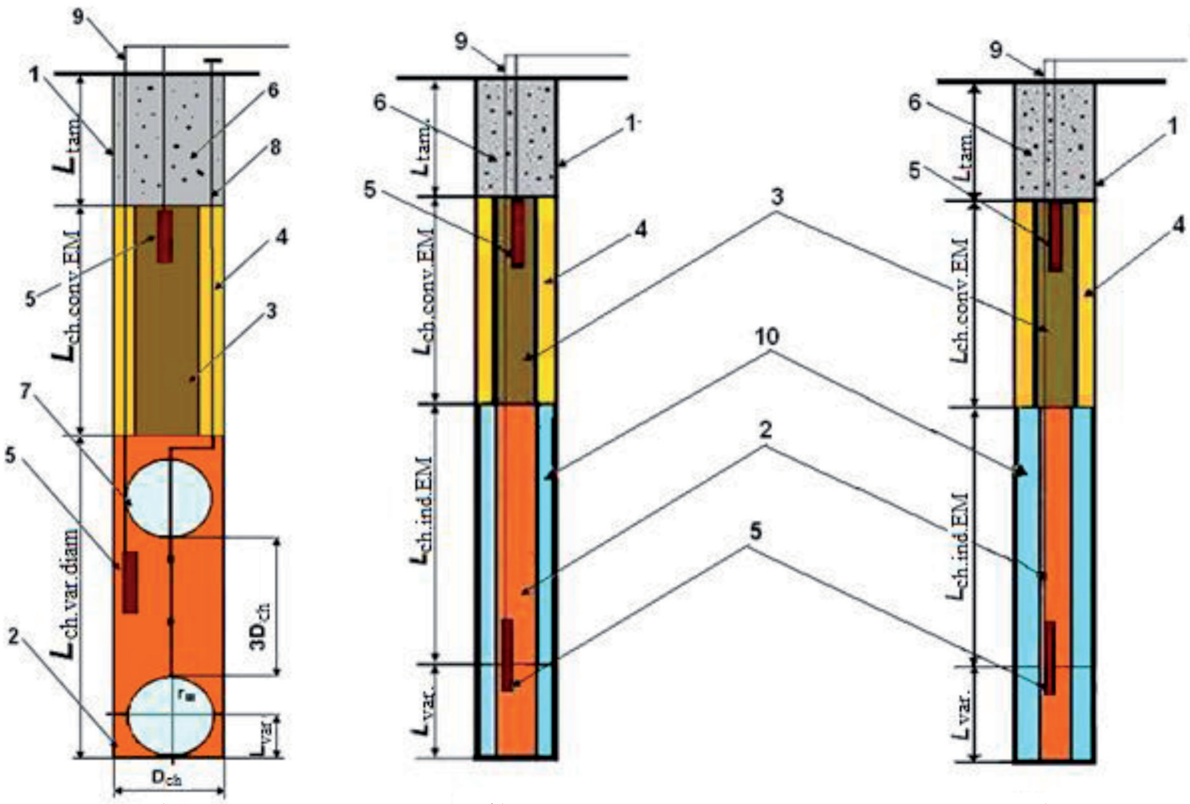
The lower part of a charge was formed in the form of triangular prism of mixed EM consisting of trotyl (hydrocarbon gas + granulated ammonium nitrate in a proportion 65/35) or emulsion EM such as Anemix in the unit in rows of boreholes located in the massif of fractured rocks, and in the top part, the sections DKRP-4 or conversion EM (pyroxylin powder) were placed. Charges were directed to the face by triangle top. Rows of boreholes in the rear of unit in more monolithic massif were charged with the multicharges with an arrangement in the lower part of charge column in the form of square prism. The lower part was charged with industrial mixed EM – trotyl (hydrocarbon gas + granulated ammonium nitrate in a proportion 65/35) or emulsion EM such as Anemix, the top was charged with conversion EM (charge section is DKRP-4 with plastid). The main and intermediate detonators made of two trotyl blocks T-400 were installed, the mouth of borehole was encapsulated by tamping of stone screening dust.

Commutation of borehole charges of EM in the rocks shoulder was carried out by the groups connected by lattice network. The linear delay elements of UNS-S and UNS-PA were placed between groups of charges in each level, and explosions were carried out starting with the charges located on the flank of destructed unit with the use of non-electric systems of initiation “Impuls”, NONEL, “PRIMA-ERA”. Structures of the developed charges of EM are presented in Figure 3.

According to results of mass explosions, the evaluation of results of crushing of the blasted mined rocks was carried out in experimental and test areas. Quality of crushing was evaluated by diameter of an average piece with measurement of particle size distribution of blasted mined rocks with application of a method of oblique-angled photoplanimetry. The calculation results are presented in Table 2.

The analysis of results of industrial experiments has shown that the application of changed DBO parameters with use of structures of charges of variable section (Table 2) reduces diameter of an average piece approximately by 30% and consumption of industrial EM by 10-40%. The output of standard piece (201-600 mm) increases by 10%.

The suggested methods of blasting of strong complex structural local-jointed rocks allow improving of quality of crushing of blasted mined rocks and increasing of technical and economic indicators of work of the mining enterprises. High-quality crushing of blasted mined rocks is achieved due to adjustment of key parameters of DBO, namely, geometrical



a) b) c)

Figure 3. Structure of the borehole multicharges: a) variable diameter; b) charge in square prism section; c) charge in triangular prism section; 1 – borehole; 2 – charge of mixed EM – HG + AN; 3 – section of conversion EM - DKRP-4; 4 – pyroxylin powder; 5 – primed blasting cartridge; 6 – tamping; 7 – spherical cavities; 8 – binder for connection of spherical cavities; 9 – non-electric system of initiation «Impuls»; 10 – inert interval

Table 2. Calculation of sizes of average piece of blasted mined rocks on experimental explosions*

Experimental area				Test area			
Classes of fineness, mm	Average size of piece on class, d_i, mm	Fractions output, W_i, mm	$d_i \times W_i$	Classes of fineness, mm	Average size of piece on class, d_i, mm	Fractions output, W_i, mm	$d_i \times W_i$
0-200	100	41,0	4100	0-200	100	26,7	2670
201-400	300	34,0	10200	201-400	300	24,5	7350
401-600	500	17,3	8650	401-600	500	20,6	10300
>600	700	7,7	5390	> 600	700	28,2	19740
Σ			28340	Σ			40060
$D_{av} = \Sigma\, d_i\, W_i /100$ =283, 4 mm				$D_{av} = \Sigma\, d_i\, W_i /100$ =400, 6 mm			

Note: * – average values on experimental explosions.

arrangement and sizes of boreholes pattern, application of new structures of borehole multicharges of various cross-sectional shapes, and also accounting of direction and intensity of cracks systems of various morphology (opening degree) in destructed rocks unit.

The use of suggested structures of borehole multicharges of various form (variable section, triangular and square prism) makes it possible to increase charge length at its constant mass and, as a result, to distribute EM along the shoulder height more uniformly.

Thus, conditions of energy transmission from explosion of EM charge are changed in case when multigradient and multidirectional field of stress is formed in the destructed massif. The role of extension and shearing stress providing more uniform crushing of rocks increases in such force field.

In course of industrial tests during 2012-2014, about 600 ths. m^3 of mined rocks were blasted in granite pits of PrJSC "Ukragrovzryvprom" according to the developed recommendations. The average economy of industrial EM in one borehole is 40 kg, thus, the general economy for one mass explosion (only of item "explosive materials") exceeded 30 ths. UAH. The comparative analysis has shown that at preservation of rocks blasting quality, the use of suggested technology allows cutting of specific consumption of EM and volume of drilling operations on average by 15% with preservation of design elevation of face toe.

Industrial tests have shown that introduction of the suggested technology of explosive works conducting in pits at blasting massifs of complex structure makes it possible to provide effective and high-quality crushing of rocks.

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Discussion on Safety and Risk Control Strategy for Overseas Mineral Resources Investment and Development

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Abstract
This paper analyzes multiple factors of politics, laws, macro economy, resource, market, community and public relations risk, etc that impact investment and development safety of overseas mineral resources, establishes overseas mineral resource investment and development safety evaluation system, an combines with safety current situation of mineral resources investment and development as well as experience and method of developed countries for ensuring safety of mineral resources, to propose the overseas mineral resource investment and development safety risk control policies as: "positively conduct resource diplomacy", enhance consciousness of overseas insurance cover, perfect financial support system of overseas merger and acquisition, pay attention to safety management and environmental protection work, speed up cultivation of international operation talent, enhance liaison and idea exchange with local government and crowd, etc. It has certain reference effect to mineral resource enterprise to further enhance safety and risk prevention and control during the process of executing internationalization strategy.
Key words: OVERSEAS, MINERAL RESOURCE, INTERNATIONALIZATION, SAFETY RISK, RISK EVALUATION, CONTROL STRATEGY

1. Introduction

With increasingly development of economic globalization, and in order to resolve the problem of resource shortage in domestic, seek out new mineral resource acquisition approach, and ensure demand of enterprise's rapid development, many enterprises