Management of Explosive Crushing of Rock Mass in Quarries

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Abstract. The article deals with improving the quality of rock blast crushing due to increase in delay intervals. The recent decades change in understanding of the rock destruction mechanism under the blast loads influence is shown. The blast mechanical effect reveal itself in rock crushing as well as in the loss of strength away from a charge. The blast waves are acting as compressive and tensile loads in this area. Existing micro-defects and micro-cracks grow as a result. The rock mass strength properties changes. A new condition of the rock mass is called pre-destroyed. The blasts time delay increasing causes cracks merging and a gradual size decrease of the rocks structural elements.

1. Introduction

It is known that the process of explosion crushing action is an active component of the rocks general destruction which results in discontinuity or separation (dispersion) of rocks by reason of the explosion physical factors acting. This process is described in detail in the paper [1]. A blast wave transforms into a compression (stress) wave which performs in an inelastic environment perturbation with a fairly smooth change in parameters and a propagation velocity equal to the sound velocity in a given environment. It takes less time to get the substance out of rest than its return time to this state. From a physical point of view the rocks explosive brittle destruction process is characterized by separation caused by tensile stresses action generated by a compression wave in the rarefaction phase. As a result, systems of cracks dividing the rocks into separate parts is formed. All rock massifs are heterogeneous and fractured. The destruction kinetics of such rocks is significantly influenced by the rate and depth of crack growth, associated with the natural cracks development mechanism and their embryos existing in the environment, and the conditions of explosion energy transition into the new surfaces formation energy.

Clear enough generally accepted notions have been formed [2] for positive effects from multi-row short-delay blasting (MSB) use, as a way of controlling the rocks crushing quality in the quarries. However, on the issue of delay value influence on the process of rocks destruction during the sequential charges sets blasting, a variety of opinions are expressed, sometimes directly opposite. There are two mutually exclusive directions: the first is to reduce the delay to a value less than the beginning of the rocks displacement, the second to increase the delay to a value ensuring the additional exposed surfaces formation [3]. Depending on the charge diameter and rocks properties the delay time between the charge groups explosions was recommended from 10 to 50 ms. A large spread of intervals of consistently triggered retarders causes considerable difficulties in determining the actual delay time in a production environment. The charges group explosion development in a rock in time and space acquires a probabilistic character and delay intervals are calculated either analytically or taken according to simulation data.
When using non-electric initiation systems ISKRA, losses and dilution of the rock mass are reduced, the yield of rock mass lumpy fractions decreases, the ledge bottom quarrying quality improves, and the seismic effect decreases. In [4], the improvement of these indicators is explained by repeated explosive loading of the rock mass when implementing the principle of “one delay - one hole”, which contributes to additional exposed surfaces formation, an blasted rock flows collisions increase. In [5], the relative delay between the holes in a row is from 29 ms/m, and between the rows of holes - from 33 ms/m. The combination of “one deceleration - one well” principle and extended delay intervals allows to improve the rock mass crushing quality.

2. Materials and methods

Specified indicators achievement is possible only when the sequence of hole charges blasting is chosen correctly, since the intensity of rock destruction is determined by the charge interaction nature, that is, the duration and frequency of explosive loads application created by each charge. It has been established that during MSB the best crushing quality is achieved when explosion crushing zone size of each charge reaches its maximum what causes formation of exposed surfaces greatest number around the exploding charges [3].

In recent years, theoretical and experimental work has determined that the mechanical action of an explosion is manifested not only in the destruction of rocks, but also in their strength loss at remote distances from the charge, where stress waves passing from the explosion lead to increased concentration of existing microdefects, growth of microcracks, and weakening intergranular and intercrystalline links [6]. Rocks array changes its strength and deformation properties, goes into a new state, called pre-destroyed, microcracks appear in the environment, its microstructure changes without achievement of discontinuity (fragmentation), but the environment effective parameters change. The explosion pre-destructive action area is characterized by a relatively small velocity range, but a significant (on average, 1,5–2 times) strength decrease at large distances from the charge - up to 200 charge radius ($R_{ch}$) [7].

At the turn of the 20th and 21st centuries, an important event occurred for natural scientists, namely understanding that the nonlinear geomechanical and geodynamic processes development basis lies in the rock massifs block-hierarchical structure in a very wide linear dimensions range - from atomic to cosmic scale levels [8]. The previously unknown phenomenon of rocks alternating reaction to dynamic effects has been established: when cavities are formed inside rock massifs by powerful explosions, nearby geoblocks displace with oscillatory motion relative to each other. This is due to constrained rotation and translational motion of rock blocks of different hierarchical levels, depending on the cavities formed size, rock pressure and explosive energy [9, 10]. The explosion “long-range action” effect was noted in [11, 12]: the noted massif deformations propagate around the resulting cavities further about an order of magnitude, than classical ideas about continuous environment explosive destruction zone would expect [13, 14].

3. Results

In [15], the passage of seven stress waves through the middle block part and twelve stress waves along its end part was noted. Multiple repetition of alternating compressive and tensile stresses, and long tearing effect of detonation products lengthens and expands previous explosions cracks, including outside the block. It makes it possible to form steep quarry sides without crossing the breakage line, with good crushing [16]. The experimental explosions performed allowed us to expand the grid of holes with a diameter of 215 mm from 5x6 to 7x7 m, increase the blasted rock mass output from 18,9 to 25,7 cubic m/m, reduce the specific flow rate explosive from 0,98 to 0,84 kg/cubic m, and reduce drilling depth per meter with providing the crushing quality. In the bottomhole it was also noted that excavator bucket often collapse rock mass large pieces. It confirms the significant fracturing growth during long-term stress waves exposure in the “compression – tension” mode, which is possible only at such large delay intervals.
Better rock cleavage from the massif and a steeper ledge slope indicate that most of detonation products energy transfer to the massif to be destroyed [17].

4. Discussion
When hole blasting, intervals delay increase can significantly increase the total time of multiple alternating loads action on the rock mass, including tensile stresses. Thus, on a block of 81 holes located in 9 rows the explosion development total time increases from 536 ms with a blasting scheme of 25x47 ms to 2800 ms with a blasting scheme of 150x200 ms.

The delay distribution between successively exploding holes changes significantly with different blasting schemes (figure 1).

![Figure 1. Quantitative characterization of delay intervals between adjacent holes exploded with different blasting schemes.](image)

Thus, in the scheme with delays of 25x47 ms, 88.7% are intervals from 1 to 8 ms, in the scheme with delays of 42x67 ms, 87.5% are intervals from 8 to 17 ms, in the scheme with delays 109x176 ms, 86.2% are intervals from 17 to 42 ms, and in the scheme with delays of 150x200 ms, 57.5% are intervals of 50 ms.

In elastic deformation region microcracks develop under tensile pulse in an elastic wave [18, 19]. The determining parameters are magnitude of tensile impulse, time of its action and speed at which microcrack begins to grow. At a certain ratio of these parameters natural germinal microcracks can grow by a certain amount, which is phenomenologically interpreted as the pre-destruction of the rock. It should be borne in mind that in elastic deformation area the rock microstructural parameters can significantly change when explosive effects series affect, since they have a cumulative effect.

The enlarged calculation shows that pre-destructive zone formation is possible at delays between serial holes explosions of more than 14 ms. On this basis, it's obvious that schemes with delays of 25x47 ms and 42x67 ms cannot provide sufficient time to complete microcracks growth and merging into cracks that form separate massifs. Only schemes with delays above 100 ms can provide sufficient time for formation both the zone of destruction and pre-destruction.

The same conclusions are given by the rocks crack development dynamics modeling results with changing external influences. It's necessary to provide multiple cyclic actions on the rock massif of stress waves from serial holes charge explosions with increased delay. This will allow all the processes of dislocations and microcrashes germination and merging into cracks to complete [20–27].

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