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Analysis and Generalization of Hypotheses of Explosive Destruction of Rock

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Abstract: As the initial process of mining technology, as well as mining, the destruction of rocks significantly affects the working conditions and productivity of loading, transport and crushing equipment. Therefore, both scientists and production workers pay great attention to the development and improvement of drilling and blasting processes. In this area, some progress has been made in solving effective methods of conducting drilling and blasting operations in mines and quarries.

Keywords: Explosion, rock, detonation pressure, acoustic stiffness, deposit, crushing, explosion energy, types of cuts, charge design, initiation scheme, recoil effect.

Drilling and blasting operations occupy a significant place in the overall complex of technological processes of mining production. Being the initial process of mining technology, as well as mining operations, they significantly affect the working conditions and productivity of loading, transport and crushing equipment. Therefore, both scientists and mining industry workers pay great attention to the development and improvement of drilling and blasting processes. In this area, some progress has been made in solving effective methods of conducting drilling and blasting operations both in mines and quarries. Based on the achievements of domestic and foreign science, as a result of considering explosive processes in fragile media from the standpoint of physical laws, effective methods of crushing rocks by explosion have been developed and introduced into industry in recent years: multi-row short-range blasting, blasting in a clamped environment, blasting of high ledges, the use of charges with air gaps, granular explosives with elongated the zone of chemical reaction, the use of various types of stemming , etc.

The variety, complexity and rapidity of the phenomena that accompany the explosion have led to the emergence of various ideas about the mechanism of destruction of the environment by explosion. Some researchers believe that the main factor determining the effectiveness of an explosion is the piston action of detonation products, others believe that the destruction of the array during an explosion occurs mainly as a result of the action of direct and reflected shock waves [1].

Scientists M. A. Lavrentiev, M. A. Sadovsky, Ya. B. Zeldovich, A. F. Belyaev, K. K. Andreev, O. E. Vlasov, G. I. Pokrovsky, F. A. Baum, K. P. Stanyukovich, A. F. Sukhanov, A. N. Khanukaev and others made a great contribution to the science of explosion, as well as foreign scientists.

In the works of M.M.Frolov, M.M. Boreskov, A.F. Sukhanov and other authors, an explosion theory has been developed that takes into account various types of resistance of a rock mass to the action of an explosion. According to their proposed theory, the explosion phenomenon is considered as a process of instantaneous transition of the potential energy of explosives into mechanical energy. In their opinion, the energy of the explosion is spent on separating a part of the destroyed massif along

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the side surface of the separation funnel and on overcoming the gravity of the exploding rock during its movement, while simultaneously consuming part of the energy for crushing [2,3]. Such an explosion energy distribution scheme is based on the recognition of the predominant role of the pressure of gaseous detonation products. Many scientists share this theory[4].

M. V. Machinsky[5] based on the basic provisions of the energy theory of explosion, explains the mechanism of rock destruction by the action of shock waves. In his opinion, the wave passes without a trace through the strong places of the rock, and in weak places cracks develop. The cracks grow intensively and at some point close, as a result of which the rock turns out to be fragmented. -

The hypothesis of M. V. Machinsky is confirmed by I.S.Danchev and M.F.Drukovany based on the results of their experimental studies [6, 7]. The results of these studies show that the destruction process begins in areas of reduced strength of the sample when the stress field propagates. Fractures characterized by the development of cracks usually begin at different distances from the charge.

According to M.F.Drukovany[8], the effect of a charge in a medium is characterized by the occurrence of stresses that cause destruction. During the passage of a stress pulse having high compressive stresses. Two types of damage are possible: as a result of the action of radial cracks and as a result of crumpling of the medium. After reflection from a free surface, the stress field reverses its sign, which leads to the formation of folding funnels. Studying the propagation of the stress field makes it possible to describe possible failures in the medium, since the latter depend on the magnitude and nature of the stress change over time.

The results of experimental studies by M.F. Drukovany on models and with rocks allowed us to establish that the mechanism of destruction is determined by the magnitude and duration of the explosive pulse. The shape of the explosive pulse depends on many factors (the direction of detonation, the type and specific flow rate of explosives, the diameter, length and design of the charge, the nature of compression of the medium, etc.) At the modern scientific level, it is possible to control the mechanism of destruction, and through it the intensity of crushing, by changing the shape of the explosive pulse in the charging chamber and the voltage pulse in the array.

In his hypothesis, A. A. Griffiths [9,10] assumes the existence of microscopic cracks in any body that develop when a stress field appears.

In the works of G.I.Barenblatt[11,12], certain issues of the mechanism of occurrence and development of cracks are considered. G.Kolsky[13], the conditions of brittle fracture of materials are described. The author of the work[13] notes that when studying the destruction caused by stress waves, it is necessary to identify three initial positions:

1. the tensile strength of most brittle bodies depends on the loading time;
2. when loaded with stress waves, destruction can occur simultaneously in a huge number of nuclei of destruction, and the load is removed so quickly that the fractures can advance only a few millimeters in the sample;
3. The tensile strength of many brittle materials significantly depends on the condition of the surface, since the crack usually begins to move from surface defects.

According to the hydrodynamic theory of O.E.Vlasov[14,15], the main prerequisites are the incompressibility of the medium and the instantaneous propagation of the explosion energy in the medium. With these assumptions, approximate solutions are obtained that are suitable for practical evaluation of the explosion effect. To describe the behavior of the medium, you can use the equations of hydrodynamics.

O. E. Vlasov developed the basics of calculating the crushing of rocks by explosion, which theoretically determine the granulometric composition of the exploded rock mass. The calculations are based on the decomposition of the initial kinetic energy of the medium into the energy of translational motion and the energy of deformation. This theory leads to an important conclusion about the need to increase the proportion of energy used to deform the rock due to the energy of translational movement of particles. This means that one should strive for explosion conditions that limit the translational motion of the particles of the medium. Such a redistribution of energies can be achieved, for example, by exploding in a clamped medium. The disadvantage of O. E. Vlasov's theory is that it does not take into account the time characteristics of destruction and the impact of an explosion on the environment, and thus greatly complicates the definition of methods for controlling the energy of an explosion.

The process of explosion in a solid medium and the destruction of rocks in the works of G.I.Pokrovsky [16,17] are physically deep, justified and have great clarity. According to these works, at the initial moment of explosion, due to the high pressure in the charging chamber, the rock adjacent to the charge is strongly compressed. The rock particles, out of equilibrium, begin to move radially and are placed behind the front of the stress waves, forming a zone of deformed rock around the charge

This zone is characterized by the occurrence of stresses significantly exceeding the temporary resistance to rupture of rocks, which leads to the appearance of radial cracks. As the distance from the charge increases, the stresses decrease to such an extent that new cracks do not form.

As a result of the expansion of the charging cavity, its increase due to destruction and the outflow of explosion products through cracks and voids, the pressure of gases decreases. The rock, strongly compressed near the charge, begins to move back towards the center of the cavity, causing the appearance of concentric cracks. Reaching the free surface, the compression wave displaces rock particles, the movement of which is transmitted to the layers deep into the massif and causes a rarefaction wave from the free surface. Cracks arising from the tensile stresses of the reflected wave are perpendicular to the direction of its propagation.

According to G. I. Pokrovsky, the main factors characterizing the effectiveness of an explosion are the pressure of detonation products and the parameters of the shock wave (the mechanical action of stress waves resulting from the dynamic impact of detonation products).

A.N. Khanukaev [18, 19] based on the theory of reflected wave rock destruction, puts forward the position that the process of rock destruction by explosion is not the same for different rocks and largely depends on their acoustic stiffness. According to this principle, A. N. Khanukaev proposes to divide all breeds into three groups:

1. rocks that have high acoustic stiffness and are destroyed mainly by the action of waves reflected from the free surfaces of the array;
2. rocks of medium acoustic hardness, which are destroyed both by the action of a reflected wave and by the action of expanding gases;
3. rocks with low acoustic stiffness (mainly soils), the destruction of which is caused by the action of expanding gases.

However, the main assumption made by A. N. Khanukaev, that the strength characteristics of rocks are directly dependent on their acoustic stiffness, does not always take place in practice. Since, when exposed to impulsive loads, destruction is determined not only by the strength of the rock and the voltage at the wave front, but also by the time of application of the explosive pulse [19]. This is confirmed by the results of research by G. Kolsky [13], in which it is noted that the strength of the material largely depends on the duration of the load application.

In the works of the authors [20, 21, 22] it is stated that there is a complex relationship between the intensity of crushing, explosion parameters and the physico-mechanical properties of rocks.

In [23], an assumption was made about the determining influence of the shape and magnitude of the explosive pulse on the nature of destruction. According to this work, the physical and mechanical properties of rocks play a subordinate role, and in principle, the mechanism of destruction for rocks with the same physical and mechanical properties can be changed. This assumption was confirmed by the results of extensive laboratory studies. ,

The wave theory of destruction is very popular among many scientists. According to the study by E. G. Baranov [24], brittle destruction of rocks or crushing of an array is possible only in the presence of a free surface and occurs under the action of tensile stresses that occur when reflected tensile waves pass through the array, and lead to the formation of cracks that dissect the array during the passage of stress waves through it. The research of this author has established that the share of stress wave energy in the total volume of destruction reaches 80-90%. The array, disturbed by a dense network of cracks that arose during the passage of a voltage wave, is in the stage of pre-collapse, which develops further to a complete violation of the strength bonds of the medium under the influence of the pressure of gaseous explosion products. The participation of gaseous explosion products in the total volume of destruction of the rock mass is completely insignificant: the energy cost of crushing is a fraction of a percent of the total energy of the explosion, and the cost of movement is from 3.5 to 14%.

The author of the work[25], based on the results of his research, proves that the effect of an explosion on the environment does not manifest itself instantly, but over a certain period of time. In his opinion, a shock wave is formed directly at the site of the impact of the detonation products, which causes a compression stress in the medium. Upon the output of the shock wave to the free surface, a reflected wave is formed, which causes a tensile stress in the array and manifests itself in the outcrop plane in the form of deflection phenomena, and inside the array in the form of minor cracking and stress state. The time spent in the stressed state of the array is determined by the rate of development of the reflected wave and the size of the line of least resictance.

According to V. N. Mosinets' experimental and theoretical studies [26], the complexity of the mechanism of rock destruction by explosion and the inconsistency of existing theories are confirmed. The author has established that the process of destruction of an array of rocks bounded by a free surface does not occur instantly, but during a certain period of time, during which the system of forces and stresses involved in destruction change significantly in space, and also that the energy of stress waves creates a pre-collapse of the array.

Further development of experimental and theoretical research, as well as in-depth study of the actual conditions of blasting (physical and mechanical properties of rocks, their structural features, etc.) significantly expanded knowledge about the processes occurring during the explosion of an explosive charge in rocks. It is quite obvious that one cannot limit oneself to the wave theory of rock destruction in an explosion. Therefore, in [27] V. N. Mosinets points out that the destruction of an array of rocks, especially strongly fractured ones, cannot be explained from the standpoint of only one hypothesis — wave or gas: obviously, the process of crushing real media with varying degrees of fracturing occurs as a result of the action of various physical factors, and the degree of crushing of a real array is determined primarily by its fracturing. In media with intensively developed fracturing, crushing under the action of tensile forces behind the front of the direct compression wave takes place only in the area directly in contact with the charge.

The clearest generalization of ideas about the mechanism of rock destruction by explosion is described in the work of F. A. Baum [28]. In this work, the author points out that the destruction of rocks by explosion is a complex process occurring under the combined influence of detonation products, shock waves and discharge waves (rarefaction). In time and by the nature of the physical phenomena that define it, the explosion process is characterized by several stages.

In the initial stage of the process, the main role is played by expanding detonation products, which at the first moment are under pressure of about 105 kg/cm^2. The expansion of the latter in a mountainous environment in the first approximation will proceed until the pressure of the detonation products becomes equal to the strength resistance of the medium.

The second stage of the process is associated with the propagation of a rarefaction wave reflected from a free surface and its interaction with the tail part of a traveling compression wave that occurs after the shock wave reaches a free surface. As a result of this process, significant tensile stresses arise in the rock, which predetermine new cracking.

The third stage of the process is mainly reduced to the impact on the rock of detonation products that have already expanded to $r = r_{cr}$, as a result of which various types of rock destruction occur (penetration of gases into cracks, separation of individual pieces from the massif, etc.), displacement of the destroyed mass and scattering of fragmented rock elements.

Thus, after analyzing the above-mentioned opinions of the authors, the following conclusions can be drawn on the process of rock destruction by explosion:

1. The destruction of rocks by explosion occurs mainly due to the piston action of the explosion, developed by gaseous products of explosive decomposition of explosives in a confined space.
2. The destruction of rocks by explosion occurs as a result of the action of stress waves coming from the charging chamber to the free surface and in all directions from the charge. .
3. The process of destruction of rocks by explosion varies depending on the acoustic stiffness of the medium and is carried out as a result of the action of gaseous products of explosive decomposition of explosives and reflected stress waves.
4. The work of the explosive charge explosion, both in terms of the volume of the rock beaten off by the explosion and in terms of the degree of its crushing, is proportional to the potential energy of the charge.
5. The mechanism of rock destruction by explosion can be changed. The nature of the destruction depends on the shape and magnitude of the explosive pulse.

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