The Main Theoretical Provisions of The Process Destruction of Rocks By The Action Of An Explosion

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Abstract: The mechanism of rock destruction by explosion is generally characterized by the short duration of the application of the load to the destroyed volume of the medium and depends on many factors. Therefore, to date there is no generally accepted theory about the mechanism of rock destruction. Generalization of the existing hypotheses about the physical nature of the explosion action in a solid medium makes it possible to improve the control of the explosion action.

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

Due to the further concentration of mining production, the deepening of mining operations, the saturation of mining enterprises with high-performance loading and transport equipment, the use of in-line and cyclic-in-line technology for both open and underground mining methods, the requirements for the quality of rock crushing are continuously increasing, since the efficiency of loading, transportation and subsequent processes is determined by the degree and the uniformity of crushing of the blasted rock.

The main method of destruction and separation of rock or ore from the massif is explosive stripping, which will not lose its importance in the coming decades. Modern methods of explosion energy management can be effectively used only if the physical and mechanical properties of the rock mass are sufficiently studied and their influence on the nature of destruction is established.

To increase the intensity and uniformity of crushing in the country's quarries, effective methods of mining are increasingly being used: blasting high ledges in a clamped environment, contour blasting, etc. New types of log cabins, charge designs, and initiation schemes have been developed, the introduction of which makes it possible to increase the speed of horizontal and vertical workings and reduce their cost.

The mechanism of rock destruction by explosion is generally characterized by the short duration of the application of the load to the destroyed volume of the medium and depends on many factors. Therefore, to date there is no generally accepted theory about the mechanism of rock destruction. Generalization of the existing hypotheses about the physical nature of the explosion action in a solid medium makes it possible to improve the control of the explosion action. These hypotheses are grouped in five main directions [1, 2].

The hypotheses of the first direction are based on the most general patterns of the destruction process. Scientists, proponents of hypotheses in this direction, consider penetration into the essence of the phenomenon to be an extremely difficult task and use empirical formulas derived from processing data on a large number of explosions under equivalent conditions to calculate the parameters of the breakdown.

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According to the hypotheses of the first direction, the explosion is accompanied by the separation of a part of the destroyed massif along the side surface of the explosion funnel and overcoming the inertia of the mass or gravity of the exploding rock. At this time, the accompanying primary crushing of the rock occurs along various planes inside the volume of the funnel, the total surface of which is proportional to the area of the lateral surface of the funnel. Due to the complexity and short duration of the processes of explosion and destruction of rocks, it makes little sense to build a universal theory of rock destruction by explosion. Such a theory would be extremely difficult to use in practice. The development of the fundamentals of the theory of explosion action should be aimed primarily at solving the most important practical problems [3, 4].

A number of scientists hold similar views [5]. The calculation formulas are based on the principle of taking into account various types of rock resistance to explosion and the degree of rock crushing [3, 4].

The empirical dependencies established by scientists who adhere to this direction are of indisputable practical value. However, the creation of a universal theory of rock destruction by explosion due to the scientific development of the main problems, the success of fundamental research and vast practical experience can only be carried out in the future.

The second direction can include hypotheses explaining the physical essence of the explosion action on the basis of the most general patterns, but using theoretical formulas developed under conditions of some schematization of the process for calculations. The main hypotheses of the second direction were developed by Prof. O. E. Vlasov [6, 7, 8]. Their main difference from the hypotheses of the first direction is the following: to simplify the problem, O.E.Vlasov assumes that the energy of detonation products is transferred to the rock instantly and the rock is an incompressible medium. The energy of the explosion is communicated to the rock in the form of kinetic energy, and the determination of the parameters of the explosion action is reduced to solving a system of differential equations [6, 8]. This calculation scheme allowed us to deepen our knowledge of the process of rock destruction and solve a number of applied problems.

According to the main provisions of the hypotheses of the third direction, the mountain range is destroyed mainly as a result of the "piston" action of detonation products on a solid medium. In this case, the explosion action is considered as a static process. Hypotheses about the predominant effect of the "piston" action of detonation products on the environment have been quite widespread in the past. However, in recent years, works confirming this hypothesis have not denied the influence of stress wave energy on the destruction of rocks.

Scientists who adhere to the hypotheses of the fourth direction believe that the results of the explosion are determined by the energy of stress waves. An example of hypotheses of the fourth direction is the idea of the effect of an explosion in a rock by Prof. G. I. Pokrovsky, who believes that when a charge explodes in the rock, the pressure of the explosion products, measured in hundreds of tons per 1 cm^2, acts simultaneously over the entire surface of the charging chamber. The temporary crushing resistance of even the most durable rocks is two orders of magnitude lower than the pressure of the explosion products. Near the surface of the charge, the rock is crushed and becomes fluid. The compression stress is approaching the rock compression modulus in magnitude. The particles receive movement in radial directions and are displaced following the deformation wave front. As a result, a zone of highly deformed rock is formed.

If the medium is homogeneous, then a system of spiral slip lines is formed in it, tangents to which form angles of about 45° to the radii radiating from the center of the charge. As you move away from the charge, the energy of the explosion is transferred to an ever-increasing mass of the medium, which is why it decreases significantly per unit volume. Compression stresses drop rapidly with distance. At a certain distance, they become less than the temporary resistance of the rock to crushing and the nature of the deformations of the medium changes, the sliding lines disappear, and the structure of the medium is basically preserved.

The wave of deformations propagating further from the charge contributes to the formation of radial cracks spreading in all directions from the charge. With further removal of the wave from the charge, the tensile tangential stresses in the rock decrease and become less than the temporary resistance to rupture. As a result, no new cracks are formed. Previously formed radial cracks can still spread for some distance, because there is a concentration of tensile forces near their ends. However, this phenomenon can only contribute to the elongation of radial cracks. After passing the compression wave, the pressure in the charging chamber drops and the rock near the charge begins to unload and expand towards the center of the charge. Therefore, annular tangential cracks may appear in the zone with radial cracks.

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When an explosion occurs near an open surface, the rock crushing pattern changes significantly. The main importance in this case is reflected compression waves from an open surface, from which a stretching wave penetrates into the rock, causing tensile stresses in the medium. The stresses in the stretching wave are lower in absolute terms than in the compression wave. However, due to the fact that the resistance of all rocks and similar materials to compression is greater than the tensile resistance, the discharge wave produces greater destruction than the compression wave [9, 10, 11].

Basically, the same ideas are contained in the works of Prof. A. N. Khanukaev [12, 13], who believes that the nature of the process depends on the properties of rocks, which he divides into three groups:

Rocks that are destroyed due to the reserve of kinetic energy acquired by the medium during the expansion of explosion products: sands, sandy loams, clays, etc. The acoustic stiffness of these rocks does not exceed 5×10^6.

Rocks that collapse both under the direct influence of explosion gases and under the influence of a stress wave. This group includes rocks with a strength coefficient from 1 to 10, with an acoustic stiffness from 5×10^5 to 15×10^6.

Rocks that collapse mainly under the influence of stress waves. The acoustic stiffness of these rocks ranges from 15×10^6 to 25×10^6.

Academician Ya. B. Zeldovich [14, 15], Prof. K. P. Stanyukovich [16], Prof. F. A. Baum [17, 18, 19], Prof. G. M. Lyakhov [20] adhere to this trend to varying degrees, as well as a number of foreign scientists whose views are set out in the book [13]. They believe that a powerful shock wave causes crushing and splintering when reflected from an open surface.

A. N. Khanukaev and others have created calculation schemes based on empirical dependencies linking the parameters of stress waves with explosion conditions. Calculation schemes based on theoretical dependencies describing the physical essence of wave processes were compiled by K. P. Stanyukovich, F. A. Baum and others.

The hypotheses of the fifth direction, which have recently been increasingly widely supported, are based on the joint "piston" action of detonation products and wave processes.

Academician I. V. Melnikov [21] proposed a hypothesis according to which a detonated explosive, turning instantly into gases with high temperature and pressure, produces an impact on the environment, causing concentrically propagating compression and stretching waves in it. Due to the enormous pressure produced by this impact, the inertia of the environment creates conditions for the phenomenon to occur similarly to the impact of elastic balls, which are accompanied by an exchange of velocity. As a result of the propagation of this phenomenon from one spherical layer to another, the medium collapses and acquires translational motion in the radial direction, spreading out in the form of a cone directed by the base towards the least resistance.

In the future, the phenomenon occurs when the medium is ejected mainly from the acquired impulse, and also partly due to the pressure of gases, which, however, quickly decreases after getting into the atmosphere. If the environment in its strength and power exceeds the charge potential capable of forming an outlet towards the least resistance of the medium, then this charge acts as a camouflage, forming the largest compression chamber possible for a given charge and causing radial and spherical destruction of the medium with a gradual drop in gas pressure due to their cooling and penetration into cracks and pores of the medium. As for the medium located deeper than the plane of placement of charges, the effect of destruction in it is limited to the formation of compression spheres, since in this direction the explosive waves meet unlimited resistance. When it comes to the placement of several charges that explode instantly or with deceleration, their location is also determined by the interference of explosive waves, the quantitative participation of which is not yet possible to take into account.

As the observations of explosions on models and in industrial conditions show, N. V. Melnikov's hypothesis about the physical essence of the mechanism of destruction of a solid medium is in many ways close to the truth.

Solving the problem of purposeful control of the energy of explosive charges explosion is of great practical importance. N. V. Melnikov and L. N. Marchenko, based on research carried out to increase the explosion energy utilization factor, developed and proposed the basics of controlling the effect of an explosion in the environment. Practically and theoretically, they have developed a way to reduce explosion energy losses

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by changing the design of the charge, applying rational ratios of the height of the charge to its diameter, introducing an air layer between the side and upper surfaces of the charge and the walls of the charging chamber, as well as between individual parts of the charge along its length.

They came to such decisions on the basis of modern ideas about the physical essence of the effect of a charge explosion on the environment.

The air shell of the charge serves as a compensator, stretching the pressure of the explosion products over time. Ultimately, the task of controlling the energy of an explosion is to excite an explosive pulse of a certain shape, duration and intensity in the environment surrounding the charge.

It is possible to control the parameters of the explosive pulse both by using charges of various designs and by choosing the type of BV. On this issue, the provisions developed by G. P. Demidyuk on the mechanism of action of explosives of the simplest composition -igdanites are interesting. Instead of a sharp pressure jump and a relatively sharp decrease in pressure during the explosion of a finely dispersed explosive, granular explosive provides a lower initial pressure during the explosion, but maintains it for a significantly longer period of time. As a result, the proportion of explosion energy transmitted to the rock by the shock wave significantly decreases, and accordingly the energy used in the form of piston action of gaseous explosion products increases. This leads to a more uniform crushing of the rock [21-25].

There are no clear boundaries between the highlighted directions in the views on the nature of the process of rock destruction by explosion. Many scientists, preferring one point of view, do not fully deny the provisions of the other [26-32].

This is explained by the fact that the nature of explosive destruction of rocks depends on many factors, the main of which are: the physical and mechanical properties of the medium, the location of charges relative to an open surface, the mass of charges and the type of explosives, the design of charges and their mutual location, parameters, the method of initiating charges, the explosion action indicator, which determines the relationship between the charge energy and distance to the open surface.

The qualitative picture of rock destruction by explosion has been studied quite well and is most fully reflected in the scheme of Prof. G. I. Pokrovsky.

As follows from the above, any of the considered schemes does not cover all sides of the process, because various assumptions were made and correction factors were introduced during their construction.

The solid medium is destroyed by the shock, elastic, static and kinetic action of the explosion. Other phenomena also have some influence on the destruction process, but their role is insignificant.

According to modern concepts, the mechanism of action of an explosion in a solid medium is as follows. When a charge explodes in the medium, disturbances occur in the form of voltage waves, the intensity of which depends both on the properties of explosives, and primarily on the density of explosives and the detonation rate, and on the properties of the rock. At the same time, during the detonation of the charge, the pressure on the walls of the well increases, reaching in some cases 4 -105 kgf/cm2, the rock compresses, forming a shock wave. The speed of the wave front exceeds the speed of sound. The most severe damage in the form of over-grinding and plastic deformations are observed in the immediate vicinity of the explosive charge. A large proportion of the shock wave energy is spent on these destructions due to significant energy losses for scattering and overcoming internal friction between the particles of the medium (dissipative losses).

At a distance of 5-8 charge radii, the shock wave becomes a voltage wave propagating at the speed of sound. Following the wave, cracks spread at a speed of 0.4 m/s, along which detonation products move, the pressure and temperature of which gradually decrease. The energy transfer of gases moving through cracks continues to a certain critical value and, as a result, the wave continues to be fueled by the energy of moving gases. Thus, the wave accumulates energy, not only transmitted through the walls of wells, but also the energy of gases propagating through cracks. From the above it becomes obvious that it is impossible to contrast the considered sources of loading, stress wave and gases, since they together take part in the destruction of rocks.

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May 2024

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