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CALCULATION OF GAS-DYNAMIC PARAMETERS IN POWDER CHAMBER OF A BLAST HOLE

Gennadiy I. Korshunov
Professor of the Department of Industrial Safety

Roman E. Andreev
Ph.D. in Technical Sciences,
Assistant Professor of the Department of Industrial Safety

Elena B. Gridina
Ph.D. in Technical Sciences,
Assistant Professor of the Department of Industrial Safety
Saint-Petersburg Mining University

ABSTRACT

The problem in question is relevant since the process of detonation and shockwaves collision and recompression of detonation products is a challenging task in terms of gas dynamics. The paper is aimed at addressing this problem that would enable to intentionally control the process of transferring energy of explosive to environment through choosing optimal structure of charge or mode of triggering. The problem is examined mostly through method for numerical simulation of non-steady detonation and gas dynamic processes occurring while blast-hole charge is exploded. An attribute-based pattern of process for transferring energy of explosion products to environment when blasting charges of different structures and with different parameters of triggering modes was pre-investigated. The paper describes mathematical model of calculating parameters of dynamic loads on a blast-hole (hole) wall when exploding charges of various structures in various triggering modes. The results of calculating parameters of stress wave generated in rock mass by explosive charge blast and gas dynamic parameters in powder chamber of a blast-hole (well) were presented. The obtained coefficients of explosion pulse effect allow to correct calculations of unit rate of differently-structured charges.

Key words: Gas dynamic task, rock mass, detonation, explosive.

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1. INTRODUCTION

Rocks are destroyed when exposed to explosion due to internal energy of charge detonation products. Therefore, the state of explosion products in explosion chamber has considerable effect on work done while blasting and defines not only the quantity of medium blasted but the quality of blasting thereof.

Distribution of energy, transmitted to rock while blasting, depends on rock compressibility in the near field of charge effect. It is known that in the near field of blasting most energy, released through chemical transformation of explosive, is absorbed that substantially reduces efficiency of blasting operations. Determining coefficient of transferring blast energy to rocks might address the issue of selecting the type of explosive for the most effective blasting of rock mass [9, 21-24].

Works [10, 18, 21-24] demonstrate the results of blast in rocks with various physical and mechanical properties. There are correlation dependencies between these properties that enable to make calculations for rocks with intermediate values of basic physical and mechanical properties.

To assess transmission of energy, an amplitude of displacing “explosive-rock” interface and velocity of displacing this interface were experimentally determined; other parameters were calculated using hydrodynamic theory of blast waves propagation.

∅53-66mm cores were used for specimens of rocks. ∅6mm and 75mm deep blast holes were drilled in specimens.

“Explosive-rock” interface displacement value was measured through X-ray pulse survey when rather clear picture of interface at the specified time intervals might be obtained based upon varied absorption of X-rays with detonation products and rock. With geometrical coefficient of displacement increase known, displacement of rock in the middle part of charge can be identified. Surveys were made with two X-ray tubes at 50,7+2,5μs and 70,1+2,5μs moments after charge triggering.

Initial velocity of “explosive-rock” interface displacement and velocity of explosive detonation in rock were identified for identical specimens using electromagnetic technique.

To measure velocity of detonation ionization detectors in the end parts of charge were used. Shock wave velocity in rocks was defined on flat specimens of rock based on distance and time of wave passing between detectors installed under end face of pressure charge and on the lower side of plate cut out of rock of interest.

While work is in progress, the authors reached conclusion that as the velocity of detonation, i.e. pressure at “explosive-rock” interface, increases, dissipation losses of energy increase. Shock compressibility of rock is the best indicator of rock behavior when subjected to dynamic loading. Since dynamic compressibility is closely related to rock porosity, it is apparent that the higher the rock porosity is, the greater dissipation losses are, which might be explained with higher specific heat of air contained in the rock pores.

The work [11, 16] demonstrates dependence between energy transmitted by compressive wave and matched distance. Here, it can be seen that the strongest dissipation of energy occurs in the near field of blast, evidencing high consumption of energy for irreversible processes, being both the result of the inelastic compression in the wave front, and plastic flow of medium beyond the wave. This has very important practical implication that to increase blast efficiency, reduction of energy losses is necessary precisely at the initial stage of blasting through accumulating energy of explosion products in charging chamber.

As studies [5, 19] shown, to improve dynamics of destruction process and increase efficiency of blast effect it is required to ensure repeated exposure of the destroyed rock mass to hole charge explosion products through changing gas-dynamics inside the hole. It can be achieved using blast hole charges of different structures, and changing modes and parameters of blast hole charge triggering as well.

Works [17, 14, 15] on hydrodynamic detonation theory contain analytical description of gas dynamic process in detonation products when core blast hole charge is triggered in many points, according to which it is inferred that when there are many points of triggering (number of points is more than two), it is possible to substantially increase shock wave pressure and ensure optimum repetition frequency of secondary compression waves. As a result, the hole walls will be exposed to repeated periodic loading that will lead to a complex interference pattern of medium motion defining the nature of loading rock mass.

On examination of blast hole charge as a source of wave field [8, 13], assumption about instantaneous detonation, when state of explosion products in chamber is supposed to be equal at all points and depends only on the chamber volume, is commonly recognized. Such assumption gives a simplified pattern of wave field created in the rock mass, if only because pressure in explosion products, when there is interaction between the hole walls and bottom, greatly exceeds pressure at the peak of detonation wave.

The problem of describing and evaluating the wave field source becomes more involved when it has blast hole charge of complex structure or charge with variable mode of detonation. In this case the process of colliding detonation and shock waves and stagnation of detonation products flow is a complex gas dynamic task. Solving this problem would enable to intentionally control the process of transferring energy of explosive to environment through choosing optimum structure or triggering mode for a charge.

The problem shall be handled by method of numerical simulation of non-steady detonation and gas-dynamic processes taking place when blast hole charge is exploded. An attribute-based pattern of process for transferring energy of explosion products to environment when blasting charges of different structures and with different parameters of triggering modes was pre-investigated; to this end, laboratory experiments were made with procedure and results given below.

2. METHOD

Opportunity for unfolding theoretical developments in the area of non-stationary gas dynamic processes due to accessibility of brand-new computer technology and information processing means facilitated numerical modelling studies of rock destruction processes in recent decade.

Work to destroy rocks by blasting is made for account of energy of charge detonation products. Therefore, the state of explosion products in explosion chamber substantially influences work done while blasting and defines not only the quantity of destroyed medium, but the quality of destruction as such.

Most energy released, while chemically transforming explosive, is absorbed in the near field of explosion that considerably reduces efficiency of blasting operations [2, 4, 6, 7].

To examine effect of charge explosion on rock mass in the near field of blasting, parameters of gas dynamic impact of explosion products and parameters of stress wave in rock mass in the near field were calculated through solving two-dimensional non-stationary problem. In doing so, detonation and gas dynamic processes, processes of discharging products via hole collar were considered, and based on calculations made, parameters of flow including shock-wave, wave, and dynamic loads on hole walls were identified.

Energy release while blasting was considered bearing in mind velocity of detonation length-wise propagation for various charge structures and modes of triggering. Given the above assumptions, detonation and gas dynamic processes in blast hole might be described with Euler equation system through adding to equation a member describing release of energy as detonation propagates. Equation of medium state is the last in the system of calculations [1, 3, 5, 9, 10, 19]. Since weight of air in a hole is low as compared to explosive detonation products, its impact can be neglected. Gas in a hole collar shall be discharged free for a case of charge without tamping.

The problem statement assumed allows evaluating relative changes in gas dynamic parameters when blasting charges of explosives with approximately the same energy release.

Shock wave refracted into rock at the “charge-rock” interface, when further propagating there, is rapidly transformed into stress wave with stress growing smoothly to its maximum value. To calculate radial and tangential stresses, a method for determining components of stress wave in the near field of explosion will be utilized.

Based on the above model, parameters of gas dynamic flows were calculated, involving parameters of dynamic loads on a hole wall, with blasting charges of different structures and triggering modes.

Work [23] theoretically shows that nature of stress wave amplitude attenuation for media with friction is different. It depends on a type of symmetry: spherical or cylindrical.

The above approach to calculating parameters of stress wave enabled to design a methodology for numerical modelling used to further calculate parameters of gas dynamic processes in powder chamber when exploding blast hole charges.

Calculation was performed for various structures of charge (charge with special tamping [19]; charge with sand-clay tamping; charge without tamping), divided into four points located along the charge axis. 2.5m long blast hole was charged with AC-8 granulite of 2m length. Direct and inverse triggering of charge were considered.

According to calculations, at the moment of wave reflecting from the hole bottom in direct triggering, the level of pressure therein is rapidly decreasing to quasi-static in the near bottom part of a hole, remaining a little lower in the near collar part than in inverse triggering. Wave processes for both patterns of triggering are further dying out rather quickly.

The waves are propagated non-uniformly only near the hole collar due to discharge, however, it has almost no impact on flow inside the hole.

When density of different explosives decreases, discharge pattern remains the same as pressure level generally decreases. For granulite AC-8, all basic regularities of discharging remain the same when density changes, parameters at the front of detonation and strong shock waves have higher values since the value of adiabatic index is higher, but pressure in a blast hole and its walls occurs faster due to lower heat of explosion.

Some results of calculating gas dynamic parameters in powder chamber of a blast hole are presented in Figure 1 in the form of characteristic curve. This calculation was made for a charge with special tamping and inverse triggering mode.

Analysis of all results shows that an attribute-based pattern of gas dynamic processes undergoes changes when there is tamping in a blast-hole. After detonation wave interacts with clay tamping, parameters of reflected shock wave propagating towards the hole bottom are comparable with parameters of detonation wave. Pressure upon tamping end face slightly differs from pressure on the hole wall near tamping, sharply decreasing at the outlet as it is ejected. Shock wave is repeatedly reflected from the hole bottom and tamping. Thus, wave amplitude is decreasing rather slowly, and quasi-static level of pressure in a hole somewhat increases.

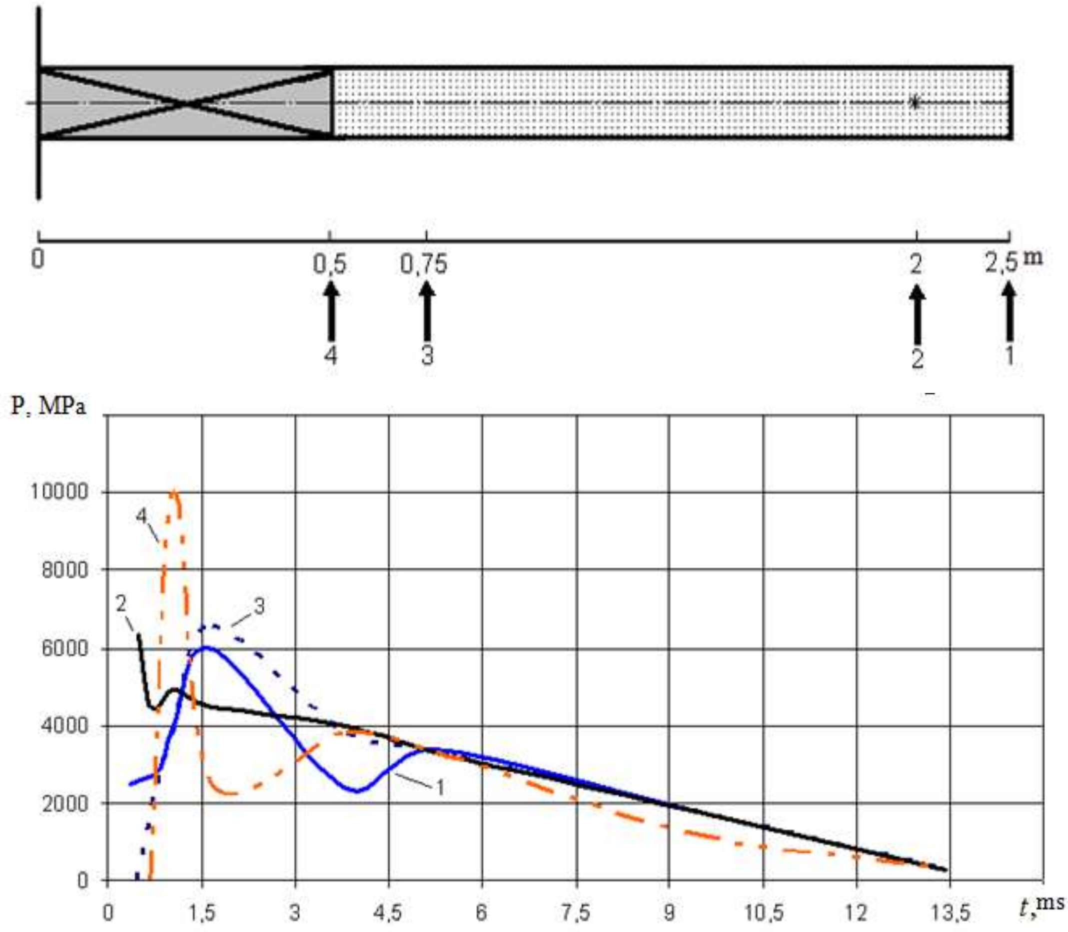

Figure 1. Structure of charge with tamping and curve of changing pressure on a hole wall when blasting with tamping in inverse triggering: along the length of charge in points 1,2,3,4 respectively

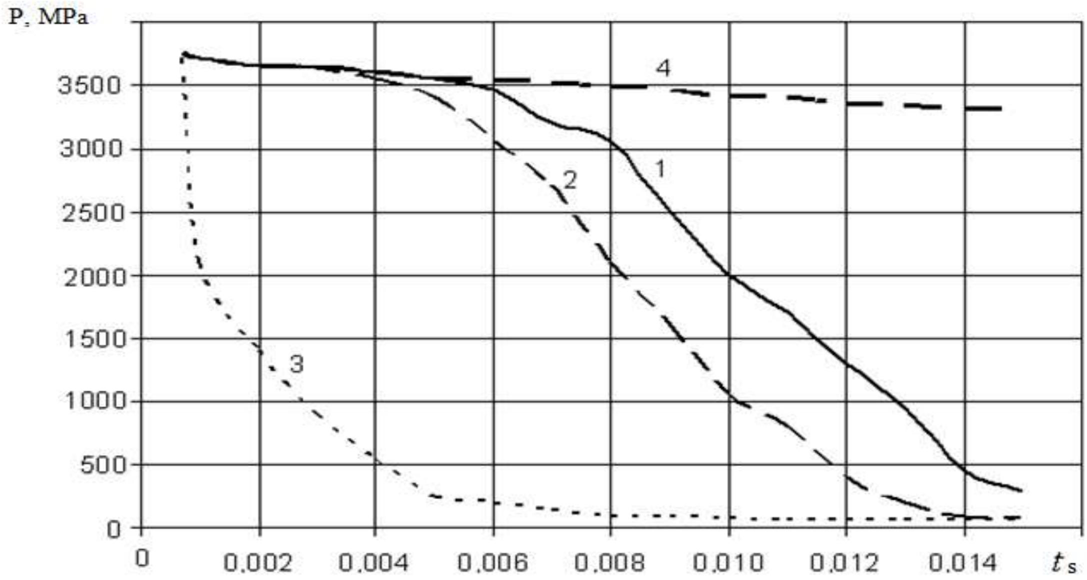

Figure 2 Shows total impact of gaseous explosion products pressure on a hole wall depending on the structure of a charge: 1 – charge with special tamping; 2 – charge with sand-clay tamping; 3 – charge without tamping; 4 – total blocking of detonation products.

Dependence of average pressure on the hole wall on time (curve 1, Figure 2) shows that reduction of pressure when using rather dense tamping is not significant, and an intense decrease in pressure (curve 3) is observed only when a charge without tamping is blasted that is evidenced by the type of curves in using various tamping. A threshold case of full blocking detonation products with a fixed wall instead of tamping was examined. Difference between curve 4 corresponding to threshold case and curves 1 and 2 in Figure 2 is indicative of decreasing pressure in explosion chamber due to discharge of detonation products through blast hole channel as tamping is ejected. At the final stage after tamping is fully ejected and part of detonation products from blast hole are removed, intense wave processes in the explosion chamber are dying out.

It should also be noted that change in length of a charge with unchanged diameter of a blast hole or detonation velocity when the ratio of charge diameter to the length of blast hole remains the same, results only in changing time characteristics with retaining all quality features of developing gas dynamic processes.

Explosion pulses (Figure 3) that define a degree of rock mass destruction, were calculated based on numerical results of pressure in charge chamber for various structures of charges. In general, explosion pulse is a relationship between pressure at the front of detonation wave and time totaled over the time of detonation products effecting rock mass.

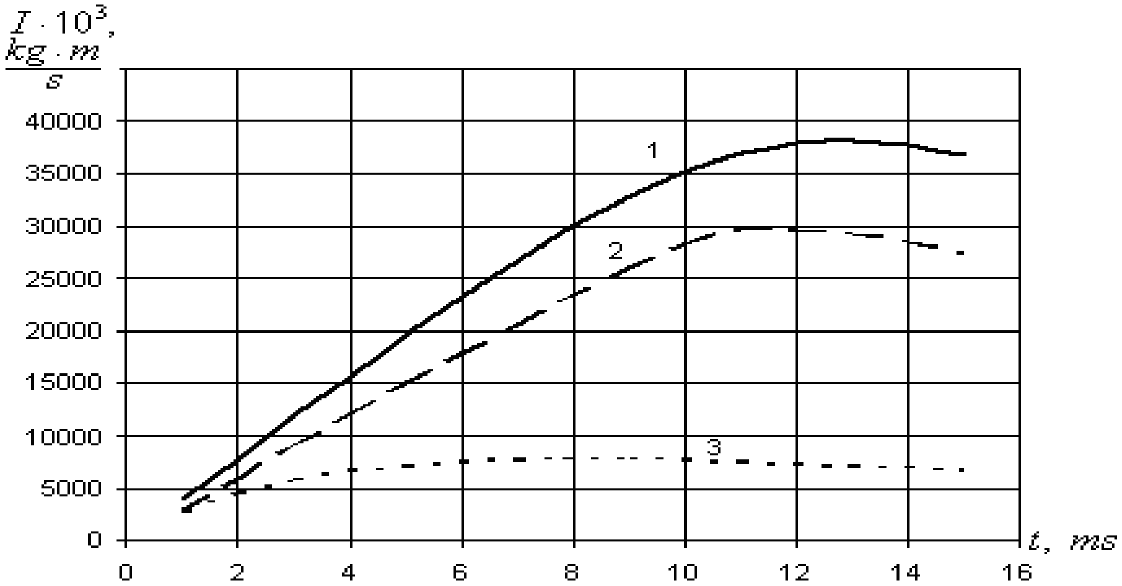

Figure 3. Explosion pulse - time and structure of charge curve: 1 – charge with shaped tamping; 2 – charge with sand-clay tamping; 3 – charge without tamping

According to the results, end time of explosion pulse active effect for charges with special tamping is 13ms, 11ms and 9ms for sand-clay and without tamping, respectively.

Thus, if coefficient of dynamic explosion pulse effect on rock mass without tamping is introduced and assumed to be one, this coefficient for charges with special tamping and sand-clay tamping will be 1.44 and 1.22, respectively.

The obtained coefficients of explosion pulse effect enable to correct calculations of unit discharge of differently structured charges.

3. RESULTS

Analysis of gas dynamic processes taking place in explosion chamber of blast hole charge allowed to identify the relationship between a change in pressure on explosion chamber wall and a type of the utilized tamping that enables to control loading of rock mass, as blasting operations proceed, through selecting blast hole design parameters. Analytical study of gas dynamic processes in charge chamber shows that a change in length of charge with unchanged diameter of blast hole or velocity of detonation with unchanged "charge diameter-blast hole length" ratio, results only in changing time characteristics of these processes with retaining all quality features.

Numerical modelling established duration of rock mass exposure to detonation products at a quasi-static stage. Values of explosion pulse for various structures of charges were obtained, namely, 9ms, 11ms, 13ms for charges without tamping, with sand-clay and shaped tamping, respectively.

4. DISCUSSION

Mechanism of blasting rocks with explosive charge is rather complex since the process of destruction occurs in a very short time with quite high values of dynamic loads. Therefore, there is no common view point so far to the problem of blasting rocks. Many scientists made attempts to discover physical principle of deforming medium by blasting, energy parameters of this process and methods for its controlling. However, the results of investigations are diversified and somewhat controversial.

The studies performed differ in approach to the problem of explosion effect on rock mass. Mostly, they involve three directions based on hydro dynamic, wave theory, and hypothesis about two components of stress field.

Explosion is a process of high-speed dynamic loading of rocks. However, nature of loading rocks when blasting and rock mass deformations resulting are interpreted in various ways. In terms of hydrodynamics and theory of shock waves, the process of explosive dynamic loading is seen as a single peak pressure pulse having effect during a certain time period. A concept of two components of stress field suggests that there is a shock load in the beginning of a process and then a quasi-static load slowly varying in time. Nature of loading and assumed criteria of destruction are different in each of these directions.

Nowadays many scientists believe that it is impossible to limit the process of transmitting energy of explosion to environment with a shock wave concept. It is supposed that detonation of explosive is pulsating. Seismographic and acoustic equipment installed at various distances from explosion records not a single peak pulse of shock wave, but a cycle of harmonic sinusoidal oscillations, where seismic receivers first register a series of low-amplitude oscillations with following oscillations of higher amplitude, rather than reverse. In such case loading of rocks when blasting is a dynamic pulsating oscillating process with relatively few active cycles of loading. A mechanism of blasting rocks can be considered in terms of low-cycle fatigue of rock materials, having relatively low tensile strength. Based on these studies, A.A.Vovk [12] suggested a hypothesis about two components of stress field near a charge: high frequency component corresponding to the front of shock wave, and a long-period one determined by a quasi-static explosive detonation products load.

The above brief analysis of basic concepts about mechanism of destroying rocks demonstrates that they greatly differ depending on the initial factor of blasting rocks assumed by the authors.

Nowadays, dynamic methods of excavating with use of explosives in contour blast holes or wells are mostly utilized in underground mining operations.

Trim blasting utilizing explosives has extensively been used being a method for cracking rock mass in a specific direction.

Trim blasting is used for detaching blocks from rock mass, excavating, making underground chambers and roadway excavations, and performing extraction underground works.

Trim blasting is a special method for performing blasting operations involving creating local stresses concentrated along designated rock mass crack plane. It produces smooth perimeter-wise surfaces with no cracks.

Advantages of drilling-and-blasting operations with trim blasting involve increased stability and strength of peripheral rock mass due to decrease in cracking when blasting explosive charges.

Shielding trim blasting with narrow crack ensures reflection of explosion waves from relieving charges, prevents cracks from propagation in peripheral rock mass and provides for better quality of blasting.

Analysis of long experience in using methods of trim blasting shows that it always improves the stable state of exposed even unstable rock mass surfaces.

There is enormous experience accumulated worldwide in carrying out underground excavations of various purpose using trim blasting methods.

In post-trim blasting contour charges after explosion break down rock to excavation at a face created through blasting of main blast hole package charges. Post-trim blasting can have two solutions: blasting of charges in blast holes drilled in excavation perimeter plane, and charges in short blast holes drilled after removing rock perpendicular to contour. It is considered that the second alternative involves minimum damages, short charges cause to rock mass with their face ends, while blasting, since elongated charge blast-induced axial stresses are rather low, propagating radially. However, a method of perpendicular blast holes is relatively rare in use, and mostly in large-section excavations.

Contour charges for trim blasting usually have less diameter or charged with explosives having less detonation velocity, as well as blasting cartridges of diameter less than that of a blast hole are used.

With lower concentrations of explosive in blast holes and rather close distances between them, a crack induced by blasting goes only through blast holes with no propagation towards other directions, particularly to peripheral part, where rock resistance to rupture is substantially higher than near the exposed surface.

In presplitting method, as opposed to post-trim blasting method, contour charges are first exploded. Main crack or split is formed between contour blast holes as a result of blasting thereof.

This split is pre-created mostly for making shield protecting peripheral rock mass from being destroyed with shock or seismic waves formed when rocks are broken down at a face.

When conducting underground excavations, presplitting method is relatively rarely used.

Efficiency of shielding split formation depends on properly selected optimum distance between contour charges in a line and mass of a charge, bearing in mind specific physical and mechanical properties of rocks and geomechanical conditions near trimmed excavation. It should be noted that in pre-trim blasting (or rock mass presplitting), impact of the above factors is higher than in post-trim blasting.

When using presplitting method, various structures of charges are utilized ensuring direct effect of explosion waves.

Trim blasting with presplitting ensures stability of rocks in peripheral part of rock mass. When used in excavating, this method provides for longer service life of tunnels designed to supply water to power plant turbines, high-level dam abutments in rocky banks for hydro power plants; various large volume pillar mining in rocks, etc.

Analysis of domestic and foreign sources of literature and work of mining enterprises shown that parameters of trim blasting are determined by empirical formulas with further experimental explosions made for verification. Distance between charges in a contour line shall be the basic parameter of trim blasting. Known from literature formulas for identifying the distance have limited range of using in conditions of underground mining operations since they lack values characterizing gas dynamic effect of explosion products pressure and parameters of stress wave in the near field of rock mass.

5. CONCLUSIONS

Numerical modelling establishes length of impact, detonation products have on rock mass at a quasi-static stage. Values of explosion pulse for different structures of charge were identified.

It should be particularly emphasized that this paper considered only certain structures of explosive charges with various parameters of triggering mode. Therefore, further theoretical and practical examination of charge structure impact on distribution of dynamic processes needs to be done.

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