Development of a mathematical model for calculating the process of crushing hard rocks by explosions of cylindrical charges of explosives

***Norov Yunus Dzhumaevich*[1]**
[1]*Doctor of Technical Sciences,*
Professor of the Navoi State Mining Institute

***Mehmonov Maksud Rabbonokul ugli*[2]**
[2]*Assistant at the Navoi State Mining Institute*

Annotation. *The article presents a developed mathematical model for calculating the granulometric composition of the blasted rock mass based on the mechanism of action of an explosion in rocks, a mathematical description of the determination of natural units (blocks) in the rock mass, the relationship between the degree of rock fragmentation and the size of the units and the definition of sections of the controlled pressure zone.*

Key words: *Mining and geological conditions, granite, granosyenite, limestone, coefficitet Puasson, radius of charge, radius of crushing, degree of explosiveness, rock density, velocity of longitudinal waves.*

1. Introduction

The developed mathematical model for calculating the granulometric composition of the blasted rock mass is based on the mechanism of action of an explosion in rocks, [1-3] a mathematical description of the definition of natural units (blocks) in the massif, the relationship between the degree of crushing of rocks and the size of units and the definition of sections of the controlled pressure zone.

According to studies [4-7], the controlled crushing zone includes crushing (fine crushing) zones and cracking zones. Within these zones, the stress state of the environment and the nature of the destruction of the rock mass are different. In the crushing zone, immediately adjacent to the charging chamber, the stress in the compression wave propagating from the charging chamber significantly exceeds the compressive strength of the rocks. In this zone, it is crushed, destruction has the character of "over-grinding". The size of the zone depends on the stress in the compression wave within this zone, the strength and elastic properties of the rock.

According to [2, 3] many researchers, the crushing zone does not exceed 3-15 charge radii.

The second zone, the fracture zone, the so-called radial fracture zone. In monolithic and weakly fractured rocks, the particles of the medium involved in the motion by the compression wave continue radial displacements. As a result, each elementary cylindrical layer released in the medium is stretched, which leads to the appearance of systems of radial cracks. The outer boundary coincides with the cylindrical surface passing through the ends of the radial cracks.

2. Main part

In a real fractured massif, this zone has a more complex structure, since these massifs are broken by one or another system of fractures and represent a combination of articulated natural units of various sizes and configurations. A crack in a rock mass is more often in a relatively closed state and the parameters of the stress waves transmitted through them are sufficient to cause the destruction of separate parts located in more distant points of the rock mass. The size of the zones of radial cracks is determined by the parameters of cracks in the rock mass, the material of the aggregates with the stress in the wave and the duration of its impact on the rock mass. According to experimental studies [6, 8], the strike of radial cracks can be traced to 20-30r_0 (r_0 – explosive charge radius). However, no rigorous justification for this value is given. To create an algorithm for calculating the granulometric composition of the blasted rock mass, the sizes of the marked crushing zones are of greatest interest. In particular, it is possible to estimate the radius of the fine crushing zone using the dependence presented in [2, 3].

$$r_{\text{раз}} = r_0 c_p \frac{\sqrt{\rho}}{5\sigma_{\text{сж}}}$$

Where, $r_{\text{раз}}$- radius of the crushing zone, m; r_0- radius of explosive charge, m;

ρ- rock density, kg / m ^{3}; c_p- longitudinal wave velocity in the massif, m / s; $\sigma_{\text{сж}}$- compressive strength of rocks, MPa.

The radius of the zone of radial cracking in the same works is proposed to be estimated by the dependence of the type.

$$r_{\text{тр}} = r_{\text{раз}} \frac{\mu}{1+\mu} \frac{\sigma_{\text{сж}}}{\sigma_{\text{р}}}$$

here, μ – Poisson's ratio characterizing the deformation properties of rocks, $\mu = ({c_p}^2 - 2{c_s}^2)/[2({c_p}^2 -$

$c_s)]$;

c_s − shear wave speed, m / s; σ_p − tensile strength, MPa.

Analysis of experimental work on blasting rocks showed that there is no clear boundary between the zone around the charge, which is characterized by crushing - over grinding (3-5%), active crushing with developed fracturing (10-15%), and a zone of radial cracks (up to 30 %), and there is also no clear boundary beyond which the formation of new cracks completely stops and only the destruction of the rock mass takes place along natural cracks.

Rocks	Category	Explosive degree	Density, kg / m 3	Longitudinal wave speed, m / s	Shear wave speed, m / s	Compressive strength, kg / m 3	Tensile strength, kg / m 3	Coefficient Poisson	Charge radius, m	Radius crushing, m.	Radial fracture radius, m.
Limestone	II	Medium explosive	2400	3800	1900	600	50	0,25	0,05	3,10	7,45
			2450	3900	2300	700	60	0,15	0,1	5,52	8,50
			2500	4000	2800	800	70	0,01	0,125	6,25	0,71
Granosyenite	III	Hard to explode	2600	4600	2600	900	80	0,18	0,05	2,61	4,48
			2700	4700	2800	1000	90	0,15	0,1	4,88	6,88
			2800	4800	3200	1100	100	0,06	0,125	5,77	3,34
Granite	IV	Very difficult to explode	3000	5000	3100	1200	120	0,12	0,05	2,28	2,37
			3100	5100	3200	1300	130	0,11	0,1	4,37	4,20
			3200	5200	3450	1400	140	0,06	0,125	5,25	2,97

Table 1. Dependence of the size of the zone of radial cracking depending on the radius of crushing, radius of the explosive charge, rock density, Poisson's ratio, velocity of longitudinal waves in the rock mass by explosions of cylindrical explosive charges

Research has established that the radius of the zones of crushing by the explosion of cylindrical explosive charges in medium-explosive (limestone), hard-to-explode (granosyenite) and very hard-to-explode (granite) steams, is directly proportional to the radius of the explosive charge and the velocity of longitudinal waves in the rock mass and the square root of the density of rocks , is inversely proportional to the compressive strength of rocks.

3. Conclusion

Studies have also established that the radius of the zone of radial cracking, created by the explosions of cylindrical explosive charges of medium explosive (limestone), difficult to explode (granosyenite) and very difficult to explode (granite) steams, is directly proportional to the radius of the crushing zones and the ultimate compressive strength of rocks, inversely proportional to the strength limit rocks in tension.

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