Definition of the destruction zone boundaries and particle size distribution of blasted rock mass in the explosion of a single explosive charge in an inorganic medium

Sergiy Tishchenko

Sc. D, Professor,
Engineering Mathematics Department
Kryvyi Rih National University

Gennady Eremenko

PhD., Associate Professor,
Open-cast Mining Department
Kryvyi Rih National University

Oleksiy Kukharenko

Senior lecturer, Engineering Mathematics Department
Kryvyi Rih National University

Andrey Pikilnyak

PhD, Associate Professor of Mechanical Engineering Technology Department
Kryvyi Rih National University

Irina Gaponenko

PhD-student
Kryvyi Rih National University

Abstract
A method for determining the destruction zone boundaries and particle size distribution of blasted rock mass during the borehole explosive charge explosion in the unbounded medium on the basis of hydrodynamic model of explosion action is proposed. The problem of the cylindrical explosive cavity expansion in the ideal incompressible fluid conditions is considered.
Keywords: PARTICLE SIZE DISTRIBUTION HYDRODYNAMIC MODEL, DESTRUCTION ZONE BOUNDARIES, ROCK MASS

An actual way to achieve the quality improvement of rocks explosion preparation under the circumstances of minerals development in the iron ore open pits is the development of explosive destruction technological methods, based on the maximum concentration of blast energy and its rational redistribution in destroying mountain massif. There is a need to develop the new technologies of blasting operations, allowing the high quality of blasting rock crushing [1, 5, 7-11]. Let's consider the problem of the cylindrical explosive cavity expansion in the ideal incompressible fluid conditions [1, 2].

In conditions of cylindrical symmetry the velocity field has the form

$\upsilon = f(t)/r$,

where r – is the distance from the charge axis, $f(t)$ – is the time function. For a gas bubble with the radial expansion

$$\mathring{A}_{\hat{e}} = \rho \int_{\grave{a}}^{\infty} \upsilon^2 \pi r dr, \quad (1)$$

where a – is the radius of the chamber expanding by explosion, ρ – is the medium density.

However, according to (1), this energy is equal to infinity. Theoretical solutions for the case of spherical symmetry give good results as compared with the experimental ones. The inability to disseminate the results of spherical symmetry to the case of cylindrical is forced the researchers to change the approach to this issue. For the problem of a cylindrical gas cavity [3] the results of research [4] are used. In the ideal case the following equation was obtained

$$a \cdot a'' + \frac{3}{4} a'^2 \cong (P(a) - P(\infty))(2\rho)^{-1} \quad (2)$$

where $P(a)$ – is the gas pressure in the cavity, $P(\infty)$ – is the pressure at infinity.

In [1] under the consideration of this problem it was taken into account that in real conditions there is a free surface and the ratio of the maximum radius of the borehole charge gas chamber to its height h is much less than unity. From the assumption that during the movement the gas bubble has a shape of a circular cylinder, and the free surface is horizontal the differential equation

$$\frac{1}{2} a^2 \cdot a'^2 \cdot \ln(2h/a) = I\rho^{-1}, \quad (3)$$

describing the expansion of the gas bubble of the cylindrical explosive charge was obtained, where

$$I = \int_{a_0}^{a} (P(a) - P(\infty)\ ada.$$

Equation (2) was obtained using the conformal mapping of the flow domain in the complex cavity of z. From the condition (a/h)<<1 on a circle $z=-hi+ae^{i\theta}$ of the complex domain $\overline{\upsilon_{\grave{a}}} = -f(t)e^{-i\theta}/a\ln(2h/a)$ or $\overline{\upsilon_{\grave{a}}} = a^{l} e^{-i\theta}$, where $f(t) = -a \cdot a' \cdot \ln(2h/a)$

By differentiating the (2) over the va-riable a, we obtain an equation of the form .

$$(a \cdot a'' + \grave{a}^2)\ln(2h \cdot a^{-1}) + a'^2/2) = (P(a) - P(\infty)\ \rho^{-1}$$

Time expansion of the cavity according to the study carried out in [1] can be defined as

$$T = (A/BC)^{1/2}\int_{a_0}^{a_к}\left((a_к/a)^{2A}-1\right)^{-1/2}da,$$

where the coefficients A, D, C are determined according to formulas

$$A = 1+\alpha(1-\varepsilon)/(1-\varepsilon^{1/2})+\alpha(\varepsilon-\varepsilon^{\alpha/2})/(2-\varepsilon^{\alpha/2})$$

$$B = \alpha/\rho(\varepsilon^{-\alpha/2}-1)$$

$$C = K(\varepsilon^{\alpha/2}-1)/2m - P\cdot\varepsilon^{\alpha/2}$$

where ε – is the volumetric deformation; $\alpha = 2m(1+m)$; $m \approx \sqrt{3}(0,1-0,4)$.

Let's consider the problem of definition of boundaries of zone of destruction and particle size distribution of blasted rock mass in the explosion of a single explosive charge in an inorganic medium based on the hydrodynamic model of explosion action. To solve this problem in [5] the kinetic energy of the fluid in the volume of a cube with edge of $2l$ was equated to elastic deformation energy. The process was considered in a rectangular Cartesian coordinate system, i.e.

$$E_к = E_0$$

or

$$\frac{u}{3}\rho l^5 D = 8l^3\sigma_3^2(2E)^{-1}.$$

wherefrom

$$l = \sqrt{3}\cdot\upsilon_s/\sqrt{D},\ \upsilon_s = \sigma_s/\sqrt{E\rho},$$

where υ_s – is the critical speed; σ_s – is the compressive and tensile strength.

Equation (3) shows the case without the elastic energy density, which is for an incompressible medium has the form

$$\omega = \grave{O}^2/2\mu,$$

where $\mu = E/2(1+\nu)$ - is the shear modulus; T – is shear stress intensity

$$T = \frac{1}{6}\sqrt{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2},$$

whete σ_i – is the principal stress, $i = \overline{1.3}$.

By denoting the value of T by Ts, which corresponds to the destruction, then the expression, according to [1] for the critical speed and the size of the fragment will take the form

$$\upsilon_3 = T_3/\sqrt{\mu\rho},\ l = T_s\sqrt{6}/H\sqrt{\mu\beta},$$

where H – is shear strain rate.

In the case of a shear we have:

$$\upsilon_s = \tau_s/\sqrt{\mu\beta},\ l = \tau_s\sqrt{3}/\sqrt{\mu\rho D},$$

where D – is the crushability criterion, τ_s – is the yield strength of the shear.

To determine the size of the destruction zone of a spherical charge, let's take the value for the velocity potential and the crushability criterion in the following form

$$\varphi = -m/r,\ D = 6m^2;\ r = \sqrt{x^2+y^2+z^2},$$

where x, y, z – are the current Cartesian coordinates.

Constant m is calculated as follows. Kinetic energy is equal to

$$E_к = -\rho/2\oint\varphi(\partial\varphi/\partial h)dS,$$

where S – is the surface area, limiting the considered volume, $\bar{h}$ - normal vector is equal to α – is the fraction of total explosive energy

$$E_к = \alpha E_o.$$

From the last equation $m = (\alpha E_0 r_0/2\pi\rho)^{1/2}$, where r_o – is the radius of charge.

From the last formula we obtain

$$l = \upsilon_s r^3(\pi\rho/\alpha E_0 r_0)^{1/2}. \quad (4)$$

The size of the fragments, as seen from (4) increases rapidly with the distance from the center of the explosion. Let's define the size of destruction zone Rs, where the size of a piece is equal to the distance from the center of the explosion.

If $R_s >> r_0$, then, according to (1)

$$R_s = (\alpha E_0 r_0/\pi\rho\upsilon_s^2)^{1/4}$$

or considering that density of explosive energy is equal to $\omega_0 = 3W/4\pi r_0^3$, we will obtain

$$R_s = r_0(4\alpha\omega_0\mu/\tau_s)^{1/4}.$$

By denoting $V(l)$ as the amount of all pieces smaller than l, and by V_o – as the volume of destruction zone, then

$$V_0 = 4/3\pi r_0^3,\ \text{then}$$

$$V(l)/V_0 = l(\pi\rho\upsilon_s^2/\alpha E_0 r_0)^{1/4}.$$

Medium piece size:

$$l_{cp} = \frac{1}{2}\left((\alpha E_0 r_0)^{-1} \cdot (\pi \rho \upsilon_s^2)^{-2}\right)^{1/4}.$$

It should be noted that the hydrodynamic theory of the explosion has been successfully used for practical engineering calculations and scientific problem solving. By denoting the border of destruction by *r*, and the radius of cylindrical charge by r_o, the average size of a piece of particle size distribution of blasted rock mass can be determined by the relation

$$\langle x \rangle = B \int_{r_0}^{r} R dr,$$

where $B = 2\pi^2 S_2 (r_2 - r_0^2)^{-1}$.

For the destruction zone $r_0 \le r$,

$$\langle x \rangle = 8 f E \varepsilon_*^2 / \rho A^2 (\alpha + 1) \sigma_*) r^{2\alpha} / Q^\alpha$$

By substitution $V = \pi r^2$, we finally obtain

$$\langle x \rangle = K (E \varepsilon_*^2 / \sigma_*)(V / Q)^\alpha, \quad (5)$$

where *K* – is the numerical coefficient, which depends on the properties of the destroyed medium.

Assuming $\sigma_* = E\varepsilon_*$ - brittle fracture, (5) takes the form

$$\langle x \rangle = K(\sigma_* / E)(V / Q)^\alpha.$$

which, is the theoretically best case for the explosive destruction process, if $\Delta Q = 0$, then according to [6]

$$\langle x \rangle_{onm} = \sigma_*^2 / 2Ef. \quad (6)$$

Equation (6) should be considered as a theoretical limit of efficiency of explosion energy use, which should be strived in real conditions during blasting.

Conclusion

The blasting technology, which allows to obtain high quality of blasting rock crushing and the issue of definition of the destruction zone boundaries and particle size distribution of blasted rock mass during the borehole explosive charge explosion in the unbounded medium based on the hydrodynamic model of the explosion action are considered. This model is used for engineering calculations and scientific and engineering problems solving under the effectiveness evaluation of the borehole explosive charges of different designs.

References

1. Kuznetsov V. (1977). Matematicheskiye modeli vzryvnogo dela [Mathematical models of the blasting work], Novosibirsk, Nauka.
2. Griffith A.A. (1920). The phenomenon of rupture and flow in solids. *Phil. Trans. Poy. Soc.,* No221, p.p. 1201-1206.
3. Moth N.F. (1948). Fracture of metals. *Theor. Conq. Enq*, No1657(16). p.p. 321-348.
4. Voropinov V. (1972). Obezbednje stabilnosti stenskin masa pri povzsinskim miniranjima primenom savremenih metoda miniranje, *Izgradnja*, No24, p.p.21-35.
5. Vlasov O., Smirnov S. (1966). *O modelirovanii deystviya vzryva. Vzryvnoye delo* [On the modeling action of the explosion. Blasting work], No 59 (16), Nedra, p.p.109-117.
6. Efremov E., Petrenko A., Pastukhov A. (1990). *Prognozirovaniye drobleniya gornykh massivov vzryvom* [Prediction of mountain ranges crushing by explosion], Kyiv, Naukova Dumka.
7. Pikilnyak A. (2015). The gas bubble size parameters monitoring and control method, *Metallurgical and Mining Industry,* No7, p.p. 21-23.
8. Morkun V., Morkun N., Pikilnyak A. (2015). Adaptive control system of ore beneficiation process based on Kaczmarz projection algorithm, *Metallurgical and Mining Industry*, No 2, p.p.35-38.
9. Pikilnyak A. (2015). Adaptive control system of the iron ore flotation using a control action based on high-energy ultrasound, *Metallurgical and Mining Industry,* No2, p.p.27-30.
10. Morkun V., Morkun N., Pikilnyak A. (2014). The adaptive control for intensity of ultrasonic influence on iron ore pulp, *Metallurgical and Mining Industry,* No 6, p.p. 8-11.
11. Morkun V., Morkun N., Pikilnyak A. (2014). Simulation of the Lamb waves propagation on the plate which contacts with gas containing iron ore pulp in Waveform Revealer toolbox, *Metallurgical and Mining Industry,* No 5, p.p. 16-19.