PRINCIPLES UNDERLYING THE UNIFORM BREAKDOWN OF ROCKS BY AN EXPLOSION

V. M. Kuznetsov and E. N. Sher

UDC 622.235.001.1

The problem of obtaining fragments of specified dimensions by means of an explosion is extremely important in the present-day mining industry. It is well known [1] that under ordinary conditions explosions yield fragments of widely varying shapes and sizes. It is economically undesirable to produce either very large peices which are inconvenient for processing or unduly fine ores and rocks. The various explosive devices [2-4] used at the present time in mines and quarries fail to provide an adequate solution to this problem. This paper sets out a fundamental form of explosion, theoretically producing absolute uniformity of fragment size.

In developing the scheme for an optimum explosion we make the following simplifying assumptions:

a) the medium is ideal and incompressible;
b) the action of the explosion is simply characterized by the momentum pressure

$$P = \int_0^\infty p(t)\,dt,$$

where p(t) is the pressure.

The first assumption (as to the ideal nature of the medium) is based on the fact that in the short- and medium-range zones around an explosion the tangential stresses in the medium are much smaller than the average hydrostatic presssure, and to a first approximation may be neglected. The slight compressibility of rocks usually has little effect on the kinematics of the motion of the main rock bulk, especially in the presence of free surfaces; it is accordingly reasonable to assume their incompressibility.

The second assumption is based on the fact that, on the one hand, we may neglect displacements of the boundaries of the medium during the time of application of the explosive load, and, on the other hand, that during this time the shock waves are able to travel through the volume of rock being broken down several times.

These assumptions greatly simplify the mathematical description of explosions in solids, and at the same time, in certain cases [5, 6], enable us to preserve the essential features of the real phenomenon in the model representation. In the model of the medium considered here, the instantaneous velocity field is given by the equation

$$\mathrm{v} = \mathrm{grad}\left(-\frac{P}{\rho}\right),$$

where ρ is the density of the medium and we have introduced $\varphi = -(P/\rho)$, the velocity potential field.

We shall here consider the plane problem. This case is approximately realized in practice for the blasting of one or several rows of boreholes in a plane perpendicular to their axis. In the plane case [7] we may introduce the following complex potential w(z):

Novosibirsk. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 3, pp. 48-51, May-June, 1975. Original article submitted October 28, 1974.

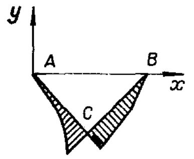

Fig. 1

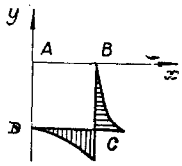

Fig. 2

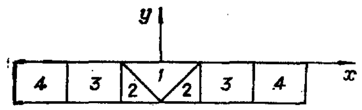

Fig. 3

$$w\,(z)=\varphi(x,\,y)+i\psi(x,\,y),\;z=x+iy. \tag{1}$$

Let a region G bounded by a convex curve be specified in the z plane. We have to place a layer of explosive on the surface Γ in such a way that after the blast the region G may be broken down in a uniform manner. This requirement amounts to the creation of a potential φ on the surface Γ, such that the velocity field determined by the complex potential w(z) may lead to deformations which are, in a certain sense, uniform over the whole region G. First of all, we must establish what deformations are under consideration here. It is clear from physical considerations that shears play a major part in the breakdown of the material. As our third assumption we therefore take the following rupture criterion: The material is broken down when maximum shear strains of a certain critical value are reached at a certain point.

In this formulation it is reasonable to simply refer to rates (velocities) of deformation. In the plane case the deformation-velocity tensor takes the form [8]

$$T_\xi=\begin{vmatrix}\xi_{xx} & \eta_{xy}\\ \eta_{xy} & \xi_{yy}\end{vmatrix},$$

where

$$\xi_{xx}=\frac{\partial v_x}{\partial x};\quad \xi_{yy}=\frac{\partial v_y}{\partial y};\quad \eta_{xy}=\frac{1}{2}\left(\frac{\partial v_x}{\partial y}+\frac{\partial v_g}{\partial x}\right), \tag{2}$$

where v_x, v_y are the components of the velocity vector. The maximum shear velocity is

$$\eta_{\max}=\frac{1}{2}\sqrt{(\xi_{xx}-\xi_{yy})^2+4\eta_{xy}^2}. \tag{3}$$

The velocity field arising in an ideal incompressible medium under the influence of momentum pressure is irrotational,

$$\frac{\partial v_y}{\partial x}-\frac{\partial v_x}{\partial y}=0.$$

In addition to this we have the equation of continuity,

$$\frac{\partial v_x}{\partial x}+\frac{\partial v_y}{\partial y}=0.$$

The first derivative of the complex potential (1) determines the complex-conjugate velocity

$$\frac{dw}{dz}=v_x-iv_y,$$

and the second determines the components of the deformation velocity tensor,

$$\frac{d^2w}{dz^2}=\frac{\partial v_x}{\partial x}-i\,\frac{\partial v_x}{\partial y}=-\frac{\partial v_y}{\partial y}-i\,\frac{\partial v_y}{\partial x}=\frac{\partial^2\varphi}{\partial x^2}-i\,\frac{\partial^2\varphi}{\partial x\partial y}. \tag{4}$$

From Eqs. (2) and (4) we obtain

$$\xi_{xx}=-\xi_{yy}=\mathrm{Re}\,\frac{d^2w}{dz^2};$$

$$\eta_{xy}=\mathrm{Im}\,\frac{d^2w}{dz^2},$$

and from Eq. (3) we obtain

$$\eta_{\max} = \left|\frac{d^2w}{dz^2}\right|.$$

Substituting Eq. (4) in here we obtain

$$\eta_{\max} = \left[\left(\frac{\partial^2\varphi}{\partial x^2}\right)^2 + \left(\frac{\partial^2\varphi}{\partial x \partial y}\right)^2\right]^{1/2}.$$

Clearly, the breakdown of the material in the region G takes place in a uniform manner if the maximum shear velocities are equal to a single constant value, constituting a strength characteristic of the material, everywhere within the region.

The breakdown factor D considered in [9] takes the following form in the plane case:

$$D = 2\left[\left(\frac{\partial^2\varphi}{\partial x^2}\right)^2 + \left(\frac{\partial^2\varphi}{\partial x \partial y}\right)^2\right].$$

We may convince ourselves that

$$D = 2\eta^2_{\max}.$$

Thus the breakdown criterion which was introduced formally on the basis of energy considerations in [9] now has a clear physical meaning. The problem of the explosion associated with the detonation of a single borehole charge was considered on this basis in [10], and the disposition of the charges in a single-row explosion was calculated.

Returning to the problem of uniform breakdown, we arrive at the following conclusion: We must ensure a momentum pressure on the surface of the region G such that the following equation may be satisfied everywhere inside the region:

$$\left|\frac{d^2w}{dz^2}\right| = \text{const.}$$

In a particular case we may put

$$\frac{d^2w}{dz^2} = \text{const.}$$

Then

$$w = Az^2 + Bz + C, \tag{5}$$

where A, B, and C are complex constants.

The practical realization of the velocity field described by the potential (5) is illustrated by the following example. Let it be required to break down the rock within the volume of a prism having an isosceles right triangle as its base (Fig. 1).

The real potential is taken in the form

$$\varphi = axy, \ (a = \text{const}).$$

The origin of coordinates and the position of the axes are indicated in Fig. 1. This potential is a particular case of Eq. (5) and satisfies the condition of being equal to zero on the free surface AB. The potential distribution on the lateral surfaces of the prism, on faces AC and BC, takes the form

$$\varphi = -ax^2;$$
$$\varphi = -ax(|AB| - x).$$

One of the possible arrangements for multirow blasting is the following. The triangular prism in question constitutes the central channel [4]. Then the two neighboring triangular prisms are blasted on an analogous principle, after which the rectangular prisms $\varphi = 0$ on AB, AD, $\varphi = a\,|AB|\,x$ on DC; $\rho = a|AB|y$ on BC are successively blasted (Fig. 2). The potential distribution on the surface of the rectangular prism is indicated in Fig. 3.

The variable potential distribution indicated in Figs. 1 and 3 may be created, for example, by placing different quantities of explosive in holes bored along the corresponding faces BB, as in the case of a directional explosion [6]. It is by no means impossible that a potential distribution of this kind may be obtained by regulating the delay time when blasting individual boreholes and rows of boreholes.

LITERATURE CITED

1. É. A. Koshelev et al., "Statistics of the fragments formed in the breakdown of solids by an explosion," Zh. Prikl. Mekh. Tekh. Fiz., No. 2 (1971).
2. V. Langefors and B. Kihlström, Modern Technique of Rock Blasting, Wiley (1967).
3. L. N. Marchenko, Increase in the Efficiency of Mining Explosions [in Russian], Nauka, Moscow (1965).
4. M. F. Drukovanyi, Methods of Controlling Explosions [in Russian], Nedra, Moscow (1973).
5. M. A. Lavrent'ev, V. M. Kuznetsov, and E. N. Sher, "On the directional projection of soil by means of explosives," Zh. Prikl. Mekh. Tekh. Fiz., No. 4 (1960).
6. V. M. Kuznetsov, "Hydrodynamic models of an explosion in soil," in: Some Problems of Mathematics and Mechanics [in Russian], Nauka, Leningrad (1970).
7. M. A. Lavrent'ev and B. V. Shabat, Methods Based on the Theory of Functions of a Complex Variable [in Russian], Fizmatgiz, Moscow (1958).
8. L. M. Kachanov, Fundamentals of Plasticity Theory [in Russian], Fizmatgiz, Moscow (1969).
9. O. E. Vlasov and S. A. Smirnov, Principles of the Calculation of Rock Breakdown by Explosions [in Russian], Izd. Akad. Nauk SSSR, Moscow (1962).
10. V. M. Kuznetsov, "Hydrodynamic calculation of blasting with long explosive charges," Fiz.-Tekh. Probl. Razrab. Polezn. Izkop., No. 4 (1974).