EFFECT OF THE SLIT POSITION AND WIDTH ON THE AMOUNT OF ROCK CRUSHED BY AN EXPLOSION

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A study of the crushing and fracture zones [1] formed by powerful camouflet explosions in ledge rocks shows the advisability of using powerful explosions to crush rocks in mines. This may greatly modify underground mining procedures and heighten the efficiency of mining operations.

To protect adits and other structures from destruction and to increase the volume of crushed ore in a rock mass, horizontal and vertical slits are made. The width of the slit h and its position R_s with respect to the center of the explosion greatly affect the results obtained by the explosion. The tendency to obtain for a charge of given power the maximum screening effect of the slit and the maximum amount of crushed ore (provided that the fragments do not exceed a certain given size) makes it necessary to use computers for the calculations and determination of the optimum values of h and R_s. These effects may be assessed from the viewpoint of a one-dimensional model only when the slit is a spherical layer in the case of a single charge or a cylindrical layer when an elongated charge is used for the explosion. Such a formulation of the problem undoubtedly differs from the common practice of using flat slits for these purposes. However, in our opinion the results of such calculations are of interest and can be used for quantitative assessments.

The mathematical problem was formulated as follows. The energy q, ktons, is initially distributed uniformly in the cavity of a sphere with radius R_c^0, filled with gas, with an equation of state

$$P=(\gamma-1)\rho E.$$

The equation of state of the rock was selected as

$$P=(\gamma-1)\rho E+\frac{\rho_0 C_0^2}{n}\left[\frac{n-\gamma}{n-1}\delta^n+\frac{n(\gamma-1)}{n-1}\delta-\gamma\right].$$

The initial pressure in the rock mass was taken as zero, and the initial density as constant. The rock was assumed to be brittle, which means that it fractured when compressed or eleongated, when the maximum tangential stress τ_{max} reached the critical value

$$\tau_{cr}=0.5Y,$$

where

$$Y=\begin{cases}Y_0+P & \text{when} \quad P<10\ \text{kbar}\ -Y_0,\\ 10\ \text{kbar} & \text{when} \quad P\geqslant 10\ \text{kbar}\ -Y_0.\end{cases}$$

Furthermore, to get the fullest picture of the manner in which the rock fractured when elongated, we also assigned the critical stress σ_{cr}. When one of the stresses σ_i reached this value, fissures orthogonal to the direction of this stress appeared in the rock. The volume of the newly formed or existing fissures Θ may vary as time passes. The change in Θ obeys a special differential equation.

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TABLE 1. Dependence of the Size of the Crushing Zone A, Fissure Zone B, and Radius R of Scab on the Tensile Strength σ_{cr} in Absence of a Slit

Calc. No.	σ_{fi}, kbar	R_1, m	R_{fi}, m	M_A, 10^3 tons	M_B, 10^6 tons	$R_1/q^{1/3}$	$R_{fi}/q^{1/3}$	Surface, m	R of scab, m
1	0,08	43,3	87,9	940	6,84	33,8	68,7	130	103
2	0,15	43,3	76,0	940	4,10	33,8	59,4	130	110
3	0,30	43,3	64,6	940	3,82	33,8	50,5	130	119

TABLE 2. Dependence of the Size of the Crushing Zone on the Elastic Limit Y_0 in Absence of a Slit (σ_{cr} = 0.15 kbar)

Calc. No.	Y_0, kbar	R_1, m	M_A, 10^3 ton	$R_1/q^{1/3}$
4	2,2	43,3	940	33,8
5	2,4	32,0	378	25,0

Fig. 1. Schematic representation of the different zones in a medium after an explosion when there is no slit. Cavity ($R \geq R_C$): A) crushing zone ($R_C \leq R \leq R_1$): B) radial fissure zone ($R_1 \leq R \leq R_{fi}$).

The following numerical values of the parameters were used in the calculations: a) in the cavity: ρ_0 = 1.4 g/cm^3, γ = 5/3, E_0 = 1500 kJ/g, R_C^0 = 1 m; b) in the rock: ρ_0 = 2.73 g/cm^3, C_0 = 2.55 km/sec, n = 5.3, γ = 1.51, Y_0 = 0.12 kbar, σ_{cr} = 0.15 kbar, Poisson's ratio γ = 0.2. In certain calculations the values of Y_0 and σ_{cr} were varied. We calculated the values of R_s and h for which the volume of crushed rock would be maximum. The calculations were performed according to the "SPRUT" program, intended for the calculation of unsteady motion of compressed media with real properties (elasticity, plasticity, brittleness, compressibility, crushability, etc.). The model of the medium and the difference method are described in [2, 3].

Let us discuss briefly the effects which occur during expansion of the cavity, propagation of the shock wave, and its interaction with the slit.

When t > 0, a shock wave, in the front of which the substance is compressed, is propagated from the surface of the cavity R_C. The tangential stresses increase and reach the critical value $\tau_{max} = \tau_{cr}$, which leads to brittle fracture of the rock (granulation or crushing). With increasing distance from the center of the explosion the amplitude of the shock wave decreases. By the time the wave reaches the radius R_1, it has weakened so markedly that no further crushing occurs in its front.

Behind the front of the shock wave the substance moves at a positive rate, as a result of which the stresses tangential to the spherical surfaces increase. If these stresses reach the critical value $\sigma_2 = \sigma_3 = \sigma_{cr}$, radial fissures appear in the region $R > R_1$. They begin at the surface with radius R_1 and are propagated in the rock toward increasing R. The fissure zone reaches the radius R_{fi}. Here the movement of the substance from the center becomes so weak that the stresses are always less than the tensile strength σ_{cr}.

Let us first examine the case when there is no slit in the medium. The size of the crushing and fissure zones (Fig. 1) depends on the elastic limit Y_0 and the tensile strength σ_{cr}. To determine the character of the change in the size of the crushing and fissure zones with σ_{cr}, three calculations (1, 2, 3) were made; a further two (4, 5) were made to determine how the size of the crushing zone depended on Y_0. The results are given in Tables 1 and 2.

From Tables 1 and 2 we can assess the values of the logarithmic derivatives, which enable us to determine the sensitivity of the model to changes in the values of certain parameters. These derivatives are as follows:

$$\frac{\partial \ln R_{fi}}{\partial \ln \sigma_{cr}} \approx 0.25, \quad \frac{\partial \ln R_1}{\partial \ln Y_0} \approx 0.62.$$

The values of the derivatives show the insensitivity of the model to errors in the determination of σ_{cr} and Y_0, because the relative errors in R_{fi} and R_1 are less than those in σ_{cr} and Y_0; they also enable us to determine the errors of the calculated values of R_{fi} and R_1 if the errors of the experimentally determined values of σ_{cr} and Y_0 are known.

When the shock wave reaches the free surface (inner surface of the slit), the fracture breaks up, as a result of which a rarefaction wave is propagated back again into the medium. This relief wave interacts with the relief wave spreading out from the boundary of the cavity, with the result that in the interference zone one observes scabbing, in the form of both crushed zones and individual scabs (spherically symmetrical). Since this is accompanied by an