ESTIMAING AMOUNT OF EXPLOSIVE FOR FRACTURE PLANE CONTROL BLASTING WITH NOTCHED BOREHOLES①

Ding, Dexin
Hengyang Institute of Technology, Hunan 421001, China
Zhu, Chengzhong
Central South University of Technology, Hunan 410083, China

ABSTRACT

With the development of fracture mechanics, the fracture plane control blasting with notched boreholes has come into being. This technique is used to create a satisfactory presplit along the contour of an excavation in rock. However, the amount of explosive loaded in each hole usually is determined by trial and error. Because of this, two approaches estimating the amount of explosive for the blasting technique are suggested.

Key words: explosive fracture plane control blasting notched hole

1 INTRODUCTION

Fracture plane control blasting plays an important part in producing a presplit along the contour of an excavation in rock. There are four such blasting techniques: line drilling, presplitting, cushion blasting and buffer blasting. The primary objective of all these techniques is to reduce the density of explosive energy (powder factor) and thereby achieve a less severe fragmentation of surrounding rock.

With the development of fracture mechanics, the fracture plane control blasting with notched holes has come into use. In essence, this is a kind of blasting technique which controls the generation and growth of the fracture plane. Based on the principles of fracture mechanics, such control can be accomplished by changing the shape of the blasthole. Therefore, this technique is just an application of fracture mechanics.

Over recent years, many investigators have been working on the technique and the related tools for producing the notches. The U.S.A.[1], Sweden[2] and the P.R. China[3] have already turned out such tools and many successful applications have been reported in these countries. This technique has been developed to such an extent that it can be applied to creating a satisfactory presplit along the excavation limit in rock. However, there is not an appropriate method for estimating the amount of explosive for the notched hole blasting and the estimation is mostly based on trial and error.

As a result, the authors try to establish approaches which can be applied for calculating the amount of explosive for fracture plane control blasting with notched boreholes.

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2 ELASTIC MECHANICS APPROACH

In this approach, the symmetrically notched hole is considered to be equivalent to an elliptical hole on which quasistatic pressure acts. The calculation can be made on the solution to the problem of a pressurised elliptical hole under plane strain in elastic theory. This problem is shown in Figure 1.

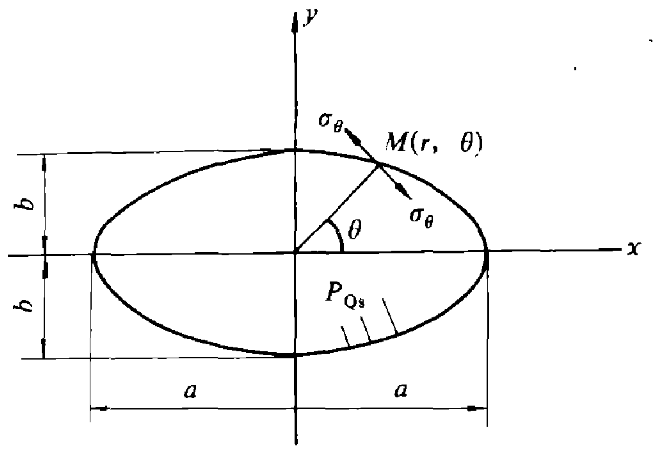

Fig. 1 The Problem of a Pressurised Elliptical Hole Under Plane Strain

In the solution, the tangential stress along the wall of the hole is given below[4]:

$$\sigma_\theta = P_{QS} \cdot \frac{4ab - a^2(1-\cos 2\theta) - b^2(1+\cos 2\theta)}{a^2(1-\cos 2\theta) + b^2(1+\cos 2\theta)} \quad (1)$$

where σ_θ—tangential stress;

P_{QS}—quasistatic pressure acting on the wall of the hole;

a—the semi-major axis;

b—the semi-minor axis;

r, θ—polar coordinates of any point along the wall.

The following expressions can be easily derived from expression(1):

$$\sigma_{max} = (\sigma_\theta)_{\theta=0,\pi} = P_{QS} \cdot (2 \cdot \frac{a}{b} - 1) \quad (2)$$

$$\sigma_{min} = (\sigma_\theta)_{\theta=\frac{1}{2}\pi} = P_{QS} \cdot (2 \cdot \frac{b}{a} - 1) \quad (3)$$

The above expressions indicate that the tensile stress reaches its maximum value at the two tips of the elliptical hole. Since rocks are very weak under tensile stress, the fracturing is bound to happen at the tips. The criterion for fracturing can be expressed as follows:

$$\sigma_{max} > \sigma_t \quad (4)$$

where σ_t—the tensile strength of the rock

Based on the above criterion, the amount of explosive in one hole reguired to generate a fracture plane can be estimated.

Meanwhile, the wall of the blast hole should be kept undamaged. Therefore, the following requirement has to be satisfied:

$$P_{QS} < \sigma_c \quad (5)$$

where σ_c—the compressive strength of the rock

By making use of the criteria given above, the amount of explosive which should be used in a single hole can be estimated.

Firstly, the gas pressure generated by a detonating charge can be calculated from the following equation:

$$P = \frac{0.01\delta D^2}{2(K+1)g} \quad (6)$$

where P—the gas pressure generated by a detonating charge in MPa;

K—the equivalent entropy coefficient of the explosive, typically 2;

g—the gravitational acceleration in m/s^2 ($9.8\ m/s^2$);

δ—the density of explosive in g/cm^3;

D—the velocity of detonation in m / s

Then the quasistatic pressure can be calculated from the following:

$$P_{QS} = P_k \cdot \left(\frac{P}{P_k}\right)^{\gamma/k} \cdot \left(\frac{\triangle}{\delta}\right)^{\gamma} \quad (7)$$

where P_k— the critical pressure generated by the detonating explosive (generally 200 MPa);

γ—the gas expansion coefficient without any heat exchange(usually 1.4);

$$\triangle = \frac{4Q}{\pi d^2 H} \quad (8)$$

where $\triangle$ —the volume density of the explosive in a blast hole in g / cm^3;

Q—the mass of the explosive in g;

d—the diameter in cm;

H—the blast hole depth in cm

The quasistatic pressure should be sufficient to gnecrate a fracture plane but not to crush the wall of the blast hole. Therefore, the amount of explosives to be used in a blasthole can be estimated from the following expression:

$$\frac{\pi d^2 H\delta}{4}\left[\frac{b\sigma_t}{(2a-b)P_k}\cdot\left(\frac{P_k}{P}\right)^{\gamma/k}\right]^{1/v} < Q < \frac{\pi d^2 H\delta}{4}\left[\frac{\sigma_c}{P_k}\left(\frac{P_k}{P}\right)^{\gamma/k}\right]^{1/v} \quad (9)$$

3 FRACTURE MECHANICS APPROACH

In this approach the symmetrically notched hole is simplified to a pressuirzed hole under plane strain with two symmetrical cracks as represented in Fig. 2.

In the model shown in Fig.2, the radius is r_0, the length of the crack is a_c and the pressure acting on the wall is P_{QS}. This represents the fracture problem under mode I loading. The stress components around the tips of the cracks are given bellow[5]:

$$\begin{bmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{bmatrix} = \frac{K_I}{\sqrt{2\pi r}}\cdot\cos\frac{\theta}{2}\begin{bmatrix}1-\sin\frac{\theta}{2}\sin\frac{3\theta}{2}\\ 1+\sin\frac{\theta}{2}\sin\frac{3\theta}{2}\\ \sin\frac{\theta}{2}\sin\frac{3\theta}{2}\end{bmatrix} \quad (10)$$

where σ_x, σ_y, τ_{xy}—stress components;

r, θ—ploar coordinates;

K_I—stress intensity factor

For the crack under mode I loading in Fig.2, the stress intensity factor is as follows[6]:

$$K_I = FP_{QS}\sqrt{\pi(r_0 + a_c}) \quad (11)$$

where F—geometric factor of the crack which can be determined from Fig.3;

r_0—the radius of the blasthole;

a_c—the length of the crack.

Based on the principles of fracture mechanics, to create a fracture plane, the following requirement has to be satisfied:

$$K_I > K_{IC} \quad (12)$$

Similarly, the pressure on the hole should not be sufficient to crush the rock, i.e., the requirement expressed in (5) should be satisfied at the same time. The amount of explosive in a hole can be calculated from the following expression:

$$\frac{\pi d^2 H\delta}{4}\left[\frac{K_{IC}}{P_k F\sqrt{\pi(r_0 + a_c)}}\left(\frac{P_k}{P}\right)^{\gamma/k}\right]^{1/\gamma} < Q < \frac{\pi d^2 H\delta}{4}\left[\frac{\sigma_c}{P_k}\left(\frac{P_k}{P}\right)^{\gamma/k}\right]^{1/\gamma} \quad (13)$$

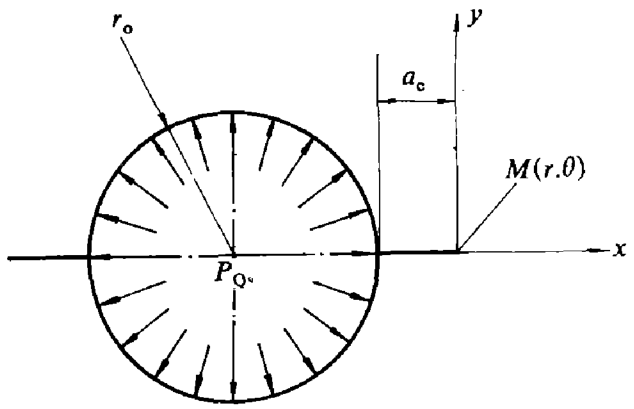

Fig. 2 The Pressurised Hole With Two Symmetrical Cracks

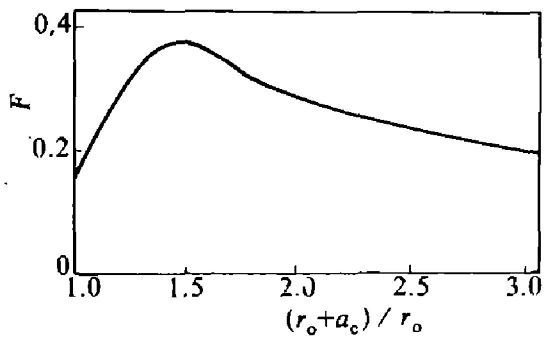

Fig. 3 The F Value Curve

4 EXPERIMENTS

A number of experiments were conducted at Shuanfeng Quarry on mortar and marble blocks whose mechanical properties and dimensions are listed in Table 1.

In the centre of each block, one blasthole was drilled. Two symmetrical notches were made with a specially designed tool. The length of the notches inside the wall of the blasthole was 5 mm. The blasthole was 40 mm in diameter and 200 mm in depth and was stemmed after being loaded. The explosive used was Powergel which was detonated with an electric cord. The experimental results are listed in Table 2 and Table 3.

Table 1 Mechanical Properties and Dimensions of Tested Blocks

Properties & dimensions	Marble Blocks	Mortar Blocks
σ_t / MPa	7.5	5.7
σ_c / MPa	71.6	63.2
K_{1c} / $kg \cdot cm^{-3/2}$	68	54
Dimensions / mm	Irregular	300 × 300 × 250

Table 2 Experimental Results on Marble Blocks

Number of Experiments	Estimated Amount of Explosive / g	The Amount of Explosive Used / g	Results of Experiment
4	EMA: 4.8 ~ 30.6	20	Each was blasted
4	FMA: 7.5 ~ 30.6	20	into two parts.

Table 3 Experimental Results on Mortar Blocks

Number of Experiments	Estimated Amount of Explosive / g	The Amount of Explosive Used / g	Results of Experiments
4	EMA: 3.9 ~ 28.1	17	Each was blasted
4	FMA: 6.3 ~ 28.1	17	into two parts.

5 CONCLUSION

The results listed in Table 2 indicate that the two approaches can be used to ectimate the amount of explosive for fracture plane control blasting with notched holes. However, since the experiments were only conducted on single, symmetrically notched holes, the two approaches will be corrected further through multi–hole blasting and field trials.

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