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# LABORATORY STUDY OF PARAMETERS OF CONTOUR BLASTING IN THE FORMATION OF SLOPES OF THE SIDES OF THE CAREER

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***Abstract:*** *Explored theoretically the interaction of explosive charges in the preliminary gap formation in quarries. A methodology has been developed for conducting experimental studies of blast well contour explosions on models, which allows one to investigate crack formation on volumetric models and wave interaction using high-speed video recording of the explosion process in transparent models, as well as determine the parameters of explosion stress waves in samples of real rocks. Theoretical and laboratory researches have established that only the creation of a screening gap for the entire height of the non-working ledge allows you to get a virtually undisturbed array with a high-quality surface of the slope.*

***Key words:*** *sides, open pit contour, slope formation, preliminary slit formation, blasting of close charges, experimental studies of the action of stress waves, crack formation research.*

**INTRODUCTION.** As a result of researches of various technological schemes for the formation of slopes in the limit contour of the sides of the quarry, it was found that the best results are achieved when using the method of pre-crevice formation. In this method, a solid gap along the contour of the ledge is created for the entire height of the ledge by simultaneously exploding a series of charges. The method of preliminary crevice formation during contour blasting is described in detail in [1-16, 18].

Let's consider the scheme of interaction of charges during preliminary crevice formation according to Fig. 1 [7].

When exploding two close charges C and $C_1$, located at a distance of a between the axes, the shock wave fronts will meet in the gap between the charges. Radial forces from the two charges intersect to form tensile forces that tend to break the rock along the $CC_1$ line. The resulting stresses at a certain mass of charge and the degree of convergence of charges will exceed the rock's resistance to rupture. Thus, along the line of the well location, a crack is formed, which is a kind of screen for reflecting the explosive waves of a mass explosion, thereby protecting the quarry side array from destruction.

**METHODS.** If we take into account the uniformity of the distribution of total stresses $\sigma$ both along the charge axis and along the charge symmetry axis, which are necessary to overcome the rock's resistance to rupture, then this condition can be written as:

$$\sigma_1/w=\sigma/r_i\ , \qquad (1)$$

or

$$\sigma_1 = w\sigma/r_i\ , \qquad (2)$$

where σ – pull generated by the explosion of a single charge at the point K, MPa; $\sigma_1$ – component of the stresses producing the array break, MPa; w – distance covered by the explosion when creating a pull $\sigma_1$ at the point K, m; $r_i$ – distance from the location of the charge to the intersection of radial forces with the axis of symmetry between charges, m.

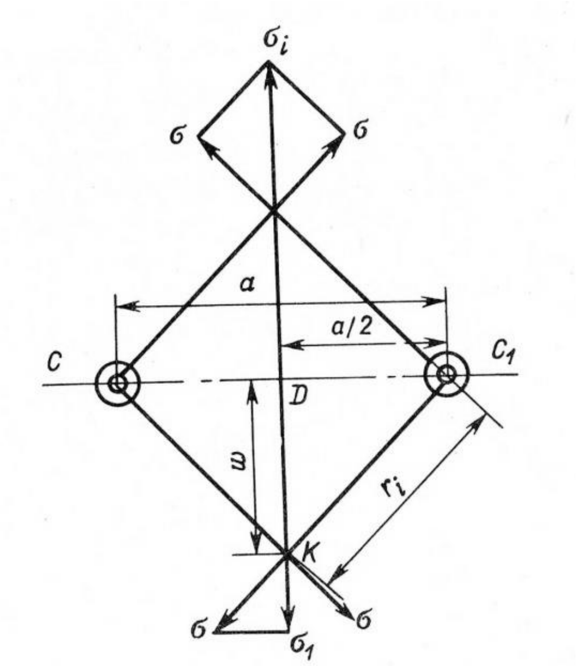

**Fig. 1.** Diagram of charge interaction during pre-crevice formation

The pull generated by the explosion of a single charge is determined by the formula:

$$\sigma=p_o r_o^2/r_i^2, \tag{3}$$

where $p_o$ - the determining pull in the shock wave front depending on the explosion pressure, MPa; $r_o$ - the charge radius, m.

Then, substituting expression (3) in formula (2), we get

$$\sigma_1=p_o r_o^2 w/r_i^2. \tag{4}$$

When a pull is created at the point K the charge C acts similarly. In this regard, the total stress that is caused by the tensile forces can be written as

$$\sigma_\mathrm{p} = \sum_{n=1}^{n=2} \sigma_i = \sigma_1 + \sigma_2 = 2p_o r_o^2 w/r_i^3. \tag{5}$$

The radius of action of an explosion in a rock depends on its strength properties (elastic modulus, Poisson's ratio, adhesion, internal friction coefficient, etc.).

Given that the explosion pressure acts radially from the center of the charge, you can get

$$p_o = E/2\,; \tag{6}$$

$$r_o = 0{,}6\sqrt[3]{\frac{u_i C_{exp}}{E(1-2\mu)}}. \tag{7}$$

where E - the elastic modulus, MPa; $u_i$ - the energy released during the explosion of 1 kg explosive, J/kg; $C_{exp}$ - the mass of the charge explosive, kg; μ - the Poisson's ratio.

Substituting expressions (6) and (7) in formula (4), we get

$$\sigma_1 = \frac{0{,}18wE}{r_i^3}\cdot\left[\frac{u_i C_{exp}}{E(1-2\mu)}\right]^{\frac{2}{3}} \tag{8}$$

In Fig. 1, it follows from the triangle $DC_1K$ that

$$r_i = \sqrt{(a/2)^2 + w^2}. \tag{9}$$

When $w = a/2$

$$r_i = \frac{a}{\sqrt{2}}, \tag{10}$$

where a - the distance between charges, m.

If the expression (10) is taken into account, the formula (8) takes the form:

$$\sigma_1 = \frac{0{,}255E}{a^2} \cdot \left[\frac{u_i C_{exp}}{E(1-2\mu)}\right]^{\frac{2}{3}} \quad (11)$$

To form a gap between the charges C and $C_1$ you must have a pull

$$\sum_{n=1}^{n=2} \sigma_i \geq \sigma_{\text{p}}. \quad (12)$$

The pull generated by a single charge of explosive must meet the condition

$$\sigma_1 \geq \sigma_{\text{p}}/2. \quad (13)$$

In this regard, for the action of a single charge, expression (11) is written as follows

$$\sigma_{\text{p}} \geq \frac{0{,}51E}{a^2} \left[\frac{u_i C_{exp}}{E(1-2\mu)}\right]^{\frac{2}{3}} . \quad (14)$$

With respect to $C_{\text{exp}}$, equation (1) is expressed as

$$\text{C}_{\text{ВВ}} \geq \frac{2{,}72a^3\sigma_{\text{p}}(1-2\mu)}{u_1} \sqrt{\frac{\sigma_{\text{p}}}{E}}. \quad (15)$$

The resulting formula (15) will determine the required minimum amount of explosives to balance the resistance of the rock. It is equal to $\sigma_{\text{p}}/2$ at the distance $r_i$ from the charge.

In [17], the ratio between the charge length $l$ and the radius of its destruction $r_i$ is established, which has the form

$$l = \frac{5}{3} r_i. \quad (16)$$

The number of elementary elongated charges in the well can be determined by the formula

$$n = 0{,}6 l_{\text{ch}}/r_i, \quad (17)$$

where $l_{ch}$ - the total charge length in the well, m.

In the production of pre-crevice formation, the amount of explosives required for charging into the well is determined by the formula:

$$Q = 0{,}6 l_{ch} C_{\text{exp}}/r_i , \quad (18)$$

From the given expressions (10) and (16), this formula can be written as:

$$Q = \frac{2.3 l_{ch} \text{a}^2 \sigma_{\text{p}}(1-2\mu)}{u_i} \sqrt{\sigma_{\text{p}}/E} . \quad (19)$$

If you use dispersed charges with air gaps, then the length of the cull is determined by the formula:

$$L_{\text{cull}} = \text{L} - (l_{\text{ch}} + h_{\text{ag}}), \quad (20)$$

where L - the depth of the well, m; $h_{\text{ag}}$ - the total length of air gaps, m.

The total length of air gaps must meet the condition

$$\text{L}_{\text{ag.}} = 0{,}17 \div 0{,}35\ l_{\text{ch}}. \quad (21)$$

Then formula (20) will take the form:

$$l_{\text{ch}} = 0{,}74 \div 0{,}85(L - l_{\text{cull}}). \quad (22)$$

Substituting the formula (22) in the expression (19), we get the final formula for determining the amount of explosives in the well:

$$Q = \frac{K\mathrm{a}^2\sigma_{\text{р}}(L-l_{ch})(1-2\mu)}{u_1}\sqrt{\frac{\sigma_{\text{р}}}{E}} \tag{23}$$

where K - the coefficient that takes into account the ultimate strength of rocks (for less strong rocks K=1,7, for stronger rocks K=1,85).

If we take into account the coefficient of fracturing of rocks, then in this case

$$Q = \frac{K\mathrm{a}^2\sigma_{\text{р}}(L-l_{ch})(1-2\mu)}{K_{\text{тр}}u_1}\sqrt{\frac{\sigma_{\text{р}}}{E}} \tag{24}$$

To reduce the maximum pressure on the walls of the charging cavity, it is necessary to leave air gaps between the explosive charge and the well wall.

As a result of theoretical research, a method for conducting laboratory studies on models has been developed that allows us to study the propagation of stress fields, the interaction of stress waves and the interference of elastic shock waves, as well as to establish patterns of interaction of contour charges during an explosion. Laboratory studies were conducted in the scientific laboratory of the Navoi State Mining Institute (Fig. 2).

Experimental studies of the action of stress waves were performed using a high-speed Olympus I-SPEED 2 video camera (Fig. 3) in transparent bodies and further oscillography in rocks using digital oscilloscope Rohde & Schwarz RTO1004 (Fig. 4).

The research also used a ZETLab Zet 048-C seismic station (Fig. 5). High-Speed video recording made it possible to simultaneously record the propagation of waves and cracks in the zone of plastic and elastic deformations without limiting the pressure amplitude in the wave. The wave propagation speed and pulse duration are also recorded.

**Fig. 2.** Experimental studies of the action of stress waves in laboratory conditions

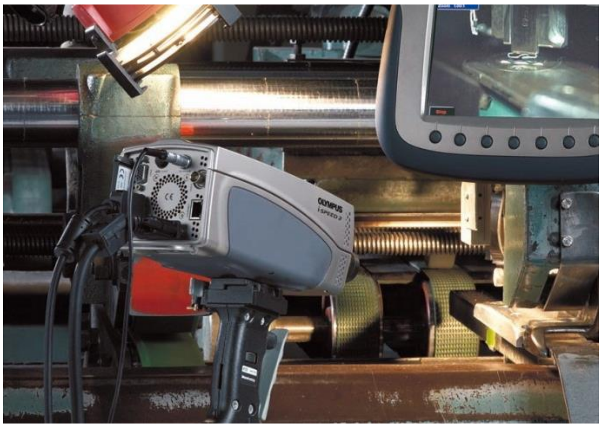

**Fig. 3.** Olympus i-SPEED 2 high-Speed video camera

**Fig. 4.** Digital oscilloscope Rohde & Schwarz RTO1004

**Fig. 5.** ZETLab Zet 048-C seismic Station

Instrumental measurements using sensors of the СВ-10Ц brand (Fig. 6) and an oscilloscope allowed us to determine the share of energy that goes to the destruction of rocks. The nature of crack formation, i.e. the presence of cleavages deep into the array or towards the free surface, was determined by linear measurements.

The methodology provided three directions for conducting experiments on models:

– study of crack formation on volumetric models;

– study of wave interaction by high-speed video recording of the explosion process in transparent models;

- determination of parameters of stress waves during explosion in samples of real rocks.

The study of fracture formation was carried out on three-dimensional models made of marble and Sandstone. The charge was placed in holes drilled in the rock. The distance between the charges was modeled taking into account the geometric scale.

The distance between the charges was changed until the optimal one for a given charge diameter and a given rock was determined. The quality of the gap formed, the degree of crushing of the tested samples, and the presence of pins were taken as the criteria for evaluating the optimal distance.

**Fig. 6. СВ-10Ц Sensor for instrumental measurement**

The wave interaction was studied based on video recording with the Olympus I-SPEED 2 high-speed camera, which allowed synchronizing the beginning of the studied process with the beginning of registration.

As a first approximation, it was assumed that the model and the mountain range behave as elastic bodies up to the moment of destruction.

For a scale factor of 100, the following model parameters were calculated:

the diameter of the charges – 1.8 mm.
model length – 24 cm,
charge length – 6 cm,
distance between charges – 2.2 cm,
model width – 15 cm,
the thickness – 0.8 cm.

Shooting was performed at a rate of 2000 frames per second. The process of rock destruction, depending on the acoustic stiffness of the medium, was largely determined by the parameters of incident and reflected stress waves. To measure the parameters of the pull waves of interacting charges in the models, sensors of the CB-10Ц type were used with recording on a memory digital oscilloscope Rohde & Schwarz RTO1004.

From the waveforms, the displacement acceleration was determined by the formula

$$a = \frac{d^2}{dt^2} = \frac{cl}{dsm}, \tag{25}$$

where c – the total capacity of the measuring system; $l$ – the amplitude of the signal recorded by the register; d – the sensor module; s – the cross – sectional area of the sensor; m – the sensitivity of the measuring circuit.

Measuring c and m did not cause difficulties. The value of the piezo module d was given in the sensor data sheet. The values of normal stresses near the free surface are calculated from the obtained values of displacements using the formula:

$$\sigma = \rho_c \int_0^{t_n} a dt, \tag{26}$$

where $\rho_c$ – the acoustic stiffness of the medium.

When decoding the waveforms, we used the passport data of the sensors.

**RESULTS.** During the simulation, it was necessary to determine the optimal distances between charges, which allow obtaining a high-quality gap with minimal destruction of the tested samples. The minimum possible charge diameter in the models was 2-2.5 mm.

Parameters in full-scale conditions and on the model when contour concentrated charges explode are shown in table 1.

**Table 1**

**Parameters in field conditions and on the model when contour concentrated charges explode**

| Parameters in field conditions | | | Model parameter | | | |
|---|---|---|---|---|---|---|
| The depth of the well, m | Well diameter, mm | Distance between wells, m | The size of the model, cm | The depth of the ищкуhole, cm | The distance between boreholes, cm | Charge diameter, mm |
| 7 | 250 | 3 | 10x20x 10 | 7 | 3 | 2.5 |
| 5.5 | 250 | 4 | 22x13x9.5 | 5.25 | 4 | 2.5 |
| 6 | 250 | 6 | 34x11x 10 | 6 | 6 | 2.5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 5.5 | 250 | 8 | 20x16x 10 | 5.5 | 8 | 2.5 |

To reduce the degree of destruction of samples, dispersed charges were modeled. With the help of glass tubes, the charge was dispersed over the entire depth of the hole into four parts with three air gaps. The distance between the holes varied from 6.5 to 35 charge diameters. The parameters in field conditions and on the model are shown in table. 2 and 3.

**Table 2**

**Parameters in field conditions**

| Parameters in field conditions | | | | |
|---|---|---|---|---|
| The depth of the well, m | Well diameter, mm | Distance between wells, m | Overall length dispersed charge, m | Total length of the air gap, m |
| 4.7 | 230 | 2 | 2.6 | 2.1 |
| 5.1 | 230 | 3 | 2.7 | 2.7 |
| 5.4 | 230 | 4 | 2.8 | 2.6 |
| 4.9 | 230 | 4 | 2.6 | 2.3 |
| 4.5 | 230 | 6 | 2.4 | 2.1 |
| 5.2 | 200 | 6 | 2.7 | 2.5 |
| 5.2 | 230 | 6 | 2.7 | 2.4 |
| 4.6 | 230 | 8 | 2.5 | 2.1 |
| 5.5 | 230 | 4 | 2.9 | 2.6 |
| 5.1 | 230 | 3 | 2.7 | 2.4 |
| 5 | 230 | 2 | 2.7 | 2.3 |
| 4.9 | 230 | 1.5 | 2.6 | 2.3 |

**Table 3**

**Parameters on the model**

| Model parameter | | | | | |
|---|---|---|---|---|---|
| The size of the model, cm | The depth of the borehole, cm | The diameter of the borehole, m | The distance between boreholes, cm | The total length of the dispersal charge, mm | Total length of the air gap, cm |
| 20x18x10 | 4.7 | 2.3 | 2 | 2.6 | 2.1 |
| 20x18x10 | 5.2 | 2.3 | 3 | 2.7 | 2.4 |
| 25x17x11 | 5.4 | 2.3 | 4 | 2.8 | 2.6 |
| 30x12x9 | 4.9 | 2.3 | 4 | 2.6 | 2.3 |
| 18x17x10 | 4.5 | 2 | 6 | 2.4 | 2.1 |

| | | | | | |
|---|---|---|---|---|---|
| 25x1 x12 | 5.2 | 2 | 6 | 2.7 | 2.5 |
| 25x2x10 | 5.1 | 2.3 | 6 | 2.7 | 2.4 |
| 25x21x10 | 4.6 | 2.3 | 8 | 2.5 | 2.1 |
| 42x27x12 | 5.5 | 2.3 | 4 | 2.9 | 2.1 |
| 42x27x12 | 5.1 | 2.3 | 3 | 2.7 | 2.4 |
| 42x27x 12 | 5 | 2.3 | 2 | 2.7 | 2.3 |
| 42x27x 12 | 4.9 | 1.5 | 2.6 | 2.6 | 2.3 |

Therefore, a method for conducting experimental studies of explosions of contour well charges on models has been developed, which allows us to study crack formation on volume models and wave interaction by high-speed video recording of the explosion process in transparent models, as well as to determine the parameters of stress waves during an explosion in samples of real rocks.

**CONCLUSIONS.** Researches of the mechanism of destruction of the legal rock mass in the design of the charge with filling its part with an inert face found that the explosion occurs asymmetric destruction of the array and reduces the impact of the explosion in the direction of the protected array due to the absorption of energy when repacking the inert cull.

The methodology of experimental studies of contour explosions of wells charges on models that examine cracking on volumetric models and wave interaction by high-speed video recording of the process of the explosion in transparent models, and to determine the parameters of the stress waves with the explosion in real samples of rocks.

Theoretical and laboratory researches have established that only the creation of a screening gap for the entire height of the non-working ledge allows you to get a virtually undisturbed array with a high-quality surface of the slope.

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