Rock Directed Breaking Under the Impulse Load

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Abstract. In the work the problem of directed chipping of facing stone material by means of managing of explosion process is considered. The technology of the mining of decorative stone by the use of explosion energy means the very rapid transfer of potential energy of elastic deformations to kinetic energy. As a result, the explosion impulse, in the expanse of the inertia of rock massive, does not cause the increase of existing cracks. In the course of explosion, the shock wave is propagated by ultrasonic velocity and in this case the medium parameters (pressure, density, temperature, velocity) increase in spurts. In spite of this fact the all three conservation laws of mechanics remain valid on basis of three laws the equations are derived by which the parameters of shock wave may be defined by means of the rock physical-mechanical properties. The load on the body volume at breaking under explosion acts over very small period of the time. Therefore, stressed-deformed state of the rock was studied when the impulse load acts on the boundary. It was considered that the mining of the blocks of facing stone is performed from the hard rocks. This means that the breaking proceeds in the zone of elastic deformation. In the conditions of mentioned assumptions, the expression of the stress tensor and displacement of vector components initiated by stressed-deformed state in the rock are written.

1. Introduction

In modern technologies for mining of the blocks of the facing stones the methods of the rock directional cutting or detaching are widely used by means of stone cutting machines plants. Their use at the quarries of low and medium hard rocks determines the improvement of engineering and economic performance of the production. But at the increase of rock hardness and abrasiveness the efficiency of existing rock cutting machines plants is significantly decreased and in some cases their use becomes impossible. Moreover, Georgian deposits of the decorative stone, for the most part, are of moderate capacity and are cracked. This fact, of course, is favourable for the wide use of the high performance stone cutting machines.

The technology for development of the deposits of the facing materials by the use of explosion energy is one of the approved efficient methods for mining of the decorative stone. This method implies the reduction of accompanying negative phenomena to minimum by means of explosion process control. The circumstance must be taken into account that at the explosion the potential energy of the elastic deformations is very rapidly transferred to kinetic energy and the detaching of the rock certain part takes place. But in spite of this fact the explosion impulse of low duration within the block does not cause the increase of existing cracks because of the inertia of the stone massif.

2. Mathematical Model and Analysis

By the transfer of the body explosion energy (especially of the rock) the destruction is a complex process which depends on the physical-mechanical properties of the body (rock), on the mechanism of explosion energy transfer to the medium charge value and on many other random factors. The results of the explosion are mainly depended on three factors: load, the form and composition of destructed body. At the boundary of the solid (rock) any load within it causes the deformations. As a result, the stresses are generated. The deformation within the body may be reversible (elastic) or irreversible (plastic). Of course, the study of the rock stressed-deformed state on the basis of all acting factors is very difficult and almost impossible. Therefore, the study of the shock waves, generated in the body, is based on the simplified model making. Accordingly, by our opinion;

a) The rock is the continuous solid which persistently fills the sub space,
b) Since the massif where the detaching of facing stone block takes place, is quite large, it may be considered that the body, the surface of which is loaded, is semi-infinite (in particular half-plane),
c) Taking into consideration the fact that at explosion destruction the load acts on the body volume over very short period of time, to a first approximation it may be supposed that we deal with the impulse load,
d) It may be considered that the mining of the facing stone blocks is carried out from the hard rocks. It means that the destruction takes place in the zone of elastic (reversible) deformation,
e) The mechanical work from the explosion is manifested in the fougasse form.

The task may be divided in two stages. First, the parameters of shock waves generated of explosion energy transfer to the rock must be calculated. Hereafter the initial and boundary conditions will be studied.

In the course of the explosion the propagation of the shock waves takes place. The shock wave is a compression wave, which is transmitted by supersonic speed in the given medium and at the propagation the medium parameters (pressure, density, temperature, speed) are step-wise varied (increased). In spite of this fact, all three laws conservation of momentum, conservation of angular momentum and conservation of energy remain valid. By the use of the mentioned laws the equations for determination of the parameters of the shock wave (D, U, P, V, T) may be written in the form of the equations set [1, 2, 3]:

$$\left.\begin{aligned}
&\frac{D}{V_0}=\frac{D-U}{V_1},\\
&\frac{DU}{V_o}=P_1-P_0,\\
&\frac{D}{V_o}\left(k-k_0+\frac{U^2}{2}\right)=P_1U,\\
&\frac{1}{\mathrm{K}-1}(P_1V_1-P_0V_0)=\frac{1}{2}\left(P_1+P_0\right)(V_0-V_1),
\end{aligned}\right\} \tag{1}$$

where D is shock wave velocity; U – environment flow velocity behind wave front; P_0 – initial pressure; P - pressure after generated shock wave; $k - k_0$ – inner energy gain; $V=\dfrac{1}{\rho}, V_0=\dfrac{1}{\rho_0}$ which specific volume is accordingly before shock and after shock wave; T- absolute temperature; K – is constant that at constant volume of gas, is characteristic for specific heat capacity correlation with specific heat capacity in constant pressure conditions. If in the mentioned system, one unknown parameter is considered as given (usually it is a wave dissemination D velocity that may be measured by testing), then the other parameters will be found.

Now we pass on the study of the effect of impulse load. Let us considered the stressed-deformed states of elastic half0plane at given dynamic load, acting on its boundary. Assume that the vertical load is given the boundary of elastic half-plane:

$$P(x,t)=\begin{cases} q\delta(t) \; when(x\,|\le 1) \\ 0 \qquad when(|\,x\,|>1) \end{cases} \tag{2}$$

where q is loading intensity, δ - Dirac function (Fig.1). Movements of vertical and horizontal points of plane should be searched.

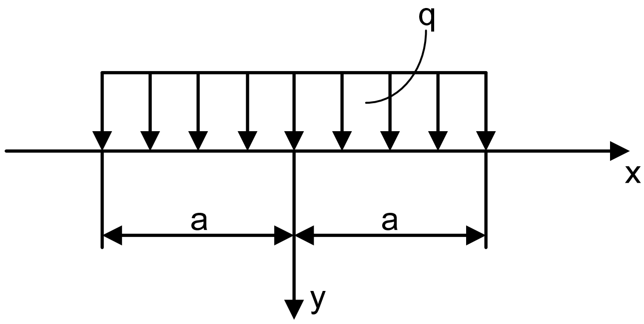

Figure 1. Mathematical model scheme

Hence the problem involves the detecting of the displacement vector $u(x,y,t)$, $v(x,y,t)$ which obey the differential equations set:

$$\begin{aligned} &\frac{\partial^2 u}{\partial t^2}+\left(1-\beta^2\right)\frac{\partial^2 v}{\partial x\partial y}+\beta^2\frac{\partial^2 u}{\partial y^2}=\beta^2\frac{\partial^2 u}{\partial t^2}, \\ &\beta^2\frac{\partial^2 v}{\partial x^2}+(1-\beta^2)\frac{\partial^2 u}{\partial x\partial y}+\frac{\partial^2 v}{\partial y^2}=\beta^2\frac{\partial^2 v}{\partial t^2}, \end{aligned} \tag{3}$$

and which are related with the stress components by equalities:

$$\begin{aligned} \sigma_x &= \frac{\partial}{a}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)+2\frac{\mu}{a}\frac{\partial u}{\partial x}, \\ \sigma_y &= \frac{\lambda}{a}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)+2\frac{\mu}{a}\frac{\partial v}{\partial y}, \\ \tau_{xy} &= \frac{\mu}{a}\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right). \end{aligned} \tag{4}$$

$y = for\, 0$ - there are boundary conditions.

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$$\sigma_y(x,0,t) = -p(x,t),$$
$$\tau_{xy}(x,0,t) = 0. \tag{5}$$

For $t = 0$, neutral initial conditions are made. (3–5) In equations

$$\beta = \frac{C_2}{C_1} = \sqrt{\frac{1}{2}\cdot\frac{1-2\nu_0}{1-\nu_0}},\ C_1 = \sqrt{\frac{\partial + 2\mu}{\rho_0}},\ C_2 = \sqrt{\frac{\mu}{\rho_0}},\ \lambda = \frac{E_0\nu}{(1+\nu_0)(1-2\nu_0)},\ \mu = \frac{E_0}{2(1+\nu_0)};$$

C_1 and C_2 in elastic semi-plane represent velocities of longitudinal and transverse wave dissemination, $\partial, \mu, E_0, \nu_0, \rho_0$ are Lame parameters, elasticity module, Poisson ratio, and material density.

$x = \frac{\bar{x}}{a},\ y = \frac{\bar{y}}{a},\ t = \frac{C_2 \bar{t}}{a}$ are non-dimension quantities.

This task in other conditions has been studied by Klimova and Ogurtsov [4]. After Laplace transform by t-parameter in the equations (2-4) and by the following Fourier transform for x-coordinate the system of common differential equations is obtained. After its solving and restoration of the original the following representation will be received for the components of displacement vector [2]:

$$u(x,y,t) = \frac{1}{\mu\sqrt{2\pi}}\cdot\frac{1}{2\pi}\cdot\int_{-\infty}^{+\infty}\cdot\int_{-\infty}^{+\infty}\frac{\xi F_1(\xi,S}{F_2(\xi,S}\left[(2\xi^2+S^2)e^{-y\sqrt{\xi^2+\beta^2 S^2}} - 2\sqrt{\xi^2+\beta^2S^2}\sqrt{\xi^2+S^2}e^{-y\sqrt{\xi^2+S^2}}\right]e^{-x\xi+st}\,d\xi dS,$$
$$v(x,y,t) = \frac{1}{\mu\sqrt{2\pi}}\frac{1}{2\pi i}\int_{-\infty}^{+\infty}\cdot\int_{-\infty}^{+\infty}\frac{\sqrt{\xi^2+\beta^2S^2}}{F_2(\xi,S)}\left[(2\xi^2+S^2)e^{-y\sqrt{\xi^2+\beta^2S^2}} - 2\xi^2 e^{-y\sqrt{\zeta^2+s^2}}\right]F_1(\xi,S)e^{-ix\xi+St}\,d\xi dS \tag{6}$$

Where S is non-dimension parameter of Laplace and Fourier transformation, and ξ - non-dimension parameter of Furrier transformation.

$$F_1(\xi,S) = \frac{a}{\sqrt{2\pi}}\int_{-\infty}^{\infty}\int_{0}^{\infty}p(x,t)e^{i\xi x - st}\,dtdx,\ F_2(\xi,S),$$
$$F_2(\xi,S) = (2\xi^2+S^2)^2 - 4\xi^2\sqrt{\xi^2+\beta^2\ S^2}\sqrt{\xi^2+S^2}. \tag{7}$$

Obtained formulas allow to describe the propagation disturbance (of wave) from the source. After calculating of the displacement of various points of elastic half-plane one can see that they take zero value as long as the longitudinal wave reaches the given point. After substitution of expressions (6) to equations set (4) the formula for calculating of the stress components will be obtained which allow to describe the stressed-deformed state generated in the rock. The numerical analysis of obtained results was carried out by the program Mat lab [5].

Fig. 2 and 3 show the diagrams of rock – generated σ_x and ι_{xy} pressure for t=0.0001 second, and Fig. 4, 5, 6 show the diagrams of σ_x, σ_y and ι_{xy} functions, when t=0.0014 sec. $y = 2,\ x = 4$.

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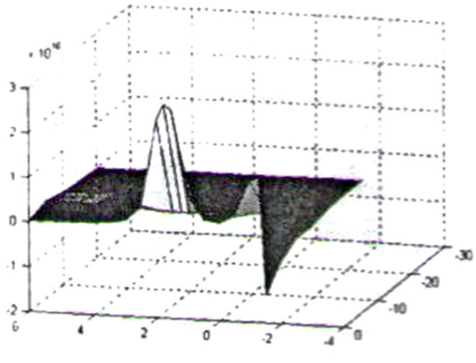

Figure 2. σ_x, t = 0.0001

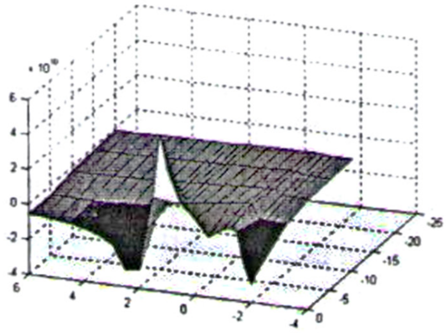

Figure 3. σ_y, t = 0.0001

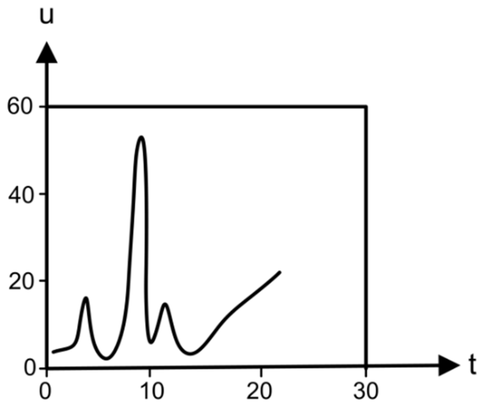

Figure 4. σ_x, t = 0.0014, x=2; y=4

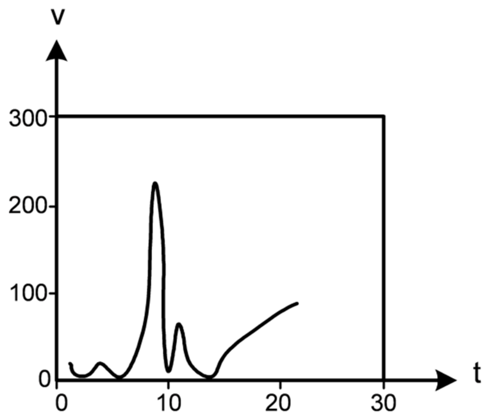

Figure 5. σ_y, t = 0.0014, x=2; y=4

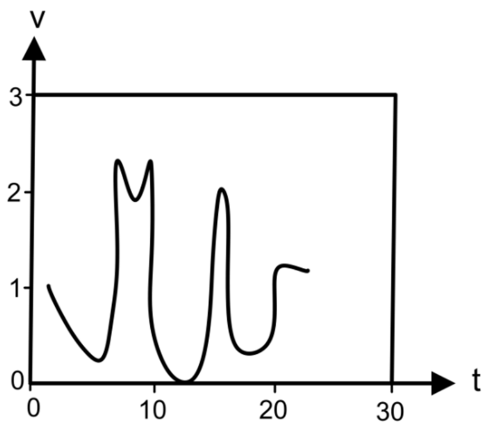

Figure 6. σ_{xy}, t = 0.0014, x=2; y=4

3. Conclusions

Thus on the basis of all above-mentioned it should be concluded that at mining of the block of facing stone preference must be given to the use of controlled explosion energy. Along with it for increase of the explosion efficiency the use of the detonators of short-term delay (60-75 milliseconds is reasonable.

The advantage of the use of mentioned detonators lies in the fact that the explosion energy of the explosive is concentrated, the explosion waves are nearly summarized increasing the explosion effect. This fact causes the increase of local stress in the rock and its additional destruction.

Acknowledgment

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