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MODELLING OF THE TWO CHARGES ASYNCHRONOUS EXPLOSION IMPACT ON THE MEDIUM USING QUASICONFORMAL MAPPINGS NUMERICAL METHODS

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Summary. The effect of successive explosions of two charges on an inhomogeneous medium is investigated using quasiconformal mappings numerical methods on the basis of a liquid model. The lines of the breach section of crater, pressed and unperturbed soil zone which has been formed in the environment because of the explosion are determined. The result of successive explosions of two charges is compared with the result of simultaneous explosion of similar charges

Keywords: mathematical modelling, explosion processes, quasiconformal mappings

1. ANALYSIS OF RECENT RESEARCHES

The explosive processes are increasingly used at the present stage of the economic development of society. They are widely used for the construction of tunnels, dams, mining, minerals extraction (in particular, oil and natural gas), construction of industrial and civil buildings, to provide the materials with the necessary engineering properties and testing their strength, with military purpose etc. The high danger of explosive processes for the environment necessitates a thorough a priori modeling of their impact on the environment in order to correctly determine the necessary technological parameters and maximize the leveling of probable risk [8]. To date, one of the most widespread mathematical models of the explosive process is liquid one [1, 7]. On the basis of it, a number of researches were carried out using two-dimensional model that determines the boundaries of the crater, pressed and unperturbed sections formed in the soil as a result of the explosion [3], determines the optimal characteristics and the location of the charges [4, 6]. The spatial model of the explosive process is investigated in [9]. The impact of simultaneous explosion of two charges on the environment is investigated in the paper [5]. The purpose of this study is to determine the impact on the environment of a sequential explosion of two charges and a comparison of its effects with the simultaneous explosion of two charges with the same characteristics.

2. PROBLEM STATEMENT

We isolate for consideration some area G_z $(z = x + iy)$, in which there are two charges of a priori given form with known quasipotentials on them in the environment where the explosions occurred (fig. 1). The motion of the particles of the medium caused by the shock wave resulting from the detonation is described by the motion equation $\vec{\upsilon} = k\, grad\varphi$ and the continuity equation $div\vec{\upsilon} = 0$. Here $\vec{\upsilon} = (\upsilon_x(x,y), \upsilon_y(x,y))$ is the particles velocity in the point (x,y), $\varphi = \varphi(x,y)$ is the quasipotential of a field generated by an explosion, $k = k(|grad\varphi|) = k(I)$ is a fictitious coefficient that characterizes the ability of particles to break off, where $I = \sqrt{\varphi_x^{\,2} + \varphi_y^{\,2}}$ is the gradient of the environment quasipotential. The investigated area is bounded by three contours: two internal ones are the charges contours $L_0 = \{z : f_0(x,y) = 0\}$ $= \{x + iy : x = x_0(t),$ $y = y_0(t), \alpha_0 < t < \beta_0\}$ and $L_1 = \{z : f_1(x,y) = 0\} = \{x + iy :$ $x = x_1(t),$ $y = y_1(t),$ $\alpha_1 < t < \beta_1\}$ the outer one $L^* = \{z : f^*(x,y) = 0\} = \{x + iy :$ $x = x^*(t),$ $y = y^*(t),$ $\alpha^* < t < \beta^*\}$, which will be specified in the problem solving process by an algorithm similar to the one that described in [3]. The values of quasipotentials on these contours are known: $\varphi|_{L_0} = \varphi|_{L_1} = \varphi_*$, $\varphi|_{L^*} = \varphi^*$.

We should to determine the position of the borders of the crater (I), the pressed (II) and unperturbed (III) soil zones formed as a result of two consecutive burst charges in the process of the problem solution (fig. 1).

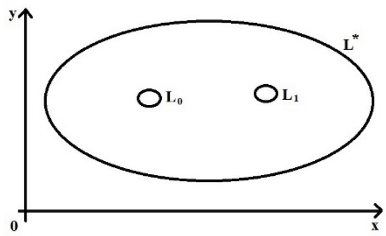


Fig. 1. Schematic representation of the investigated domain

In order to take into account the presence of mutual influence of the characteristics of the medium (soil) and process (explosion) in solving the problem, we perform a refinement of the coefficient k according to the formula

$$k = k_0 + \frac{1}{2}\beta\,\left(I - I^*\right)\left(\left(I - I^0\right) + \left|I - I^0\right|\right). \tag{1}$$

Here I^0, I^* are the critical values of the quasipotential gradient used to establish the boundaries of the crater, the pressed and unperturbed soil zones formed as the explosion result, the parameter β depends on the type of soil and is determined experimentally.

3. IDEA OF THE PROBLEM SOLVING

Since charges do not explode synchronously (the effect of the second charge explosion on the medium begins after the complete impact of the first one), the task of determining their total impact on the medium is to sequentially solve two subtasks, where the resulting state of the medium for the first subtask will be initial for the second one, and it's resultant distribution for the second subtask is the result of the total impact of both charges explosion on the environment. Both problems are solved with the same algorithm, only the initial distribution of the coefficient for the second problem is it's resultant distribution, obtained as a result of the solution of the first one (thus taking into account the influence on the environment of the previous explosion of the first charge). When solving each subtask, we consider the outer contour and contour of one charge, ignoring another charge.

4. DETERMINATION OF THE IMPACT OF THE FIRST CHARGE EXPLOSION

Let the charge bounded by the contour L_0 explode first (fig. 2).

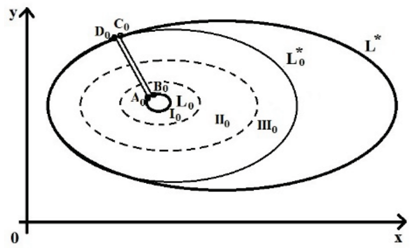


Fig. 2. Schematic representation of the domain to investigate the explosion of the first charge

So, within the scope of the first subtask we consider the double-connected domain $G_z^{'}$ bounded by the contours L_0 and L_0^*, where L_0^* is the contour needed to study the impact of the first charge explosion. We identify it as described in [3]. We introduce the function $\psi = \psi(x, y)$, complex conjugated to $\varphi = \varphi(x, y)$ and reduce the investigated double-connected domain to a single-connected one by passing through a certain fixed point $A_0 \in L_0$ of a conditional section along one of the flow lines (this line will be specified in the process of solving the problem) [2]. We obtain the problem on the quasiconformal mapping $\omega = \omega(z) = \varphi(x, y) + \mathrm{i}\psi(x, y)$ of the obtained single-connected domain $G_z^0 = G_z^{'} / A_0D_0$ on the corresponding rectangular quasicomplex potential domain $G_\omega^0 = \{\omega = \varphi + i\psi :\ \varphi_* < \varphi < \varphi^*,\ 0 < \psi < Q_0\}$ with the unknown parameter Q_0, which will also be determined in the process of solving the problem:

$$\begin{aligned} &\kappa\left(|\,grad\varphi)\,|\right)\frac{\partial\varphi}{\partial x}=\frac{\partial\psi}{\partial y}, \\ &\kappa\left(|\,grad\varphi)\,|\right)\frac{\partial\varphi}{\partial y}=-\frac{\partial\psi}{\partial x} \end{aligned}\quad,\ \left(x,y\right)\in G_z^0 \tag{2}$$

with the initial conditions $\varphi\big|_{L_0}=\varphi_*$, $\varphi\big|_{L^*}=\varphi^*$, $\psi\big|_{A_0D_0}=0$, $\psi\big|_{B_0C_0}=Q_0=\oint\limits_{L_0}-\upsilon_y dx+\upsilon_x dy.$ Also the initial distribution of the coefficient k is known as k_0.

We turn to the solution of the inverse boundary value problem on a quasi-conformal mapping $z=z\left(\omega\right)=x\left(\varphi,\psi\right)+iy\left(\varphi,\psi\right)$ the quasicomplex potential domain G_ω^0 to the corresponding physical domain G_z^0 to identify the real $x=x\left(\varphi,\psi\right)$ and imagine $y=y\left(\varphi,\psi\right)$ parts of the equation of the characteristic function of the flow line and the unknown parameter Q_0 value. Conditions of the Cauchy-Riemann type will be written as:

$$\begin{aligned} &\kappa\left(\frac{1}{J}\sqrt{(\frac{\partial x}{\partial\psi})^2+(\frac{\partial y}{\partial\psi})^2}\right)\frac{\partial y}{\partial\psi}=\frac{\partial x}{\partial\varphi}, \\ &\kappa(\left(\frac{1}{J}\sqrt{(\frac{\partial x}{\partial\psi})^2+(\frac{\partial y}{\partial\psi})^2}\right)\frac{\partial x}{\partial\psi}=-\frac{\partial y}{\partial\varphi}, \\ &\left(\varphi,\psi\right)\in G_\omega^0,\quad J=x_\varphi y_\psi-x_\psi y_\varphi, \end{aligned} \tag{3}$$

The equation of the region boundary are written as

$$\begin{aligned} &f_0\left(x(\varphi_*,\psi),y(\varphi_*,\psi)\right)=0, \\ &f^*\left(x(\varphi^*,\psi),y(\varphi^*,\psi)\right)=0, \end{aligned}\qquad 0\le\psi\le Q_0. \tag{4}$$

In addition, the conditions of "gluing" on the line of fake cut must be observed:

$$x(\varphi,0)=x(\varphi,Q_0),\quad y(\varphi,0)=y(\varphi,Q_0),\quad \varphi_*<\varphi<\varphi^*. \tag{5}$$

From the conditions of the Cauchy-Riemann type (3), we turn to the Laplace type equations (as described, for example, in [2]):

$$\begin{aligned} &\frac{\partial}{\partial\varphi}\left(\frac{1}{\kappa}(\frac{1}{J}\sqrt{\frac{\partial x^2}{\partial\psi}+\frac{\partial y^2}{\partial\psi}})\frac{\partial x}{\partial\varphi}\right)+\frac{\partial}{\partial\psi}\left(\kappa(\frac{1}{J}\sqrt{\frac{\partial x^2}{\partial\psi}+\frac{\partial y^2}{\partial\psi}})\frac{\partial x}{\partial\psi}\right)=0. \\ &\frac{\partial}{\partial\varphi}\left(\frac{1}{\kappa}(\frac{1}{J}\sqrt{\frac{\partial x^2}{\partial\psi}+\frac{\partial y^2}{\partial\psi}})\frac{\partial y}{\partial\varphi}\right)+\frac{\partial}{\partial\psi}\left(\kappa(\frac{1}{J}\sqrt{\frac{\partial x^2}{\partial\psi}+\frac{\partial y^2}{\partial\psi}})\frac{\partial y}{\partial\psi}\right)=0. \end{aligned} \tag{6}$$

In doing so, we also require the fulfillment of the conditions of the Cauchy--Riemann type (3) in the boundary nodes of the mesh domain.

To solve a formed subtask by the quasiconformal mappings numerical methods we construct a uniform orthogonal grid $G_\omega^0 = \{(\varphi_i, \psi_j):\quad \varphi_i = \varphi_* + i\Delta\varphi,\ i = \overline{0, n+1};$ $\psi_j = j\Delta\psi,\ j = \overline{0, m+1};\ \Delta\varphi = \dfrac{\varphi^* - \varphi_*}{n+1};\ \Delta\psi = \dfrac{Q_0}{m+1};\ \gamma = \dfrac{\Delta\varphi}{\Delta\psi};\ n, m \in N\}$ in the quasi-complex potential domain. The equation (4)–(6) is approximated by the difference scheme in the "cross" type, as described, for example, in [2]. Solving the problem for the explosion of the first charge is carried out by means of a stepwise parameterization of the parameters of the environment and process: iteratively specify the value of the quasiconformal invariant γ, boundary and internal nodes of the physical region G_z^0 and coefficient k until the required precision is reached. The result of solving the first sub task will be the distribution of the crater, pressed and unperturbed zones of the soil resulting from the explosion of the first charge (fig. 3) and the distribution of the value of the coefficient k in each of the nodes of the physical domain $G_z^{'}$, which will be needed to solve the second subtask.

5. DETERMINATION OF THE SUMMARY EFFECTS OF TWO EXPLOSIONS ON THE ENVIRONMENT

The task of determining the impact of the second charge explosion on the environment is determined by an algorithm similar to the algorithm for determining the impact of the first charge. This does not take into account the fact of the explosion of the first charge, but only takes into account the distribution of the coefficient $k = k(x, y, \varphi, \psi)$, formed in the environment as a result of its influence.

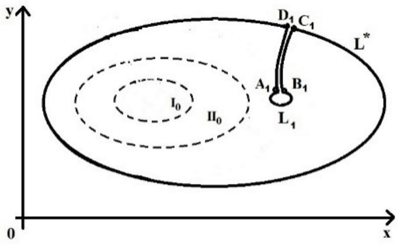
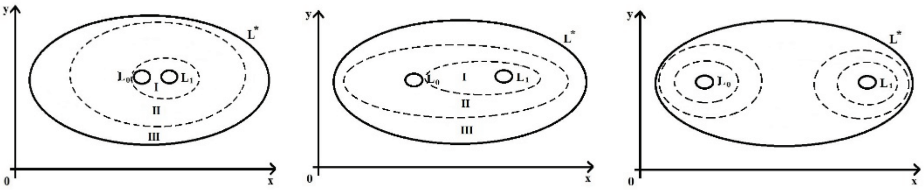


Fig. 3. Schematic representation of the area to investigate the explosion of the second charge

Consider now the two-bounded domain G_z^*, bounded by the contours L_1 and L^* with given values of quasipotentials on them. By fixing a point $A_1 \in L_1$ reduce the domain to the single-connected one $G_z^1 = G_z^* / A_1 D_1$. Similarly to the first sub task, we construct a problem on a quasiconformal mapping of the physical region G_z^* to the corresponding quasicimplex potential domain G_ω^1 and proceed to the solution of the corresponding inverse problem for mapping the region of quasicomplex potential to the physical region. The algorithm for numerical solving of the second subproblem is also constructed in the same way as the first one; however, the initial distribution of the coefficient $k = k(x, y, \varphi, \psi)$ for the second subtask will be the one obtained as a result of the solution of the first; in the process of solving the value of this coefficient will be specified according to the formula (1).

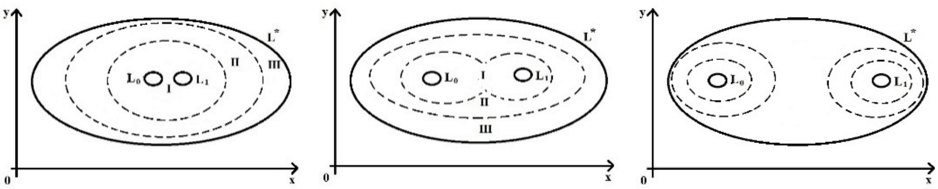


a) b) c)

Fig. 4. Schematic reconstruction of the resulting area for the case of close charge placement (a); "medium" (b); distant (c)

Fig. 4 shows the typical cases of formation of crater, pressed and unperturbed soil zones, obtained as a result of the numerical experiments developed on the basis of the developed algorithm for cases of near initial charge placement (a), some "middle" (b) and the distant one (c).

For comparison, Fig. 5 shows typical methods of soil zones distribution for the case of a synchronous explosion of charges [5].



a) b) c)

Fig. 5. Schematic reconstruction of the resulting area for the case of close charge placement (a); "medium" (b); distant (c)

6. CONCLUSIONS

The effect of a sequential explosion of two charges on the medium has been investigated based on liquid model. The numerical experiments carried out on the basis of the developed algorithm confirm the adequacy of the mathematical model. Results of the impact on the environment of successive explosions of two charges (fig. 4) are compared with the results of a synchronous explosion of similar charges (fig. 5).

The comparative analysis carried out shows that the question of choosing the method of conducting blasting works (the use of simultaneous explosion or sequential one) depends on the goal to be achieved. So, if the purpose of the explosion is to create a hole of the maximum possible size, it is expedient to use a synchronous explosion, because then each charge increases the effect of another; In the case of asynchronous explosion, the action of the latter partly alleviates the effect of the first one. If the purpose of the explosion is to press the maximum ground area, it is advisable to use successive explosions. Also, the essential factor in choosing the method of explosion is the required degree of soil pressing. Thus, in the case of asynchronous explosion, it is achieved more of a pressing of some parts of the soil than with synchronous, which is caused by repetitive suppressive action on these areas.

Also the mutual charge placement is important. So, the closer the charges are to each other, the more their interaction is observed, but a greater degree of soil pressing can be obtained. At an average distance between charges, the degree of soil pressing is lower, but the larger part of it is trampled. In the case where the charges are far from each other, their interaction is practically invisible.

In the long term is the study of the effect of three charges, taking into account the presence of significant in homogeneities in the studied region (immutable objects, in particular, blindages), the identification of "safe" zones in the explosion of several charges and the location of charges in the presence of known "safe" zones.

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MODELOWANIE WPŁYWU ASYNCHRONALNEGO WYBUCHU DWÓCH OPŁAT NA ŚRODOWISKO POPRZEZ QUASICFORMAT METODY WYŚWIETLANIA

Streszczenie

Zbadano wpływ kolejnych eksplozji dwóch ładunków na niejednorodny ośrodek metodami quasiconformal mapowania. Określa się położenie linii przekroju, osadzone w niezakłóconych odcinkach utworzonych w środowisku w wyniku wybuchu. Porównuje wynik kolejnych eksplozji dwóch ładunków z jednoczesnym wybuchem podobnych ładunków.

Słowa kluczowe: modelowanie matematyczne, procesy wybuchowe, odwzorowania quasiconformal