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About the removal - shear impact on the surface of the soil half-space and the application of the method of characteristics

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ABSTRACT: The article presents the development results propagation of an elastic - plastic wave. Impact force is accompanied by plastic deformation. The issues of strength of various machines and structures experiencing impacts can be investigated only with a clear understanding of the laws of propagation of elastic - plastic deformation.
A method for determining the parameters of the deformed state of the soil at a small shear strain is obtained.

KEYWORDS: σ_x, σ_y – components of the voltages, ε, ε_{xy} –components deformation, v_x, v_y – velocities of the moving the particles, D, C –velocities of the spreading the shock waves, ρ_0, ρ(x) –density, U,V,W –components of the displacement, $F(\varepsilon)$ – the function, defining dependency between voltage and deformation i.e. $\sigma= F(\varepsilon)$, $F(\varepsilon_i)$ - the function, defining dependency between intensity of the voltages and intensity deformation i.e. $\sigma_i= F(\varepsilon_i)$.

I. INTRODUCTION

The solution of a number of modern economic problems is associated with the study of the movement of soils and rocks at high pressures and high strain rates.
The main sectors of the national economy and technology requiring the study of soil behavior under dynamic impacts are:
• Ultra-deep and deep well drilling for exploration and production purposes.
• Open pit mining using an explosion.
• Actions on underground and ground structures of underground, ground and air explosions.
• Studies on the penetration of solids at low and high speeds into soils.
• The creation of the explosion of mine shafts and underground tanks, etc.
The actions of loads suddenly applied to the body do not spread instantly, but are transmitted from one particle to another in an aqueous manner.
Until recently, only the motion of elastic waves was studied, i.e. disturbance propagation in an elastic medium; The dynamic theory of elasticity has important applications in seismology and technology.
Since the end of World War II, great interest has been shown in the propagation of disturbances in an elastoplastic medium. This is due to the following reasons.
Any amount of intense impact loading is accompanied by plastic deformation. Strength issues of various machines and structures experiencing impacts can be investigated only with a clear understanding of the laws of propagation of elastic - plastic deformation preceding fracture. On the other hand, real media are not completely

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elastic and there is a need to take into account the influence of plastic properties and the properties of the nonlinear coupling of stresses from deformations.

II. METHODOLOGY

Currently, a number of problems have been solved by the method of characteristics, by the method of sources and sinks. In this work, we also use the method of characteristics. The book of Rakhmatullin describes the application of the method of characteristics to the task. On the basis of the deformation theory of plasticity, the exact solution of the wave one-dimensional elastic - plastic problem is sought.
It is shown that, depending on the laws of medium deformation, both shock and centered waves can propagate in it. Solved problems in the first case, i.e. The problem of the propagation of shock waves is solved.

III. EXPERIMENTAL RESULTS

Consider a homogeneous resting soil occupying the lower half-space.
Let at the initial moment of time $t = 0$ all particles lying on the soil surface $(x = 0)$ be informed of the same speed $\overrightarrow{v_0}$, which will remain constant in the future, and let the vector $\overrightarrow{v_0}$, be parallel to the *XOY* plane: (v_0) $^{\rightarrow}$ $\overrightarrow{v_0}$ (v_{xo}, v_{yo}, o).
Flat one-dimensional motion occurs in the soil; all medium parameters depend only on *x*, *t*. The study of the problem was carried out from the point of view of the theory of small strains. Since $w = 0$.
Flat one-dimensional motion occurs in the soil; all medium parameters depend only on *x*, *t*. The study of the problem was carried out from the point of view of the theory of small strains. Since $w = 0$.

$$\varepsilon_{xx} = \frac{\partial u}{\partial x}, \qquad \varepsilon_{xy} = \frac{\partial v}{\partial x}, \qquad \varepsilon_{yy} = \varepsilon_{zz} = \varepsilon_{yz} = \varepsilon_{zx} = 0 \qquad (1)$$

$$\varepsilon = \varepsilon_{xx}, \qquad \varepsilon_i = \frac{2}{3}\sqrt{\varepsilon^2 + \frac{3}{4}\varepsilon_{xy}^2}$$

Then the relationship between stresses and strains are expressed as:

$$\left.\begin{array}{l} \sigma_x = (\lambda + 2G)\,\varepsilon_{xx} = (\lambda + 2G)\varepsilon \\ \sigma_y = G\varepsilon_{xy} \end{array}\right\} \qquad (2)$$

Where λ and G

$$\lambda = \frac{F(\varepsilon)}{\varepsilon} - \frac{2}{9}\frac{F(\varepsilon_i)}{\varepsilon_i}$$

$$G = \frac{1}{3}\frac{F(\varepsilon_i)}{\varepsilon_i}$$

Functions $F(\varepsilon)$ and $F(\varepsilon_i)$ are approximated by the following parabolas of degree *n*

$$\Phi(\varepsilon) = \alpha_1\varepsilon + (-1)^{n+1}\alpha_2\varepsilon^n$$
$$\Phi(\varepsilon_i) = \beta_1\varepsilon_i + (-1)^{n+1}\beta_2\varepsilon_i^n$$

We put the expression λ and G in (2), then

$$\left.\begin{array}{l} \sigma_x = F(\varepsilon) - \frac{4}{9}\frac{F(\varepsilon_i)}{\varepsilon_i}\varepsilon \\ \sigma_y = \frac{1}{3}\frac{F(\varepsilon_i)}{\varepsilon_i}\varepsilon_{xy} \end{array}\right\} \qquad (2`)$$

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We introduce the notation

$$G=\frac{2}{3}\varepsilon_i$$

$$Q(G)=\frac{F(\varepsilon_i)}{9\varepsilon_i}$$

Then

$$\left.\begin{aligned}\sigma_x&=F(\varepsilon)+4Q(G)\varepsilon\\ \sigma_y&=3Q(G)\varepsilon_{xy}\\ G&=\sqrt{\varepsilon^2+\frac{3}{4}\varepsilon_{xy}^2}\end{aligned}\right\}\qquad(3)$$

The equation of motion has the form:

$$\left.\begin{aligned}\frac{\partial\sigma_x}{\partial x}&=\rho_0\frac{\partial^2 U}{\partial t^2}\\ \frac{\partial\sigma_y}{\partial x}&=\rho_0\frac{\partial^2 V}{\partial t^2}\end{aligned}\right\}\qquad(4)$$

But $\frac{\partial U}{\partial t}=v_x$, $\frac{\partial V}{\partial t}=v_y$, differentiating these relations with respect to X, taking into account (1) and combining with (4), it is easy to obtain a system of equations.

$$\left.\begin{aligned}&\frac{\partial\varepsilon}{\partial t}=\frac{\partial v_x}{\partial x},\ \frac{\partial\varepsilon_{xy}}{\partial t}=\frac{\partial v_y}{\partial x}\\ &\frac{\partial\sigma_y}{\partial x}=\rho_0\frac{\partial v_x}{\partial t},\ \ \frac{\partial\sigma_y}{\partial x}=\rho_0\frac{\partial v_y}{\partial t}\end{aligned}\right\}\qquad(5)$$

Relation (3) and (5) together represent a closed system of equations that must be solved under conditions

$v_x=v_{x0}$, $v_y=v_{y0}$, at $x=0$ (6)

$v_x=0$, $v_y=0$, $\varepsilon=0$, $\varepsilon_{xy}=0$ at $x=\infty$ (7)

substituting (3) in (4) the system can be reduced to the following form:

$$\left.\begin{aligned}&\frac{\partial\varepsilon}{\partial t}=\frac{\partial v_x}{\partial x},\ \frac{\partial\varepsilon_{xy}}{\partial t}=\frac{\partial v_y}{\partial x}\\ &\frac{\partial v_x}{\partial t}-a\frac{\partial\varepsilon}{\partial x}-b\frac{\partial\varepsilon_{xy}}{\partial x}=0\\ &\frac{\partial v_y}{\partial t}-b\frac{\partial\varepsilon}{\partial x}-c\frac{\partial\varepsilon_{xy}}{\partial x}=0\end{aligned}\right\}\qquad(8)$$

Notation used here:

$$\left.\begin{aligned}a&=\frac{1}{\rho_0}\left[\frac{dG}{d\varepsilon}+4Q(G)+\frac{4\varepsilon^2}{G}\frac{dQ}{dG}\right]\\ b&=\frac{1}{\rho_0}\frac{3\varepsilon\,\varepsilon_{xy}}{\Gamma}\frac{dQ}{dG}\\ c&=\frac{1}{\rho_0}\left[3Q(G)+\frac{9}{4}\frac{\varepsilon_{xy}^2}{G}\frac{dQ}{dG}\right]\end{aligned}\right\}\qquad(9)$$

The characteristics of the system of equations (8) are found from the equations

$$\left(\frac{dx}{dt}\right)^2 = \frac{a + c \pm \sqrt{(a+c)^2 + 4b^2}}{2}$$

The conditions for the existence of all four families of characteristics is the inequality

$a + c > \sqrt{(a+c)^2 + 4b^2}$ or

$$\left(Q + \frac{3}{4}\frac{\varepsilon_{xy}^2}{G}Q^`\right)F^` + 4Q\left(Q + GQ^`\right) > 0 \qquad (10)$$

Since $F(\varepsilon)$, $Q(G)$ are essentially independent of functions, it is obvious that the inequality $Q + GQ^` > 0$ is necessary for the validity of (10).

It can be shown that it is also a sufficient condition for (10) if $F(\varepsilon) > 0$. We make the assumption that the inequality $(Q + GQ^`) > 0$ always holds. It is easy to see that a necessary but insufficient condition for the fulfillment of this inequality is the monotonic increase in the function $F(\varepsilon_i)$. Now it is easy to show the inequalities $a + c > 0$.

Under accepted assumptions, the system has 4 families of characteristics:

$$\left.\begin{aligned} \left(\frac{dx}{dt}\right)_I^2 &= \frac{a + c + \sqrt{(a+c)^2 + 4b^2}}{2} \\ \left(\frac{dx}{dt}\right)_{II}^2 &= \frac{a + c - \sqrt{(a+c)^2 + 4b^2}}{2} \end{aligned}\right\} \qquad (11)$$

It can be noted that for the case of pure compression (resolution) without a shift ($v_y \equiv 0$, $\varepsilon \equiv 0$) system (8) has 2 families characteristic, calculated by the first formula (11).

For the case of a pure shift ($v_y \equiv 0$, $\varepsilon \equiv 0$), system (8) has 2 families of characteristics defined by the second formula (11).

Therefore, further characteristics $\left(\frac{dx}{dt}\right)_I^2$ conditionally called compression characteristics, and characteristics $(\left(\frac{dx}{dt}\right)_{II}^2)$ - shear characteristics.

It is easy to prove that $\left(\frac{dx}{dt}\right)_I^2 > \left(\frac{dx}{dt}\right)_{II}^2$.

A wave of pure compression (resolution) propagates along an unperturbed medium, along which a shear wave propagates with compression (rarefaction).

Analysis of constants in equations (8) and the conditions for them (6) and (7) lead to the conclusion that the problem under consideration is self-similar. The parameters v_x, v_y, ε, ε_{xy}, σ_x, σ_y depend only on the variable $= \frac{x}{t}$.

With this in mind, system (8) and conditions (6), (7) can be transformed

$$\left.\begin{gathered} \frac{\partial v_x}{\partial \xi} + \xi\frac{\partial \varepsilon}{\partial \xi} = 0, \quad \frac{\partial v_y}{\partial \xi} + \xi\frac{\partial \varepsilon_{xy}}{\partial \xi} = 0 \\ (\xi^2 - a^2)\frac{\partial \varepsilon}{\partial \xi} = b\frac{\partial \varepsilon_{xy}}{\partial \xi}, \quad (\xi^2 - c^2)\frac{\partial \varepsilon}{\partial \xi} = b\frac{\partial \varepsilon_{xy}}{\partial \xi} \\ v_x = v_{xo}, \; v_y = v_{yo}, \; at \;\; \xi = 0 \\ v_x = v_y = 0, \; \varepsilon = \varepsilon_{xy} = 0, \;\; at \;\; \xi = \infty \end{gathered}\right\} \qquad (12)$$

The motion in a wave of pure compression (rarefaction) adjacent to the rest zone is described by the equations obtained from (12).

$v_y \equiv 0$, $\varepsilon \equiv 0$:

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$$\frac{\partial v_x}{\partial \xi} + \xi \frac{\partial \varepsilon}{\partial \xi} = 0, \quad (\xi^2 - a_0^2)\frac{\partial \varepsilon}{\partial \xi} = 0 \qquad (13)$$

Where

$$a_0 = a_0(\varepsilon) \equiv \frac{1}{\rho_0}\left[\frac{dF}{d\varepsilon} + 4Q(|\varepsilon|) + 4|\varepsilon|Q`(|\varepsilon|)\right]$$

The general solution of system (13) reflects a constant flow:

$v_x = v_{x1} = const, \quad \varepsilon = \varepsilon 1 = const$

the zone of which should be separated from the rest zone by the shock wave of compression (rarefaction). The conditions on the shock wave taking into account (3) are written as follows (8):

$$\left.\begin{aligned} & v_{x1} = D\varepsilon_1 = 0, \\ & \rho_0 D v_{x1} = -(\sigma_{x1} - \sigma_{x0}), \\ & \sigma_{x1} = F(\varepsilon_1) + 4Q(|\varepsilon_1|)\varepsilon_1 \\ & \sigma_{x0} = F(0) \end{aligned}\right\} \qquad (14)$$

Here D is the velocity (constant) of the shock wave; Index I provides the parameters in the constant flow zone behind the shock wave.

As is known, a shock or continuous wave arises in the medium depending on the mode (compression or rarefaction) and on the direction of convexity of the curve $\sigma_{x1}(\varepsilon_1)$ calculated by formula (3). For this problem, the following conclusion follows from this rule [3].

If for compression (rarefaction) strains $\frac{da_0}{d|\varepsilon|} < 0$, then a centered compression (rarefaction) wave $\frac{da_0}{d|\varepsilon|} > 0$,then the front wave can be a compression (rarefaction) shock wave. At $a_0 = const$, the shock wave of compression (rarefaction) is ahead. For simplicity, the case when $\frac{da_0}{d|\varepsilon|}$ changes sign, not considered.

We are now investigating the shear wave — compression (rarefaction), propagating over the region of pure compression (rarefaction). The general solution of system (12) describes a constant flow

$v_x = v_{x2} = const$
$v_y = v_{y2} = const$
$\varepsilon = \varepsilon_2 = const$
$\varepsilon_{xy} = \varepsilon_{xy\,2} = const$

the constant flow region with shear should be separated by the shock wave from the region $\varepsilon_{xy} = 0$, $v_y = 0$.

We write down the conditions on this shock wave, denoting the parameters before and behind the wave, respectively, with indices *1* and *2* ($v_{x2} = v_{x0}$, $v_{y2} = v_{y0}$).

Let the wave velocity relative to the fixed space b, and the wave equation $x = x_c = ct$.

Then from the relations

$$\int_0^t b dt = x_c^* + U_1(x_,^* t), \qquad \varepsilon = \frac{\rho_0}{\rho} - 1$$
$$U_1(x_c^* t) = U_1(x_,^* t), \qquad v_2(x_c^*, t) = 0$$

Easy to get

$$(b - v_{x1})\rho_1 = \rho_0 c$$

as well as

$$v_{y0} = c\varepsilon_{xy2}, \quad v_{x0} + c\varepsilon_2 = v_{x1} + c\varepsilon_1 \qquad (15)$$

relations (8)

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$$\rho_1(b - v_{x1})v_{y0} = -x_{y2}$$

$$\rho_1(b - v_{x1})(v_{x0} - v_{x1}) = -(x_{x2} - x_{x1})$$

Take the form

$$\rho_0 c v_{y0} = -x_{y2}$$

$$\rho_0 c(v_{x0} - v_{x1}) = -(x_{x2} - x_{x1}) \qquad (16)$$

Equation (13) must be added to conditions (15) and (16)

$$\sigma_{x2} = F(\varepsilon_2) + 4\varepsilon_2 Q(G_2)$$

$$\sigma_{y2} = 3\varepsilon_{xy2} Q(G_2)$$

$$G_2 = \sqrt{\varepsilon\frac{2}{2} + \frac{3}{4}\varepsilon_{xy2}^2} \qquad (17)$$

Here v_{x0}, v_{y0} are known. To determine the constants ε_1, ε_2, v_{x1}, D, c, there is a system of equations (14) and (17).

$$\varepsilon_2 = \frac{\rho_0 v_{y0}^2(\sigma_{x2} - \sigma_{x0} + \rho_0 D v_{x0}) - \sigma_y^2 v_{x0}^2 + v_{y0}\sigma_{y2}(\sigma_{x2} - \sigma_{x0})}{\sigma_{y2}(\rho_0 D v_{y2} + \sigma_{y2})}$$

$$\varepsilon_{xy2} = \frac{\rho_0 v_{y0}^2}{\sigma_{y2}} \qquad (18)$$

It is seen from formulas (18) that by measuring the velocity of the front shock wave D, as well as four parameters at the soil surface (v_{x0}, v_{y0}, σ_{x2}, σ_{y2}) , ε_2, ε_{xy} can be calculated.

IV. CONCLUSION

Thus, the following issues are considered in the work done:
1. Statement of the problem and application of the characteristic method to the problem.
2. A method for determining the parameters of the deformed state of the soil is obtained.
3. The result is obtained in the case of a small shear strain.
4. A method for determining the parameters and motion is derived, when the stresses at the boundary instantly acquire finite values at t = 0, monotonically decreases with time.

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