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Stressed-Deformed State of the Inhomogeneous Soil-Basing in Conditions of Plane Deformation

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ABSTRACT: In the paper, the stress-strain states of an inhomogeneous base are investigated using the Vlasov's variation method. This theory makes it possible to simplify the theoretical calculations, will give an opportunity to get the solution of the problem for an arbitrary law of change of the elastic characteristics of the base is sufficiently accurate and simple for practical applications.
The resulting system of differential equations with variable coefficients describing a generalized model of an inhomogeneous base constructed on the basis of a general variation method.

KEYWORDS: ground, base, heterogeneity, variation method, plane, deformation, boundary conditions, equations of state, layer, displacement.

I. INTRODUCTION

In the paper, the stress-strain states of an inhomogeneous base are studied using Vlasov's variation method of [1]. This theory makes it possible to substantially simplify the theoretical calculations and will make it possible to obtain the solution of the problem for an arbitrary law of variation of the elastic characteristics of the base, is sufficiently accurate and simple for practical applications[2-8].

As an example, a dimensionless diagram of the sedimentation of the surface of a homogeneous and heterogeneous substrate should be concluded, in terms of depth and along the strike.

Comparing the sediments of the surface of a homogeneous and heterogeneous base, it should be concluded that if the soil deformation modulus increases in depth, the sediment of the surface of the inhomogeneous base decreases in comparison with the homogeneous one. It can also be noted that the attenuation of the sediment from the load along the coordinate axis *Ox* in a non-uniform base occurs relatively faster than in the homogeneous one.
Taking into account inhomogeneous properties along the base cause an asymmetric precipitation of the base from the concentrated load applied on its surface.

II.RESULTS

Equation of state nonuniform elastic base plane strain conditions are given by [9,10]

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$$\left.\begin{aligned} \sigma_x &= \frac{E(x,y)}{1-\nu^2(y,x)}\left[\frac{\partial u}{\partial x}+\nu(x,y)\frac{\partial \upsilon}{\partial y}\right], \\ \sigma_y &= \frac{E(x,y)}{1-\nu^2(y,x)}\left[\frac{\partial \upsilon}{\partial y}+\nu(x,y)\frac{\partial u}{\partial x}\right], \\ \tau_{xy} &= \tau_{yx} = \frac{E(x,y)}{2[1-\nu(x,y)]}\left[\frac{\partial u}{\partial y}+\frac{\partial \upsilon}{\partial x}\right] \end{aligned}\right\} \qquad (1)$$

$$E(x,y) = \frac{E_{гр}(x,y)}{1-\nu^2_{гр}(x,y)}, \quad E_{гр}(x,y) > 0 \qquad (2)$$

$$\nu(x,y) = \frac{\nu_{гр}(x,y)}{1-\nu_{гр}(x,y)}, \quad 0 < \nu_{гр}(x,y) \le \frac{1}{2} \qquad (3)$$

where $E_{гр}(x,y)$ and $\nu_{гр}(x,y)$are deformation and Poisson's ratio of an elastic non-homogeneous base.

We assume that the base under consideration is a compressible layer of thickness H located on an infinitely rigid massif and operating under conditions of plane deformation (Fig. 1, b). Forming the expressions for the work of all external and internal forces of the strip of width $dx = 1$ and the height H extracted from this base layer, on the possible for it$m + n$ displacements, we obtain:

$$\left.\begin{aligned} &\int \frac{\partial \sigma_x}{dx}\varphi_j dF - \int \tau_{x,y}\varphi_j^I dF + \int P(x,y)\varphi_j dy = 0 \\ &\qquad\qquad\qquad\qquad (j = 1,2,\ldots,m) \\ &\int \frac{\partial \tau_{x,y}}{dx}\psi_h dF - \int \sigma_y \psi_h^I dF + \int q(x,y)\psi_h dy = 0 \\ &\qquad\qquad\qquad\qquad (h = 1,2,\ldots,n) \end{aligned}\right\} \qquad (4)$$

Unknown displacement of a point $M(x,y)$ of the base represented by the following finite expansions:

$$\left.\begin{aligned} u(x,y) &= \sum_{i=1}^{m} U_i(x)\varphi_i(y) \qquad (i = 1,2,\ldots,m) \\ \upsilon(x,y) &= \sum_{k=1}^{n} V_k(x)\varphi_k(y) \qquad (k = 1,2,\ldots,n) \end{aligned}\right\} \qquad (5)$$

Here $U_i(x)$ and $V_k(x)$are unknown generalized displacements; $\varphi_i(y)$; $\psi_k(y)$ are unknown dimensionless functions characterizing the transverse distribution of the base displacement [2].

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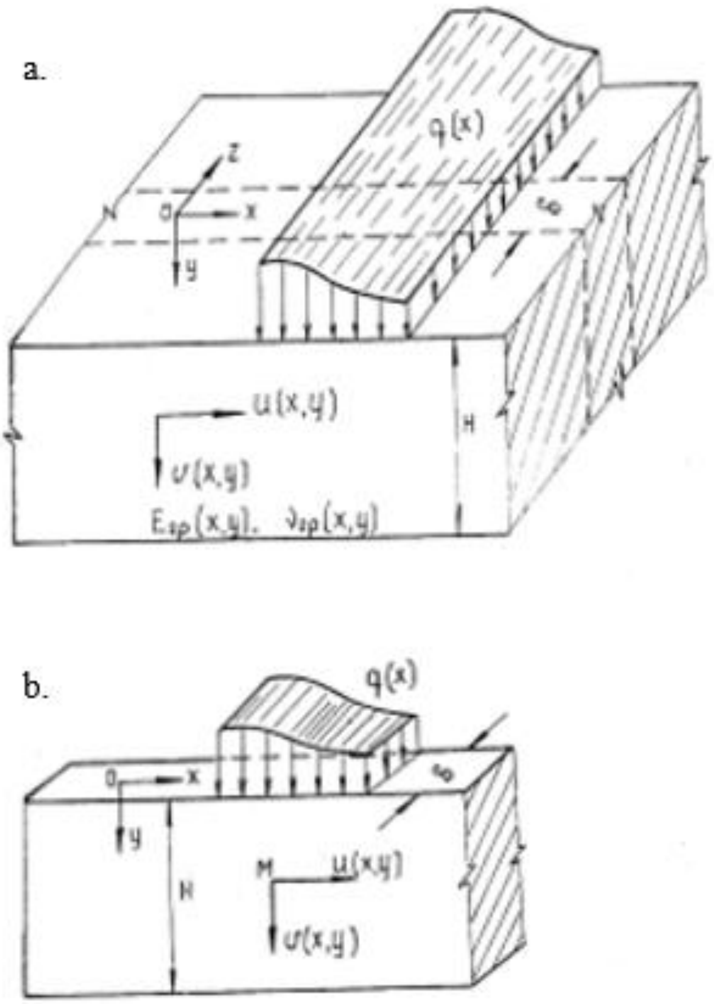

Figure 1 Compressible layer of an inhomogeneous substrate.

Using equations of state (1) and expansions (5), relations (4) can be written in the form *(m + n)* of a differential equation with variable coefficients with respect to the unknown functions $U_i(x)$ and $V_k(x)$. Compressible layer of an inhomogeneous substrate.

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$$\left.\begin{array}{l}\sum_{j=1}^{m} a_{ij}U_i^{II} + \sum_{j=1}^{m} d_{ji}U_i^{I} - \frac{1-\nu_0}{2}\sum_{i=1}^{m} b_{ij}U_i + \\ + \sum_{k=1}^{n}\left(\nu_0 t_{j,k} - \frac{1-\nu_0}{2}C_k^I\right)V_k^I + \nu_0\sum_{k=1}^{n}\Theta_{jk}V_k + \frac{1-\nu_0^2}{E_0(t)}P_j = 0 \\ \qquad\qquad\qquad\qquad (j=1,2,\dots,m) \\ -\sum_{j=1}^{m}\left(\nu_0 t_{hj} - \frac{1-\nu_0}{2}C_{hi}\right)U_i^I + \frac{1-\nu_0}{2}\left(\sum_{k=1}^{n} e_{hi}U_i + \sum_{k=1}^{n}\eta_{hk}V_k^{II} + \sum_{k=1}^{m}\Theta_{nk}V_h^I\right) - \\ -\sum_{k=1}^{n} S_{hk}V_k + \frac{1-\nu_0^2}{E_0}q_h = 0 \qquad\qquad (h=1,2,\dots,n)\end{array}\right\} \quad (6)$$

The coefficients of equation (6) is determined from the following relationships:

$$\left.\begin{array}{ll} a_{ji} = a_{ij} = \int M\varphi_i\varphi_i\,dF, & d_{ji} = \int M_x^I\varphi_i\varphi_i\,dF, \\ b_{ji} = b_{ij} = \int \Phi\varphi_i^I\varphi_i\,dF, & t_{ji} = \int MN\psi_k\varphi_i\,dF, \\ C_{jk} = \int \Phi\psi_k\varphi_j^I dF, & \theta_{jk} = \int M_x^I N\varphi_j\psi_k^I dF, \\ \theta_{jk}^I = \int MN_x^I\varphi_j\psi_k^I dF, & dF = \delta dy, \\ t_{hi} = \int MN\psi_h^I\varphi_i dF, & C_{hi} = \int \Phi\psi_h\varphi_i^I dF, \\ e_{hi} = \int \Phi_x^I\psi_h\varphi_i^I dF, & \eta_{hk} = \eta_{kh} = \int \Phi\psi_h\psi_k dF, \\ \theta_{hk} = \int \Phi_x^I\psi_h\psi_k dF, & S_{hk} = S_{kh} = \int M\psi_h^I\psi_k^I dF. \end{array}\right\} \quad (7)$$

$$\left.\begin{array}{l} M(x,y) = \frac{E(x,y)}{E_0}\frac{1-\nu_0^2}{1-\nu^2(x,y)}, \\ \Phi(x,y) = \frac{E(x,y)}{E_0}\frac{1-\nu_0}{1+\nu(x,y)}, \\ E_0 = \frac{E_{гр}}{1-\nu_{гр}}, \quad \nu_0 = \frac{\nu_{гр}}{1-\nu_{гр}}, \quad N = \frac{\nu(x,y)}{\nu_0}. \end{array}\right\} \quad (8)$$

In formulas (7), the integrals propagate to the entire thickness H of the base and depend on the form of the function $\varphi_i(x,y)$, $\psi_k(x,y)$, $M(x,y)$, $N(x,y)$, $\Phi(x,y)$,and their derivatives.

Free terms $P_j(x,y)$ and $q_h(x,y)$ of the equations (6) are given horizontal work $P_h x,y)$ and vertical $q(x,y)$ to move the loads respectively $\varphi_j(y)$ and $\psi_h(y)$ and computed generally by the formulas:

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$$\left.\begin{aligned} P_j(x,y) &= P(x,0)\varphi(0) + \int P(x,y)\varphi_i(y)dy = 0, \\ q_h(x,y) &= q(x,0)\psi_h(0) + \int q(x,y)\psi_h(y)dy = 0 \end{aligned}\right\} \qquad (9)$$

where $P(x,0)$ and $q(x,0)$ are respectively the shear and the normal surface force, the positive direction of which coincide with the positive directions of the coordinate axes;

$\varphi_j(0)$ and $\psi_h(0)$ are the values of the functions $\varphi_j(y)$ and $\psi_h(0)$ on the surface (y = 0) of the non-homogeneous base; $P(x,y)$ и $q(x,y)$ are mass forces.

If we assume that the heterogeneous base operates only on loads applied to its surface, then the arrays by forces distributed along the thickness of the base should be neglected. In this case, relations (9) take the form:

$$\left.\begin{aligned} P_j(x) &= P(x)\varphi_j(0) \\ q_h(x) &= q(x)\psi_h(0) \end{aligned}\right\} \qquad (10)$$

Integration of systems of differential equations with variable coefficients (6) determines the unknown functions $U_i(x)$ and $V_k(x)$.

The number of arbitrary unknown integrations is in full correspondence with the number of independent geometric conditions that can be specified for the extreme sections of the base. The boundary conditions $x = 0$ and $x = l$ can be specified in the effort or in the displacements. Proceeding from the concept of the virtual work of the normal and shear forces $\sigma_x\delta$ and $\tau_{xy}\delta$of the plate cross-section on each of their $m + n$ possible displacements of the points of this section (Fig. 1, b), we obtain for generalized quasistatic magnitudes of the formula:

$$\left.\begin{aligned} T_j(x) &= \int \sigma_x\varphi_j dF, \qquad (j=\overline{1,n}) \\ S_h(x) &= \int \tau_{yx}\psi_h dF, \qquad (h=\overline{1,n}) \end{aligned}\right\} \qquad (11)$$

where $dF = \delta dy$; $T_j(x)$ and$S_h(x)$ are generalized longitudinal and transverse forces of the base in the cross section x = const.

In formulas (11), the integrals propagate to the entire thickness of the base.

Substituting (1) into (11), we obtain:

$$\left.\begin{aligned} T_j(x) &= \int \sigma_x\varphi_j dF = \frac{E_0}{1-\nu_0^2}\left[\sum_{i=1}^{m}\left(a_{ji}U_i^I + \frac{1}{2}d_{ji}U_i\right) + \nu_0\sum_{k=1}^{n} t_{jk}V_k\right], \\ &\qquad (j=1,2,\ldots,m) \\ S_j(x) &= \int \tau_{yx}\psi_h dF = \frac{E_0}{1-\nu_0^2}\left[\sum_{i=1}^{m} C_{hi}U_i + \sum_{k=1}^{n} r_{hk}V_h^I\right], \\ &\qquad (h=1,2,\ldots,m). \end{aligned}\right\} \qquad (12)$$

Relations (12) make it possible to establish generalized boundary conditions on the transverse edges of the base *(x = 0 and x = l) 2 (m + n).*

Thus, a given system of linear normal $P^0(x_0,y)$ and shearing forces $q^0(x_0,y)$ acts on any edge $x = x_0$ of the base.

Considering the equilibrium conditions of the strip dx, isolated from the plate in the form of which the base is represented, on the basis of the principle of possible displacements we have (Fig. 1, b):

$$\left.\begin{aligned} &\int \left(\sigma_x^0\delta - P^0\varphi_i\right)dy = 0, \\ &\int \left(\tau_{yx}^0\delta - q^0\psi_h\right)dy = 0. \end{aligned}\right\} \qquad (13)$$

Comparing (11) with (13), we have:

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$$\left.\begin{aligned} S_h^0(x_0) = \int q^0 \psi_h dy, \\ T^0(x_0) = \int P^0 \varphi_j dy. \end{aligned}\right\} \quad (14)$$

The general integral of systems of differential equations with variable coefficients (6) and boundary conditions (12) and (14) allow one to determine the deformations and the stressed state of an inhomogeneous base of finite thickness H at any boundary conditions specified in the forces in displacements or partly in forces and partly in displacements.

It should be noted that a system of differential equations with variable coefficients (6) describes a generalized base model constructed on the basis of a general variation method.

Indeed, choosing different expressions for $\varphi_j(y)$, $\psi_k(y)$, $M(x,y)$, $N(x,y)$, $\Phi(x,y)$ depending on the coordinates *(x, y)* and corresponding to the physical content of the problem, we have the opportunity to obtain a number of base models of approximate ones from the point of elasticity theory point of view of practical applications.

1 . If we assume that $\nu(x,y) = \nu_0 = \text{const}$, then

$$M(x,y) = \frac{E(x,y)}{E_0}, \qquad N(x,y) = 1, \qquad \Phi(x,y) = \frac{E(x,y)}{E_0} \quad (15)$$

we obtain a generalized model of an elastic inhomogeneous base, the Poisson's ratio, which is constant, and the modulus of deformation by a continuous function of the base coordinate points [4].

2 .If we assume:

$$E(x,y) = E_0 = \text{const}, \; \nu(x,y) = \nu_0 = \text{const}, \text{ то} \quad (16)$$

we obtain a generalized model of an elastic homogeneous base [1].

An increase in the number of terms in the series (5) improves the model of the inhomogeneous base described by the differential equations (6), and. improves the accuracy of calculation. But improving the model and improving the accuracy of calculation in this way is undesirable, for two reasons.

First, an excessive increase in the number of members in the series (5) leads to complex computational procedures that allow for certain inaccuracies; secondly, it is impractical in engineering applications. Therefore, in order to improve the model and improve the accuracy of the calculation, another approach seems to be effective, namely, a more successful choice of functions that characterizes the heterogeneous soil properties-bases and functions that characterize the transverse distributions of the base displacements [2, 4].

If these functions are the result of experimental or valid theoretical studies, then limiting ourselves to the minimum number of terms in the expansions (5), one can obtain the stress-strain state of an inhomogeneous base sufficiently close to the true one.

As an example, in Figure 2 and 3, a dimensionless diagram of the sediment $\overline{V}$ of the surface of an inhomogeneous base is constructed

in depth $f(y) = \dfrac{H+y}{H}$ and (17)

along strike $f(x) = e^{\lambda x}$ (18)

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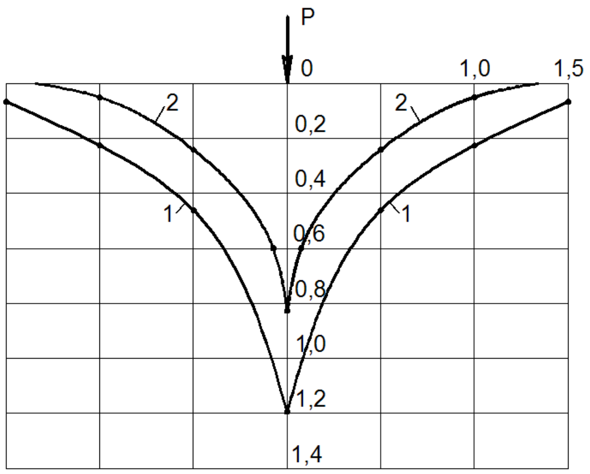

Figure 2 Dimensionless plots of the sediments of a surface of a uniform (1) non-uniform in thickness (2) base with a finite thickness from the concentrated force.

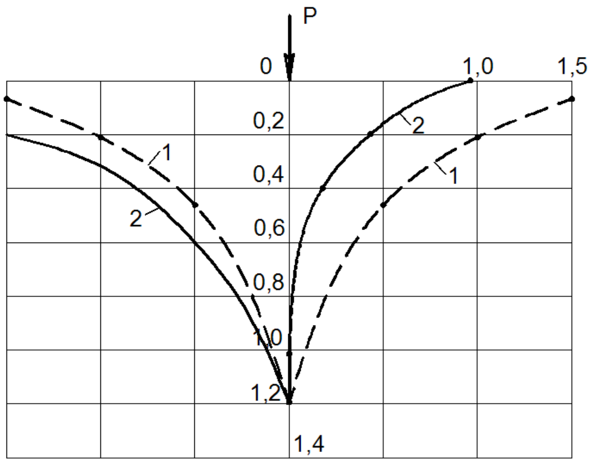

Figure 3 Dimensionless plots of the sediments of a surface of a uniform (1) horizontally nonuniform (2) base with a finite thickness from the concentrated force.

III.DISCUSSION

Comparing the sediments of the surface of a homogeneous and inhomogeneous base (Figure 2), we come to the conclusion that if the function characterizing inhomogeneous properties of the soil along the thickness obeys the law (17), then the sediment of the surface of the inhomogeneous base in comparison with the homogeneous base decreases by 22.5%. It can also be noted that the attenuation of the sediment from the load along the coordinate axis *Ox* in an inhomogeneous substrate, occurs relatively faster than in the homogeneous one.

IV.CONCLUSION

Allowance for inhomogeneous properties along the base (18) leads to an asymmetric deposit of the base from the concentrated load applied on its surface.

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