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CALCULATION OF PIPELINE BRANCHES WITH ACCOUNT NONLINEARITY OF ELASTIC BASE

Tolib Kurbonovich Ostonov

Samarkand State University

Ilhom Shahobiddinovich Suvonkulov

Samarkand State University

Gayratjon Subhonovich Bakaev

Samarkand State University

Asliddin Erkinovich Nuriddinov

Samarkand State University

Najmiddin Husanovich Jalilov

Samarkand State University

Abstract. When calculating systems on an elastic foundation, the generalized Reissner-Vlasov-Filomenko-Borodich model is traditionally used. Such models are acceptable for small displacements. For large displacements, there are some deviations from reality.

In the study, models of saline soil as a structurally unstable viscoelastic material were constructed, which provides for taking into account suffusion sediments, physical and geometric nonlinearity of soil behavior. On the basis of the variational approach of V.Z.Vlasov, viscoelastic and hypoviscoelastic analogies, soil foundation models were constructed that generalize the Pasternak-Vlasov-Reissner model for the case of viscoelastic and hypoviscoelastic behavior of the soil and provide for taking into account physical and geometric nonlinearity.

On the basis of these soil foundation models, within the framework of the classical theory of bending of rods and shells, the statements of the main ones are formulated: boundary value problems of the theory of structures on saline soil foundations.

The article discusses the calculation of the deformation of an underground pipeline laid on saline soil, corresponding to a nonlinear elastic foundation using a nonlinear model of the type [1], taking into account these shortcomings.

Key words: Pipelines, modulus of elasticity, Poisson's ratio, Laplace operator, base repulsion, displacement, small parameter, solution in zero approximation, numerical experiment, Winkler-Fauss-Zimmeron model, Reissner-Vlasov-Filomenko-Borodich model.

Introduction.

The issues of construction on saline soils belonging to the class of structurally unstable soils are of particular importance due to the need to take into account the specific properties of these soils in their engineering use. The dissolution of the crystalline salts contained in these soils and their washing out under the influence of the filtration flow leads to an increase in their porosity, and, consequently, to additional so-called suffusion precipitation, which often causes the loss of stability of objects built on these soils.

The complexity of construction on saline soils is due to the fact that deformations are manifested both during the construction of structures and during their operation. On saline soils (clayey) of a solid consistency, deformations occur during soaking and manifest themselves in the form of a sharp subsidence of buildings. This is explained by the fact that when soils are saturated with water and salts are dissolved, the contact strength of individual particles decreases sharply, as a result of which the strength characteristics and the value of the total deformation modulus change.

Therefore, the study of the patterns of deformation of such soils and the creation of calculation models based on these studies, the operation of saline soils in the foundations of structures, the development of engineering methods for calculating structures on saline soil foundations within the framework of these models are very relevant in scientific and practical terms of tasks.

II. MATERIALS AND METHODS

In the studies applied methods of theoretical mechanics and agricultural mechanics.

From experimental studies, the compression curves of saline soils were determined to be significantly non-linear [1], and there is a significant dependence of the mechanical properties of soils on gypsum content, lime content, etc.

In this regard, the Fuss-Winklea-Zimmeran model when calculating structures on saline soil bases seems to be incorrect.

Therefore, at constant moisture and gypsum, the short-term behavior of the soil is nonlinearly elastic.

- with pure shear

$$\tau = G_1\gamma + G_2\gamma^3 \tag{1}$$

- under volume compression

$$\sigma = K_1\varepsilon + K_2\varepsilon^3 \tag{2}$$

where, σ - hydrostatic pressure, τ - shear stress, γ - charcoal, ε - bulk deformation.

Here G_1, G_2, K_1, K_2 - soil elastic constants depending on moisture content, gypsum content and other factors.

We also note that the soil is practically unable to perceive tensile volumetric stresses, so that within the entire interval $-\infty < \varepsilon > \infty$ for the bulk state, the law

$$\sigma = \left(K_1\varepsilon + K_2\varepsilon^3\right)H(\varepsilon) \tag{3}$$

Neglecting the possible anisotropy of the soil and representing the strain and stress tensors by their polar expansions, the potential energy of the soil strain can be represented as the following non-linear form of the strain deviator γ volumetric deformation ε:

$$\omega = bI_2(\gamma) + dI_2^2(\gamma) + \left[a\varepsilon + c\varepsilon^3\right]\varepsilon\left|H(\varepsilon) + (g + h\varepsilon)I_2(\gamma)\right|\varepsilon\left|H(\varepsilon)\right. \tag{4}$$

where $|\cdot|$ - the operation of taking an absolute value, $H(\gamma)$ is the second invariant of the strain deviator, a, b, c, d, g, h - material constants depending on its structure (silt content, humidity, salinity, etc.).

When constructing potential (4), it was taken into account that the experiments did not reveal the influence of quadratic γ, ε terms in the approximation of compression curves for simple states, and a fourth-order form restriction is adopted when dilatation effects are taken into account to ensure consistency in the accuracy of describing various states.

Along with physical nonlinearity, saline soils are characterized by a very complex rheological behavior [2]. The complexity of the rheology is due to both the viscoelastic properties characteristic of all soils and the structural instability of saline soils.

To take into account the viscoelastic properties of soils, a number of models have been proposed [3]. The most common of these is the Feicht-Kelvin model, according to which

$$\sigma = K\varepsilon + K'\dot{\varepsilon} \tag{5}$$

$$\tau = G_1\gamma + G'\dot{\gamma} \tag{6}$$

where the dot denotes differentiation with respect to time, and, as a rule, volumetric deformation is assumed to be elastic. To describe soil deformation in the framework of the Feicht-Kelvin model, neglecting the nonlinearity of viscosity and viscous dilatation, we introduce, along with the deformation potential (4), specific dissitation.

$$r = \eta I_2\dot{\gamma} + \mu\left(\dot{\varepsilon}\right)^2 \tag{7}$$

Varying the specific strain energy with respect to ε and the specific dissipation with respect to the strain rate, then applying the Laplace transform with respect to time k in the Laplace transform space, performing the inverse Laplace transform, varying the Lagrangian of the nonlinearly elastic layer, determined by the potential of external forces and the strain potential, and performing a number of mathematical transformations, we have obtained model in the form

$$\begin{aligned} p = &-\frac{8}{3h}\left(a + \frac{8b}{3}\right)w - \frac{64}{5h^3}\left(c + \frac{64}{9}d\right)w^3 + \frac{256}{21h}dw\left[2\left(\frac{\partial w}{\partial x}\right)^2 + 2\left(\frac{\partial w}{\partial y}\right)^2 + w\left\langle\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2}\right\rangle\right] + \\ &+ \frac{4bh}{5}\left[\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2}\right] + \frac{16dh}{9}\left[\left(\frac{\partial w}{\partial x}\right)^2\left\langle 3\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2}\right\rangle + \left(\frac{\partial w}{\partial y}\right)^2\left\langle 3\frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial x^2}\right\rangle\right] + 4\frac{\partial w}{\partial x}\frac{\partial w}{\partial y}\frac{\partial w}{\partial x\partial y} \end{aligned} \tag{8}$$

In the case of considering a one-dimensional structure based on this type, the expression for the linear force of the reaction of the base will be written in the form $p = -k_1 w_0 - k_2 w^3 + C\left[2w\left(\frac{dw}{dx}\right)^2 + w^2\frac{d^2w}{dx^2}\right] + t_1\frac{d^2w}{dx^2} + t_2\left(\frac{dw}{dx}\right)^2\frac{d^2w}{dx^2}$

(9)

where are the constants k_1, k_2, c_1, t_1, t_2 are obtained by integrating (8) over the width of the beam.

As can be seen from the constructed solutions, for sufficiently extended structures such as pipeline branches, taking into account the nonlinearity of elastic behavior, as well as in the case of linear elastic consideration, the solution is represented as a superposition of the ground state, which is realized far from the fixings, and corrective solutions decaying with distance from the edge fixings, and the ground state can be assumed to be flat, so that the original differential equation reduces to an algebraic one.

Let us consider from this point of view the deformation of an underground pipeline laid in saline soil. Within the framework of the beam model, the main state of the pipeline is described by the equation

$$k_1 w_0 + k_2 w_0^2 = q \tag{10}$$

when adopting the foundation model (9).

Equation (10) admits the exact solution

$$w_0 = \sqrt[3]{\frac{q}{2k_1}}\left[\sqrt[3]{1+\sqrt{1+\frac{4k_1^3}{27k_2 q^2}}} + \sqrt[3]{1-\sqrt{1+\frac{4k_1^3}{27k_2 q^2}}}\right] \tag{11}$$

The relation for the ground state, coinciding up to the notation, can also be obtained in the geometrically nonlinear case. Let us now substitute the solution of the original problem in the form

$$w = w_0 + w_{кэ} \tag{12}$$

and substitute it into the original equation of statics, for example

$$EJw^{IV} + k_1 w + k_2 w^3 - \frac{d^2w}{dx^2} - t_1\left(\frac{dw}{dx}\right)^2\frac{d^2w}{dx^2} - C_1\left[w\left(\frac{dw}{dx}\right)^2 + w\frac{d^2w}{dx^2}\right] = q \tag{13}$$

Then for $w_{кэ}$ we have

$$\begin{aligned} &EJw_{кэ}^{IV} + k_1 w_{кэ} + k_2\left[w_{кэ}^3 + 3w_{кэ}^2 w_0 + 3w_{кэ} w_0^2\right] - t_1 w_{кэ}'' - t_2\left(w_{кэ}'\right)^2 w_{кэ}'' \\ &- C_1\left[\left(w_{кэ}'\right)^2\left(w_{кэ} + w_0\right) + \left(w_0 + w_{кэ}\right)^2\left(w_{кэ}''\right)\right] = 0 \end{aligned} \tag{14}$$

In this case, alternative boundary conditions have the form

$$w_0 + w_{кэ} = w^0 \tag{15}$$

or

$$EJw_{кэ}''' - t_1 w_{кэ}' - \frac{t_2\left(w_{кэ}'\right)^2}{3} - C_{\cdot}\left(w_{кэ} + w_0\right)^2 w_{кэ}' = Q^* \tag{16}$$

$$w_{кэ}' = Q_0$$

or $\quad EJw_{кэ}'' = M^*$

where solutions decaying with increasing x are sought $w_{кэ}$.

Note that for a solution of the edge effect type, equation (6) is homogeneous, which greatly simplifies its integration and allows one to construct a solution using the Poincaré methods. Indeed, we apply to (6) the procedure of the small parameter method:

$$w_{кэ} = w_0\left[y_0 + \varepsilon y_0 + \cdots\right] \tag{17}$$

having previously transformed equation (6) and dimensionless form

$$y^{IV} - 2\tau_*^2 y'' + 4m_*^4 y = \varepsilon\left[\theta\left(y'\right)^2 y'' + \lambda(1+y)\left(y'\right)^2 + \lambda(2+y)y \cdot y'' - by^2(3+y)\right] \tag{18}$$

where

$$2\tau_*^2 = 2\tau^2 + \varepsilon\lambda \qquad 4m_*^4 = 4m^4 + 3\varepsilon b \tag{19}$$

moreover, the displacement of the ground state is taken as a normalizing factor for displacements.

Conditions (15) - (16) will then take the form

$$y = \frac{w^0}{w_0} - 1 \quad \text{or} \quad y''' - 2\tau_*^2 y' - \varepsilon\left[y'\left\langle\frac{Q}{3}\left(y'\right)^2 + \lambda y(2+y)\right\rangle\right] = \overline{Q} \tag{20}$$

$$y' = \frac{Q_0 l}{w_0} \quad \text{or} \quad y'' = \overline{M}$$

where $\overline{Q}$, $\overline{M}$ - reduced to a dimensionless form, taking into account the rule of signs, the external transverse force and moment.

Note that in the case of a floating termination ($\overline{Q_0} = \overline{Q}$ = *0*) or free edge ($\overline{M} = \overline{Q}$ = *0*) Equation (18) with the corresponding boundary conditions admits only a trivial solution, so that the SSS of the beam is determined only by the ground state.

The cases of hinged support and edge fixing, as well as the case of beam bending by edge forces and moments, require more detailed consideration.

The equations for the generating solution and the corrective functions have the form

$$y_0^{IV} - 2\tau_*^2 y_0'' + 4m_*^4 y_0 = 0 \tag{21}$$

$$y_1^{IV} - 2\tau_*^2 y_1'' + 4m_*^4 y_1 = \lambda\left[(y_0+2)y_0 y_0'' + (1+y_0)\left(y_0'\right)^2\right] + \theta\left(y_0'\right)^2 y_0'' - by_0^2(3+y_0)$$

and the boundary conditions take the form

$$y_0 = \frac{w^0}{w_0} - 1 \quad \text{or} \quad y_0''' - 2\tau_*^2 y_0' = \overline{Q}$$

$$y_0' = \frac{Q_0 l}{w_0} \quad \text{or} \quad y_0' = \overline{M} \tag{22}$$

$$y_1 = 0 \quad \text{or} \quad y_1''' - 2\tau_*^2 y_1' = \frac{Q}{3}\left(y_0'\right)^3 + \lambda y_0' y_0 (2+y_0)$$

$$y_1' = 0 \quad \text{or} \quad y_1' = 0$$

… … …

Consider, for example, the case of termination.

The generating solution in this case has the form

$$y_0 = -e^{-\alpha\eta}\left(\cos\beta\eta + \frac{\alpha}{\beta}\sin\beta\eta\right) \tag{23}$$

Where α, β are determined by the relations

$$\alpha = \sqrt{m_*^2 + \frac{\tau_*^2}{2}} \qquad \beta = \sqrt{m_*^2 - \frac{\tau_*^2}{2}} \tag{24}$$

The first correction equations then take the form

$$y_1^{IV} - 2\tau_*^2 y_1^{"} + 4m_*^4 y_1 =$$
$$= \frac{\alpha^2+\beta^2}{2\beta^2} e^{-2\alpha\eta} \left\{ \left[\lambda\left(3\alpha^2 - \beta^2\right) - 3b \right] - 6b\frac{\alpha\cdot\beta}{\alpha^2+\beta^2}\sin 2\beta\eta + 3\cos 2\beta\eta \left[\frac{b\left(\alpha^2-\beta^2\right)}{\alpha^2+\beta^2} - \lambda\left(\alpha^2+\beta^2\right) \right] \right\} + \quad (25)$$
$$+ \frac{1}{2} e^{-3\alpha\eta} \left\{ \cos 3\beta\eta \left[\lambda\alpha^2 \frac{\alpha^2+\beta^2}{\beta^2} - \theta\frac{\alpha^2+\beta^2}{\beta^2} + b\frac{\beta^2 - 3\alpha^2}{\beta^2} \right] \quad \ldots \right\}$$

the solution of equation (26) is represented as the following expansion

$$y_1 = e^{-\alpha\eta}\left(A_1^{'}\cos\beta\eta + A_2^{'}\sin\beta\eta\right) + e^{-2\alpha\eta}\left(C_2 + C_2^c\cos 2\beta\eta + C_2^s\sin 2\beta\eta\right) +$$
$$+ e^{3\alpha\eta}\left(C_3^{1c}\cos\beta\eta + C_3^{1s}\sin\beta\eta + C_3^{3c}\cos\beta\eta + C_3^{3s}\sin\beta\eta\right) \quad (26)$$

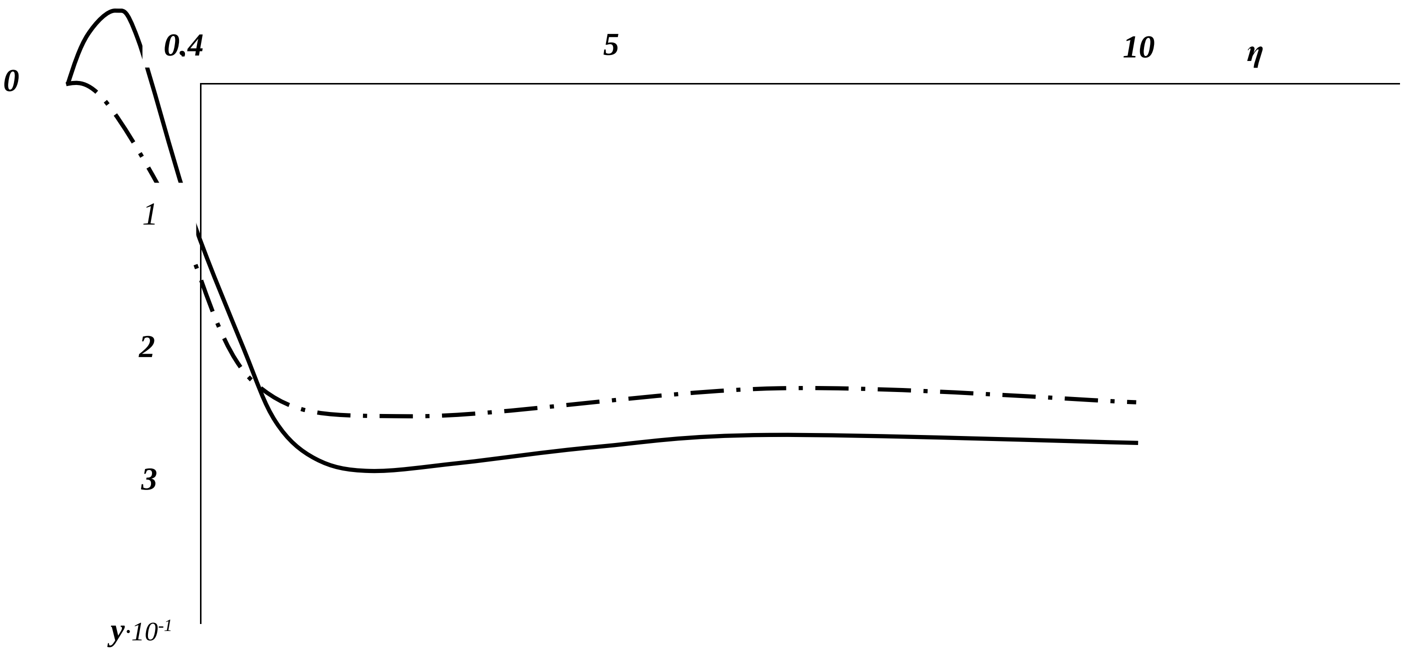
where are the constants $C_2,\ C_2^c,\ C_2^s,\ C_3^{1c},\ C_3^{1s},\ C_3^{3c},\ C_3^{3s},\ C_2$ determined

from equation (26) by equating the coefficients at the same functions, and $A_1^{'},\ A_2^{'}$ are then found from conditions (22).

III. Results and discussion

The numerical solution by the method of dismemberment for this problem in comparison with the solution obtained by the Lyapunov-Linstedt method shows that already the zero approximation of the method of dismemberment as a whole satisfactorily describes the deformed state of the pipeline.

The use of the SSS partitioning method makes it possible to more accurately analyze the deformation of pipelines laid in saline soils, since, as is known [4], predominantly beam effects develop in the edge zones, and the ground state can be determined based on the theory of an elastic ring.



Picture. Dimensionless deflections in a semi-infinite beam. Application of the VAT breakdown method.

IV. CONCLUSIONS

On the basis of the systematic application of asymptotic methods and the SSS partitioning method, effective calculations of the method for studying mechanical fields in bar structures and pipelines on saline soil bases are constructed. It is shown that the neglect of physical nonlinearity and rheological characteristics of soil deformation leads to quantitative errors in the assessment of the stress of structures up to 50% and then to a qualitatively incorrect description of the deformation near the support fastenings.

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