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Calculation of Pipeline Branches With Considering Nonlinearity of Elastic Base

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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. 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.

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

Introduction

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 of the volume strain ε:

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

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

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

1. Materials and methods

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, it was 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

$$p = -k_1 w_0 - k_2 w^3 + C\left[2w\left(\frac{dw}{dx}\right)^2 + w^2\frac{d^2w}{dx^2}\right] + t_1\frac{d^2w}{dx^2} + t_2\left(\frac{dw}{dx}\right)^2\frac{d^2w}{dx^2} \tag{9}$$

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, when taking into account the nonlinearity of elastic behavior, 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 that decay 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

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

Coinciding up to the notation, the relation for the ground state 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

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

Then for wke 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

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

$$w_{кэ}^{'} = Q_0$$

$$EJw_{кэ}^{''} = M^*$$

Or

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

$$y = \frac{w^0}{w_0} - 1 \quad \text{or} \quad y''' - 2\tau_*^2 y' - \varepsilon\left[y'\left\langle\frac{Q}{3}(y')^2 + \lambda y(2+y)\right\rangle\right] = \overline{Q} \tag{20}$$
$$y' = \frac{Q_0 l}{w_0} \quad \text{or} \quad y'' = \overline{M}$$

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 ($\overline{M} = \overline{Q} = 0$) the equation (18) with appropriate 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

$$y_0^{IV} - 2\tau_*^2 y_0'' + 4m_*^4 y_0 = 0 \tag{21}$$
$$y_1^{IV} - 2\tau_*^2 y_1'' + 4m_*^4 y_1 = \lambda\left[(y_0+2)y_0 y_0'' + (1+y_0)(y_0')^2\right] + \theta(y_0')^2 y_0'' - b y_0^2(3+y_0)$$

and the boundary conditions take the form

$$y_0 = \frac{w^0}{w_0} - 1 \quad \text{or} \quad y_0''' - 2\tau_*^2 y_0' = \overline{Q}$$
$$y_0' = \frac{Q_0 l}{w_0} \quad \text{or} \quad y_0' = \overline{M} \tag{22}$$
$$y_1 = 0 \quad \text{or} \quad y_1''' - 2\tau_*^2 y_1' = \frac{Q}{3}(y_0')^3 + \lambda y_0' y_0(2+y_0)$$
$$y_1' = 0 \quad \text{or} \quad y_1' = 0$$
$$\ldots \qquad \ldots \qquad \ldots$$

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

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

3. **Result and Discussion**

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

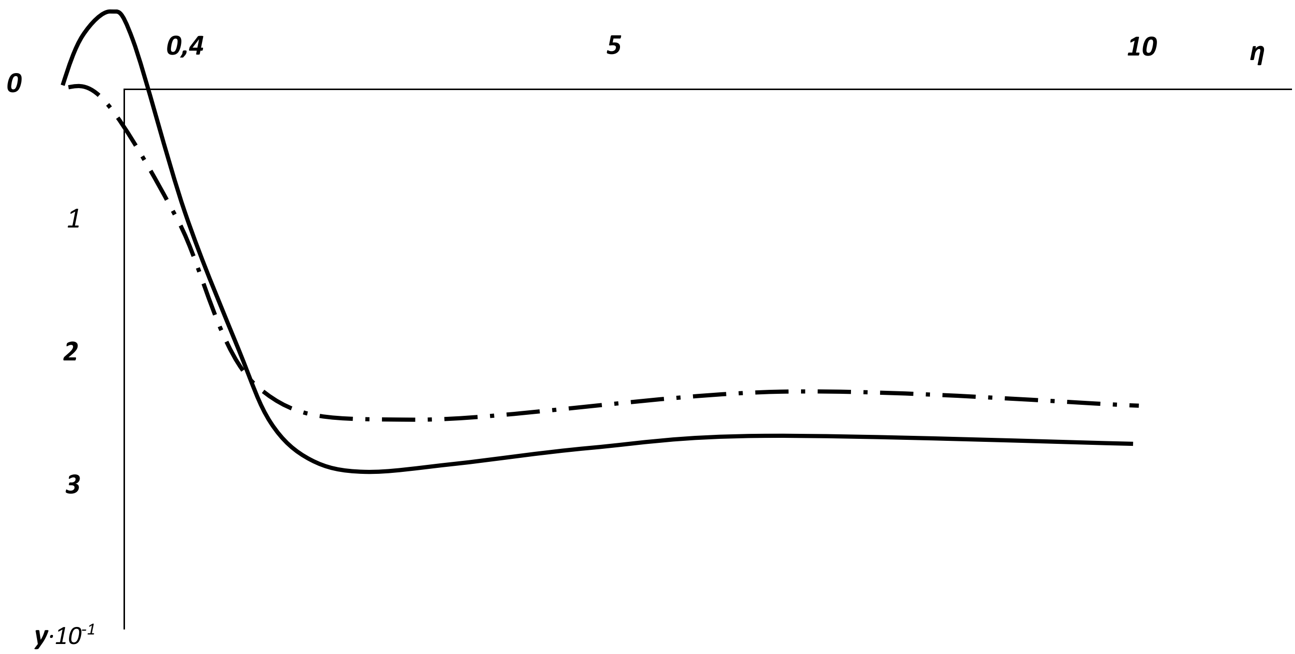
$$y_1 = e^{-\alpha\eta}\left(A_1' \cos\beta\eta + A_2' \sin\beta\eta\right) + e^{-2\alpha\eta}\left(C_2 + C_2^c \cos 2\beta\eta + C_2^s \sin 2\beta\eta\right) + $$
$$+ e^{3\alpha\eta}\left(C_3^{1c}\cos\beta\eta + C_3^{1s}\sin\beta\eta + C_3^{3c}\cos\beta\eta + C_3^{3s}\sin\beta\eta\right) \quad (26)$$

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 for functions of the same name, a A_1', A_2' are then found from the conditions (22).

4. Conclusions

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.



Rice. Dimensionless deflections in a semi-infinite beam. Application of the VAT splitting method.

References

1. Kuzmin S.E., Murzakhanov N.Kh., Ostonov T.K. Model of reactance of gypsum soils. - M.MGMI, 1989, supervisor dep. in VINITI 21.07.89, No. 4897-B89.
2. Mustafaev A.A. Deformations of saline soils in the foundations of structures. -M.; Stroyizdat, 1988. -290 p., ill.
3. Shulgin D.F. Questions of the dynamics of groundwater and salts in the soils of irrigated lands. Dissertation for the competition of the academic degree. doc. tech. Sciences. M., 1971.
4. Novichkov Yu.N., Kuzmin A.S. Models and methods of statics of layered elastocomposite shells.//Problems of mechanical engineering and automation, issue, 13.-M,-Budapest: ICSTI-Informelectro, 1987.-8s.
5. Aleksandrov A.V. Potapov V.D. Fundamentals of the theory of elasticity and plasticity. – M.: Higher school. 1990.-400 p.
6. Kamke E. Handbook of ordinary differential equations. – M.: Nauka, 1970.-580 p.
7. Shirinkulov T.Sh., Zaretsky Yu.K. Creep and consolidation of soils. - Tashkent. "Fan", 1986.-390 p.