INVESTIGATION OF THE INTERACTION OF TUNNEL STRUCTURES WITH GROUND MASSES UNDER THE INFLUENCE OF DYNAMIC LOADS

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Annotation: In this paper, the task is to calculate the VAT of the underground part of tunnel structures, taking into account the viscosity of the soil. The object of the study is tunnel structures located in an underground massif under the influence of a distributed load from the upper part of the building, the garage's own weight and the weight of the soil.

Keywords: Underground structure, pipeline, support structure, foundation, resource.

1. Introduction. Underground structures of the system are one of the main components of oil and gas and petrochemical production, therefore their safety largely depends on the technical condition of pipelines. Underground structures of the system of pumping and compressor units are in the most unfavorable operating conditions, since they experience significant vibration effects, both from the machines and from the transported medium. These effects have a complex nature and are caused by pressure pulsation, flow disruption, changes in the direction and speed of its movement, acoustic resonances, interaction of flows at the points of pipeline branching and other factors. In some cases, the vibration effect is transmitted to the supports of the structure through the soil [1,2,3,4]. Any structure is built on a soil foundation and has some parts located in the soil. Therefore, the strength, stability and normal operation of a structure are determined not only by its design features, but also by the properties of the soil and the conditions of interaction between the structure and the foundation. The cost of a foundation averages 12% of the cost of a structure, labor costs for its construction often reach 15% or more of the total costs, and the duration of work reaches 20% of the construction period. In difficult soil conditions, these indicators increase significantly. Therefore, the improvement of design and technological solutions in the field of foundation construction leads to significant savings in material and labor resources, and a reduction in the construction time of buildings and structures [5,6,7].

2. Application of the finite element method. The problem is solved numerically, using the finite element method. The basic idea of the finite element method is that continuous quantities (displacements, stresses, pressures, etc.) are approximated by a discrete model on a finite number of subdomains. For this purpose, a computational domain is allocated, which is discretized into a finite number of elements. These elements have common nodal points and together approximate the original computational domain. The continuous quantity is approximated on each element through the nodal values using interpolation polynomials. Interpolation polynomials are used to approximate continuous functions in mathematical equations describing the physical process being studied. Then the discrete model constructed in this way must satisfy the boundary (boundary and initial) conditions of the problem. These conditions are satisfied using various approaches known in FEM. Discretization of the computational domain S into elements is the first step towards solving the problem. This step is very important, since poor or imperfect discretization can lead to erroneous results. When choosing discretization, the main attention is paid to the following rules: - finer discretization should be carried out in areas where large gradients of quantities are expected, and in places where the boundary of the computational domain changes; - to achieve rational numbering of elements and nodes of the discretized domain, it is necessary to use sequential numbering of nodes when moving in the direction of the smallest body size. After the discretization of the computational domain is carried out, the calculation parameters are selected and entered into the program, it is possible to obtain a solution to the selected class of problems. It is necessary to test the solution to the problem on a model problem for this class of problems. After the problem is tested, it is possible to proceed to complicating the computational domain, boundary conditions, etc. The smaller the differences in the model problem and the specific technical problem, the greater the reliability of the obtained solution. Therefore, the need for rigorous analytical solutions will always be relevant. Any calculation should be duplicated by a calculation with a finer discretization of the computational domain. Depending on the difference in the results of such comparative calculations with a continuous value, one can judge the ratio of the obtained results of the calculation scheme used. For a numerical solution to the problem, it is necessary to introduce O0, which is a finite part of the half-space P, i.e. it is necessary to pose and solve problems for a finite region

$$\Omega = \Omega_1 + \Omega_2 + \Omega_0 \,. \qquad (1)$$

Let us consider linear oscillations of an elastic half-space containing a rectangular obstacle under the influence of a harmonic wave. The physical properties of the soil are described quite accurately by a model of homogeneous elastic soil taking into account viscosity. Therefore, it is assumed that the total deformation consists of elastic deformation and viscous deformation (creep): $\varepsilon = \varepsilon^e + \varepsilon^c$. Soil creep is taken into account according to the flow theory [8] in the form $\dot{\varepsilon}_{ij}^c = \sigma_i^n B \sigma_{ij}$, where $\dot{\varepsilon}_{ij}^c$ – creep rate, σ_i^n – stress intensity, B – creep matrix, σ_{ij} – voltage.

3. Mathematical formulation of problems. For the mathematical formulation of problems, the principle of possible displacements was used, according to which the sum of the work of active and mass forces acting on the system, with possible displacements, is equal to zero.

$$\begin{aligned} \delta A = &- \int_{\Omega_0} \sigma_{ij}\delta\varepsilon_{ij} d\Omega - \int_{\Omega_1} \sigma_{ij}\delta\varepsilon_{ij} d\Omega - \int_{\Omega_2} \sigma_{ij}\delta\varepsilon_{ij} d\Omega - \\ &- \int_{\Omega_0} \rho_0 \ddot{\vec{U}}\delta\vec{U} d\Omega - \int_{\Omega_1} \rho_1 \ddot{\vec{U}}\delta\vec{U} d\Omega - \int_{\Omega_2} \rho_2 \ddot{\vec{U}}\delta\vec{U} d\Omega + \\ &+ \int_{1_1 + {}_2 + {}_3} \sigma_{ij} v_j \delta u d \quad + \int_{\Omega 2} \vec{f}\delta\vec{v} d\Omega + \int_{2} \vec{p}\delta\vec{U} d \quad = 0 \end{aligned} \qquad (2)$$

Here $\vec{U}$, $\sigma_{ij}, \varepsilon_{ij}$ - displacement vectors, components of stress and strain tensors; $\delta \vec{U}$; $\delta\varepsilon_{ij}$- variations of displacements and deformations; ρ_1, ρ_2, ρ_3 – density of the material of the elements of the system under consideration, νJ – direction cosines of the outer normal; $\vec{f}$ - vector of mass forces; $\vec{p}$ 1- vector of external forces applied to the area $_2$. To solve the problem (2), boundary and initial conditions are required, which are automatically satisfied in the variational formulation. In the absence of external influences, the natural oscillations of the mechanical system are considered.

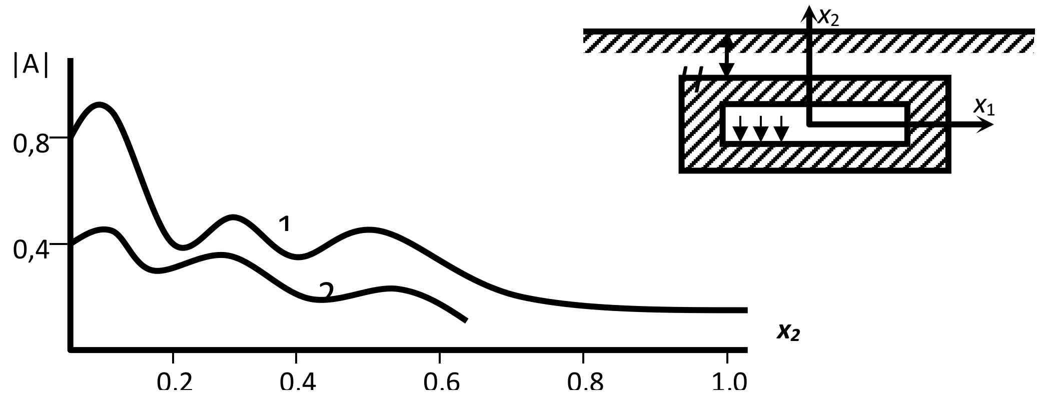


Fig. 1. Change in the amplitude of displacements from the coordinate.

In this case, solutions (2) are sought in the form

$$\vec{U}(\vec{x},t)=\vec{U}^{*}(\vec{x})\exp(-i\omega t)$$

Where $\omega=\omega_R-i\omega_I$ и $\vec{U}^{*}=\vec{U}_R^{*}-iU_I^{*}$ - complex quantities.

The mathematical formulation of the problem of natural oscillations includes variational equations (1), which are written in the form

$$\delta A=-\int_{\Omega}\sigma_{ij}\delta\varepsilon_{ij}\,d\Omega-\int_{\Omega}\rho_n\ddot{\vec{U}}\delta\vec{U}\,d\Omega=0\,. \qquad (3)$$

It is necessary to find *w* and its corresponding proper form $\vec{U}^{*}$, satisfying equation (3) for any $\delta\vec{U}^{*}$.

If a harmonic wave acts on the hole, then the displacements $\vec{U}$ points (selected area) are sought in the form of a sum [3,4].

$$\vec{U}(\vec{x},t)=\vec{U}_0(\vec{x},t)+\vec{U}^{*}(\vec{x},t), \qquad (4)$$

Where $\vec{U}_0(\vec{x},t)$ - displacements that need to be determined.

The problem statement for the desired function includes a variational equation

$$-\int_{\Omega}\sigma^{*}_{ij}\delta\varepsilon_{ij}\delta\Omega_1-\int_{\Omega_1}\sigma_{ij}\delta\varepsilon_{ij}\delta\Omega-\int_{\Omega_2}\sigma_{ij}\delta\varepsilon_{ij}d+\omega^2\int_{\Omega_1}\rho_1^{11}U^{*}\delta U d\Omega+\omega^2\int_{\Omega_2}\rho_2^{11}U\delta U d\Omega-$$

$$-i\omega \int_{x+\,_3+\,^1_3+\,_1} \sigma^{*}_{ij} v_j \delta u^{*}_j d \quad \int_{3} \vec{\rho}_1 \delta\vec{U} d \quad = 0 , \tag{5}$$

radiation conditions at $\vec{x} \quad {}_3 u \quad {}^1_3 : \quad \dfrac{d\vec{U}^*}{dx_1} \pm \dfrac{i\vec{U}^*}{c} = 0$ (6)

$$\vec{x} \quad {}^1_1 \quad \vec{U} = 0$$

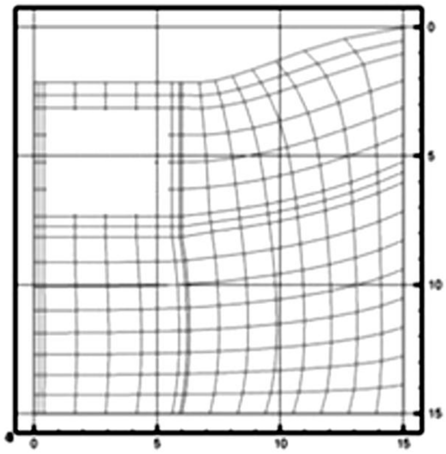
It is necessary to determine a time-periodic solution of the variational problem (6) that satisfies the boundary conditions for any δŪ*. To solve the initial boundary value problem (1) – (6), we use the FEM formed in displacements.

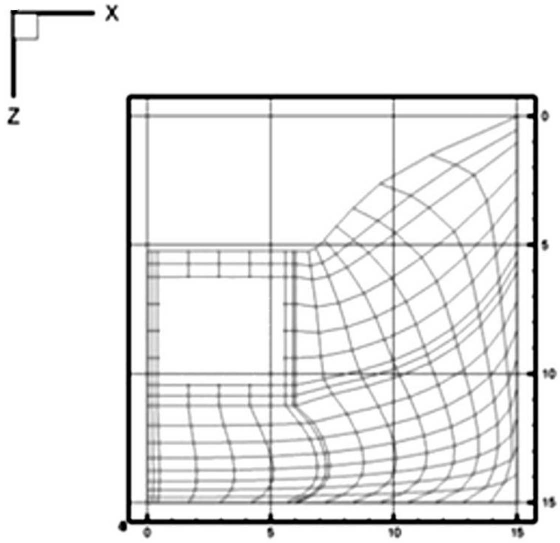
4. Natural oscillations of piecewise homogeneous deformable systems taking into account internal and wave energy dissipation. Let us consider natural oscillations of a medium in the presence of a cylindrical hole. The mathematical formulation of the problem of natural oscillations includes variational equations, which are written in the form

$$\delta A = -\int_{\Omega} \sigma_{ij} \delta\varepsilon_{ij} dv + \omega^2 \int_{\Omega} \rho_1 u \, \delta U d\Omega = 0 \tag{24}$$

Table 1

Researcher	Number of nodes	Frequency ω ᵢ i (rad/sec)					
		1	2	3	4	5	6
I.A.Konstantinov	25	29,73	68,42	79,94	124,21	156,14	173,52
	36	29,1	68,01	75,33	122,21	152,43	176,00
	144	1441	68,43	73,61	114,23	161,47	168,83
L.A.Rozin	144	27,53	68,45	73,67	114,4	161,47	168,63
Author of the work	144	27,45	64,88	73,87	125,37	161,41	173,41
	78	28,56	66,75	77,79	121,72	187,8	188,22
	45	28,67	69,39	76,17	131,8	166,4	207,11





Picture. 2 Picture. 3

Using the developed FEM algorithm, the variational problem (6) is reduced to a complex algebraic eigenvalue problem

$$([k]-i\omega[c]-\omega^2[m])\{q\} = 0, \qquad (7)$$

where [M], [C], [K] are respectively the mass mattresses, damping stiffness of the system; {q} are the displacement vectors; To determine the natural frequencies of oscillations, it is necessary to find the natural values, which are the roots of the frequency equations (7). All natural values can be determined using the iterative Muller method [1]. The iterative Muller method is a quadratic interpolation scheme that provides rapid convergence in the vicinity of the root of the solution even with a rough first approximation. The reliability of the approach to finding natural frequencies adopted in the work is shown by the example of the problem of oscillations of a plate in the form of a right triangle 100 m long and a base 75 m long, considered by I.A. Konstantinov and L.A. Rozin (Table 1). It is also shown that the values of the oscillation frequencies become stable at a number of nodes of 60-80; further increase in the number of nodes does not lead to a significant refinement of the frequencies, although significant machine time is spent. As an example, let us consider the natural oscillations of a cylindrical layer located in an elastic medium. The problem is reduced to solving a system of homogeneous algebraic equations (7). From the condition of existence of a solution of homogeneous algebraic equations, it should be determined that equations (7) must be equal to zero. The frequency equation is solved by the Muller method, and the value of the left-hand side of (6) at each iteration is determined by the Gauss method with the selection of the main element. If we assume that $\upsilon_1=\upsilon_2$, $\rho_1=\rho_2$, $E_1=E_2$ we obtain the results of calculations of natural frequencies of oscillations of a cylindrical hole in an elastic medium. The obtained results coincide with the results obtained in work [1] with a difference of up to 10% (N=150, v=0.20). Fig. 2 and Fig. 3 present some calculation results - pictures of the deformed state of half of the object, obtained without taking into account creep and with taking into account the viscosity (creep) of the soil. Analysis of the results of calculating the SSS of the underground garage model without taking into account and with taking into account soil creep allows us to draw the following conclusions:

- when taking into account soil creep, the movements of the study object increase significantly;

- taking into account creep leads to a significant change in the stress state of the object.

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