ELASTIC WAVES IN SOILS DURING ROTATIONAL MOVEMENT OF UNDERGROUND PIPELEINE

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Abstract. *The article reviews the propagation of elastic waves in soils during rotational movement of underground pipeline. One-dimensional cylindrical shear waves are discussed and solution methods are developed that allows the application arbitrary loads on the boundary. Based on the publication the numerical calculation program was compiled. The calculation results displayed that when underground pipeline moves single direction, the stress increase, a reverse pattern was obtained, the stress decreases. Attenuation of waves with distance is due to the fact that deformation energy is dissipated into an expanding cylindrical layer of soil.*
Keywords: *soil, underground pipeline, cylindrical wave, sections, wave parameters.*

1. Introduction

Underground structures, particularly underground pipelines are involved in movement due to the forces (stresses) arising on their surface interacting with soil. The value of these stresses and the movement of the pipeline itself are determined by the process that occurs in the soil around the pipeline. Therefore, to solve problems of seismic stability of underground structures and for the "soil medium–pipeline" system, it is necessary to study the dynamic behavior in the soil environment surrounding the underground pipeline, taking into wave processes. The need for such a formulation to obtain reliable results when solutions applied problems of seismic stability of underground pipelines have mentioned in [1–3].

Considering wave processes in the soil medium when solving problems of seismic stability of underground structures for the "soil medium–pipeline" system significantly complicates the mathematical formulation of applied problems. However, thanks to effective numerical methods for solving complex systems of partial differential equations that describe wave processes in the "soil medium–pipeline" system and the possibility of their realization, as well as modern powerful computers become possible to obtain solutions to applied problems.

According to [4], using a finite element model of beam elements for the pipeline and nonlinear springs for the soil, the ability of the considered "soil medium–pipeline" model system to resist reverse fault movement was investigated. The results obtained in [5], it devotes to the safety of underground steel natural gas pipelines. The formation of bulging of main gas pipelines during earthquakes was studied in [6].

During solving problems of seismic stability of underground structures [1, 2–6, 7–8], the main attention is focused to the movement and vibrations of the underground pipeline. It is obvious that the stress-strain state of the soil around the pipeline operates a significant and sometimes decisive role in the formation of the stressed state of the pipeline [1, 2].

The purpose of the work is to develop a numerical solution method that makes it possible to apply arbitrary loads on the boundary and complex deformation properties, as well as to study the behavior of soils around underground pipelines during the propagation of one-dimensional elastic soil waves.

2. Research methods

During solving problems, finite-difference methods were used [9]. Thus, the parameters of the wave propagation in the soil medium until the required moment in time have been determined. A program for solving the problem was compiled and graphs of the wave parameters were presented.

3. Statement of the Problem

There is a fairly long and rigidly fixed underground pipeline with an outer radius $r = r_0$ in the unbounded elastic soil medium.

Let the underground pipeline begin to rotate around its axis from the beginning of the time, while neglecting the deformation of the pipeline, meaning we consider it absolutely non-deformable. Then cylindrical shear waves begin to propagate in the soil medium, the parameters of these waves are axisymmetric relative to the pipeline axis and they depend on the radial coordinate and time, i.e. the problem is one-dimensional.

Therefore, we consider a one-dimensional problem in a cylindrical coordinate system [10]. The equation of ground motion in the absence of body forces in the Euler representation has the following form:

$$\rho^0 \frac{dv_\varphi}{dt} = \frac{\partial \tau_{r\varphi}}{\partial r} + \frac{2\tau_{r\varphi}}{r}. \quad (1)$$

where r is the radial coordinate, $v_\varphi = du_\varphi/dt$ is the velocity of soil particles, $u_\varphi = u_\varphi(r,t)$ is movement of soil particles along a cylindrical coordinate, $\tau_{r\varphi} = \sigma_{r\varphi}(r,t)$ is the soil shear stress along the radial coordinate.

Let us add the Cauchy relation in the form

$$\frac{d\varepsilon_{r\varphi}}{dt} = \frac{\partial v_\varphi}{\partial r} + \frac{2v_\varphi}{r}. \quad (2)$$

To obtain a closed system of equations, it is necessary to add the equation of state into (1)-(2):

$$\dot{\tau}_{r\varphi} = G\dot{\varepsilon}_{r\varphi} = G\frac{\partial \dot{v}_\varphi}{\partial r}. \quad (3)$$

Thus, the closed system of equations consists of equations (1)–(3) for the unknowns $v_\varphi(r,t)$, $\tau_{r\varphi}(r,t)$ and $\varepsilon_{r\varphi}(r,t)$. To solve this system of equations, we accept the following initial conditions:

for $t = 0, \quad r > r_0$:

$$v_\varphi(r,0) = 0, \quad \tau_{r\varphi}(r,0) = 0, \quad \varepsilon_{r\varphi}(r,0) = 0 \quad (4)$$

and boundary conditions: for $r = r_0, \quad t \geq 0$:

$$v_\varphi(r_0,t) = v_0(t) \text{ или } \tau_{r\varphi}(r_0,t) = \tau_0(t). \quad (5)$$

4. Numerical results and their analysis

We solve the problem posed numerically using the finite difference method.

Let us present the numerical results in the form of graphs. Solutions were obtained with the following initial density of soil - ρ^0 =2000 kg/m^3; velocity of longitudinal and transverse wave propagation - c_P =2000 m/s and c_S =1000 m/s; outer radius of the underground pipeline - r_0 =1 m. Let the particle velocities (6) be given at the boundary in the form

$$v_0(t) = v_{max}\sin(\omega t), \quad (6)$$

where v_{max} =0.2 m/s, ω is the frequency of the pipeline motion.

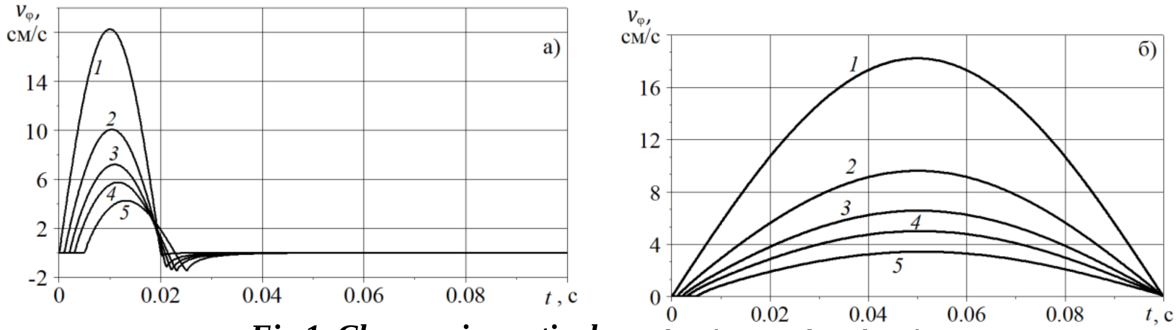

Fig.1. Changes in particular velocity v_φ of soil in time

Figures 1–2 show changes in particle velocity $v_\varphi(t)$ and shear stress $\tau_{r\varphi}(t)$ in fixed cylindrical soil layers at different impact frequencies. Curves 1–5 correspond to sections r=1.1, 2, 3, 4 and 6 m. Graphs a) and b) in the figures were obtained at $\omega = 2\pi$, $\omega = 10\pi$, $\omega = 20\pi$ and ω =50π rad/s. As can be seen from Fig.1 and Fig.2, in the case of setting the shear velocity at the boundary $r = r_0$, the amplitude of the values of the particle velocity v_φ and the shear stress $\tau_{r\varphi}$ decreases. These decreases (attenuation) occur at the first arrival of the wave; then, in fixed sections, attenuation over time is not observed.

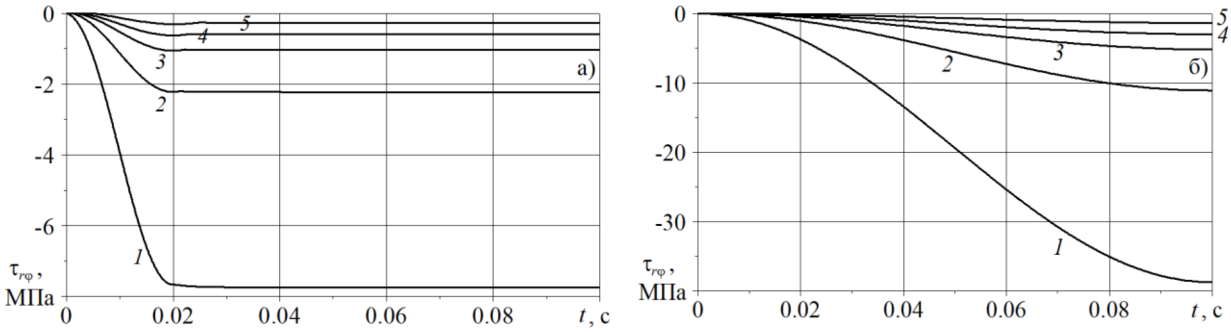

Fig.2. Changes in particle shear stress $\tau_{r\varphi}$ in time

Figure 3 shows changes in displacements of the soil over time $u_\varphi(t)$ in the same considered fixed sections at $\omega = 2\pi$ s with a limited action time (6) T =0.02 s.

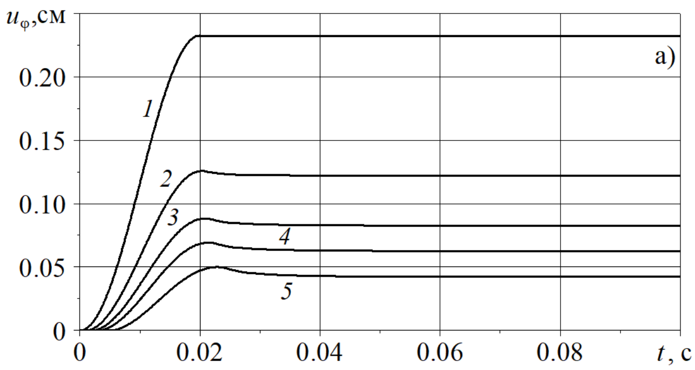

Fig.3. Changes displacements u_φ in time: curves 1–5 correspond to sections r =1.1, 2, 3, 4 and 6 m

Let us consider, when shear stress (5) is specified at the boundary $r = r_0$. Fig.4–5 show dependences similar to Fig.1–3 when setting following form

$$\tau_0(t) = \tau_{max}\sin(\omega t), \qquad (7)$$

where τ_{max} =0.2 MPa. The graphs of changes in particle velocities $v_\varphi(t)$, shear stresses $\tau_{r\varphi}(t)$ and displacements $u_\varphi(t)$ are also analogous to those shown in Fig.1–3. Here, wave attenuation with distance from the initial cylindrical section is also observed. At the first arrival of the wave, the particle velocity v_φ rises to a maximum value and changes in time similarly to the previous results.

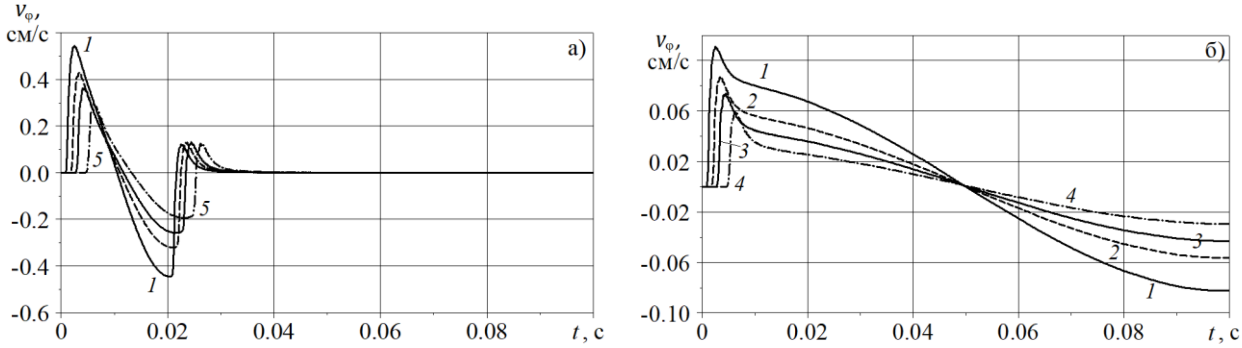

Fig.4. Changes particle velocities v_φ in time: curves 1–5 correspond to sections r =1.1, 2, 3, 4 and 6 m

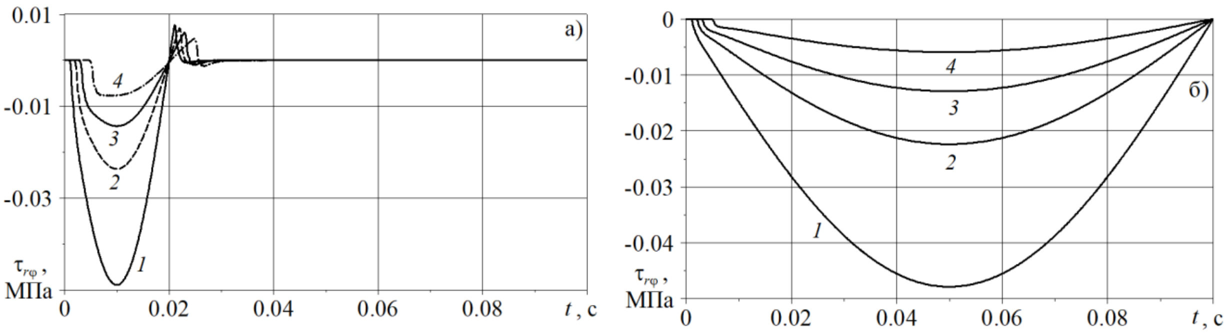

Fig.5. Changes shear stresses $\tau_{r\varphi}$ in time: curves 1–4 correspond to sections r =1.1, 2, 3 and 4 m

In general, during elastic deformation of soil, a cylindrical wave attenuates with distance and energy dissipation does not occur.

4. Conclusion

During rotation of pipeline in elastic soils, a problem was set and a numerical technique for solving the problem posed using the method of finite differences. As a result of numerical calculations, graphs that changes in wave parameters were obtained. Analysis of the graphs showed that with a positive value of the particle velocity, meaning when moving in one direction, the shear stress increases. In reverse movement (with a negative particle velocity), the stresses decrease (the stress state is unloaded). An increase in the frequency of the specified particle velocity at the boundary reduces the period of “load-unload” oscillations, which shows a decrease in the maximum values of shear stresses. In this case, the periodic frequency of the propagating wave does not change. The energy dissipation occurs on a cylindrical layer, which expands with distance and this causes the attenuation of waves.

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