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DYNAMIC CALCULATION OF PIPELINES SHALLOW BASIS ON THE BASIS OF THE THIN SLIM THEORY

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ABSTRACT
The article gives the basics of the methodology for calculating the action of moving loads of extended underground swan structures, taking into account the influence of the earth’s surface. On elastic models, the dynamic stress-strain state of unreinforced and reinforced cylindrical structures with different depths is considered.

KEY WORDS: load, underground, pipelines, shell surface, depth of laying, dynamic behavior.

INTRODUCTION
In the world, the construction of modern transport tunnels using new fundamental solutions for tunnel lining, the improvement of methods for calculating their strength and durability, as well as the application of advanced technologies and technical design tools to them, occupies leading positions. Extensive development of the construction of underground pipelines, received the development of the late 20th century 1. Predicted estimates of the behavior of tunnel structures under seismic and dynamic loads require their dynamic calculation of □2.3□. Among the dynamic loads and impacts on underground tunnel structures in the form of tunnels, (operational) mobile loads and impacts should be distinguished blast waves of natural or artificial origin.
To assess the deformed state of underground tunnel structures when they move, the load is an urgent task 4.5. A tunnel loaded with a stream of seismic or external pressures, placed in a routing medium, is a complex system whose behavior has not been fully studied. We give examples of works related to our article and describing linear systems. In the classical works [6,7], the foundations of the study of unsteady effects in pipelines were laid. In [8], the stress state of shells in a fluid and gas flow was studied. Articles [9, 10] are devoted to the study of fluid flow in a blood vessel. In the study of the stress state of shells of large radius, a computational algorithm was developed to solve a system of ordinary differential equations with complex coefficients. Based on the proposed mathematical models and the algorithm for calculating tunnel structures, programs have been developed. The aim of this work is to formulate the problem and build a solution to the linear problem under the influence of sublingual loads. The results of calculations of such problems are used to calculate the elements of the nuclear energy facility, in the aircraft industry, the oil and gas industry, in chemical production facilities, in water supply systems for residential buildings and others.

FORMULATION OF THE PROBLEM
Let a circular cylindrical tunnel in an elastic deformable array be supported (or not supported) by a lining. The main geometric parameters are shown in Fig. 1. The task is posed in Cartesian coordinate systems x, y,

z. On the inner surface of the tunnel lining, a stationary load P acts, moving with a constant subsonic speed c in the direction of the Z axis.

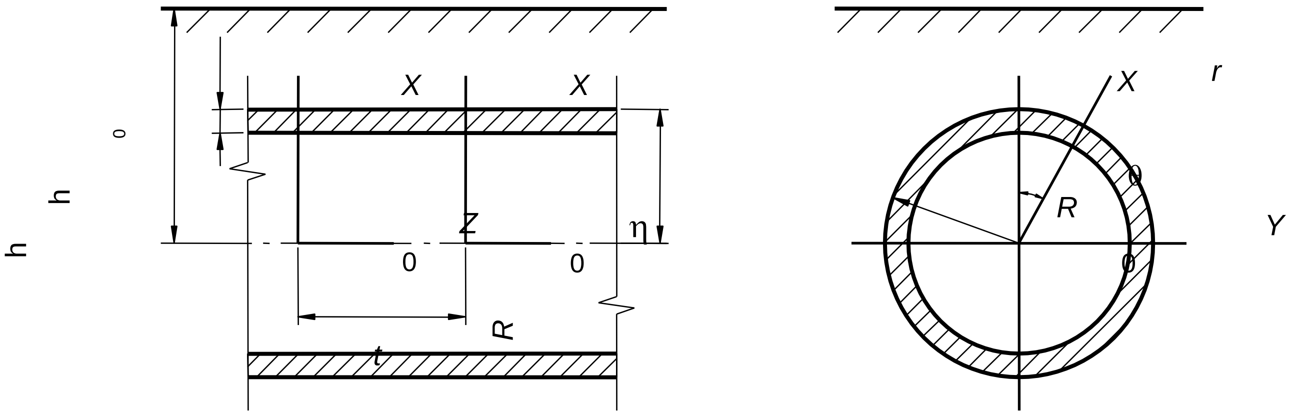

Figure 1 - Design diagram of the reinforced tunnel and underground pipeline

It is assumed that a stationary load acts inside the cylindrical body. As given at work (4.5), the multiplier $e^{-i\omega t}$ (Where i- imaginary number, frequency forced load, t-time) omit everywhere. The thickness of the reinforced tunnel h0 (Figure 1).

To describe the dynamic behavior of a cylindrical reinforced tunnel structure, we use the classical equations of the theory of thin elastic shells in spatial coordinates.

$$\frac{\partial^2 u_{0z}}{\partial z^2}+\frac{1-\nu_0}{2R^2}\frac{\partial^2 u_{0z}}{\partial\theta^2}+\frac{1+\nu_0}{2R}\frac{\partial^2 u_{0\theta}}{\partial z\partial\theta}+\frac{\nu_0}{R}\frac{\partial u_{0r}}{\partial z}-\rho_0\frac{1-\nu_0}{2\mu_0}\frac{\partial^2 u_{0z}}{\partial t^2}-\frac{1-\nu_0}{2\mu_0 h_0}\left(P_z-q_z\right)=0,$$

$$\frac{1+\nu_0}{2R}\frac{\partial^2 u_{0z}}{\partial z\partial\theta}+\frac{\left(1-\nu_0\right)}{2}\frac{\partial^2 u_{0\theta}}{\partial z^2}+\frac{1}{R^2}\frac{\partial^2 u_{0\theta}}{\partial\theta^2}+\frac{1}{R^2}\frac{\partial u_{0r}}{\partial\theta}-\rho_0\frac{1-\nu_0}{2\mu_0}\frac{\partial^2 u_{0\theta}}{\partial t^2}-\frac{1-\nu_0}{2\mu_0 h_0}\left(P_\theta-q_\theta\right)=0,$$

$$\frac{\nu_0}{R}\frac{\partial u_{0z}}{\partial z}+\frac{1}{R^2}\frac{\partial u_{0\theta}}{\partial\theta}+\frac{h_0^2}{12}\nabla^2\nabla^2 u_{0r}+\frac{u_{0r}}{R^2}+\rho_0\frac{1-\nu_0}{2\mu_0}\frac{\partial^2 u_{0r}}{\partial t^2}+\frac{1-\nu_0}{2\mu_0 h_0}\left(P_r-q_r\right)=0\,, \qquad (1)$$

где u_{0z}, $u_{0\theta}$, u_{0r} – components of the mixing vector of the points of the middle surface of the lining :P_z, P_θ, P_r – moving load vector components P; $q_z=\sigma_{rz}\big|_{r=R}$, $q_\theta=\sigma_{r\theta}\big|_{r=R}$, $q_r=\sigma_{rr}\big|_{r=R}$ – reaction components: μ_0, ν_0, ρ_0– respectively, the shear modulus, Poisson's ratio and density of the lining material.

To solve the problem, a movable coordinate system is used, then the equation of motion of the shell (lining) takes the following form

$$\left[\frac{2\mu_0-\left(1-\nu_0\right)\rho_0 c^2}{2\mu_0}\right]\frac{\partial^2 u_{0\eta}}{\partial\eta^2}+\frac{1+\nu_0}{2R}\frac{\partial^2 u_{0\theta}}{\partial\eta\partial\theta}+\frac{1-\nu_0}{2R^2}\frac{\partial^2 u_{0\eta}}{\partial\theta^2}+\frac{\nu_0}{R}\frac{\partial u_{0r}}{\partial\eta}-\frac{1-\nu_0}{2\mu_0 h_0}\left(P_\eta-q_\eta\right)=0,$$

$$\frac{\left(1-\nu_0\right)}{2}\left(\frac{\mu_0-\rho_0 c^2}{\mu_0}\right)\frac{\partial^2 u_{0\theta}}{\partial\eta^2}+\frac{1+\nu_0}{2R}\frac{\partial^2 u_{0\eta}}{\partial\eta\partial\theta}+\frac{1}{R^2}\frac{\partial^2 u_{0\theta}}{\partial\theta^2}+\frac{1}{R^2}\frac{\partial u_{0r}}{\partial\theta}-\frac{1-\nu_0}{2\mu_0 h_0}\left(P_\theta-q_\theta\right)=0, \quad (2)$$

$$\frac{h_0^2}{12}\nabla^2\nabla^2 u_{0r}+\frac{\left(1-\nu_0\right)\rho_0 c^2}{2\mu_0}\frac{\partial^2 u_{0r}}{\partial\eta^2}+\frac{u_{0r}}{R^2}+\frac{\nu_0}{R}\frac{\partial u_{0\eta}}{\partial\eta}+\frac{1}{R^2}\frac{\partial u_{0\theta}}{\partial\theta}+\frac{1-\nu_0}{2\mu_0 h_0}\left(P_r-q_r\right)=0\,.$$

The motion of half-space is described by the dynamic equations of the theory of elasticity in Lame potentials. Consider two cases of conjugation of the shell with the environment: rigid and sliding. In these cases, the boundary conditions in moving coordinate systems have the form:

$$\sigma_{rj}\big|_{r=R}=0,\quad u_r\big|_{r=R}=u_{0r};\qquad j=\eta,\theta;\quad (3,a)$$

$$u_j\big|_{r=R}=u_{0j},\; j=\eta,\theta,r\,. \qquad (3,б)$$

Thus, in this formulation, to determine the components of the stress-strain state of the environment, it is necessary to solve equations (1) - (3) taking into account the boundary conditions.

Let the shell be affected by a rolling load P, periodic in the оси axis.
$q_j(\theta,\eta)-Q_j(\theta)e^{i\xi\eta}=0,\quad Q_j(\theta)-\sum_{n=-\infty}^{\infty}q_{nj}e^{in\theta}=0$, (4)

$u_{0j}(\theta,\eta)-U_{0j}(\theta)e^{i\xi\eta}=0,\quad U_{0j}(\theta)-\sum_{n=-\infty}^{\infty}u_{0nj}e^{in\theta}=0,\quad j=r,\theta,\eta$.

If we substitute the found formulas (4) (for the nth term of the expansion) with the basic equations, then we obtain a system of algebraic equations $-\varepsilon_1^2u_{0n\eta}-\nu_{02}n\xi_0u_{0n\theta}+2i\nu_0\xi_0u_{0nr}=-G_0(-P_{n\eta}+q_{n\eta})$,

$$2inu_{0nr}-\nu_{02}n\xi_0u_{0n\eta}-\varepsilon_2^2u_{0n\theta}-2inu_{0nr}=-G_0(-P_{n\theta}+q_{n\theta}), \qquad (5)$$

$$2inu_{0n\theta}+2i\nu_0\xi_0u_{0n\eta}+\varepsilon_3^2u_{0nr}=G_0(P_{nr}-q_{nr}),$$

где $\varepsilon_1^2=\alpha_0^2-\varepsilon_0^2,\ \varepsilon_2^2=\beta_0^2-\varepsilon_0^2,\ \varepsilon_3^2=\gamma_0^2-\varepsilon_0^2,\quad \xi_0=\xi R,$

$\alpha_0^2=2\xi_0^2+\nu_{01}n^2,\ \beta_0^2=\nu_{01}\xi_0^2+2n^2,\ \gamma_0^2=\chi^2(\xi_0^2+n^2)^2+2,\ \varepsilon_0^2=\nu_{01}\xi_0^2M_{s0}^2,$

$\nu_{01}=1-\nu_0,\ \nu_{02}=1+\nu_0,\ M_{s0}=c/c_{s0},\ c_{s0}=\sqrt{\frac{\mu_0}{\rho_0}},\ \chi^2=\frac{h_0^2}{6R^2},\ G_0=-\frac{\nu_{01}R^2}{\mu_0h_0}$. $u_{0n\eta}$, $u_{0n\theta}$, u_{0nr}

$$u_{0n\eta}=\frac{G_0}{\delta_n}\sum_{j=1}^{3}\delta_{\eta j}(P_{nj}-q_{nj}),$$

$$u_{0n\theta}=\frac{G_0}{\delta_n}\sum_{j=1}^{3}\delta_{\theta j}(P_{nj}-q_{nj}),$$

$$u_{0nr}=\frac{G_0}{\delta_n}\sum_{j=1}^{3}\delta_{rj}(P_{nj}-q_{nj}). \qquad (6)$$

$$\delta_n=\delta_{|n|}=(\varepsilon_1\varepsilon_2\varepsilon_3)^2-(\varepsilon_1\xi_1)^2-(\varepsilon_2\xi_2)^2-(\varepsilon_3\xi_3)^2+2\xi_1\xi_2\xi_3,$$

$$\delta_{\eta1}=(\varepsilon_2\varepsilon_3)^2-\xi_1^2,\quad \delta_{\eta2}=\xi_1\xi_2-\xi_3\varepsilon_3^2,\quad \delta_{\eta3}=i(\varepsilon_2^2\xi_2-\xi_1\xi_3),$$

$$\delta_{\theta1}=\delta_{\eta2},\quad \delta_{\theta2}=(\varepsilon_1\varepsilon_3)^2-\xi_2^2,\quad \delta_{\theta3}=i(\varepsilon_1^2\xi_1-\xi_2\xi_3),$$

$$\delta_{r1}=-\delta_{\eta3},\quad \delta_{r2}=-\delta_{\theta3},\quad \delta_{r3}=(\varepsilon_1\varepsilon_2)^2-\xi_3^2,$$

$$\xi_1=2n,\quad \xi_2=2\nu_0\xi_0,\quad \xi_3=\nu_{02}\xi_0n,$$

Substituting the corresponding expressions from (1), (2), (3) into (4), (5), we obtain the following boundary conditions in the potentials of displacements: For a sliding contact, for r = R

$$2\xi\frac{\partial\Phi_1}{\partial r}i+\frac{\xi}{r}\frac{\partial\Phi_2}{\partial\theta}i-\xi^2(1+m_S^2)\frac{\partial\Phi_3}{\partial r}=0,$$

$$\frac{2}{r}\frac{\partial^2\Phi_1}{\partial\theta\partial r}-\frac{2}{r^2}\frac{\partial\Phi_1}{\partial\theta}+\frac{1}{r^2}\frac{\partial^2\Phi_2}{\partial\theta^2}-\frac{\partial^2\Phi_2}{\partial r^2}+\frac{1}{r}\frac{\partial\Phi_2}{\partial r}+\frac{2\xi}{r}\frac{\partial^2\Phi_3}{\partial r\partial\theta}i-\frac{2\xi}{r^2}\frac{\partial\Phi_3}{\partial\theta}i=0, \qquad (7,a)$$

$$\frac{\partial\Phi_1}{\partial r}+\frac{1}{r}\frac{\partial\Phi_2}{\partial\theta}+\xi\frac{\partial\Phi_3}{\partial r}i=G_0\sum_{n=-\infty}^{\infty}\left(\sum_{j=1}^{3}\frac{\delta_{rj}}{\delta_n}P_{nj}-\frac{\delta_{r3}}{\delta_n}q_{nj}\right)e^{in\theta};$$

r = R

$$\frac{1}{r}\frac{\partial\Phi_1}{\partial\theta}-\frac{\partial\Phi_2}{\partial r}+\frac{\xi}{r}\frac{\partial\Phi_3}{\partial\theta}i-G_0\sum_{n=-\infty}^{\infty}\sum_{j=1}^{3}\frac{\delta_{\theta j}}{\delta_n}\left(P_{nj}-q_{nj}\right)e^{in\theta}=0,\ \xi\Phi_1 i-\xi^2 m_S^2\Phi_3-G_0\sum_{n=-\infty}^{\infty}\sum_{j=1}^{3}\frac{\delta_{\eta j}}{\delta_n}\left(P_{nj}-q_{nj}\right)e^{in\theta}=0,$$

(7,б)

$$\frac{\partial\Phi_1}{\partial r}+\frac{1}{r}\frac{\partial\Phi_2}{\partial\theta}+\xi\frac{\partial\Phi_3}{\partial r}i-G_0\sum_{n=-\infty}^{\infty}\sum_{j=1}^{3}\frac{\delta_{\theta j}}{\delta_n}\left(P_{nj}-q_{nj}\right)e^{in\theta}=0.$$

$$\frac{\xi}{r}\frac{\partial\Phi_2}{\partial\theta}i+2\xi\frac{\partial\Phi_1}{\partial r}i-\xi^2\left(1+m_S^2\right)\frac{\partial\Phi_3}{\partial r}=0,$$

$$\frac{1}{r}\frac{\partial\Phi_2}{\partial r}+\frac{2\xi}{r}\frac{\partial^2\Phi_3}{\partial r\partial\theta}i-\frac{2\xi}{r^2}\frac{\partial\Phi_3}{\partial\theta}i+\frac{\xi}{r}\frac{\partial\Phi_2}{\partial\theta}i=0, \qquad (8,a)$$

$$\frac{\partial\Phi_1}{\partial r}+\frac{1}{r}\frac{\partial\Phi_2}{\partial\theta}+\xi\frac{\partial\Phi_3}{\partial r}i+G_0\frac{\delta_{r3}}{\delta_n}\sigma_{rr}/e^{i\xi\eta}-G_0\sum_{n=-\infty}^{\infty}\sum_{j=1}^{3}\frac{\delta_{rj}}{\delta_n}P_{nj}e^{in\theta}=0;$$

$$\xi\Phi_1 i-\xi^2 m_S^2\Phi_3+G_0\sum_{j=1}^{3}\frac{\delta_{\eta j}}{\delta_n}\sigma_{rj}/e^{i\xi\eta}-G_0\sum_{n=-\infty}^{\infty}\sum_{j=1}^{3}\frac{\delta_{\eta j}}{\delta_n}P_{nj}e^{in\theta}-0,$$

$$\xi\Phi_1 i-\xi^2 m_S^2\Phi_3+G_0\sum_{j=1}^{3}\frac{\delta_{\eta j}}{\delta_n}\sigma_{rj}/e^{i\xi\eta}-G_0\sum_{n=-\infty}^{\infty}\sum_{j=1}^{3}\frac{\delta_{\eta j}}{\delta_n}P_{nj}e^{in\theta}-0,$$

$$\frac{1}{r}\frac{\partial\Phi_1}{\partial\theta}-\frac{\partial\Phi_2}{\partial r}+\frac{\xi}{r}\frac{\partial\Phi_3}{\partial\theta}i+G_0\sum_{j=1}^{3}\frac{\delta_{\theta j}}{\delta_n}\sigma_{rj}/e^{i\xi\eta}-G_0\sum_{n=-\infty}^{\infty}\sum_{j=1}^{3}\frac{\delta_{\theta j}}{\delta_n}P_{nj}e^{in\theta}=0, \qquad (8,б)$$

$$\frac{\partial\Phi_1}{\partial r}+\frac{1}{r}\frac{\partial\Phi_2}{\partial\theta}+\xi\frac{\partial\Phi_3}{\partial r}i+G_0\sum_{j=1}^{3}\frac{\delta_{rj}}{\delta_n}\sigma_{rj}/e^{i\xi\eta}-G_0\sum_{n=-\infty}^{\infty}\sum_{j=1}^{3}\frac{\delta_{rj}}{\delta_n}P_{nj}e^{in\theta}=0.$$

A further solution to the problem is reduced to equations is reduced to a first-order differential equation together with the boundary conditions of a sliding contact (or with a hard contact). When calculating a reinforced tunnel or an underground pipeline on the impact of a local load, one should use formulas (4) if the speed of the load is less than its critical speeds and Rayleigh speed. Dispersion curves are solved by the Mueller method.

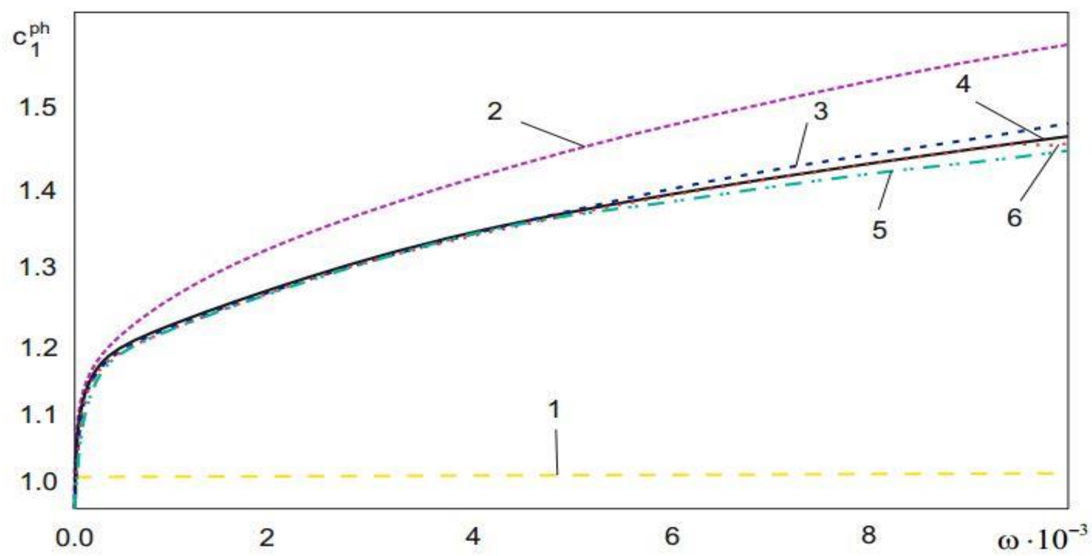

Figure 2 - Change in the real parts of the phase velocity versus frequency 1-h_0 = 0,0001 м,2-h_0 = 0,0008 м,3-h_0 = 0,003 м,4-h_0 = 0,004 м, 5-h_0 = 0,007 м,6-h_0 = 0,01 м.

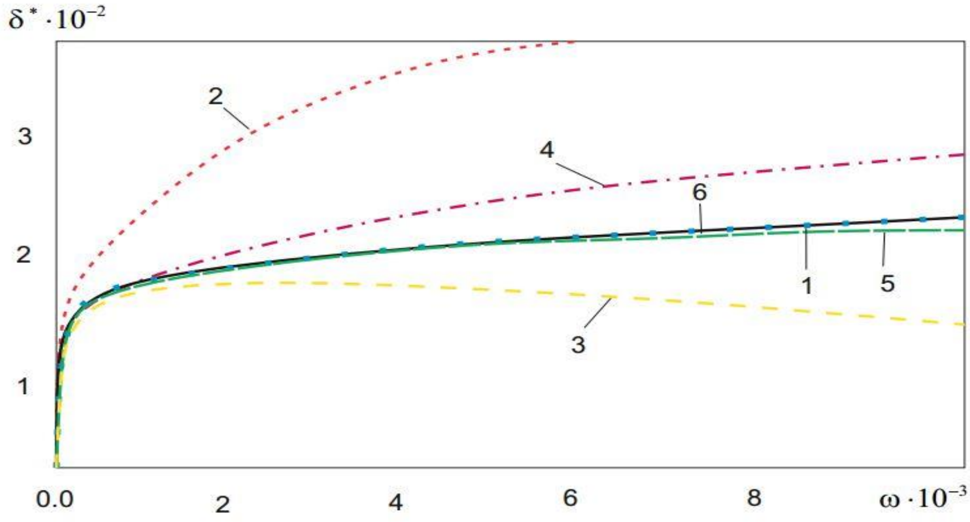

Figure 3. - Change the imaginary part of the phase velocity of the frequency 1-h_0 = 0,0001 м,2-h_0 = 0,0008 м,3-h_0 = 0,003 м,4-h_0 = 0,004 м, 5-h_0 = 0,007 м,6-h_0 = 0,01 м.

Figure 2 and 3 for $\xi > 0$ dispersion curves are shown, obtained for a tunnel (pipeline) supported by a concrete shell passing in a siltstone massif (from above, the graphing area is limited by the condition of the load moving at subsonic speed $c < c_s = 990$ м/c)

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