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STABILITY AND PROTECTION OF DRAINAGE PIPELINES FROM ENVIRONMENTAL INFLUENCES

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Abstract- The presented article considers the solution to the issue of sustainability and protection from environmental influences of drainage pipelines used for draining swamps and leaching saline soils. Since the design of the drainage pipe belongs to the class of thin-walled shells, the issue of its stability, discussed in the article, is solved on the basis of the principle of flat sections. This property was also taken into account, since the material of drainage pipelines is porous (two-phase). Since the drainage pipe construction material in question is considered to be two-phase, it contains physical and mechanical constants that determine the two-phase nature of the material in the structural stability equations. These constants were determined during the solution. When choosing the material from which the drainage pipe structure is made, the corresponding values of the elastic constants are taken into account in the equations. When porous bodies are exposed to liquids, liquids penetrate into them, because of which they turn into a two-phase medium. When we talk about liquids, we mean both liquids and gases. True liquids will be considered as slightly compressed liquids, while gases will be considered as highly compressed liquids. The rest of the body, except for the pores, is called the skeleton. The pores in the bodies communicate with each other through capillary tubes. Under the influence of external forces, the skeleton of a porous body is deformed, and over time the volume of the pore's changes, which leads to a change in the specific gravity of the liquid in its body. Thus, a change in pore volume over time leads to the formation of deformations that are a function of time. When such deformations are reversible (at low stresses), they are called viscoelastic deformations. When solving the issue under consideration, the mixed energy method was used, that is, the principle of the extremum of potential energy. The equation of motion of the system in a mixed form, taking into account the boundary conditions of the problem, was solved numerically. Critical stresses are found using the condition that the main determinant of the equation of the obtained system is equal to zero, as the minimum value of the obtained transcendental equation. and mechanical parameters of the drainage pipe, and the results for the critical force were obtained. At the end of the task, a numerical calculation was performed corresponding to the set values of the geometric, physical and mechanical parameters of the drainage pipe, and the results for the critical force were obtained.

Keywords: Drainage Installations, Porous Material, The Mixed Energy Method, Critical Stress.

1. INTRODUCTION

Quite large areas of the globe consist of swampy and saline soils. According to the International Commission on Irrigation and Drainage (IDBC) in 1973, out of 87.8 million hectares of irrigated land, 28.4 million hectares were saline to varying degrees in 23 countries. This, in turn, leads to food shortages on Earth. Swamps also create serious problems in nature (fauna and flora), such as salinization. To eliminate the problems mentioned in the presented article, the issue of sustainability and protection of drainage pipelines from environmental influences was resolved.

Wetlands arise mainly due to the disturbance of the water balance in these areas, that is, because incoming water exceeds the amount of evaporated or exported water. On the other hand, the very low slope of the relief, as well as low flow of groundwater and surface water, also lead to the long-term existence of swamps. Saline soils contain easily soluble harmful salts in quantities that can negatively affect the normal development of crops. The main characteristic of these areas is that the total evaporation from the Earth's surface is significantly higher than atmospheric precipitation. Saline soils are most common in areas with arid climates (Figure 1) [1].

Porous bodies include soils with natural materials, rocks, wood materials, as well as concrete with artificial materials, bricks, ceramics, polymers, metal parts produced in powder metallurgy, etc. an example can be given. The soil, which is the basis of agriculture, is also a

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porous body. A characteristic feature of all these materials is that they accumulate liquids in themselves and allow these liquids to move under the influence of external forces. The movement of moisture in the soil also plays this role. Ultimately, it is the liquid moving in the soil that brings nutrients to plants, which leads to the nutrition of the living world as a whole (Figure 2) [2- 4].

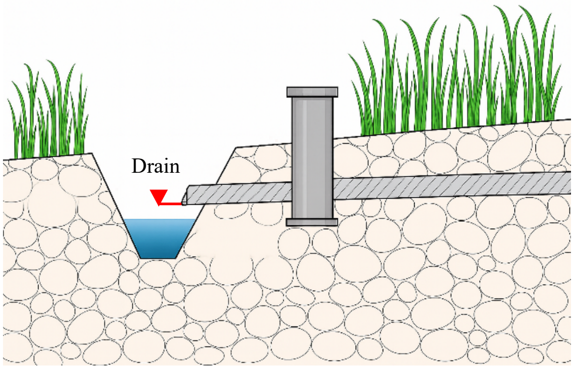


Figure 1. General view of the drainage pipeline

Figure 2. The procedure for the construction of a drainage pipeline

2. EFFECT OF POROSITY ON MECHANICAL PROPERTIES OF MATERIAL

Let us clarify some of the features of such materials, since the structural element of the drainage pipe studied in the article is made of a porous material. Below we will prove that the physical properties of a porous material depend on the specific gravity of the liquid in its pores. The results obtained here are summarized on the basis of the works of the author himself and his doctoral students, obtained in different years and published in journals [5, 15, 16].

When porous bodies are exposed to liquids, liquids penetrate into them, because of which they turn into a two-phase medium. When we talk about liquids, we mean both liquids and gases. True liquids will be considered as slightly compressed liquids, while gases will be considered as highly compressed liquids. The rest of the body, except for the pores, we will call the skeleton. The pores in the bodies communicate with each other through capillary tubes. Under the influence of external forces, the skeleton of a porous body is deformed, and over time the volume of the pore's changes, which leads to a change in the specific gravity of the liquid in its body. Thus, a change in pore volume over time leads to the formation of deformations, which are a function of time. When such deformations are reversible (at low stresses), they are called viscoelastic deformations.

Now let's try to obtain formulas that determine the physical properties of two-phase media. We will call them the given ones. Let us take the following notation: the volume of the porous body is V; skeleton volume V_s; the volume of liquid in the pores is V_m; skeleton mass m_s; body weight, the pores of which are filled with liquid- m; the mass of liquid in the pores is m_m; skeleton density ρ_s; the density of a body whose pores are filled with liquid is ρ; the density of the liquid in the pores is ρ_m. There are the following dependencies between these nine values:

$$m_m = m - m_s;\ V_m = \frac{m - m_s}{\rho_m};\ V_s = V - V_m = V - \frac{m - m_s}{\rho_m}$$

$$\rho_s = \frac{m_s}{V_s} = \frac{m_s}{V - V_m};\ m_m + m_s = m;\ \frac{m_m}{m} + \frac{m_s}{m} = 1$$

Now we find an expression for the reduced Young's modulus of a body whose pores are filled with liquid. Hooke's law of tension and compression $\varepsilon = \frac{\sigma}{E}$. Here is Young's E-module, σ is the tensile stress; and ε relative elongation.

$$E_s = \frac{F}{\frac{m_s}{m} S\varepsilon} = \frac{m}{m_s} \times \frac{F}{S\varepsilon} = \frac{m}{m_s} E$$

Thus, the Young's modulus of the skeleton is $\frac{m}{m_s}$ times different from the Young's modulus of the body, the pores of which are filled with liquid. When the drainage pipe is compressed, the deformation of the skeleton and the deformation of the column of liquid in which it is located inside the pores become the same, i.e., $\varepsilon_s = \varepsilon_m$ in it. $T_s/S_sE_s = T_m/S_mE_m$; where, T_s and T_m are the compressive forces acting on parts of the skeleton and pores, respectively, S_s, E_s and S_m, E_m are, respectively, the cross-sectional area of the skeleton and fluid and Young's modulus. On the other hand, the compressions of both the skeleton, the column of fluid, and the common element are equal to each other, namely

$$\frac{T_s}{S_s E_s} = \frac{T_m}{S_m E_m} = \frac{T_s + T_m}{\left(S_s + S_m\right) E_g}$$

where, E_g is the reduced young module. From the last expression, you can get.

$$E_g = \frac{m_s E_s + M_m E_m}{M}$$

In a similar way, the following expressions can be obtained for the reduced Poisson's ratio ν_g and yield strength σ_g.

$$V_g = \frac{m_s V_s + m_m V_m}{m};\ \sigma_g = \frac{m_s \sigma_{sa} + m_m \times \sigma_{ma}}{m}$$

In the written formulas, the values with the s index refer to the skeleton, and the values with the m index refer to the liquid.

$$m = m_s + m_m;\ E_g = \frac{m_s E_s + m_m E_m}{\left(m_s + m_m\right)^2}$$

Since the volume of the skeleton is small during deformation, and the volume of the pores varies greatly, we can look at m_m as a variable and get the derivative of E_g in m_m.

$$E'_g = \frac{m_s\left(E_m - E_s\right)}{\left(m_s + m_m\right)^2}$$

If $E_m > E_s$ then E^l_g it will be positive, $E_m < E_s$ then E^l_g will be negative.

This means that regardless of the mass of liquids in the pores, when the Young's modulus of the liquid is greater than the Young's modulus of the skeleton, the reduced Young's modulus increases when the mass of the liquid increases, and vice versa, when the Young's modulus of the liquid is less than that of the skeleton. If we plot the dependence of E_g on m_m, we get (Figure 3) If the fluid in the pores is incompressible, $\nu_m = 0.5$, then $\nu'_g = \frac{m_s\left(0.5 - V_s\right)}{\left(m_s + m_m\right)^2}$. It can be seen from this formula that in the presence of an incompressible fluid in the pores, the Poisson's ratio always increases as the fluid in the pores increases. The graph of the dependence of ν_g on m_m becomes the same as in Figure 4.

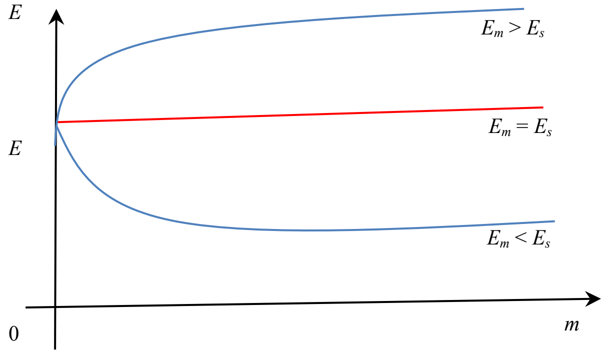


Figure 3. Graph of the dependence of the reduced Young's modulus on the mass of the liquid in the pores

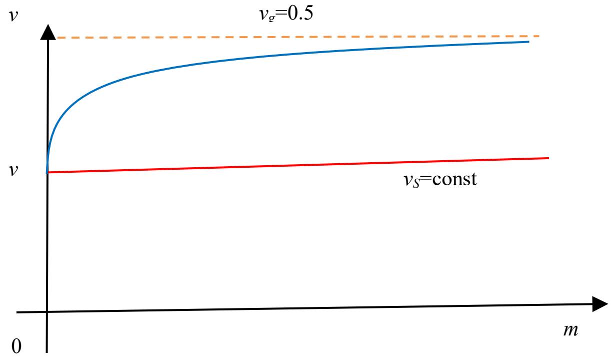


Figure 4. Graph of the dependence of the reduced Poisson's ratio on the mass of the liquid in the pores

The materials of structural elements are divided into the following three groups according to their porosity [5]:

1. The materials are pre-porous. Such materials turn into a two-phase (skeletal and liquid) body, as their pores are filled with liquid or gas.
2. The materials have a nanostructure, that is, the pore sizes in the materials are about 10^{-9} meters, and under the influence of high temperatures, these sizes increase over time.
3. The material of the structural element has no initial pores. Over time, because of neutron radiation, the body becomes porous.

However, in recent years, due to global warming, the dynamics of the formation of swamps has increased due to floods caused by heavy rains that hit the land. Therefore, the issue of calculating drainage structures for stability and the selection of new structural materials is relevant. The elastic constants E and ν used here relate to the design of the drainpipe. The coefficients included in all the equations of the drainage structure are conventionally designated as $E_g = E, \nu_g = \nu, \rho_g = \rho$ (Figure 3).

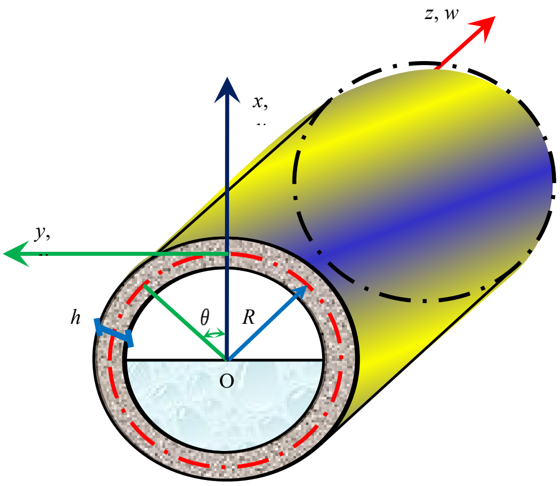


Figure 5. General view of the drainage pipe element

2. PROBLEM STATEMENT AND CHOOSING A SOLUTION

As is well known, cylindrical shells are the most common structural elements made of shells of various shapes. Their equations of motion can be obtained from more general equations describing the motion of shells of an arbitrary contour. The issue of stability from ground pressure on the surface of the drainage structural element was solved completely on the basis of the equations of the classical theory of elasticity, and it was considered possible to determine the critical force. The principle of plane sections (Kirchhoff-Law) was expected to be satisfied here.

When setting the problem, the fixed x, y, z right-hand coordinate system was chosen. For the points of the shell, in accordance with the coordinate system, the displacements u, v, w accepted in the theory of elasticity are taken. With the help of these displacement components, the stress-strain state of the coating can be determined. The rotation φ_1, φ_2 angles of a normal passing through an arbitrary point of the shell surface along the y and z axes are expressed by offsets as follows [6].

$$\varphi_1 = -\frac{\partial \upsilon}{\partial z}, \varphi_2 = -\left(\frac{\partial \upsilon}{\partial x} + \frac{u}{R}\right) \tag{1}$$

where, R is the radius of the drainage pipe (Figure 5).

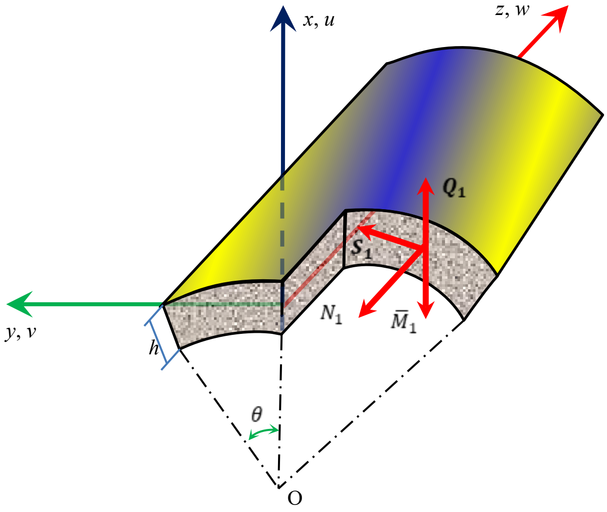


Figure 6. Structural element of the drainage (shell) [8]

External forces q_x, q_y, q_z affecting the design of the drainage pipe, generally assume that it creates a deformation in length, width and bending moments applied to the edges of the shell T_1, S_1, Q_1, M_1 and T_2, S_2, Q_2, M_2, respectively, on curved and rectilinear edges).

The energy method (potential and kinetic energy of the structure) was used to solve the problem, and the stability equation was obtained from the stationary condition of the variational principle. The potential energy of the structure will be as follows [7].

$$\begin{aligned}\Pi_0 = {} & \frac{Eh}{2\left(1-\nu^2\right)} \int_{x_1}^{x_2} \int_{y_1}^{y_2} \left\{ \left(\frac{\partial u}{\partial x} + \frac{\partial u}{\partial y} - \frac{w}{R} \right)^2 - \right. \\ & \left. -2(1-\nu)\left[\frac{\partial u}{\partial x}\left(\frac{\partial \vartheta}{\partial y} - \frac{w}{R} \right) - -\frac{1}{4}\left(\frac{\partial u}{\partial y} + \frac{\partial \vartheta}{\partial x} \right)^2 \right] \right\} dxdy + \\ & + \frac{Eh^3}{24\left(1-\nu^2\right)} \int_{x_1}^{x_2} \int_{y_1}^{y_2} \left\{ \left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{1}{R}\frac{\partial \vartheta}{\partial y} \right)^2 - \right. \\ & \left. -2(1-\nu)\left[\frac{\partial^2 w}{\partial x^2}\left(\frac{\partial^2 w}{\partial y^2} + \frac{1}{R}\frac{\partial \vartheta}{\partial y} \right) - \left(\frac{\partial^2 w}{\partial x \partial y} + \frac{1}{R}\frac{\partial \vartheta}{\partial x} \right)^2 \right] \right\} dxdy\end{aligned} \tag{2}$$

The work performed by external forces on the structure is calculated and added to the total energy expression (the work done is potential energy with a negative sign) [8]:

$$\begin{aligned}A_0 = {} & -\int_{x_1}^{x_2} \int_{y_1}^{y_2} \left(q_x u + q_y \vartheta + q_z w \right) dxdy - \\ & -\int_{y_1}^{y_2} \left(T_1 u + S_1 \vartheta + Q_1 w + M_1 \varphi_1 \right)\Big|_{x=x_1}^{x=x_2} dy - \\ & -\int_{x_1}^{x_2} \left(S_2 u + T_2 \vartheta + Q_2 w + M_2 \varphi_2 \right)\Big|_{y=y_1}^{y=y_2} dx.\end{aligned} \tag{3}$$

The final potential energy of the structure

$$\Pi = \Pi_o + A_o \tag{4}$$

The expression of kinetic energy is written in the analogical order:

$$K_0 = \rho_0 h \int_{x_1}^{x_2} \int_{y_1}^{y_2} \left[\left(\frac{\partial u}{\partial t} \right)^2 + \left(\frac{\partial \vartheta}{\partial t} \right)^2 + \left(\frac{\partial w}{\partial t} \right)^2 \right] dxdy \tag{5}$$

where, ρ_0 is shell material density. The principle of stationarity has the form:

$$\delta W = 0 \tag{6}$$

where, $W = \int_{t'}^{t''} \tilde{L} dt$, $\tilde{L} = K - \Pi$ is the Lagrange function, $[t', t'']$ are arbitrary time points. Considering that the operations of variation and differentiation are permutable, Equation (6) can be reduced to the form

$$\begin{aligned}& \int_{t'}^{t''} \int_{x_1}^{x_2} \int_{y_1}^{y_2} \left\{ -\left[L_x'(u,\vartheta,w) + q_x \right] \delta u - \left[L_y'(u,\vartheta,w) + q_y \right] \delta \vartheta + \right. \\ & \left. + \left[L_z'(u,\vartheta,w) + q_z \right] \delta w \right\} dxdydt - \int_{t'}^{t''} \int_{y_1}^{y_2} \left[\left(T_1 - T_1' \right) \delta u + \right. \\ & \left. + \left(S_1 - S_1' \right) \delta \vartheta + + \left(Q_1 - Q_1' \right) \delta w + \left(M_1 - M_1' \right) \delta \varphi_1 \right] \Big|_{x=x_1}^{x=x_2} \\ & dydt - \int_{t'}^{t''} \int_{x_1}^{x_2} \left[\left(S_2 - S_2' \right) \delta u + + \left(T_2 - T_2' \right) \delta \vartheta + \left(Q_2 - Q_2' \right) \times \right. \\ & \left. \times \delta w \left(M_2 - M_2' \right) \delta \varphi_2 \right] \Big|_{y=y_1}^{y=y_2} dydt - \int_{t'}^{t''} \left(R_1 - R_1' \right) \\ & \delta w \Big|_{x=x_1}^{x=x_2} \Big|_{y=y_1}^{y=y_2} dt = 0\end{aligned} \tag{7}$$

where,

$$\begin{aligned}& L_x'(u,\vartheta,w) = \frac{Eh}{1-\nu^2} \left[\left(\frac{\partial^2}{\partial x^2} + \frac{1-\nu}{2}\frac{\partial^2}{\partial y^2} \right) u + \frac{1+\nu}{2}\frac{\partial^2 \vartheta}{\partial x \partial y} - \frac{\nu}{R}\frac{\partial w}{\partial x} \right] - \\ & -\rho_0 h \frac{\partial^2 u}{\partial^2 t}, L_y'(u,\vartheta,w) = \frac{Eh}{1-\nu^2} \left\{ \frac{1+\nu}{2}\frac{\partial^2 u}{\partial x \partial y} + \right. \\ & + \left[\frac{1-\nu}{2}\left(1 + 4a^2 \right)\frac{\partial^2}{\partial x^2} + \left(1 + a^2 \right)\frac{\partial^2}{\partial y^2} \right] \vartheta + \frac{1}{R} \times \\ & \left. \times \left[-\frac{\partial}{\partial y} + \frac{h^2}{12}\left\{ (2-\nu)\frac{\partial^3 u}{\partial x^2 \partial y} + \frac{\partial^3}{\partial y^3} \right\} \right] w \right\} - \rho_0 h \frac{\partial^2 u}{\partial^2 t},\end{aligned}$$

$$L_z^{'}(u,\vartheta,w)=\frac{Eh}{1-\nu^2}\left\{-\frac{\nu}{R}\frac{\partial u}{\partial x}+\frac{1}{R}\left\{-\frac{\partial}{\partial y}+\frac{h^2}{12}\left[\left(2-\nu\right)\frac{\partial^3}{\partial x^2\partial y}+\frac{\partial^3}{\partial y^3}\right]\right\}\right.$$

$$\left.\vartheta+\frac{w}{R^2}+\frac{h^2}{12}\Delta\Delta w\right\}+\rho_0 h\frac{\partial^2 w}{\partial^2 t}$$

$$T_1^{'}=\frac{Eh}{1-\nu^2}\left[\frac{\partial u}{\partial x}+\nu\left(\frac{\partial \vartheta}{\partial y}-\frac{w}{R}\right)\right] \tag{8}$$

$$S_1^{'}=\frac{Eh}{1+\nu}\left[\frac{1}{2}\left(\frac{\partial\vartheta}{\partial x}+\frac{\partial u}{\partial y}\right)+\frac{h^2}{12R}\frac{\partial}{\partial x}\left(\frac{\partial w}{\partial y}+\frac{\vartheta}{R}\right)\right]$$

$$Q_1^{'}=-\frac{Eh^3}{12\left(1-\nu^2\right)}\left[\frac{\partial^3 w}{\partial x^3}+\left(2-\nu\right)\left(\frac{\partial^3 w}{\partial x\partial y^2}+\frac{1}{R}\frac{\partial^2\vartheta}{\partial x\partial y}\right)\right]$$

$$M_1^{'}=-\frac{Eh^3}{12\left(1-\nu^2\right)}\left[\frac{\partial^2 w}{\partial x^2}+\nu\frac{\partial}{\partial y}\left(\frac{\partial w}{\partial y}+\frac{\vartheta}{R}\right)\right]$$

$$T_2^{'}=\frac{Eh}{1-\nu^2}\left(\frac{\partial\vartheta}{\partial y}-\frac{w}{R}+\nu\frac{\partial u}{\partial x}\right);\ S_2^{'}=-\frac{Eh}{2\left(1+\nu\right)}\left(\frac{\partial\vartheta}{\partial x}+\frac{\partial u}{\partial y}\right)$$

$$Q_2^{'}=-\frac{Eh^3}{12\left(1-\nu^2\right)}\left[\frac{\partial^3 w}{\partial y^3}+\frac{1}{R}\frac{\partial^2\vartheta}{\partial y^2}+\left(2-\nu\right)\frac{\partial^3 w}{\partial x^2\partial y}+\frac{2\left(1-\nu\right)}{R}\frac{\partial^2\vartheta}{\partial x^2}\right]$$

$$M_2^{'}=-\frac{Eh^3}{12\left(1-\nu^2\right)}\left(\frac{\partial^2 w}{\partial y^2}+\nu\frac{\partial^2 w}{\partial x^2}+\frac{1}{R}\frac{\partial\vartheta}{\partial y}\right)$$

Due to the independence and arbitrariness of variations $\delta u,\delta\vartheta,\delta w$ from (7) we obtain the following system of equations of motion:

$$\int_{t'}^{t''}\int_{x_1}^{x_2}\int_{y_1}^{y_2}\left\{-\left[L_x(u,\vartheta,w)+q_x\right]\delta u-\left[L_y(u,\vartheta,w)+q_y\right]\delta\vartheta+\right.$$

$$\left.+L_z(u,\vartheta,w)-q_z\right\}dxdydt-\int_{t'}^{t''}\left[\left(\overline{T}_1-\overline{\overline{T}}_1\right)\delta u+\left(\overline{S}_1-\overline{\overline{S}}_1\right)\delta\vartheta+\right.$$

$$\left.+\left(\overline{Q}_1-\overline{\overline{Q}}_1\right)\delta w+\left(\overline{M}_1-\overline{\overline{M}}_1\right)\delta\varphi_1\right]\Bigg|_{x=x_1}^{x=x_2}dydt-\int_{t'}^{t''}\left[\left(\overline{S}_2-\overline{\overline{S}}_2\right)\right. \tag{9}$$

$$\left.\delta u+\left(\overline{T}_2-\overline{\overline{T}}_2\right)\delta\vartheta+\left(\overline{Q}_2-\overline{\overline{Q}}_2\right)\delta w+\left(\overline{M}_2-\overline{\overline{M}}_2\right)\delta\varphi_2\right]\Bigg|$$

$$\substack{y=y_2\\ y=y_1}dxdt-\int_{t'}^{t''}\left(\overline{R}-\overline{\overline{R}}\right)\delta w\Big|\substack{x=x_2\\ x=x_1}\Big|_{y=y_1}^{y=y_2}dt=0$$

Equation (9) of motion can be written according to the principle of independence of variation as follows:

$$L_x(u,\vartheta,w)-q_x=0;\ L_y(u,\vartheta,w)-q_y=0;\ L_z(u,\vartheta,w)+q_z=0 \tag{10}$$

And natural boundary conditions: on the curved edges of the shell, i.e. at

$$\begin{aligned}&z=z_1;\overline{T}_1=0;z=z_2;\overline{T}_2=0;u=u_1\\&S=S_1;Q=Q_1;M=M_1;\theta=\varphi_1\end{aligned} \tag{11}$$

On the contours of the shell, i.e., at $x=x_1$; and

$$\begin{aligned}&\overline{T}_1=0;x=x_2;\overline{T}_2=0;u=u_2\\&S=S_2;Q=Q_2;M=M_2;\theta=\varphi_1\end{aligned} \tag{12}$$

where, the external load acts symmetrically, then the $\theta=\varphi_1=\varphi_2$ conditions are satisfied.

The article will consider the issue of the stability of a drainage pipe from a regular distributed load over its entire surface, the length of the pipe is finite, the angle of distribution of the distributed load is in the range $0\le\theta\le 2\pi$. For convenience, dimensionless coordinates are used in the equations of motion.

$$\xi=\frac{z}{R},\ \theta=\frac{y}{R},\ t_1=\omega_0 t,\ \omega_0=\sqrt{\frac{E}{\left(1-\nu^2\right)\rho_0 R^2}} \tag{13}$$

The equations of motion have the form:

$$\left(\frac{\partial^2}{\partial\xi^2}+\frac{1-\nu}{2}\frac{\partial^2}{\partial\theta^2}\right)u+\frac{1+\nu}{2}\frac{\partial^2\vartheta}{\partial\xi\partial\theta}-$$

$$-\nu\frac{\partial w}{\partial\xi}-\frac{\partial^2 u}{\partial t_1^2}=-\frac{R^2\left(1-\nu^2\right)}{Eh}q_x$$

$$\frac{1+\nu}{2}\frac{\partial^2 u}{\partial\xi\partial\theta}+\left[\frac{1-\nu}{2}\left(1+4a^2\right)\frac{\partial^2}{\partial\xi^2}+\left(1+a^2\right)\frac{\partial^2}{\partial\theta^2}\right]$$

$$\vartheta+\left\{-\frac{\partial}{\partial\theta}+a^3\left[\left(2-\nu\right)\frac{\partial^3}{\partial\xi^3\partial\theta}+\frac{\partial^3}{\partial\theta^3}\right]\right\}w- \tag{14}$$

$$-\frac{\partial^2\vartheta}{\partial t_1^2}=-\frac{R^2\left(1-\nu^2\right)}{Eh}q_y$$

$$-\nu\frac{\partial u}{\partial\xi}+\left\{-\frac{\partial}{\partial\theta}+a^2\left[\left(2-\nu\right)\frac{\partial^3}{\partial\xi^3\partial\theta}+\frac{\partial^3}{\partial\theta^3}\right]\right\}$$

$$\vartheta+\left(1+a^2\Delta\Delta\right)w+\frac{\partial^2 w}{\partial t_1^2}=0$$

Equation of motion of a drainage pipe structure in a mixed form are obtained if we assume that in (14) the inertia force in the direction of the *Oz* axis is zero. Based on the above, the system (14) takes the form:

$$\left(\frac{\partial^2}{\partial\xi^2}+\frac{1-\nu}{2}\frac{\partial^2}{\partial\theta^2}\right)u+1+\nu/2\cdot\partial^2\vartheta/\partial\xi\partial\theta-$$

$$-\nu\frac{\partial w}{\partial\xi}=-R^2 q_x\left(1-\nu^2\right)/Eh,$$

$$(1+\nu)/2\partial^2\cdot u/\partial\xi\partial\theta+\left(\frac{1-\nu}{2}\frac{\partial^2}{\partial\xi^2}+\frac{\partial^2}{\partial\theta^2}\right)\vartheta-$$

$$-\frac{\partial w}{\partial\theta}=-R^2 q_y\left(1-\nu^2\right)/Eh,$$

(15)

$$-\nu\partial u/\partial\xi-\frac{\partial\vartheta}{\partial\theta}+w+a^2\Delta\Delta w=0.$$

Next, we introduce the stress function in the form of formulas:

$$\begin{aligned}&\frac{\partial u}{\partial\xi}+\nu\left(\frac{\partial\vartheta}{\partial\theta}-w\right)=\frac{\partial^2\Phi}{\partial\theta^2}\\&\frac{\partial u}{\partial\theta}+\frac{\partial\vartheta}{\partial\xi}=-\frac{2}{1-\nu}\frac{\partial^2\Phi}{\partial\xi\partial\theta}\\&\frac{\partial\vartheta}{\partial\theta}-w+\nu\frac{\partial u}{\partial\xi}=\frac{\partial^2\Phi}{\partial\xi^2}\end{aligned} \tag{16}$$

It is easy to see that after substituting (16) into (15), the first two equations are equivalent, leaving only one of the two equations. The third equation, however, is not necessary, since it does not take into account the effect of the displacement of w in the direction of the Z axis on the stability of the structure.

$$\frac{\partial^2 u}{\partial \xi^2}+(1+\nu)\frac{\partial^2 u}{\partial \xi \partial \theta}+\frac{\partial^2 u}{\partial \theta^2}=-R^2\left(1-\nu^2\right)q_y / Eh \text{, or}$$

$$\Delta u+(1+\nu)\frac{\partial^2 u}{\partial \xi \partial \theta}=-R^2\left(1-\nu^2\right)q_x \tag{17}$$

Excluding from (17) the components of the displacement vector W and equating the displacements u and ϑ, we obtain an equation that must satisfy Φ;

$$\Delta\Delta\Phi=-\left(1-\nu^2\right)\frac{\partial^2 u}{\partial \xi^2} \tag{18}$$

The system of equations of motion (17), (18) is a system of equations in a mixed form that is convenient for solving problems using numerical methods [9]. To solve the problems of static stability of closed shells, a mixed energy method is used, in which the condition of extremality potential energy is used instead of equation (17).

$$\begin{aligned}Э=&\frac{\mathrm{Eh}^3}{24\left(1\text{-}\nu^2\right)R^2}\int_0^{\xi_1}\int_0^{2\pi}\left\{\left(\frac{\partial^2 w}{\partial \xi^2}+\frac{\partial^2 w}{\partial \theta^2}\right)^2-\right.\\&\left.-\left(1-\nu^2\right)\frac{\partial^2 u}{\partial \xi^2}.-2(1\text{-}\nu)\left[\frac{\partial^2 w}{\partial \xi^2}\frac{\partial^2 w}{\partial \theta^2}-\left(\frac{\partial^2 w}{\partial \xi \partial \theta}\right)^2\right]\right\}d\xi d\theta+\\&+\frac{\mathrm{h}}{2\mathrm{E}r^2}\int_0^{\xi_1}\int_0^{2\pi}\left\{\left(\frac{\partial^2 \varphi}{\partial \xi^2}+\frac{\partial^2 \varphi}{\partial \theta^2}\right)^2-\right.\\&\left.-2(1\text{+}\nu)\left[\frac{\partial^2 \varphi}{\partial \xi^2}\frac{\partial^2 \varphi}{\partial \theta^2}-\left(\frac{\partial^2 \varphi}{\partial \xi \partial \theta}\right)^2\right]\right\}d\xi d\theta\end{aligned} \tag{19}$$

And instead of the equation of joint deformations (18), a similar equation, we can take:

$$\Delta\Delta\varphi=E\left\{\left[\frac{\partial^2(w)}{\partial \xi \partial \theta}\right]^2-\frac{\partial^2(w)}{\partial \xi^2}\left[\frac{\partial^2(w)}{\partial \theta^2}+r\right]\right\} \tag{20}$$

where, $\varphi=\frac{ER\Phi}{1-\nu^2}$.

The Winkler model accepted the influence of an external force applied to the structure.

$$q_{xx}=k_c u \tag{21}$$

3. CHOOSING A SOLUTION TO THE PROBLEM UNDER CONSIDERATION

Equation (14) the offsets assumed for solving the equation

$$u=u_0 e^{\chi\xi}\cos n\theta,\ \vartheta=\vartheta_0 e^{\chi\xi}\sin n\theta \tag{22}$$

The equation of equilibrium of an elastic medium in the cylindrical coordinate system x, φ, r has the form [3]:

$$\begin{aligned}&\left(\lambda_s+2\mu_s\right)\frac{\partial \theta}{\partial r}-\frac{2\mu_s}{r}\frac{\partial \omega_x}{\partial \varphi}+2\mu_s\frac{\partial \omega_\varphi}{\partial x}=0\\&\left(\lambda_s+2\mu_s\right)\frac{1}{r}\frac{\partial \theta}{\partial \varphi}-2\mu_s\frac{\partial \omega_r}{\partial x}+2\mu_s\frac{\partial \omega_x}{\partial x}=0\\&\left(\lambda_s+2\mu_s\right)\frac{\partial \theta}{\partial x}-\frac{2\mu_s}{r}\left[\frac{\partial}{\partial r}\left(r\omega_\varphi\right)+\frac{\partial \omega_r}{\partial \varphi}\right]=0\end{aligned} \tag{23}$$

where, s_x, s_φ, s_r λ_s, μ_s x, r, φ are the components of the displacement vector of the medium, the mechanical constants, and the spatial coordinates, respectively. Here the components θ, $\omega_x, \omega_\varphi, \omega_r$ are found from the following equations:

$$\begin{aligned}&\theta=\frac{\partial s_r}{\partial r}+\frac{\partial s_x}{\partial x}+\frac{1}{r}\left[r+\frac{\partial s_\varphi}{\partial \varphi}\right];\ 2\omega_\varphi=\frac{\partial s_r}{\partial x}-\frac{\partial s_x}{\partial r}\\&2\omega_x=\frac{1}{r}\left[\frac{\partial\left(rS_\varphi\right)}{\partial r}-\frac{\partial s_r}{\partial \varphi}\right];\ 2\omega_r=\frac{1}{r}\frac{\partial s_x}{\partial \varphi}-\frac{\partial s_\varphi}{\partial x}\end{aligned} \tag{24}$$

In turn, the stresses are expressed s_x, s_φ, s_r:

$$\begin{aligned}&\sigma_{rx}=\mu_s\left(\frac{\partial s_x}{\partial r}+\frac{\partial s_r}{\partial x}\right)\\&\sigma_{r\varphi}=\mu_s\left[r\frac{\partial}{\partial r}\left(\frac{s_\varphi}{r}\right)+\frac{1}{r}\frac{\partial s_r}{\partial \varphi}\right]\\&\sigma_{rr}=\lambda_s\left(\frac{\partial s_x}{\partial x}+\frac{1}{r}\frac{\partial\left(rs_r\right)}{\partial r}+\frac{1}{r}\frac{\partial s_\varphi}{\partial \varphi}\right)+2\mu_s\frac{\partial s_r}{\partial r}\end{aligned} \tag{25}$$

The components of the displacement vector are found from Equation (25) [5]:

$$\begin{aligned}&s_x=-r\frac{\partial^2\Phi_*}{\partial r\partial x}-4\left(1-\nu_s\right)\frac{\partial\Phi_*}{\partial x}+\frac{\partial\Psi}{\partial x}\\&s_r=r\frac{\partial^2\Phi_*}{\partial x^2}+\frac{\partial\Psi}{\partial r}+\frac{1}{r}\frac{\partial \mathrm{X}}{\partial\theta};s_\theta=\frac{1}{r}\frac{\partial\Psi}{\partial\theta}-\frac{\partial \mathrm{X}}{\partial r}\end{aligned} \tag{26}$$

With the help of equation (26), the components of the voltage Tensor $\sigma_{rx}, \sigma_{r\varphi}, \sigma_{rr}$ are expressed by elastic potentials Φ_*, Ψ, X.

$$\begin{aligned}&\sigma_{rx}=G_s\times\left[\frac{\partial\Phi_*}{\partial x}(\frac{1}{r}\frac{\partial^2\Phi_*}{\partial\theta^2}-\frac{\partial^2\Phi_*}{\partial r\partial\theta}-4\left(1-\nu_s\right)\frac{\partial\Phi_*}{\partial r})+\frac{\partial\Psi}{\partial x}(2\frac{\partial\Psi}{\partial r}+\frac{1}{r}\frac{\partial \mathrm{X}}{\partial\theta})\right]\\&\sigma_{r\varphi}=G_s\left[\frac{\partial}{\partial\theta}(\frac{\partial^2\Phi_*}{\partial x^2}+\frac{2}{r}\frac{\partial\Psi}{\partial r}-\frac{2}{r^2}\Psi)-\frac{\partial^2 \mathrm{X}}{\partial r^2}+\Delta \mathrm{X}\right]\\&\sigma_{rr}=2G_s\left[\left(1-2\nu_s\right)\frac{\partial^2\Phi_*}{\partial x^2}+r\frac{\partial^3\Phi_*}{\partial r\partial x^2}+\frac{\partial^2\Psi}{\partial r^2}+\frac{1}{r}\frac{\partial^2 \mathrm{X}}{\partial r\partial\theta}-\frac{1}{r^2}\frac{\partial \mathrm{X}}{\partial\theta}\right]\end{aligned} \tag{27}$$

where, G_s, ν_s are the elastic constants of the structure:

Elastic potentials Φ_*, Ψ, X satisfy the Laplace equation:

$$\nabla^2\Phi_*=\nabla^2\Psi=\nabla^2\mathrm{X}=0 \tag{28}$$

We will look for solution Φ_*, Ψ, X in the form [13]:

$$\Phi_*=f_1(r,\varphi,x), \Psi=f_2(r,\varphi,x),\ \mathrm{X}=f_3(r,\varphi,x) \tag{29}$$

where, $f_1(r,\varphi,x), f_2(r,\varphi,x), f_3(r,\varphi,x)$ are unknown function, needs to be determined. If we take into account Equation (29) in the Laplace equation and select the coordinates a, we obtain the Bessel equation [7].

$$\begin{aligned}
&R_1(r)=A_sI_n(kr)+\tilde{A}_sK_n(kr)\\
&R_2(r)=B_sI_n(kr)+\tilde{B}_sK_n(kr)\\
&R_3(r)=C_sI_n(kr)+\tilde{C}_sK_n(kr)
\end{aligned} \tag{30}$$

where, I_n, K_n as Bessel functions are expressed by modified functions of the n-th order and the second kind, where, the unknown $A_s, \tilde{A}_s, B_s, \tilde{B}_s, C_s, \tilde{C}_s$ are constants. From expressions (28), (29) and (30) we obtain:

$$\begin{aligned}
&\Phi_* = \left[A_sI_n(kr)+\tilde{A}_sK_n(kr)\right]\cos n\varphi \sin kx\\
&\Psi = \left[B_sI_n(kr)+\tilde{B}_sK_n(kr)\right]\cos n\varphi \sin kx\\
&\mathrm{X} = \left[C_sI_n(kr)+\tilde{C}_sK_n(kr)\right]\sin n\varphi \sin kx
\end{aligned} \tag{31}$$

Taking into account expression (31) in (28), for the case when the external environment is intact, the displacement is assumed

$$\begin{aligned}
&s_x = \left[\begin{array}{l}\left(-kr\dfrac{\partial I_n(kr)}{\partial r}-4(1-v_s)kI_n(kr)\right)A_s+\\ +kI_n(kr)B_s\end{array}\right]\cos n\varphi \cos kx\\
&s_\theta = \left[-\frac{n}{r}I_n(kr)B_s-\frac{\partial I_n(kr)}{\partial r}C_s\right]\sin n\varphi \sin kx\\
&s_r = \left[-k^2rI_n(kr)A_s+\frac{\partial I_n(kr)}{\partial r}B_s+\frac{n}{r}I_n(kr)C_s\right]\cos n\varphi \sin kx
\end{aligned} \tag{32}$$

Then, if contact conditions are also added to Equations 15 (23) and (32)., then the σ_{rr}, σ_{rx}, $\sigma_{r\varphi}$ components of the stress tensor are. Taking into account expression (31) in (26), for the case when the external environment is intact, the displacement is assumed.

$$\begin{aligned}
&s_x = \left[\begin{array}{l}\left(-kr\dfrac{\partial I_n(kr)}{\partial r}-4(1-v_s)kI_n(kr)\right)A_s+\\ +kI_n(kr)B_s\end{array}\right]\cos n\varphi \cos kx\\
&s_\theta = \left[-\frac{n}{r}I_n(kr)B_s-\frac{\partial I_n(kr)}{\partial r}C_s\right]\sin n\varphi \sin kx\\
&s_r = \left[-k^2rI_n(kr)A_s+\frac{\partial I_n(kr)}{\partial r}B_s+\frac{n}{r}I_n(kr)C_s\right]\cos n\varphi \sin kx
\end{aligned} \tag{33}$$

The contact conditions will be as follows: By

$$r=R,\ u=s_x \tag{34}$$

$$q_z=-\sigma_{rz}=0,\ \ q_\theta=-\sigma_{r\theta}=0,\ \ \ q_{xx}=-\sigma_{rr} \tag{35}$$

Displacement of construction points [6]:

$$u=A\cos n\theta\cos\chi\xi;\ \upsilon=B\sin n\theta\sin\chi\xi;\ w=C\cos n\theta\sin\chi\xi \tag{36}$$

Using the contact conditions (34) and (35), the constants A, B, C are determined and expressed by the constants A_s, B_s, C_s, which are included in the voltage formulas. For the stress σ_{rr} on the coating surface, i.e. in the presence of $r=R$, the following expression is taken.

$$\begin{aligned}
&\sigma_{rr}=-\mu_s\Big[\big(2(1-2v_s)I_n(\chi)+2\chi I_n'(\chi)\big)\chi^2A_s-\\
&-2\chi^2I_n''(\chi)B_s++2n\big(I_n(\chi)-\chi I_n'(\chi)\big)C_s\Big]\cos n\theta\sin\chi\xi
\end{aligned} \tag{37}$$

After complex mathematical transformations, the q_r contact pressure is found [14].

$$q_r=\tilde{C}_{rr}C\cos n\theta\sin\chi\xi \tag{38}$$

Equation (38) the constants included in the expression are in the solution. After complex mathematical calculations (coating equilibrium equations, displacement equation of the medium, joint solution of contact conditions), the critical force is obtained as follows [5].

$$\begin{aligned}
&\bar{q}_{cr}=\frac{1}{\bar{n}^4\left(\bar{n}^2-1\right)}\left(1+\gamma_c^{(1)}-\nu^2\right)B_5^4+\frac{1-\nu}{2}\bar{n}^4\tilde{q}_z^{(0)}+\\
&+\bar{n}^4\left(\bar{n}^2-1\right)^2a^2+\frac{(1+\nu)^2\,\tilde{q}_z^{(0)}}{16\left(\bar{n}^2-1\right)}B_5^2
\end{aligned} \tag{39}$$

The obtained formula allows us to calculate the value of the critical stability force subjected to external pressures of the cylindrical shell (Figure 4).

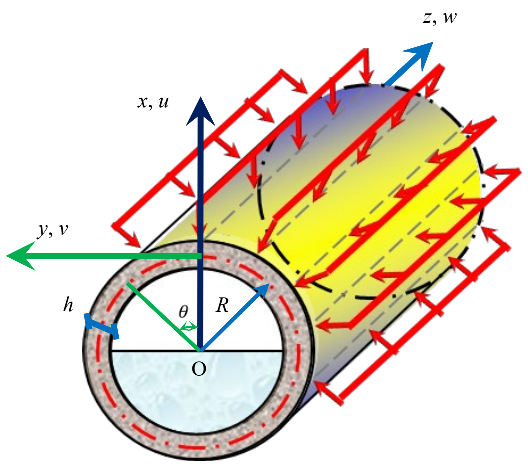


Figure 7. Diagram of the force of the soil on the drainage pipe

4. A NUMERICAL EXAMPLE

By solving Equations (15), (33) together, taking into account the coverage offsets (36), (34), (35) under contact conditions, the critical force can be found in formula (39). The magnitude of the critical force in solving the problem is determined depending on the longitudinal half-waves of the coating and is shown graphically. The presented article is devoted to solving the issue of the stability of the three-dimensional drainage pipe structure. During the solution of such issues, the stress-strain state should be investigated using the ANSYS software. This program was applied in the article. The equations obtained in the article are solved taking into account the following values:

$$h^*=\frac{h}{R}=0.25\times10^{-2};\ \ \xi_1=1;\ \ \frac{F_c}{2\pi Rh}=0.1591\times10^{-1}$$

$$\nu=0.3;\ \frac{I_{yc}}{2\pi R^3h}=0.8289\times10^{-6};\frac{I_{zc}}{2\pi R^3h}=0.1326\times10^{-6}$$

$$\frac{I_{kpc}}{2\pi R^3h}=0.5305\times10^{-6};\ \ h_c=0.01375R;\ G_c=\frac{E}{2(1+\nu)}$$

$$E_c=E=6.67\times10^9\,\mathrm{H/m^2},\tilde{q}/\tilde{q}_0=3$$

$$\tilde{q}_0/E=0.002,\ \ q=10^5\,\mathrm{H/m^2},\ q_{xx}=k_cu$$

Table 1. Material parameters and their definitions

Symbol / Term	Value	Unit	Description
ρ (Density)	7850	kg/m³	Mass per unit volume
α (Thermal Expansion Coeff.)	1.2×10^{-5}	$°C^{-1}$	Isotropic secant coefficient of thermal expansion
E (Young's Modulus)	2.0×10^{11}	Pa	Elastic modulus of the solid skeleton
ν (Poisson's Ratio)	0.3	–	Ratio of lateral to axial strain
K (Bulk Modulus)	1.6667×10^{11}	Pa	Volumetric stiffness
G (Shear Modulus)	7.6923×10^{10}	Pa	Resistance to shear deformation
σ′f (Strength Coefficient)	9.2×10^{8}	Pa	Fatigue strength coefficient
b (Strength Exponent)	–0.106	–	Fatigue strength exponent
ε′f (Ductility Coefficient)	0.213	–	Fatigue ductility coefficient
c (Ductility Exponent)	–0.47	–	Fatigue ductility exponent
σ′f,c (Cyclic Strength Coeff.)	1.0×10^{9}	Pa	Cyclic fatigue strength coefficient
n′ (Cyclic Strain Hardening Exp.)	0.2	–	Describes strain-hardening under cyclic loading
σy,t (Tensile Yield Strength)	2.5×10^{8}	Pa	Yield strength under tension
σy,c (Compressive Yield Strength)	2.5×10^{8}	Pa	Yield strength under compression
σu,t (Tensile Ultimate Strength)	4.6×10^{8}	Pa	Ultimate tensile strength
σu,c (Compressive Ultimate Strength)	4.6×10^{8}	Pa	Ultimate compressive strength

Table 2. Details of mesh

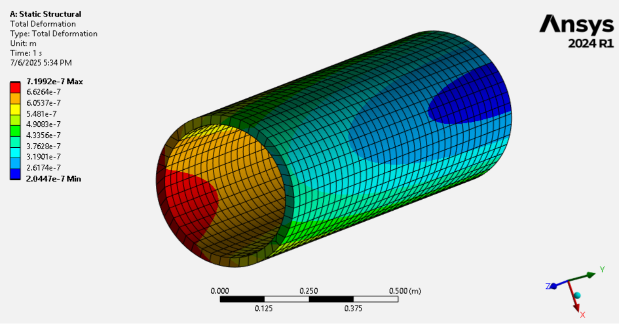
Bounding Box Diagonal	1.1489 m
Average Surface Area	0.60802 m²
Minimum Edge Length	1.131 m
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Nodes	Nodes
Elements	1,620

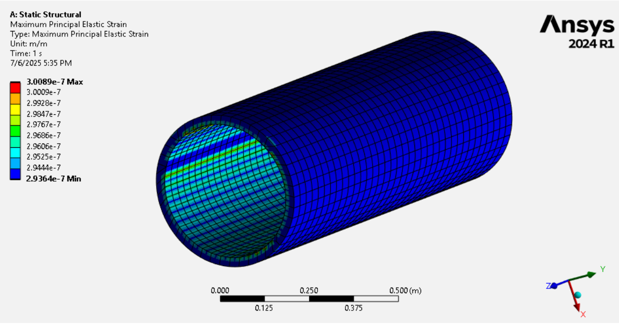
Table 3. Water liquid properties

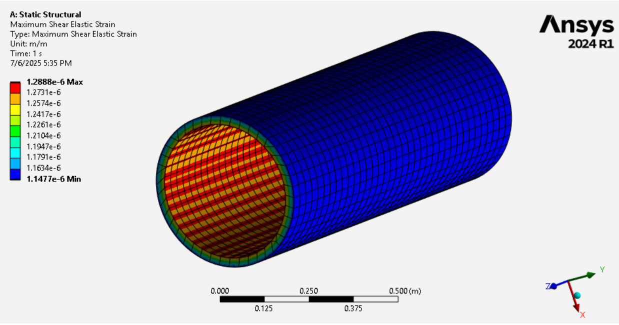
Category	Parameter	Value	Unit
General	Density	998.2	kg/m³
Thermal	Isotropic Thermal Conductivity	0.6	W/m×°C
	Specific Heat Constant Pressure	4182	J/kg×°C
Fluid	Speed of Sound	1482.1	m/s
	Viscosity	0.001003	Pa×s
Other	Latent Heat	2.2631e+06	J/kg
	Vaporization Temperature	10.85	°C
	Boiling Point	99.85	°C
	Volatile Fraction	1	-
	Binary Diffusivity	3.05e-05	-
	Dpm Surften	0.07194	-
	Vapor Pressure	2658	J/m³
	Molecular Weight	18.015	kg/kmol
	Species Phase	1	-
	Formation Enthalpy	-2.858e+08	J/mol
	Reference Temperature	24.85	°C
	Lennard Jones Length	1	m
	Lennard Jones Energy	100	J
	Formation Entropy	69902	J/°C
	Absorption Coefficient	0	1/m

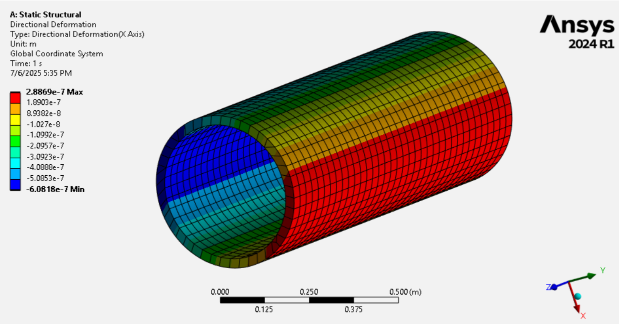
Table 4. Air properties

Category	Parameter	Value	Unit
General	Density	1.225	kg/m³
Thermal	Isotropic Thermal Conductivity	0.0242	W/m×°C
	Specific Heat at Constant P	1006.4	J/kg×°C
Magnetic	Isotropic Relative Permeability	1	–
Fluid	Speed of Sound	346.25	m/s
	Viscosity	1.7894e-05	Pa×s
Other	Molecular Weight	28.966	kg/kmol
	Lennard-Jones Length	3.711	m
	Lennard-Jones Energy	78.6	J
	Thermal Accom. Coefficient	0.9137	–
	Velocity Accom. Coefficient	0.9137	m/s
	Formation Entropy	1.9434e+05	J/°C
	Reference Temperature	25	°C
	Critical Pressure	3.758e+06	J/m³
	Critical Temperature	-140.85	°C
	Acentric Factor	0.033	–
	Critical Volume	0.002857	m³
	Absorption Coefficient	0	1/m









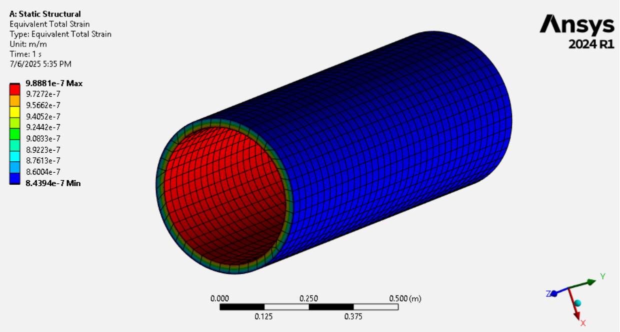


Figure 8. The spectrum of the stress-strain state of the structure obtained using the Ansys program

5. PROTECTION OF DRAINAGE PIPELINES FROM PLANTS

In addition to the load on the soil, drainage pipelines must also be protected from plant roots. To this end, warning signs should be placed on the area where the pipeline runs and attention should be paid to the depth of the roots of plants planted in the area.

Experiments have shown that plants (trees) should be used to drain swamps, which evaporate more water in the area of drainage pipelines, plants that increase soil fertility in areas where drainage pipelines are built to wash out saline soils. In both cases, the length of the plant roots should be less than the critical depth of the drainage pipelines. It is known from biology that one of the trees, whose height is high enough and the ability to evaporate water during the day is very high, is eucalyptus, and the other is oak. The roots of both tree's branch deeper and deeper. To protect the drainage device, trees can be planted at a distance of at least half the height of the trees from the drainage pipe. In these conditions, the drainage system can be considered protected.

6. CONCLUSIONS

The following conclusions were obtained from the solution of the problem under study:

1. To solve the problem of stability, a mathematical and physical model of drainage pipelines has been constructed;
2. Equations are obtained for finding the critical force to which drainage pipelines are subjected, which violates their stability;
3. In the article, the critical force was calculated by numerical calculation depending on the selected geometric, physical and mechanical values of drainage pipelines;
4. A graph of the dependence of the critical force on the value of the pastel coefficient of the soil is constructed and analyzed;
5. Numerical calculations are performed by the finite element method;
6. The results obtained were submitted as building codes to the Azerbaijan Research and Design Institute of Hydro-Reclamation;
7. The advantage of drainage pipelines is that they are made of porous material;
8. The accuracy of the analytical solution of the problem (the degree of satisfaction of the boundary conditions for solving the equation) was mathematically verified and accepted, since the error is very small;
9. To protect drainage pipelines from vegetation, a classification of plants that will be planted on the territory of the belt is given, and the distance from the belt is determined;
10. Finally, recommendations are given for students and doctoral students studying in the specialty of hydro-reclamation.

NOMENCLATURES

Symbol and Parameters

x, y, z : Cartesian coordinate system

u, v, w: Displacement of construction points

φ_1, φ_2 : Rotation angles

ρ_0 : Shell material density

A, B, C : Unknown constants

$\varphi = \dfrac{ER\Phi}{1-\nu^2}$: Biharmonic function

$L_1 = z_2 - z_1$: Shell length

$\chi = kR = \dfrac{m\pi R}{L_1}$: Coefficient of curvature

$\Delta = \partial^2 / \partial\xi^2 + \partial^2 / \partial\theta^2$: Two-dimensional Laplace operator

$a^2 = h^2 / 12R^2$: The legend

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