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THE PROBLEM OF TUNNEL SHIELD DURABILITY

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Abstract. Structural elements made of orthotropic materials are widely used in construction. Heterogeneous orthotropic round and rectangular plates and cylindrical shells with rounded cross-section are widespread among them. The above-mentioned specific properties include inhomogeneous orthotropy, specific gravity, a mathematical solution to the problem of the presence of a variable and the dependence of bases on spatial coordinates, and this complicates calculations. Moreover, if they are ignored, serious mistakes are made. The article studies the stability and oscillatory movements of beams, plates, and cylindrical shells with circular cross-section made of inhomogeneous orthotropic materials, taking into account their inhomogeneous linear apotropic and viscoelastic resistances, and identifies specific quantitative and qualitative effects.

Keywords: Structural elements, Heterogeneous orthotropic, oscillatory movements, inhomogeneous orthotropic.

Introduction. Nowadays, structural elements made of elastic homogeneous and heterogeneous natural and artificial orthotropic materials are widely used in the design and calculations of various engineering complexes, the construction of mainline railway lines, bridges, oil and gas pipelines and many other industries. Among them, rectangular and round boards, cylindrical shells and beams with various cross-sections are most widely used. Of the requirements currently imposed on designers and engineers who perform calculations during the construction of important building complexes for various purposes, bridge construction and other industries, the most important is the correct and efficient use of the material. In addition, this is a correct assessment of the actual physical and mechanical properties of the materials used and the justification of real mathematical models characterizing the environmental impact with which the structure comes into contact during operation [1-3].

It should be noted that biotropic (orthotropic) materials can be artificial or natural (plywood, wood, etc.) they can be. Paper, concrete, rolled sheets, etc. can be distinguished from artificially produced materials, and structurally isotropic (for example, reinforced slabs) materials can be specified. Summing up the above, we can conclude that diotropic materials can be divided into three classes: natural, technological, and constructive. It should be noted that the division of isotropic materials into classes is conditional in nature to carry and obtain new isotropic materials using new technological problems. It is implemented in new designs using well-knownotropic and isotropic materials. He has published several monographs and a large number of scientific articles on the theory of elastically hygotropic bodies [4, 5, 6-8].

Statement of problem. The indicated approximate calculation method can be constructed using the simplified formula of strain intensity. It should be borne in mind that this formula can be applied with an accuracy acceptable for shells for which displacements of their contours are possible [4].

By writing expression (12) instead of (6), we obtain the expression of the work (potential energy) of the internal forces [5]:

$$U = \iint \int_{-\frac{h}{2}}^{\frac{h}{2}} \left[\frac{2}{3} E (e + \chi_z)^2 - \frac{4}{9} E_1 (e + \chi_z)^4 \right] dx\, dy\, dz \tag{1}$$

We integral the last expression according to $z -$ and get:

$$U = \frac{2}{\sqrt{3}} \sigma_a \iint \cdot \left\{ \frac{2}{3} E \cdot \left[\frac{\left(e + \chi \frac{h}{2}\right)^3 - \left(e - \chi \frac{h}{2}\right)^3}{\chi} \right] - - \frac{4}{9} E_1 \cdot \left[\frac{\left(e + \chi \frac{h}{2}\right)^5 - \left(e - \chi \frac{h}{2}\right)^5}{\chi} \right] \right\} dx\, dy. \tag{2}$$

Here, the double Integral covers the entire area of the shell support. In this regard, we will determine the general nature of the relationship between force and tilt. To do this, in calculations using the cubature formula [2], let us be content with only one zero point:

$$U = \frac{2}{\sqrt{3}} \sigma_a \left\{ \frac{\frac{2}{3} E \cdot \left[\left(e_o + \chi_o \frac{h}{2}\right)^3 - \left(e_o - \chi_o \frac{h}{2}\right)^3 \right]}{\chi_o} - - \frac{\frac{4}{9} E_1 \cdot \left[\left(e_o + \chi_o \frac{h}{2}\right)^5 - \left(e_o - \chi_o \frac{h}{2}\right)^5 \right]}{\chi_o} \right\} dx\, dy. \tag{3}$$

Where are the values of quantities e_o and χ_o at point α of coordinates $(a/2,\ b/2)$. Taking into account formulas (3), we take the following expression:

$$e_o = (e + e_1)a_o - (k_x + k_y)w_o\ \overline{w}_o - \frac{w_o^2}{2}b_o . \tag{4}$$

Here, the functions $a_o, \overline{w}_o, b_o - u, \vartheta$ and w and their derivatives are some coefficients of the lattice that express their values at a point with coordinates $(a/2,\ b/2)$. the curve in the middle of the shell is pointed. When composing formula (3), expression (2) (1) was taken into account.

Another assumption is that we assume a line of dependence with coefficients α, α_1 and w_o according to the theory:

$$\left.\begin{aligned} c &= w_o\ k_x\ a_1 - \frac{w_o^2}{2}a_2; \\ c_1 &= w_o\ k_y\ b_1 - \frac{w_o^2}{2}b_2, \end{aligned}\right\} . \tag{5}$$

Here are some coefficients that require $a_1, a_2, b_1, b_2 -$ determining.

Let us collect expressions (3) from side to side:

$$c + c_1 = w_o - (k_x + k_y)(a_1 + b_1) - \frac{w_o^2}{2}(a_2 + b_2). \tag{6}$$

We write (6) instead of (4) and get:

$$e_o = w_o(k_x + k_y)\cdot s + \frac{w_o^2}{2}m, \tag{7}$$

Here

$$s = (a_1 + b_1)a_o - \overline{w}_o; \quad m = b_o - (a_2 + b_2)\,a_o \tag{8}$$

Taking into account formula (2) for the operation of external forces, as well as dependence (8), we define the expression of the total energy of the system [4]

$$W = \frac{2}{\sqrt{3}}ab\sigma_a \left\{ \frac{\frac{2}{3}E\cdot\left[\left(e_o + \chi_o\frac{h}{2}\right)^3 - \left(e_o - \chi_o\frac{h}{2}\right)^3\right]}{\chi_o} - \right.$$

$$-\left.\frac{\frac{4}{9}E_1\cdot\left[\left(e_o+\chi_o\frac{h}{2}\right)^5-\left(e_o-\chi_o\frac{h}{2}\right)^5\right]}{\chi_o}\right\} q\,w_o\,\frac{16ab}{\pi^2}. \qquad (9)$$

From this expression, we get the derivative of $w_o -$ and determine the relationship between force and slope. This dependence expression (4) instead writes down its values and takes the following form (the formula is obtained if $k_y = 0; b = a$ is for a quadratic shell in a cylindrical plan):

$$q=\frac{2\pi^2\sigma_a}{\sqrt{3}}\left[\frac{B(3cw_o-B)-\overline{B}(3\overline{c}w_o-\overline{B})}{w_o^2\cdot c_o}-\frac{B(5cw_o-B)-\overline{B}(5\overline{c}w_o-\overline{B})}{w_o^2\cdot c_o}\right]. \qquad (10)$$

Here:

$$\left.\begin{aligned}
B&=w_o\,k_x\,s+\frac{w_o^2}{2}m+\frac{h}{2}\,c_o\,w_o;\\
\overline{B}&=w_o\,k_x\,s+\frac{w_o^2}{2}m-\frac{h}{2}\,c_o\,w_o;\\
c&=w_o\,b_o-w\cdot k_x+\frac{h}{2}c_o;\\
\overline{c}&=w_o\,b_o-w\cdot k_x-\frac{h}{2}c_o
\end{aligned}\right\}. \qquad (11)$$

Let us introduce the following dimensionless parameters:

$$p=\frac{q(2a)^4}{Eh^4};\quad \frac{w_o}{h}=\xi;\quad \frac{f_o}{h}=\xi_o;\quad k_x=\frac{1}{R}=\frac{2f_o}{a^2}=\frac{2\xi_o h}{a^2}. \qquad (12)$$

Where $f_o -$ is the initial rise of the hull; $a -$ is half of the side of the square hull plan.

In expressions (11), the values corresponding to some measurements are assumed:

$$m=\frac{\overline{m}}{a^2};\quad b_o=\frac{\overline{b}_o}{a^2};\quad c_o=\frac{\overline{c}_o}{a^2}. \qquad (13)$$

We write down expressions (12) and (13) instead of (11) and get:

$$\left.\begin{aligned}B&=\frac{h^2}{a^2}\left(2s\xi_o+\frac{m}{2}\xi+\frac{\bar{c}_o}{2}\right)=\frac{h^2}{a^2}b^*\xi;\\ \bar{B}&=\frac{h^2}{a^2}\left(2s\xi_o+\frac{m}{2}\xi-\frac{\bar{c}_o}{2}\right)=\frac{h^2}{a^2}b^*\xi;\\ c&=\frac{h}{a^2}\left(\bar{b}_o\xi-2\bar{w}_o\xi_o+\frac{\bar{c}_o}{2}\right)=\frac{h}{a^2}c^*;\\ \bar{c}&=\frac{h}{a^2}\left(\bar{b}_o\xi-2\bar{w}_o\xi-\frac{\bar{c}_o}{2}\right)=\frac{h}{a^2}\bar{c}^*\end{aligned}\right\} \tag{14}$$

We write down expressions (12) and (14) instead of (10) and get:

$$P=D_k\left\{\left[(b^*)(3\bar{c}^*-b^*)-(\bar{b}^*)(3\bar{c}^*-\bar{b}^*)\right]-\left[(b^*)(5\bar{c}^*-b^*)-(\bar{b}^*)(5\bar{c}^*-\bar{b}^*)\right]\right\}\cdot\xi^*, \tag{15}$$

where

$$\left.\begin{aligned}b^*&=2s\xi_o+\frac{m}{2}\xi+\frac{\bar{c}_o}{2};\\ \bar{b}^*&=2s\xi_o+\frac{m}{2}\xi-\frac{\bar{c}_o}{2};\\ c^*&=\bar{b}_o\xi-2\bar{w}_o\xi_o+\frac{\bar{c}_o}{2};\\ \bar{c}^*&=\bar{b}_o\xi-2\bar{w}_o\xi_o-\frac{\bar{c}_o}{2};\end{aligned}\right\} \tag{16}$$

$$D_k=\frac{2\pi^2\sigma_o}{\sqrt{3}}. \tag{17}$$

The decisive coefficients in expressions (16) $\left(\bar{m}, \bar{b}_o, s, \bar{w}_o, \bar{c}_o\right)$ are determined from the following conditions [2].

1. When $k=0;\ A=\sigma_o;\ \xi_o=0$ expression (15) is replaced by $\sigma_o=\sigma_{мh}$ expression (with its proportional limit), formula (48) reduces to the following image:

$$q=\frac{\pi^4\sigma_{мh}\sigma_o h}{16a^2\sqrt{3}} \tag{18}$$

2. When $k=1;\ A=E$ expression (48) takes this form:

$$P=\alpha_1\xi^3+\alpha_2\xi^2\xi_o+\alpha_3\xi\xi_o^2+\alpha_4\xi. \tag{19}$$

From formula (15), we summarize terms 1 and 2 and obtain two dependencies between force and slope:

1. $k = 0;\ A = \sigma_{мh}$:

$$q = \frac{\pi^2}{3\sqrt{3}} \frac{\bar{b}_o w_o h}{a^2} \sigma_{мh}; \tag{20}$$

2. $k = 1;\ A = E$:

$$P = \frac{16\pi^2}{9} \bar{m}\, \bar{b}_o\ \xi^3 \frac{32}{9} \pi^2 \left(2s\, \bar{b}_o - \bar{m}\, \bar{w}_o\right) \xi_o \xi^2 - \frac{128\pi^2}{9} s \bar{w}_o \xi_o^2 \xi + \frac{8\pi^2}{27} c_o^2 \xi. \tag{21}$$

Comparing (19) with (18) and (21) with (19), we obtain the following five equations for determining the five coefficients $\bar{b}_o, \bar{m}, s, \bar{w}_o$ and $\bar{c}_o$:

$$\left.\begin{array}{l} \bar{b}_o = \dfrac{3\pi^2}{9}; \quad \dfrac{16\pi^2}{9} \bar{b}_o\ \bar{m} = \alpha_1; \\ \dfrac{32\pi^2}{9}\left(2s\ \bar{w} - \bar{m}\ \bar{w}_o\right) = \alpha_2; \\ -\dfrac{128\pi^2}{9} \bar{w}_o s = \alpha_3; \quad -\dfrac{8\pi^2}{27} \bar{c}_o^{\,2} = \alpha_2 \end{array}\right\} \tag{22}$$

Having solved the system of equations (22), we find these coefficients:

$$\left.\begin{array}{l} \bar{b}_o = \dfrac{3\pi^2}{9}; \quad \bar{m} = \dfrac{3\alpha_1}{\pi^4}; \quad s = \dfrac{3\alpha_2}{8\pi^4} \beta_{1,2}; \\ \bar{w}_o = -\dfrac{3\pi^2}{16} \dfrac{\alpha_3}{\beta_{1,2}} = \dfrac{3\pi^2}{64} \dfrac{\alpha_2}{\alpha_1} \beta_{1,2}; \\ \bar{c}_o = \dfrac{3\sqrt{3}}{2\sqrt{2}} \cdot \dfrac{\sqrt{\alpha_4}}{\pi} \end{array}\right\} \tag{23}$$

CONCLUSIONS

In this study, the free vibration problem of a vertical bridge support structure composed of four arc-shaped orthotropic panels reinforced with rings and filled with soil was investigated using the variational principle. The developed mathematical formulation enabled the derivation of a frequency equation, which was subsequently solved numerically. The results provided insight into how both the material properties and the geometrical dimensions of the panels, as well as the number of reinforcing rings, influence the dynamic response of the support column.

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