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SYSTEM OF EQUATIONS OF COUPLED DYNAMIC PROBLEMS OF A VISCOELASTIC SHELL IN A TEMPERATURE FIELD

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ANNOTATION

At in the present work, a mathematical model of coupled dynamic problems of a viscoelastic shell located in a temperature field is obtained.

Keywords; mathematical model, temperature and deformation, Viscoelastic shell, viscoelastic orthotrope , dynamic, coefficient.

A mathematical model and formulation of dynamic problems for a viscoelastic orthotropic shell are considered, taking into account the interconnectedness of temperature fields and strain fields.

We proceed to the derivation of the equation for the oscillation of a viscoelastic shell.

Let the shell be heated unevenly over the thickness and in the middle surface to a temperature $T(x,y,z,t)$ varying with time. Let us direct the axis z along the normal to the middle surface towards the center of curvature, and choose the origin of coordinates at the point of the middle surface. The axes Ox and Oy let coincide with the directions of the lines of the main curvature of the shell. Let us denote the thickness of the shell through h, its dimensions along the axes Ox and Oy - through a and b.

The dependence of temperature T with strain L_x, L_y, L_{xy} and stress components $\sigma_x, \sigma_y, \sigma_{xy}$ in the case of a plane stress state has the form

$$\sigma_x = \frac{E_1}{1-\vartheta_1\vartheta_2}[(1-R*_{11})l_x + \vartheta_2(1-R*_{12})l_y - (a_1 + a_2\vartheta_2)(1-R*_{13})T];$$

$$\sigma_y = \frac{E_2}{1-\vartheta_1\vartheta_2}[(1-R*_{22})l_y + \vartheta_1(1-R*_{21})l_x - (a_2 + a_1\vartheta_2)(1-R*_{23})T];$$

$$\tau_{xy} = G(1-R*_{33})l_{xy}$$

where E_1, E_2 are the moduli of elasticity of the material in the direction of the axes Ox and Oy respectively; ϑ_1 - coefficient of transverse compression in the direction Oy when stretched in the direction Ox when stretched in the direction Oy; a_1, a_2 – coefficients of linear expansion in the direction of the axes Ox and, Oy respectively; there is a dependence $E_1\vartheta_2 = E_2\vartheta_1$; $R*_{ij}$ between the characteristics $E_1, E_2, \vartheta_1, \vartheta_2$ - integral operators with relaxation $R_{ij}(t)$; kernels

$$R*_{ij}\,\varphi = \int_0^t R_{ij}(t-\tau)d\tau, \quad i, \quad j = 1,2,3.$$

For the component of deformation and changes in the curvature of the middle surface of the shell and displacements of its middle layer, the following relations take place [1-4];

$$\varepsilon_x = \frac{\partial U}{\partial x} + \frac{1}{2}\left[\left(\frac{\partial W}{\partial x}\right)^2 - \left(\frac{\partial W_0}{\partial x}\right)^2\right] - k_1 W;$$

$$\varepsilon_y = \frac{\partial V}{\partial y} + \frac{1}{2}\left[\left(\frac{\partial W}{\partial y}\right)^2 - \left(\frac{\partial W_0}{\partial y}\right)^2\right] - k_2 W;$$

$$\gamma_{xy} = \frac{\partial U}{\partial y} + \frac{\partial V}{\partial x} + \frac{\partial W}{\partial x}\frac{\partial W}{\partial y} - \frac{\partial W_0}{\partial x}\frac{\partial W_0}{\partial y};$$

$$\chi_x = \frac{\partial^2 U}{\partial x^2}, \qquad \chi_y = \frac{\partial^2 W}{\partial y^2}, \qquad \chi_x = \frac{\partial^2 W}{\partial x \partial y},$$

where $W_0 = W(x, y)$ - initial deflection.

According to the hypothesis of direct normals, the deformations l_x, l_y, l_{xy} for a layer separated from the middle one by a distance can be written as z

$$l_x = \varepsilon_x + z\chi_x, \quad l_y = \varepsilon_y + z\chi_y, \quad l_{xy} = \gamma_{xy} + 2z\chi_{xy}$$

We calculate N_x, N_y - normal, N_{xy} - tangential forces, - M_x, M_y bending moments. H -torque:

$$N_x = \int_{-h/2}^{h/2} \sigma_x dz = \frac{hE_1}{1-\vartheta_1\vartheta_2}\left\{(1-R^*_{11})\left(\frac{\partial U}{\partial x} + \frac{1}{2}\left[\left(\frac{\partial W}{\partial x}\right)^2 - \left(\frac{\partial W_0}{\partial x}\right)^2\right] - k_1 W\right) + \right.$$

$$+\vartheta_2(1-R^*_{22})\left(\frac{\partial V}{\partial y} + \frac{1}{2}\left[\left(\frac{\partial W}{\partial y}\right)^2 - \left(\frac{\partial W_0}{\partial y}\right)^2\right] - k_2 W\right) -$$

$$\left. -(a_1 + \vartheta_2 a_2)(1-R^*_{13})T_N \right\};$$

$$N_y = \int_{-h/2}^{h/2} \sigma_y dz = \frac{hE_2}{1-\vartheta_1\vartheta_2}\left\{(1-R^*_{22})\left(\frac{\partial V}{\partial y} + \frac{1}{2}\left[\left(\frac{\partial W}{\partial y}\right)^2 - \left(\frac{\partial W_0}{\partial y}\right)^2\right] - k_2 W\right) + \right.$$

$$+\vartheta_1(1-R^*_{11})\left(\frac{\partial U}{\partial x} + \frac{1}{2}\left[\left(\frac{\partial W}{\partial x}\right)^2 - \left(\frac{\partial W_0}{\partial x}\right)^2\right] - k_1 W\right) -$$

$$\left. -(a_2 + \vartheta_1 a_1)(1-R^*_{23})T_N \right\};$$

$$N_{xy} = \int_{-h/2}^{h/2} \tau_{xy} dz = Gh(1-R^*_{33})\left(\frac{\partial U}{\partial y} + \frac{\partial V}{\partial x} + \frac{\partial W}{\partial x}\frac{\partial W}{\partial y} - \frac{\partial W_0}{\partial x}\frac{\partial W_0}{\partial y}\right):$$

$$M_x = \int_{-h/2}^{h/2} \sigma_x z dz = -\frac{E_1 h^3}{12(1-\vartheta_1\vartheta_2)}\left[(1-R^*_{11})\frac{\partial^2 W}{\partial x^2} + \vartheta_2(1-R^*_{22})\frac{\partial^2 W}{\partial y^2}\right] -$$

$$-\frac{E_1 h^3}{12(1-\vartheta_1\vartheta_2)}(a_1 + \vartheta_2 a_2)(1-R^*_{11})T_M;$$

$$M_y = \int_{-h/2}^{h/2} \sigma_x z dz = -\frac{E_2 h^3}{12(1-\vartheta_1\vartheta_2)}\left[(1-R^*_{22})\frac{\partial^2 W}{\partial y} + \vartheta_1(1-R^*_{11})\frac{\partial^2 W}{\partial x^2}\right] -$$

$$-\frac{E_2h^2}{1-\vartheta_1\vartheta_2}(a_2+\vartheta_1 a_1)(1-R*_{22})T_M;$$

$$H=-\frac{Gh^3}{6}(1-R*_{33})\frac{\partial^2 W}{\partial x\partial y},$$

and substituting them into the equations of motion [3-5,8]

$$\frac{\partial N_x}{\partial x}+\frac{\partial N_{xy}}{\partial y}+p_x-ph\frac{\partial^2 U}{\partial t^2}=0; \qquad \text{(one)}$$

$$\frac{\partial N_x}{\partial x}+\frac{\partial N_{xy}}{\partial y}+p_x-ph\frac{\partial^2 U}{\partial t^2}=0; \qquad (2)$$

$$\frac{\partial^2 M_2}{\partial x^2}+2\frac{\partial^2 H}{\partial x\partial y}+\frac{\partial^2 M_y}{\partial y^2}+k_1N_x+k_2N_y+\frac{\partial}{\partial x}\left(N_x\frac{\partial W}{\partial x}+N_{xy}\frac{\partial W}{\partial y}\right)+$$
$$\frac{\partial}{\partial y}\left(N_{xy}\frac{\partial W}{\partial x}+N_y\frac{\partial W}{\partial y}\right)+q-ph\frac{\partial^2 W}{dt^2}=0 \qquad (3)$$

we obtain the following system of nonlinear integro -differential equations:

$$\frac{E_1}{1-\vartheta_1\vartheta_2}\left\{(1-R*_{11})\left[\frac{\partial^2 U}{\partial x^2}+\left(\frac{\partial W}{\partial x}\frac{\partial^2 W}{\partial x^2}-\frac{\partial W_0}{\partial x}\frac{\partial^2 W_0}{\partial x^2}\right)-k_1\frac{\partial W}{\partial x}\right]+\right.$$
$$\left.+\vartheta_2(1-R*_{22})\left[\frac{\partial^2 V}{\partial x\partial y}+\left(\frac{\partial W}{\partial y}\frac{\partial^2 W}{\partial x\partial y}-\frac{\partial W_0}{\partial y}\frac{\partial^2 W_0}{\partial x\partial y}\right)-k_2\frac{\partial W}{\partial x}\right]\right\}+$$
$$+G(1-R*_{11})\left(\frac{\partial^2 U}{\partial y^2}+\frac{\partial^2 V}{\partial x\partial y}+\frac{\partial^2 W}{\partial x\partial y}\frac{\partial W}{\partial y}+\frac{\partial W}{\partial x}\frac{\partial^2 W}{\partial y^2}-\frac{\partial^2 W_0}{\partial x\partial y}\frac{\partial W_0}{\partial y}-\right.$$
$$\left.-\frac{\partial^2 W_0}{\partial x}\frac{\partial^2 W_0}{\partial y^2}\right)-\frac{E_1}{1-\vartheta_1\vartheta_2}(a_1+a_2\vartheta_2)(1-R*_{13})\frac{\partial T_N}{\partial x}+\frac{p_x}{h}-p\frac{\partial^2 U}{\partial t^2}=0;$$

$$\frac{E_2}{1-\vartheta_1\vartheta_2}\left\{(1-R*_{22})\left[\frac{\partial^2 V}{\partial y^2}+\left(\frac{\partial W}{\partial y}\frac{\partial^2 W}{\partial y^2}-\frac{\partial W_0}{\partial y}\frac{\partial^2 W_0}{\partial y^2}\right)-k_2\frac{\partial W}{\partial y}\right]+\right.$$
$$\left.+\vartheta_1(1-R*_{11})\left[\frac{\partial^2 U}{\partial x\partial y}+\left(\frac{\partial W}{\partial x}\frac{\partial^2 W}{\partial x\partial y}-\frac{\partial W_0}{\partial x}\frac{\partial^2 W_0}{\partial x\partial y}\right)-k_1\frac{\partial W}{\partial y}\right]\right\}+$$
$$+G(1-R*_{11})\left(\frac{\partial^2 U}{\partial x\partial y}+\frac{\partial^2 V}{\partial x^2}+\frac{\partial^2 W}{\partial x^2}\frac{\partial W}{\partial y}+\frac{\partial W}{\partial x}\frac{\partial^2 W}{\partial x\partial y}-\frac{\partial^2 W_0}{\partial x^2}\frac{\partial W_0}{\partial y}-\right.$$
$$\left.-\frac{\partial W_0}{\partial x}\frac{\partial^2 W_0}{\partial x\partial y}\right)-\frac{E_2}{1-\vartheta_1\vartheta_2}(a_2+a_1\vartheta_1)(1-R*_{23})\frac{\partial T_N}{\partial y}+\frac{p_y}{h}-p\frac{\partial^2 V}{\partial t^2}=0;$$

$$\frac{1}{h}\left\{D_1(1-R*_{11})\frac{\partial^4 W}{\partial x^4}+[D_1\vartheta_2(1-R*_{22})+D_2\vartheta_1(1-R*_{11})+2D_G(1-\right.$$
$$\left.-R*_{33})]\frac{\partial^4 W}{\partial x^2\partial y^2}+D_2(1-R*_{22})\frac{\partial^4 W}{\partial y^4}\right\}=\frac{\partial}{\partial x}\left\{B_{11}\left[(1-R*_{11})\left(\frac{\partial V}{\partial y}+\right.\right.\right.$$

$$+\frac{1}{2}\left[\left(\frac{\partial W}{\partial x}\right)^2-\left(\frac{\partial W_0}{\partial x}\right)^2\right]-k_1W\Bigg)+\vartheta_2(1-R*_{22})\left(\frac{\partial V}{\partial y}+\right.$$

$$+\frac{1}{2}\left[\left(\frac{\partial W}{\partial y}\right)^2-\left(\frac{\partial W_0}{\partial y}\right)^2\right]-k_2W)\Bigg]\frac{\partial W}{\partial x}+G(1-R*_{33})\left(\frac{\partial U}{\partial y}+\right.$$

$$\left.+\frac{\partial V}{\partial x}+\frac{\partial W}{\partial x}\frac{\partial W}{\partial y}-\frac{\partial W_0}{\partial x}\frac{\partial W_0}{\partial y}\right)\frac{\partial W}{\partial y}\Bigg\}+\frac{\partial}{\partial y}\Bigg\{B_{22}\Bigg[(1-R*_{22})\left(\frac{\partial V}{\partial y}+\right.$$

$$+\frac{1}{2}\left[\left(\frac{\partial W}{\partial y}\right)^2-\left(\frac{\partial W_0}{\partial y}\right)^2\right]-k_2W\Bigg)+\vartheta_1(1-R*_{11})\left(\frac{\partial U}{\partial x}+\frac{1}{2}\left[\left(\frac{\partial W}{\partial x}\right)^2-\right.\right.$$

$$-\left(\frac{\partial W_0}{\partial x}\right)^2\Bigg]-k_1W\Bigg)\Bigg]\frac{\partial W}{\partial y}+G(1-R*_{33})\left(\frac{\partial U}{\partial y}+\frac{\partial V}{\partial x}+\frac{\partial W}{\partial x}\frac{\partial W}{\partial y}-\right.$$

$$\left.-\frac{\partial W_0}{\partial x}\frac{\partial W_0}{\partial y}\right)\frac{\partial W}{\partial x}\Bigg\}-B_{11}(a_1+\vartheta_2a_2)\frac{\partial}{\partial x}\left[\frac{\partial W}{\partial x}(1-R*_{11})T_N\right]-$$

$$-B_{22}(a_2+\vartheta_1a_1)\frac{\partial}{\partial y}\left[\frac{\partial W}{\partial y}(1-R*_{23})T_N\right]-B_{11}h(a_1+\vartheta_2a_2)(1-R*_{11}\Big)\times$$

$$\times\frac{\partial^2T_M}{\partial x^2}-B_{22}h(a_2+\vartheta_1a_1)(1-R*_{22})\frac{\partial^2T_M}{\partial y^2}+\frac{q}{h}-p\frac{\partial^2W}{\partial t^2}, \qquad \text{(four)}$$

where

$$B_{11}=E_1/(1-\vartheta_1\vartheta_2);\quad B_{22}=E_2/(1-\vartheta_1\vartheta_2);\quad B_{12}=B_{21}=\vartheta_1B_{22}=\vartheta_2B_{11};$$

$$T_N=\frac{1}{h}\int_{-h/2}^{h/2}T(x,y,z,t)dz,\quad T_M=\frac{1}{h^2}\int_{-h/2}^{h/2}T(x,y,z,t)zdz,$$

$$D_1=\frac{B_{11}h^3}{12},\quad D_2=\frac{B_{22}h^3}{12},\quad D_G=\frac{Gh^3}{6},$$

The resulting system is fairly general .

Let's turn to some special cases.

1. If the dynamic process can be considered without taking into account inertial loads corresponding to displacements U and V , then equations (1)-(3) are simplified. The result obtained in [9] can be used to substantiate the assumption made . The system of equations obtained in this case will not be presented here.2. When $k_1=0,\ k_2=1/R,$ where R is the radius of curvature of the middle surface, we obtain a system of equations for a circular cylindrical shell.

3. At $k_1=k_2=1/R,$, we will have equations for a spherical shell.

Starting to work similarly to [5-7, 9,11] to determine the temperature distribution, we obtain the coupled heat equation for orthotropic solids in the form

$$a_1\frac{\partial^2T}{\partial x^2}+a_2\frac{\partial^2T}{\partial y^2}+a_3\frac{\partial^2T}{\partial z^2}-pc_T\frac{\partial T}{\partial t}=\frac{a_1+a_2\vartheta_2}{1-\vartheta_1\vartheta_2}\frac{\partial\sigma_x}{\partial t}+\frac{a_2+a_1\vartheta_1}{1-\vartheta_1\vartheta_2}\frac{\partial\sigma_y}{\partial t},$$

where - a_1, a_2, a_3 thermal conductivity coefficients in three mutually perpendicular directions, c_T - specific heat capacity.

If the right side of this equation is written with respect to displacement, then it takes the form

$$a_1\frac{\partial^2 T}{\partial x^2}+a_2\frac{\partial^2 T}{\partial y^2}+a_3\frac{\partial^2 T}{\partial z^2}-pc_T\frac{\partial T}{\partial t}=\frac{E_1(a_1+a_2\vartheta_2)}{(1-\vartheta_1\vartheta_2)^2}\frac{\partial}{\partial t}\{(1-R*_{11})\times$$

$$\times\left(\frac{\partial U}{\partial x}+\frac{1}{2}\left[\left(\frac{\partial W}{\partial x}\right)^2-\left(\frac{\partial W_0}{\partial x}\right)^2\right]-k_1W\right)+\vartheta_2(1-R*_{22})\left(\frac{\partial V}{\partial y}+\right.$$

$$\left.+\frac{1}{2}\left[\left(\frac{\partial W}{\partial y}\right)^2-\left(\frac{\partial W_0}{\partial y}\right)^2\right]-k_2W\right)-(a_1+\vartheta_2a_2)(1-R*_{13})T\}+$$

$$+\frac{E_2(a_2+a_1\vartheta_1)}{(1-\vartheta_1\vartheta_2)^2}\frac{\partial}{\partial t}\{(1-R*_{22})\left(\frac{\partial V}{\partial y}+\frac{1}{2}\left[\left(\frac{\partial W}{\partial y}\right)^2-\left(\frac{\partial W_0}{\partial y}\right)^2\right]-k_2W\right)+$$

$$+\vartheta_1(1-R*_{11})\left(\frac{\partial U}{\partial x}+\frac{1}{2}\left[\left(\frac{\partial W}{\partial x}\right)^2-\left(\frac{\partial W_0}{\partial x}\right)^2\right]-k_1W\right)-$$

$$-(a_2+\vartheta_1a_1)(1-R*_{22})T\}.$$

The resulting systems of equations (4) and (5) are interconnected. Thus, this system of equations describes the deformation of a viscoelastic orthotropic shell arising from non-stationary mechanical and thermal effects, as well as the inverse effect - a change in its temperature field due to deformation. Such a problem is called the coupled dynamic problem of thermoviscoelasticity .

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