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**BOUNDARY CONDITIONS DETERMINATION OF THE TANK MODEL AS A RIGID CYLINDRICAL SHELL WITH THE ELASTIC BOTTOM ON THE ELASTIC WINKLER BASE**

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**ABSTRACT**

The tank model as a rigid cylindrical shell of radius  $R$  with the elastic bottom on the elastic Winkler base has been built. It has been considered the tank is partially filled with the ideal incompressible liquid to a height of  $H$ , Fig. 1. Let  $S_0$  denote the liquid free surface,  $S_1$  is the rigid cylindrical surface, and  $S_{\text{bot}}$  is the bottom elastic surface.

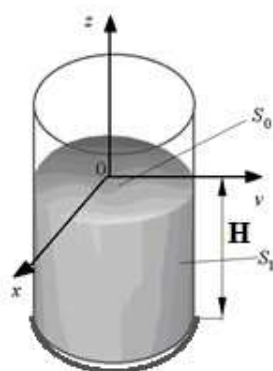


Figure 1. Cylindrical tank with the elastic bottom on the Winkler elastic base. If the thickness  $h$  of a homogeneous plate is constant, then the motion equation of the plate in cylindrical coordinates has the form

$$D\Delta\Delta w + \rho_p h \frac{\partial^2 w}{\partial t^2} + Kw = q(r, \varphi, t). \quad (1)$$

Here  $D = 12 \frac{E_1 h^3}{1 - \nu_2^2}$  is cylindrical stiffness,  $\rho_p$  is plate density,  $K$  – Winkler module,  $q(r, \varphi, t)$  – external force acting on the plate.

If the plate is in contact with the liquid, then

$$q(r, \varphi, t) = p(r, \varphi, t) + q_0(r, \varphi, t),$$

where  $p(x, y, t)$  is fluid pressure on the plate,  $q_0(r, \varphi, t)$  is disturbing force.

To find the pressure, it has been made the following assumptions: the liquid is ideal and incompressible, and its motion is vortex-free. Under these conditions, there is the velocity potential  $\varphi(x, y, z, t)$  that satisfies the Laplace equation

$$\frac{\partial^2 \varphi}{\partial x^2} + \frac{\partial^2 \varphi}{\partial y^2} + \frac{\partial^2 \varphi}{\partial z^2} = 0. \quad (2)$$

The correlation between the velocity potential and the pressure determined from the linearized Cauchy-Lagrange integral [1-5]

$$p - p_0 = -\rho_l \left[ \frac{\partial \phi}{\partial t} + a_x(t)x + (g + a_z(t))\zeta \right],$$

where  $\rho_l$  is liquid density;  $p_0$  is atmospheric pressure,  $a_x(t)$ ,  $a_z(t)$  are the acceleration components of the exciting force in horizontal and vertical directions,  $\zeta$  – is the function describing the position and elevation level of the liquid free surface. Thus,

$$a_x(t) = a_h \cos \omega_h t, \quad a_z(t) = a_v \cos \omega_v t.$$

The boundary conditions for equation (1) are follows.

The no-flow condition has been fulfilled on the rigid cylindrical surface  $S_1$

$$\left. \frac{\partial \phi}{\partial \mathbf{n}} \right|_{S_1} = 0. \tag{3}$$

On the elastic bottom, the no-flow condition takes the form

$$\left. \frac{\partial \phi}{\partial \mathbf{n}} \right|_{S_{bot}} = \frac{\partial w}{\partial t}, \tag{4}$$

where  $w$  is deflection of the plate determined from equation (1) and the corresponding boundary conditions determined below [6-8].

On the free surface, the kinematic and dynamic boundary conditions in the form must be fulfilled

$$\left. \frac{\partial \phi}{\partial \mathbf{n}} \right|_{S_0} = \frac{\partial \zeta}{\partial t}, \quad p - p_0|_{S_0} = 0. \tag{5}$$

Here the function  $\zeta = \zeta(t, x, y)$  characterizes the change in the level and free surface position over time,  $\mathbf{n}$  is the external unit normal to the surface.

It has been used the boundary conditions for fixing the plate along the contour. The cylindrical coordinate system  $(r, \phi, z)$  has been applied. In the case of rigid fixation, there have been obtained the following boundary conditions:

$$w|_{r=R} = 0, \quad \left. \frac{dw}{dr} \right|_{r=R} = 0. \tag{6}$$

The natural oscillations of the cylindrical shell – liquid system have been considered.

Thus,  $q_0(r, \phi, t) = 0$ ,  $a_x(t) = a_z(t) = 0$ , and equation (1) takes the form

$$D\Delta\Delta w + \rho_p h \frac{\partial^2 w}{\partial t^2} + Kw = -\rho_l \frac{\partial \phi}{\partial t}. \tag{7}$$

Therefore, it is necessary to find the unknown functions  $w$ ,  $\phi$ ,  $\zeta$ , that satisfy the system of differential equations

$$D\Delta\Delta w + \rho_p h \frac{\partial^2 w}{\partial t^2} + Kw = -\rho_l \left( \frac{\partial \phi}{\partial t} + \frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} + \frac{\partial^2 \phi}{\partial z^2} \right) = 0 \tag{8}$$

and boundary conditions

$$\left. \frac{\partial \phi}{\partial \mathbf{n}} \right|_{S_1} = 0, \quad \left. \frac{\partial \phi}{\partial \mathbf{n}} \right|_{S_0} = \frac{\partial \zeta}{\partial t}, \quad \left. \frac{dw}{dr} \right|_{r=R} = 0$$

$\partial \underline{\mathbf{n}}|_{S_1} = 0$ ,  $\partial \underline{\mathbf{n}}|_{S_{bot}} = \underline{\underline{\partial t}}$ ,  $\partial \underline{\mathbf{n}}|_{S_0} = \partial t \underline{\underline{\quad}}$ ,  $p - p^0|_{S_0} = 0$ ,  $w|_{r=R} = 0$ ,  $\underline{\underline{\quad}}_{dr}|_{r=R} = 0$ . (9) To obtain the unique solution of the system of equations (8) with boundary conditions (9), there have been added the Neumann condition

$$\iint \underline{\underline{\quad}} dS_0 = 0_S \partial \underline{\mathbf{n}} \quad . \quad (10)$$

■

The tank model has been built as the rigid cylindrical shell of radius R with the elastic bottom on the elastic Winkler base. Boundary conditions of the reservoir model have been defined.

**Keywords:** technogenic influence, hazardous liquid, seismic loads, storage tanks, petroleum products, sloshing.