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Content

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_{bot} is the bottom elastic surface.

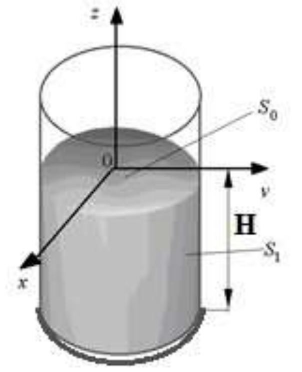

Figure 1. Cylindrical tank with the elastic bottom on the Winkler elastic base If the thickness h of a homogeneous plate is constant, then the motion equation of the plate in cylindrical coordinates has the form

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

Here $D = \frac{Eh^3}{12(1-\nu^2)}$ is cylindrical stiffness, ρ_p is plate density, K – Winkler module, $q(r, \square, t)$ – external force acting on the plate.

If the plate is in contact with the liquid, then

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

where $p(x, y, t)$ is fluid pressure on the plate, $q_0(r, \square, t)$ 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 φ(x,y,z,t) that satisfies the Laplace equation

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

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

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

where ρ_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, ζ – is the function describing the position and elevation level of the liquid free surface. Thus,

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

The boundary conditions for equation (1) are follows.

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

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

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

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

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

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

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 $(r, \square, z)$ has been applied. In the case of rigid fixation, there have been obtained the following boundary conditions:

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

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

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

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

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

$$D\Delta\Delta w + \rho_p h \frac{\partial^2 w}{\partial t^2} + Kw = -\rho_l \frac{\partial \square}{\partial t},\quad \frac{\partial^2 \square}{\partial x^2} + \frac{\partial^2 \square}{\partial y^2} + \frac{\partial^2 \square}{\partial z^2} = 0 \tag{8}$$

and boundary conditions

$$\partial \square \qquad \partial \square \qquad \partial w \ \partial \square \qquad \partial \zeta \qquad\qquad dw$$

∂__$\mathbf{n}|S_1 = 0$, $\partial\mathbf{n}|S_{bot} =$ __∂t , $\partial\mathbf{n}|S_0 = \partial t$__ , $p - p^0|^{S}{}_0 = 0$, $w|^{r=R} = 0$, __${}_{dr}\,|r{=}_R = 0$. (9) To obtain the unique solution of the system of equations (8) with boundary conditions (9), there have been added the Neumann condition

$$\iint \frac{\partial\varphi}{} dS_0 = 0_{S\partial\mathbf{n}} \quad . \tag{10}$$

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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.