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MEMBRANE INSTALLATION IN STORAGE TANKS FOR SEISMIC LOADS IMPACT PROTECTION

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There are about 1 million earthquakes of varying intensity every year in the world. The research of seismic loads on the important technogenic objects remains the urgent issue both globally and regionally. The paper aim is to prevent emergencies and negative impact on the environment in case of damage, destruction and leakage of storage tanks for toxic and flammable liquids due to seismic loads of different strength. The liquid vibrations in rigid and elastic reservoirs have been considered. It has been established that level changing via time for reservoirs without covering membrane can be very large and lead to the appearance of excess pressure on the tank wall. The installation of the floating membrane leads to decreasing both the free surface level and the pressure on the tank walls. The results of the research will allow to reduce sloshing effects and pressure on the reservoir walls, and so to extend the service life, minimize the ecologically hazardous impact on the environment, and prevent emergencies.

Keywords: storage tanks, environmental safety, earthquakes, seismic loads, free and forced vibrations, membrane cover.

INTRODUCTION

In the modern world, natural disasters turn into social catastrophes, often due to the unpreparedness of society for the next manifestations of the elements. The first and most important step in reducing earthquake damage should be to study the "seismic climate" of the area, i.e. its zoning according to the degree of seismic hazard, and the corresponding seismic construction and preventive measures for objects that could dangerously affect the environment.

Every year there are about 1 million earthquakes of varying intensity in the world. Therefore, the study of seismic loads on important technogenic objects remains the urgent issue both globally and regionally (1).

It should be noted that strong subcortical earthquakes of the Vrancea zone (Romania) are felt throughout Ukraine. The last strong earthquakes occurred in 1940, 1977, 1986 and 1990. In general, up to 40% of the territory of Ukraine could be covered by the direct impact of dangerous seismic events and up to 70% - the joint impact of earthquakes with flooding, landslides, subsidence and other engineering and geological processes that adversely affect the stability of structures (2,3). Seismic areas of Ukraine, with the projected

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seismic intensity of 6-9 points, occupy about 20% of the territory (≈120 thousand km^2), inhabited by more than 10 million people. Areas with the intensity of 7–9 points occupy about 12% of the territory and include about 80 settlements inhabited by more than 7 million people (4,5).

Containers and tanks for oil storage, toxic and flammable liquids are widely used in various fields of engineering practice, such as aircraft, chemical, oil and gas industry, energy engineering and transport. These tanks operate under conditions of high technological loads and filled with oil, flammable or toxic substances. As a result of the sudden action of seismic loads, the liquid stored in the tanks begins to experience intense sloshing (6).

Sloshing is the phenomenon observed in the number of industrial facilities: in containers for storage of liquefied gas, oil, fuel tanks, in the tanks of cargo tanks. It is known that partially filled tanks are exposed to particularly intense sloshes. This could lead to high pressure on the tank walls, destruction of the structure or loss of stability and could cause the outflow of hazardous contents, which in turn could lead to serious environmental consequences. In case of tank accidents, oil products spill and pollute the surrounding areas and water basins. The ingress of toxic and flammable liquids from the tanks for their storage into the environment and their further spread to the territory of settlements could cause mass people and animals poisoning, and lead to environment pollution. Liquid spills could lead to explosions and fires that could spread to nearby reservoirs and surrounding areas. As the tanks store the huge supply of combustible substances, the fire could have serious consequences. Economic losses from oil leakage and fire accidents include not only direct losses, but also the cost of environmental restoration measures, as well as the cost of replenishing the stock of petroleum products (6-8).

The structural damage of reservoirs for the preservation of toxic and flammable liquids of strong winds has been calculated in (9).

Kendzera O.V. has treated the different seismic loads and responses in soils (4, 5).

Most of the research papers of Korgin A.V. (10), Qin F. (11), and Khalmuradov B. (12) devoted to assessing the significance of the effects of reservoirs for the preservation of toxic and flammable liquids on the environment and monitoring changes in the tightness of reservoirs, the rate of their destruction under technogenic and climatic factors, but such the significant impact on reservoir stability as earthquakes insufficiently studied.

Analysis of research on the sloshing issues of liquid in tanks, provided in the R.A. Ibrahim papers (13, 14). Note also the papers on the liquid sloshing in cylindrical tanks under the action of seismic loads (15-17).

A finite element model has been developed in (18) to study free vibration of a liquid in a tank of arbitrary geometry with a flexible membrane constraining the liquid free-surface. However, other papers have also considered the moving containers to prevent resonance and such different loads on the containers.

The membrane implementation in liquid containers has been investigated in (19).

Improving tank material characteristics has been studied in papers (20-23).

Dynamic testing of tanks and silos could be traced to the late 1960s, however, the development in the last 15-20 years is more interesting to the reader and it might allow him to better understand the work and locate it as a new contribution to this field (24-28).

The aim of the paper is to prevent emergencies and negative impact on the environment in case of damage, destruction and leakage of storage tanks of toxic and flammable liquids due to seismic loads of different strength.

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MATERIALS AND METHODS

Estimation of seismic strength has been carried out as follows. At the first stage, the frequencies and modes of the natural vibrations of the tank have been determined using the methods developed in papers (23, 29, 30).

Next, the model inertial seismic loads on the structure have been determined.

Analysis of experimental studies of seismic resistance in paper (31) have been shown that usually only the lowest natural frequencies of oscillations are located in the region of seismic resonance. The higher natural frequencies are significantly away from the region of seismic resonance. Usually, already the second natural frequency is higher than the upper limit of the spectrum.

As in paper (31), it has been established that the lower frequencies of oscillations of a tank with a liquid at given mechanical and geometric characteristics are the sloshing frequencies. The frequency spectra of free surface oscillations and elastic walls are separated.

Forced oscillations of the reservoir under a given seismic load have been studied.

Here liquid vibrations have been considered with and without covering the free surface.

In the paper the issue of fluid vibrations in the arbitrary shell of revolution has been considered.

First, the frequencies and modes of the natural vibrations of the tank have been determined using the Boundary Element Methods (BEM).

It has been denoted the wetted surface of the shell by S_1, and the free surface by S_0 (Figure 1). The cylindrical shell with the flat bottom, partially filled with liquid has been considered as the model of the oil storage.

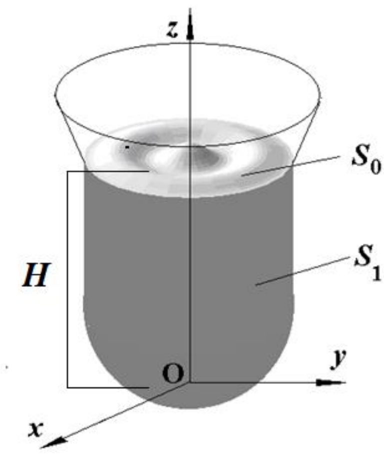

Figure 1. Shell of revolution

It has been assumed that the Cartesian coordinate system 0xyz connected to the shell, the free surface of the liquid S_0 coincides with the plane $z=H$ at rest. It has been presumed that the fluid is ideal, incompressible, and its motion, which began at rest, is vortex-free. Under these conditions, there is the potential for fluid velocities that satisfies the Laplace equation:

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$$V_x = \frac{\partial \Phi}{\partial x};\ V_y = \frac{\partial \Phi}{\partial y};\ V_z = \frac{\partial \Phi}{\partial z}, \qquad [1]$$

The pressure p value on the shell walls has been determined from the linearized Bernoulli's integral by the formula:

$$p = -\rho_l \left(\frac{\partial \Phi}{\partial t} + gz\right) + p_0 + a_s(t)x, \qquad [2]$$

in which Φ is the velocity potential, g is gravity acceleration, z is the point coordinate of the fluid measured in the vertical direction, ρ_l is the fluid density, p_0 is the atmospheric pressure, $a_s(t)$ is the function that characterizes the external influence (horizontal seismic acceleration). In equation [2] the value gz is the gravitational potential, and so according to [14], at the free surface, the pressure is equivalent to the ambient pressure, i.e. $p = p_0$.

So, the following kinematic and dynamic conditions must be fulfilled on the free surface of the liquid:

$$\left.\frac{\partial \Phi}{\partial \mathbf{n}}\right|_{S_0} = \frac{\partial \zeta}{\partial t}; \quad p - p_0|_{S_0} = 0, \qquad [3]$$

where the function ζ describes the shape and position of the free surface.

Thus, for the velocity potential it has been obtained the following boundary value issue:

$$\nabla^2 \Phi = 0;\ \left.\frac{\partial \Phi}{\partial \mathbf{n}}\right|_{S_1} = 0; \left.\frac{\partial \Phi}{\partial \mathbf{n}}\right|_{S_0} = \frac{\partial \zeta}{\partial t}; \quad p - p_0|_{S_0} = 0;\ \left.\frac{\partial \Phi}{\partial t} + g\zeta + a_s(t)x\right|_{S_0} = 0. \qquad [4]$$

Determined the potential of velocities Φ and the function ζ, it has been set the height of the rise of the free surface and determined the pressure of the liquid on the shell walls.

It has been presented the potential Φ in the form:

$$\Phi = \sum_{k=1}^{M} \dot{d}_k \phi_k. \qquad [5]$$

For the functions φ_k, the following boundary value problems have been considered:

$$\nabla^2 \phi_k = 0, \left.\frac{\partial \phi_k}{\partial \boldsymbol{n}}\right|_{S_1} = 0, \qquad [6]$$

$$\left.\frac{\partial \phi_k}{\partial \boldsymbol{n}}\right|_{S_0} = \frac{\partial \zeta}{\partial t}; \quad \frac{\partial \phi_k}{\partial t} + g\zeta = 0. \qquad [7]$$

It has been differentiated the second ratio in equation [5] by t and substitute in the obtained equality $\frac{\partial \zeta}{\partial t}$ from the first ratio.

Next, it has been presented as the functions ϕ_k as $\phi_k(x,y,z,t) = \exp(i\chi_k t)\phi_k(x,y,z)$. It has been gained the eigenvalues problem, and the following equality will be satisfied on the free surface:

$$\frac{\partial \phi_k}{\partial n} = \frac{\chi_k^2}{g}\phi_k. \qquad [8]$$

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For the free surface level, the next expression has been obtained:

$$\zeta = \sum_{k=1}^{M} d_k \frac{\partial \phi_k}{\partial n}. \quad [9]$$

In a cylindrical coordinate system, expressions for the required functions have been gained as follows:

$$\phi_k(r, z, \theta) = \phi_k(r, z) \cos \alpha\, \theta \quad [10]$$

Here α is the harmonic number. Thus, the frequencies and modes of free oscillations for different α have been considered separately.

It has been represented φ as the potentials sum of the simple and double layer (18):

$$2\pi\Phi(P_0) = \iint_S \frac{\partial \Phi}{\partial \mathbf{n}} \frac{1}{|P-P_0|} dS - \iint_S \Phi \frac{\partial}{\partial \mathbf{n}} \frac{1}{|P-P_0|} dS. \quad [11]$$

Here $S = S_1 \cup S_0$; points P and P_0 belong to the surface S, and $|P - P_0|$ is the Cartesian distance between points P and P_0. Equation [11] is a consequence of the third Green's identity in the case when the point P_0 belongs to the surface S (18) This is the integral form of Laplace's equation and it will be used here in numerical implementation of boundary element method (19).

Satisfying the boundary conditions in (6) and (7), it has been achieved the next system of integral equations:

$$\begin{cases} 2\pi\varphi_1 + \iint_{S_1} \varphi_1 \frac{\partial}{\partial n}\left(\frac{1}{r}\right) dS_1 - \frac{\chi^2}{g} \iint_{S_0} \varphi_0 \frac{1}{r} dS_0 + \iint_{S_0} \varphi_0 \frac{\partial}{\partial z}\left(\frac{1}{r}\right) dS_0 = 0, \\ -\iint_{S_1} \varphi_1 \frac{\partial}{\partial n}\left(\frac{1}{r}\right) dS_1 - 2\pi\varphi_0 + \frac{\chi^2}{g} \iint_{S_0} \varphi_0 \frac{1}{r} dS_0 = 0. \end{cases} \quad [12]$$

Here, for convenience, it has been denoted the potential value on the free surface as φ_0, and as φ_1 on the shell walls.

The solution of system (12) in the form (10) has been found.

To solve this system of singular integral equations, it has been applied the boundary elements method described in papers (7, 8).

So, the modes and frequencies of own tank vibrations have been determined. These modes are hereinafter considered as basic functions.

Next stage of the research has been devoted to simulation of the forced vibrations. To determine the basic relations for d_k in equation [9] it has been substituted basic functions into expressions for the velocity potential equation [5] and to the free surface shape equation [9]. The resulting series have been substituted into the boundary condition on the free surface:

$$\frac{\partial \Phi}{\partial t} + \left(g + a_z(t)\right)\zeta + a_x(t)x\Big|_{S_0} = 0.$$

Since in the cylindrical coordinate system, $x = r\cos\theta$, there will be only first harmonic, i.e. in formula [6] it has been considered only α=1. Further, it has been performed correlation on the free surface S_0:

$$\sum_{k=1}^{M} \ddot{d}_k \phi_k + \big(g + a_z(t)\big) \sum_{k=1}^{M} d_k \frac{\partial \phi_k}{\partial n} + a_x(t) r = 0.$$

But on the surface S_0 the ratio [8] has also been fulfilled. Then the above equality will take the form:

$$\sum_{k=1}^{M} \ddot{d}_k \phi_k + \big(g + a_z(t)\big) \sum_{k=1}^{M} \frac{\chi_k^2}{g} d_k \phi_k + a_x(t) r = 0. \qquad [13]$$

Multiplying equation [9] scalarly on ϕ_l $\left(l = \overline{1, M}\right)$ and using the eigenforms orthogonality, it has been obtained the system of second-order ordinary differential equations:

$$\ddot{d}_k + \frac{\chi_k^2}{g}\big(g + a_z(t)\big) d_k + a_x(t) F_k = 0, \quad F_k = \frac{(r, \phi_k)}{(\phi_k, \phi_k)}, \quad k = \overline{1, M}. \qquad [14]$$

It has been assumed that before the horizontal load applied, the tank was at rest. Then equation [14] has been solved under zero initial conditions. To solve the system [14], the numerical method has been used as in papers (25, 26). This numerical solution allows us to receive the tie history for the free surface level ζ, ad well as the pressure *p*, obtained by the formula:

$$p = -\rho_l \left(\frac{\partial \Phi}{\partial t} + \big(g + a_z(t)\big)\zeta\right) + p_0 + a_x(t) x. \qquad [15]$$

It could be concluded from equation [15] that in the case of horizontal seism, the only first harmonic contributes to the studied values of ζ and *p*.

Considering nonlinear sloshing and coupled vertical and horizontal excitations, the Bernoulli equation has to be used:

$$p - p_0 = -\rho_l \left[\frac{\partial \Phi}{\partial t} + a_x(t) x + \big(g + a_z(t)\big)\zeta + \frac{1}{2}(\nabla\Phi, \nabla\Phi)\right] \qquad [16]$$

where $a_x(t)$ and $a_z(t)$ are vertical and horizontal driving force accelerations.

RESULTS AND DISCUSSION

As an example, the elastic cylindrical shell with radius *R* = 1 m and the filling level *H* = 1 m under the action of seismic load with different parameters has been considered. It has been supposed that shell thickness *h* = 0.01 m, Young's modulus $E = 2 \cdot 10^5$ MPa, Poisson's ratio ν = 0.3, shell material density ρ = 7800 kg/m3, liquid density $\rho_0 = 1000$ kg/m^3. It is assumed that the shell is rigidly fixed to the contour, that is, the boundary conditions are as follows: $u_r = u_z = u_\theta = 0$ at *z*=0 and *r*=*R*, Fig.1.

The linear formulation has been applied at the first stage. As it has been shown in paper (21), the non-linear effects associated with the sloshing of the filler have the greatest influence on the vibration damping. But to analyse the maximum level of liquid rise, there could be restricted ourselves to a linear formulation.

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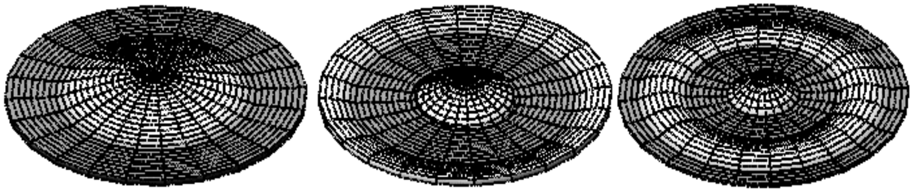
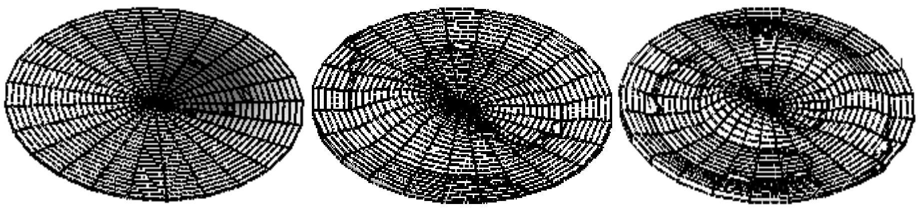
First of all, it is necessary to receive the own modes of the liquid vibrations, i.e. to obtain the system of basic functions. It has been done according to techniques, described in papers (12, 30). As it has been mentioned before, the first harmonic (α=1) is a subject of interest. It should be noted that axially-symmetrical harmonic (α=0) also will be involved in consideration, if even a very small vertical component of the seismic load has been observed. Fig. 2 demonstrates the first three vibration modes corresponding to these harmonics.



α=0



α=1

Figure 2. The first modes of axisymmetric and non-axisymmetric oscillations of the free surface

Table 1 shows the lowest vibration frequencies of the free liquid surface and the tank walls.

Table 1. Lowest vibration frequencies of cylindrical shell

Frequency, Hz proposed BEM	Frequency, Hz analytical values (13)	Harmonics, frequency number	Vibration type
0.6418	0.6418	1, 1	sloshing
0.9739	0.9739	0, 1	sloshing
1.1509	1.1510	1, 2	sloshing
1.3208	1.3209	0, 2	sloshing
1.4564	1.4566	1, 3	sloshing
1.7054	1.7058	1, 4	sloshing
1.7096	-	0, 1	bottom vibration
1.9212	1.9215	1, 5	sloshing

It has been established that the lower frequencies of vibrations of the liquid-filled tank with given mechanical and geometric characteristics are sloshing frequencies. The frequency spectra of free surface oscillations and elastic walls are separated. However, in sup-

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position that the shell bottom is elastic, it could be found that for sufficiently thin shells, the bottom oscillation frequency is comparable (and even very close) to one of the fundamental frequencies. The results of Table 1 testify it, namely one could see that sloshing frequency ω_{14}= 1.7054Hz is very close to the frequency of the axially-symmetric bottom vibration ω_{01}= 1.7096Hz. So, these results reveal the necessity to consider first and zero harmonics at vibrations analysis taking into account the elasticity of the reservoir's walls (32,33). It leads to the next presentation of unknowns as in paper (34):

$$\mathbf{U} = \sum_{k=1}^{N} c_k \boldsymbol{u}_k,\ \Phi = \sum_{k=1}^{N} \dot{c}_k \varphi_{1k} + \sum_{k=1}^{N} \dot{d}_k \varphi_{2k},\ \zeta = \sum_{k=1}^{N} c_k \frac{\partial \varphi_{1k}}{\partial \mathbf{n}} + \sum_{k=1}^{N} d_k \frac{\partial \varphi_{2k}}{\partial \mathbf{n}} \quad [17]$$

Presentation [17] leads to the following system of second order ordinary differential equations has been received:

$$\ddot{c}_l(t) + \Omega_l^2 c_l(t) = + \sum_{k=1}^{M} \ddot{d}_k(t)(\varphi_{2k}, u_l) + a_x(t)(x, u_l) + +a_z(t)(z, u_l) = 0, \quad [18]$$

$$\ddot{d}(\varphi_{2l}, \varphi(_{2l}) + (1 + a_z(t)/g)\chi_k^2(\varphi_{2l}, \varphi_{2l}) + \sum_{k=1}^{N} c_k \left(\frac{\partial \varphi_{1k}}{\partial \mathbf{n}}, \varphi_{2l}\right) + a_x(t)(x, \varphi_{2l}) = 0.$$

From equations [18], the unknown time dependent functions $c_k(t)$ and $d_k(t)$ will be received. For their unambiguous definition the initial conditions have been used in the form:

$$c_k(0) = c_k, \dot{c}_k(0) = c_{k1},\ d_k(0) = d_k, \dot{d}_k(0) = d_{k1} \quad [19]$$

Forced oscillations of the reservoir under a given seismic load have been studied.

Table 2 as in paper (33) provides accelerations for a given earthquake force.

Table 2. The level of acceleration via the seismicity

Magnitude	**5**	**6**	**7**	**8**	**9**	**10**
Maximum acceleration level of (in fractions of g)	0.025	0.050	0.100	0.200	0.400	0.800

The characteristic frequency of the seismic load at 6 points is equal to 2Hz.

The system of differential equations in the form [13], and initial data [14] has been obtained taking into account the entire frequency spectrum given in Table 1. Initial conditions are following:

$$c_k(0) = 0, \dot{c}_k(0) = 0,\ d_k(0) = 0, \dot{d}_k(0) = 0.$$

Furthermore, it has been supposed that before earthquake the liquid-filled the reservoir was in state of rest.

Next, the coupled problem of the liquid vibration in the rigid cylindrical shell with covering the free surface by thin elastic membrane has been considered. Assuming there is no

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gap between fluid and the elastic cover, the dynamic boundary condition on the interface of liquid domain and the elastic membrane could be given as follows:

$$\rho_m h_m \frac{\partial^2 w}{\partial t^2} + T\Delta^2 w = -\rho_l \frac{\partial \Phi}{\partial t} - \left(g + a_z(t)\right)w - a_x(t)x, \quad [20]$$

where *w* is the deflection of the elastic plate, *t* is the time, and *T* is a tension, and ρ_m, h_m are, respectively, membrane's density and thickness. The right-hand side of [18] is the fluid pressure acting on the elastic cover, which is obtained from the linearized Bernoulli equation.

The linearized kinematic condition at the interface surface can be written as:

$$\left.\frac{\partial \Phi}{\partial \boldsymbol{n}}\right|_{S_0} = \frac{\partial w}{\partial t} \quad [21]$$

On the rigid side walls and bottom of the tank the impermeable boundary condition has been applied:

$$\left.\frac{\partial \Phi}{\partial \boldsymbol{n}}\right|_{S_1} = 0 \quad [22]$$

The potential Φ has been satisfied to the Laplace equation:

$$\nabla^2 \Phi = 0. \quad [23]$$

In addition, the boundary conditions for membrane contour have been imposed. The most commonly used types have been clamped, free, and simply supported conditions. For clamped contour the Dirichlet condition is in use, namely *w*(*R*) = 0, and for free contour the Newman condition has been involved:

$$\left.\frac{\partial \mathrm{w}}{\partial \boldsymbol{r}}\right|_{r=R} = 0. \quad [24]$$

It is namely condition [24] that should be chosen to adequately describe the floating cover.

Moreover, the following boundary value problem, described by equations [20], and [23] with boundary conditions [21], [22], and [24] has been gained.

For its numerical solution there have been used the mode superposition method as described in (27). First, the frequencies and modes of the membrane without interaction with the liquid have been obtained from the equation:

$$\rho_m h_m \frac{\partial^2 w}{\partial t^2} + T\Delta^2 w = 0 \quad [25]$$

Then the presentation for *w* has been applied as:

$$w = \sum_{k=1}^{M} c_k w_k, \quad [26]$$

where w_k are their own membrane modes. For function Φ has been used the next presentation:

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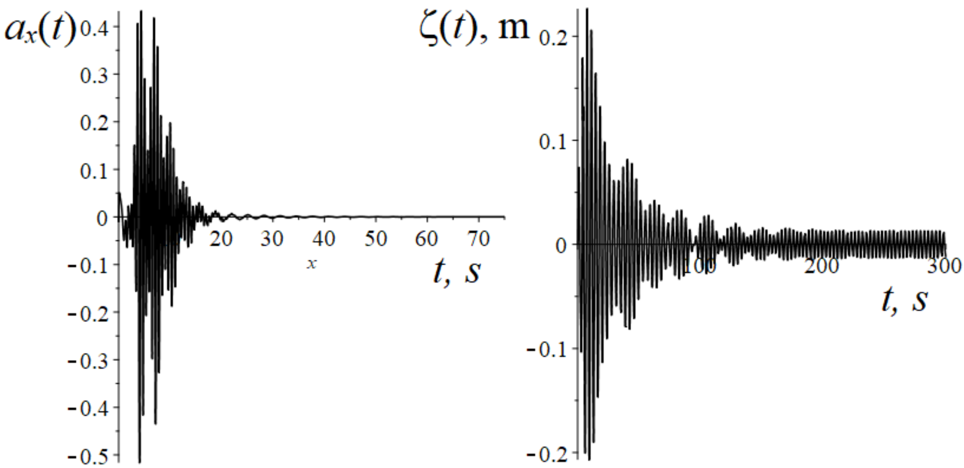
$$\Phi = \sum_{k=1}^{M} \dot{c}_k \phi_k, \qquad [27]$$

where functions ϕ_k are solutions of following boundary value problems:

$$\nabla^2 \phi_k = 0, \qquad \left.\frac{\partial \phi_k}{\partial \boldsymbol{n}}\right|_{S_0} = \frac{\partial w_k}{\partial t}, \qquad \left.\frac{\partial \phi_k}{\partial \boldsymbol{n}}\right|_{S_1} = 0. \qquad [28]$$

Substituting series [26] and [27] into [20] we come to the system of second order differential equations relative to time-dependent unknowns$[c_1, c_2, \dots . c_M\ ]$.

According to papers (33, 34) the artificial accelerogram has been constructed for $a_x(t)$. Figure 2a demonstrates $a_x(t)$ for the earthquake with magnitude 6 points and characteristic frequency equals to 2Hz, and Figure 2b shows the free surface level via time. Here we consider the reservoir without covering the membrane.



a) *b*)

Figure 3. Accelerogram and the free surface level via time.

As vertical acceleration we consider $a_z(t)$ =0.005 m/s^2. Figure 2b) shows time dependence of ζ in the point with coordinates *r*=*R*, *z*=*H*, θ=0.

From numerical results it has been concluded that change of the liquid level is near 0.4m. Such changing can lead to a large pressure on the tank walls. The normalized pressure p_n has been calculated using equation [15]. Here $p_n=(p-p_0)/\rho_l$. The dependence of p_n via time is plotted in Figure 3a. For comparison in Figure 3b one could see the dependence of p_n via time when neglecting the effects of sloshing. The same point with coordinates *r*=*R*, *z*=*H*, θ=0 has been chosen for numerical simulation.

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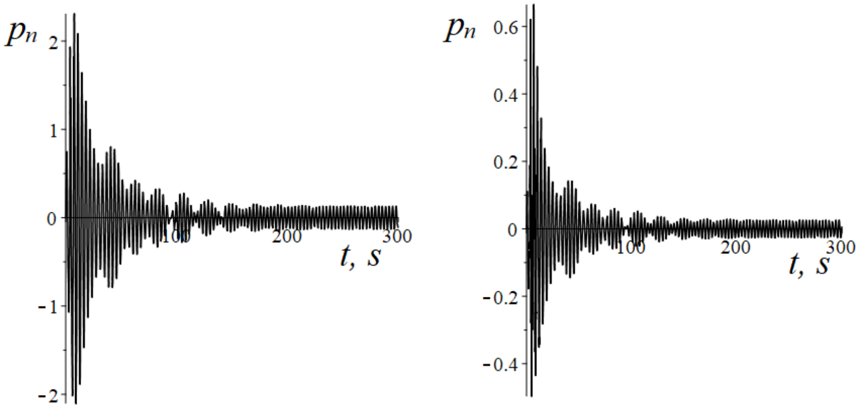

Figure 3. Time histories of p_n

The results obtained indicate the need to reduce the level of sloshing. For this, various damping devices have been used. Among them there are horizontal and vertical partitions as suggested in paper (30). The installation of baffles leads to a shift in the frequency spectrum. But the frequencies of excitation forces as a result of artificial earthquakes, terrorist attacks could have a wide spectrum.

Paper (31) shows that the installation of a floating cover leads to a significant change in frequencies.

As reported in paper (31), the elastic membrane has been used to reduce sloshing. But here the time dependent solutions have been obtained. The clamped silicon membrane with radius $R = 1$ m, thickness $h_m = 0.001$ m, material density $\rho_m = 2800$ kg/m3, the Young modulus $E = 50$Mpa, Poisson's ratio $\nu = 0.49$ has been supposed to be applied.

Figure 4a demonstrates comparison of the free surface level changing with and without the membrane as a cover, and Figure 4b shows the dependence of p_n via time. The black lines correspond to vibrations without cover, and by the grey lines the curves have been obtained assuming the presence of the elastic membrane installed at the level of the free surface have been marked.

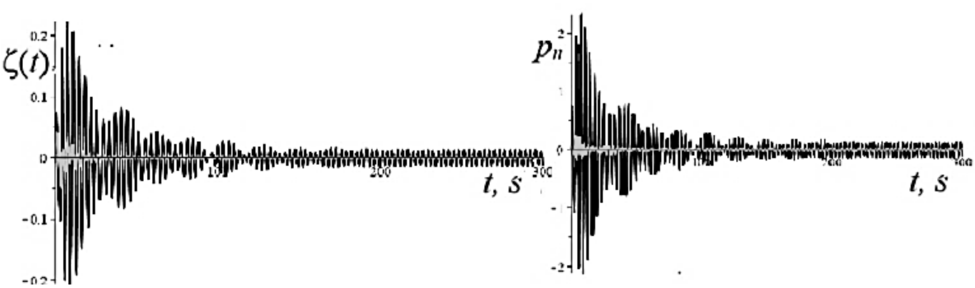

Figure 4. Time histories of of ζ and p_n

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The results obtained allow us to conclude that the installation of the membrane leads to a significant decrease in both the level of free surface rise and the pressure on the tank walls.

These data could be useful in assessing the stability of reservoirs under seismic loads.

CONCLUSION

The liquid vibrations in rigid and elastic reservoirs have been considered. It has been established that level changing via time for reservoirs without covering membrane can be very large and lead to the appearance of excess pressure on the tank wall. The installation of the floating membrane leads to decreasing both the free surface level and the pressure on the tank walls.

These results allow us to prevent tanks destruction and to extend their service life using the floating membrane cover. It will increase the environmental safety level of the areas adjacent to the tanks and prevent emergencies.

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