Diffraction Of Elastic Harmonious Waves On Parallel Pipes With Liquid

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***Abstract*—In work the intense and deformable condition of in parallel located cylindrical pipes with liquid is considered. The task is solved in Bicylindrical coordinates at influence of harmonious waves. The analytical decision in Bessel and Henkel's special functions and also numerical results is received. The parametrical analysis of dynamic factor of tension is carried out.**

Keywords—cylindrical pipe, liquid, harmonious waves, Bicylindrical coordinates, special functions,

Some main ratios of the theory of elasticity

In this paragraph some main equations of the theory of elasticity are given in curvilinear coordinates. It is known that from the static theory of elasticity the equation to the Lama in a vector form looks like [1, 2, 3]:

$$(\lambda+2\mu)grad\ div\,\vec{u} - \mu rot rot\vec{u} + Q\vec{f} = 0 \qquad (1)$$

Where λ and μ - the factors to the Lama determined by formulas

$$\lambda = \frac{\nu E}{(1-2\nu)(1+\nu)},$$

$$\mu = \frac{E}{2(1+\nu)}$$

; $\vec{u}$ - vector of moving, $Q\vec{f}$ - vector of mass forces. The operators entering into the equation [1], for the right system of curvilinear orthogonal coordinates, are defined as follows

$$grad\phi = \frac{1}{\sqrt{q_{11}}}\frac{\partial\phi}{\partial\alpha_1}\vec{i}_1 + \frac{1}{\sqrt{q_{22}}}\frac{\partial\phi}{\partial\alpha_2}\vec{i}_2 + \frac{1}{\sqrt{q_{33}}}\frac{\partial\phi}{\partial\alpha_3}\vec{i}_3,\quad rot u = \frac{1}{\sqrt{q}}G$$

$$div u = \frac{1}{\sqrt{q}}\left[\frac{\partial}{\partial\alpha_1}\left(u_1\sqrt{\frac{q}{q_{11}}}\right) + \frac{\partial}{\partial\alpha_2}\left(u_2\sqrt{\frac{q}{q_{22}}}\right) + \frac{\partial}{\partial\alpha_3}\left(u_3\sqrt{\frac{q}{q_{33}}}\right)\right]$$

$$G = \begin{vmatrix} \sqrt{q_{11}}\vec{i}_1 & \sqrt{q_{22}}\vec{i}_2 & \sqrt{q_{33}}\vec{i}_3 \\ \frac{\partial}{\partial\alpha_1} & \frac{\partial}{\partial\alpha_2} & \frac{\partial}{\partial\alpha_3} \\ u_1\sqrt{q_{11}} & u_2\sqrt{q_{22}} & u_3\sqrt{q_{33}} \end{vmatrix}$$

Where α_i - curvilinear coordinates (i-1,3), q_{ij} - the components of a metric tenzor determined by a formula: $q_{ij} = \sum_{k=1}^{3}\frac{\partial x_k}{\partial\alpha_i}\frac{\partial x_k}{\partial\alpha_j}$, x_k - Cartesian coordinates (k=1,3), q- Jacobean's square of transformation of the Cartesian system of coordinates and curvilinear system of coordinates. Thus for orthogonal curvilinear coordinates only diagonal members of a matrix of a tenzor of q_{ij} are not equal to zero. In this case $q = \sqrt{\prod_{i=1}^{3} q_{ii}}$, and the main differential quadric quantic is determined by a formula:

$$ds^2 = \sum_{i=1}^{3} q_{ii} d^2\alpha_1 .$$

For definition of a tension of soil and statement of the mixed boundary conditions it is necessary to have the formulas expressing tension through moving. We use the geometrical equations deduced by Novitsky V.

$$\varepsilon_{ii} = \frac{\partial}{\partial\alpha_i}\left(\frac{u_i}{h_i}\right) + \frac{1}{2h_i^2}\sum_{j=1}^{3}\frac{\partial h_i^2}{\partial\alpha_j}\frac{u_j}{h_j}$$

(2)

$$\varepsilon_{ij} = \frac{1}{2h_i h_j}\left[h_i^2\frac{\partial}{\partial\alpha_i}\left(\frac{u_i}{h_i}\right) + h_j^2\frac{\partial}{\partial\alpha_i}\left(\frac{u_j}{h_j}\right)\right]$$

$$i \neq j, \quad j = \overline{1,3}$$

$$\sigma_{ij} = \lambda\sum_{k=1}^{3}\left[\frac{\partial}{\partial\alpha_k}\frac{u^k}{h_k} + \frac{1}{2h_k^2}\sum_{j=1}^{3}\frac{\partial h_k^2}{\partial\alpha_j}\frac{u_j}{h_j}\right] + 2\mu\left[\frac{\partial}{\partial\alpha_i}\frac{u_i}{h_i} + \frac{1}{2h_i^2}\sum_{j=1}^{3}\frac{\partial h_i^2}{\partial\alpha_j}\frac{u_j}{h_j}\right] \quad (4,a)$$

$$\sigma_{ij} = \frac{\mu}{h_i h_j}\left[h_i^2\frac{\partial}{\partial\alpha_i}\frac{u_i}{h_i} + h_j^2\frac{\partial}{\partial\alpha_i}\frac{u_j}{h_j}\right], \qquad i \neq j \quad (4,6)$$

Where $h_i^2 = q_{ii}$. Now we will set the task of the linear theory of elasticity for settlement schemes in cylindrical coordinates of r, θ and z.

As the use of unknowns components of the displacement vector u_r, u_θ и u_z.

The cylindrical coordinate system is related to the Cartesian coordinate system by the following relationships:

$$h_1^2 = h_3^2 = q_{11} = q_{33} = 1, \qquad h_{22}^2 = q_{22} = r^2$$

As coordinates α_i (i=1,3) apply:

α_1=r, α_2=θ, α_3=z (6)

Besides, we use the condition equation (Guk's law) [2]

$$\sigma_{ij} = \lambda\delta_{ij}\sum_{k=1}^{3}\varepsilon_{kk} + 2\mu\varepsilon_{ij} \quad (3)$$

Having substituted (2) in (3), we will receive

x=rcosθ; y=rsinθ, z=z,
$ds^2=dr^2+r^2d\theta^2+dz^2$.
(5)

Using equation (5), we obtain

Substituting (5) and (6) (1), and the resulting expression into the formula (4) and taking into account the following system of Lame equations in cylindrical coordinates:

$$(\lambda+2\mu)(u_r)_{rr} + \frac{\mu_2}{r}(u_r)_{\theta\theta} + \mu(u_2)_{zz} + \frac{\lambda+\mu}{r}(u_\theta)_{\theta r} + (\lambda+\mu)(u_z)_{zz} +$$
$$+\frac{\lambda+2\mu}{r}(u_r)_r - \frac{\lambda+3\mu}{r^2}(u_\theta)_\theta - \frac{\lambda+2\mu}{r^r}u_r = 0, \quad (7)$$

$$\mu(u_\theta)_{22} + \frac{\lambda+2\mu}{r^2}(u_\theta)_\theta + \mu(u_\theta)_{zz} + \frac{\lambda+\mu}{r}(u_r)_{r\theta} + \frac{\lambda+\mu}{r}(u_z)_{z\theta} +$$
$$+\frac{\mu}{r^2}(u_r)_\theta - \frac{\mu}{r}u_\theta = 0,$$

$$\mu(u_z)_{rr} + \frac{\mu}{r^2}(u_\theta)_{\theta\theta} + (\lambda+2\mu)(u_z)_{zz} + (\lambda+\mu)(u_r)_{rr} +$$
$$+\frac{\lambda+\mu}{r}(u_\theta)_{\theta z} + \frac{\lambda+\mu}{r}(u_r)_z = 0$$

Where the indices r, θ и z, for brackets denote partial derivatives with corresponding coordinates. The boundary conditions on the outer surface of the pipe - a condition of perfect contact with the ground, the internal surface is free:

$$r = R: u_{r1} = u_{r2}, u_{\theta 1} = u_{\theta 2}, u_z = u_{z2},$$
$$\sigma_{rr1} = \sigma_{rr2}, \sigma_{r\theta 1} = \sigma_{r\theta 2}, \sigma_{rz1} = \sigma_{rz2}, \qquad (8)$$
$$r = R_0: \sigma_{rr2} = 0, \sigma_{r\theta 1} = 0, \sigma_{rz1} = 0,$$

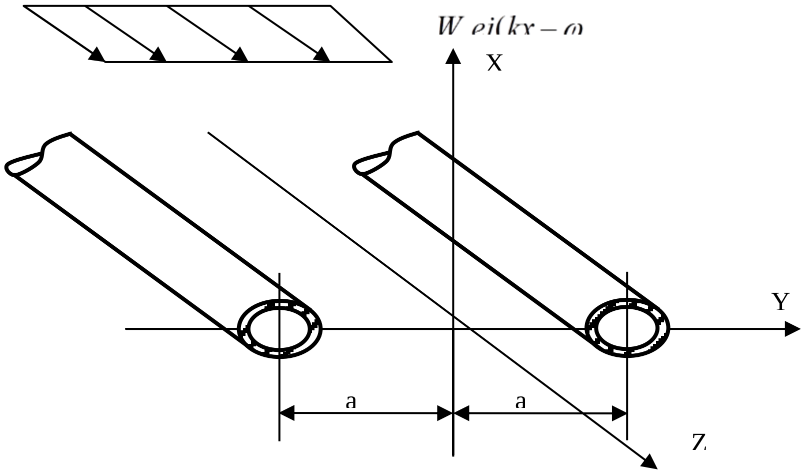
where the subscripts "1" and "2" denote the materials and the environment of the pipe. The boundary conditions to ensure equality of the normal components of the velocity of the liquid and the shell are

$$(\vec{V} \ \vec{n})\Big|_{r=a} = +\frac{\partial u_{r2}}{\partial t} \quad (9)$$

Where $\vec{v}$ - the rate of fluid particles; $\vec{n}$ - surface normal at *r=a*, *w*- radial movement of the shell. To fully close the statement of the problem, it is necessary for the conditions (8) and (9) to add conditions at infinity $u \to 0$

At $R = \sqrt{x^2+y^2+z^2} \to \infty$, (10) Filled with some conditions on radiation.

For the time-dependent problems as conditions of radiation required to fulfill the principle of causality, and environment should be no movement outside the region bounded by the leading edge of the waves from vibration sources.



I. FIG. 1. CALCULATED SCHEME

Consider the dynamical theory of linear elasticity of the impact of seismic waves on the pipe, laid in a high mound in two lines and filled with an ideal compressible liquid. Here consider the case where the wave is incident perpendicular to the axis connecting the centers of the pipes, and to the longitudinal axis of the pipe. Design scheme presented in Figure 1. Bicylindrical coordinate system is related to the Cartesian coordinate system by the following relationships:

$x=(a\sin\xi)/(\mathrm{ch}\eta-\cos\xi)$, $y=(a\,\mathrm{sh}\eta)/(\mathrm{ch}\eta\ \cos\xi)$, $z=z$ (11) where: a - half the distance between points $\eta=-\infty$ и $\eta=\infty$.

Then, presenting (11) (5.6), and the resulting expression (6) takes the following form:

$$ds^2 = a^2(\mathrm{ch}\eta-\cos\xi)^{-2}\, d\xi^2 + a^2(\mathrm{ch}\eta-\cos\xi)^{-2} d\eta^2 + dz^2 \qquad (12)$$

Using equation (11), we obtain

$$h_1^2 = h_2^2 = q_{11} = q_{22} = a^2(\mathrm{ch}\eta-\cos\xi)^{-2}, h_3^2 = q_{33} = 1. \qquad (13)$$

Assuming that: $\alpha_1=\xi$, $\alpha_2=\eta$, $\alpha_3=z$ and substituting (12) and (13) (1) - (11), and, given that the task is flat, we obtain the following equation Helmholtz bipolar coordinates:

$$\left[a^{-2}(\mathrm{ch}\eta-\cos\xi)^2\right]\left[(v)_{\xi\xi}+(v)_{\eta\eta}\right]+k^2v=0 \qquad (14)$$

where

$$\frac{\sin\xi}{\mathrm{ch}\eta-\cos\xi}=\begin{cases}2\sum\limits_{n=1}^{\infty}e^{-n\eta}\sin n\xi & \eta>0\\ 2\sum\limits_{n=1}^{\infty}e^{n\eta}\sin n\xi & \eta<0\end{cases} \qquad (15)$$

Equation (14), after some transformation reduces to a

$$(v)_{\xi\xi}+(v)_{\eta\eta}+(2kae^{\pm\eta})^2v=0 \quad (16)$$

Solution of the equation (14) will be sought in the form of a series:

$$v = \sum_{n=0}^{\infty}\left[v_n^a(\eta)\cos n\xi + v_n^b(\eta)\sin n\xi\right]\varepsilon^{-iwt} \quad (17)$$

Substituting (17) into (16) and equate the coefficients of the corresponding harmonics, we obtain the following ordinary differential equation:

$$v_n'' + \left[(2kae^{\pm\eta})^2 - n^2\right]v_n = 0 \quad (18)$$

Standard replacement

$$v_n(\eta) = z(t) \quad , t=\exp(\pm\eta)$$

Reduce (18) to the Bessel equation of the form

$$t^2 z'' + tz' + (4k^2a^2 - n^2)z = 0 \quad (19)$$

which has a particular solution in the form of a cylindrical function $z(2ake^{-\eta})$, and the solution of the Helmholtz equation takes the following form:

$$\varphi^{(i)} = Ae^{i\alpha.x - iwt} \quad (21).$$

For the representation (21) as (20), write (21) through (12) in the bipolar cylindrical coordinates.

$$\varphi_1^{(i)} = Ae^{ik2a\exp(\mp)^{\eta}\sin\xi e^{-iwt}} \quad (22)$$

$$\varphi = \sum_{n=0}^{\infty} A_n Z_n(2ake^{\mp\eta})\cos n\xi e^{-iwt},$$

$$\psi = \sum_{n=0}^{\infty} B_n Z_n(2ake^{\mp\eta})\sin n\xi e^{-iwt}. \quad (20)$$

Now put the boundary conditions. To do this, use the condition (20), replace r=η и θ=ξ. Taking into account the above relations, we seek a solution of the boundary value problem for the case of two underground pipes P - compression wave and SV- shear wave is perpendicular to the axis y. Wave potential wave is

Expanding the second factor of (22) in a Fourier series (integrated form), and after some transformations we obtain the final expression for the potential of the incident P - wave:

$$\varphi_1^{(i)} = A\sum_{n=0}^{\infty}\varepsilon_n J_n(\alpha_1\tau)\cos n\xi e^{-iwt} \quad (23)$$

Where $\tau=2a\exp(\mp\eta)$and for the potential of the incident SV- wave:

Other potential (20), by analogy with (23) have the form:

$$\varphi_2^{(r)} = \sum_{n=0}^{\infty}\left[C_n H_n^{(1)}(\alpha_2\tau) + D_n H_n^{(2)}(\alpha_2\tau)\cos n\xi e^{-iwt}, \psi_2^{(r)} = \sum_{n=0}^{\infty}\left[E_n H_n^{(1)}(\beta_2\tau) + F_n H_n^{(2)}(\beta_2\tau)\sin n\xi e^{-iwt}\right.\right.$$

$$\varphi_3^{(r)} = \sum_{n=0}^{\infty} G_n J_n^{(1)}(\alpha_3\tau)\cos n\xi e^{-iwt} \quad (24)$$

Dynamic VAT expressed in terms of the potentials φ_1 and ψ_2:

$$u_{\eta i} = \delta\left[(\varphi_i)_\eta - (\psi_i)_\xi\right] \quad u_{\xi i} = \delta\left[(\varphi_i)_\xi - (\psi_i)_\eta\right],$$

$$u_{\eta 3} = -\delta(iw)^{-1}(\varphi_3) \quad (25)$$

$$\sigma_{\eta\eta i} = -\sigma_{\xi\xi i} = 2\delta^2\left\{d_i\left[0{,}5\varphi_{\eta\eta} - (\varphi_\xi + \varphi_\eta)\sin\xi\right] + 0{,}5\lambda_i\varphi_{\xi\xi} - \mu_i(\psi_{\xi\xi} - \varphi_\eta + \psi_\xi)\right\}$$

$$\tau_{\eta\eta 3} = \sigma_{\xi\xi 3} = -iw_3\rho_3\varphi_3\,,\tau_{\eta\xi i} = 2\mu_i\delta^2\left[\varphi_{\xi\eta} + 0{,}5\psi_{\eta\eta} - 0{,}5\psi_{\xi\xi} + \varphi_\xi + \psi_\eta + (\varphi_\xi - \psi_\xi)\sin\xi\right]$$

$$i = 1{,}2; \delta = e^{\mp\eta} / 2a.$$

Substituting (24) and (25) (8), we obtain the final solution of problems of the fall, respectively P- and SV - waves in two underground pipes. The arbitrary constants A_n, B_n, C_n et al. are determined from the system of algebraic equations with complex coefficients

[C]{q}={ρ}

Where C - determinant (12x12) - order the elements of which are a function of Bessel and Henkel 1st 2nd kind of n-th order, q - column vector of unknowns, ρ - right hand side vector.

The system of algebraic equations with complex coefficients is solved by Gauss with the release of the main element. Dynamic VAT in case of fall - the shear wave into two underground pipes recorded in bipolar coordinates in the asymptotic form:

$$u_z = w, \sigma_{\eta z} = \mu_i\delta(u_z)_\eta, \sigma_{\xi z} = \mu_i\delta(u_z)_\xi$$

As the boundary conditions of use condition (23) and replacing r = n. The final solution of the problem of falls for SH - wave on the two pipes is:

$$u_{z1} = w_0\sum_{n=0}^{\infty}\left[\varepsilon_n J_n(k_1\tau) + A_n H_n^{(1)}(k_1\tau)\right]\cos n\xi e^{-iwt}; u_{z2} = -w_0\sum_{n=0}^{\infty}\left[B_n H_n^{(1)}(k_2\tau) + C_n H_n^{(2)}(k_2\tau)\right]\cos n\xi e^{-iwt};$$

$$\sigma_{rz1} = \mu_1 w_0 k_1\sum_{n=0}^{\infty}\left[\varepsilon_n J_n(k_1\tau) + A_n H_n^{(1)}(k_1\tau)\right]\cos n\xi e^{-iwt}; \sigma_{rz2} = -\mu_2 w_0 k_2\sum_{n=0}^{\infty}\left[B_n H_n^{(1)}(k_2\tau) + C_n H_n^{(2)}(k_2\tau)\right]\cos n\xi e^{-iwt}; \quad (27)$$

$$\sigma_{\theta z1} = -\mu_1 w_0 n\sum_{n=0}^{\infty}\left[\varepsilon_n(k_1\tau) + A_n H_n^{(1)}(k_1\tau)\right]\sin n\xi e^{-iwt};\ \sigma_{\theta z2} = \mu_2 w_0 n\sum_{n=0}^{\infty}\left[B_n H_n^{(1)}(k_2\tau) + C_n H_n^{(2)}(k_2\tau)\right]\sin n\xi e^{-iwt};$$

Uncertain factors A_n, B_n, C_n determined by the boundary conditions.

Consider the definition of dynamic stress-strain state of a cylindrical tube under the influence of harmonic waves.

To solve this problem apply the addition theorem. Addition theorems for cylindrical wave functions are derived in [4, 5, 6]. Suppose there are two different polar coordinate system (r_g,θ_g) and (r_k,θ_k) (3), in which the polar axis of the same direction. Coordinate pole θ_k в q system will R_{kq}, θ_{kq}, so that the equality

$$Z_g = R_{kg}e^{i\theta_{kg}} + Z_k \quad (28)$$

Then the addition theorem is:

$$b_n(\alpha r_q)e^{in\theta_q} = \sum_{p=-\infty}^{\infty} b_{n-p}(\alpha R_{kq})e^{i(n-p)\theta_{kq}}Tp(\alpha r_k)\exp(ip\theta_k),\ r_k < R_{kq}\,,$$

$$b_n(ar_q)e^{in\theta_q} = \sum_{p=-\infty}^{\infty} J_{n-p}(\alpha R_{kq})e^{i(n-p)\theta_{kq}}b_p(\alpha r_k)\exp(ip\theta_k),\ r_k < R_{kq} \quad (29)$$

Equation (28) makes it possible to convert the solution of the wave equation (1) from one coordinate system to another. Consider the calculation of the extended multi-line underground pipeline on the seismic action in the framework of the plane problem of the dynamic theory of elasticity. In this study the case of the stationary diffraction of plane waves on a number of periodically arranged cavities, backed rings with an ideal compressible liquid inside. The solution of the problem of implementing the method of potentials. The boundary conditions have the form (8). Do not change the form and potential of the incident. The potentials of the reflected waves from the tube after applying the addition theorem, and taking into account the frequency of the task will be:

$$\varphi_1^{(r)} = e^{-iwt}\sum_{n=0}^{\infty}\left[A_n H_n^{(1)}(\alpha_1 r) + S_n J_n(\alpha_1 r)\right]e^{in(\theta-\gamma)},$$

$$\psi_1^{(r)} = e^{-iwt}\sum_{n=0}^{\infty}\left[B_n H_n^{(1)}(\beta_1 r) + \sigma_n J_n(\beta_1 r)\right]e^{in(\theta-\gamma)},$$

$$S_n = \sum_{p=0}^{\infty}\sum_{m=1}^{\infty} A_p E_p\left[e^{im\xi}H_{n-p}^{(1)}(\alpha_1 m\delta) + e^{-im\xi}H_{n-p}^{(1)}(\alpha_1 m\delta)\right], \qquad (30)$$

$$Q_n = \sum_{p=0}^{\infty}\sum_{m=1}^{\infty} B_p E_p\left[e^{im\xi}H_{n-p}^{(1)}(\beta_1 m\delta) + e^{-im\xi}H_{n-p}^{(1)}(\beta_1 m\delta)\right],$$

where: $\xi = k\delta\cos\gamma, \delta$ - the distance between the center of the pipe.

Potentials of refracted waves in the pipes can be written as

$$\varphi_2 = e^{i(m\xi - w\xi)}\sum_{n=0}^{\infty} E_n\left[C_n H_n^{(1)}(\alpha_1 r) + D_n H_n^{(2)}(\alpha_2 r)\right]e^{in(\theta-\gamma)},$$

$$\psi_2 = e^{i(m\xi - w\xi)}\sum_{n=0}^{\infty} E_n\left[E_n H_n^{(1)}(\beta_1 r) + F_n H_n^{(2)}(\beta_2 r)\right]e^{in(\theta-\gamma)}, \qquad (31)$$

and the velocity potential in perfect shape compressible fluid

$$\varphi_3 = e^{i(m\xi - w\xi)}\sum_{n=0}^{\infty} E_n G_n J_n(\alpha_3 r)e^{in(\theta-\gamma)}, \qquad (32)$$

The unknown coefficients A_n-G_n defined staging (29) - (32) (8). The result is an infinite set of linear equations which is solved by the method of approximate reduction, with the proviso that the ratio is not satisfied

$$k\delta(1 \mp \cos\gamma) = 2\pi n$$

A general characteristic of the program is designed for multi-line pipes in the mound for the case of seismic wave's perpendicular to the axis passing through the center of the pipe.

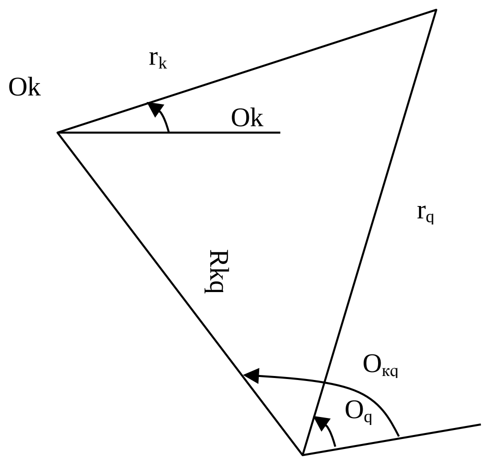


FIG. 2. SCHEME FOR THE ADDITION THEOREM.

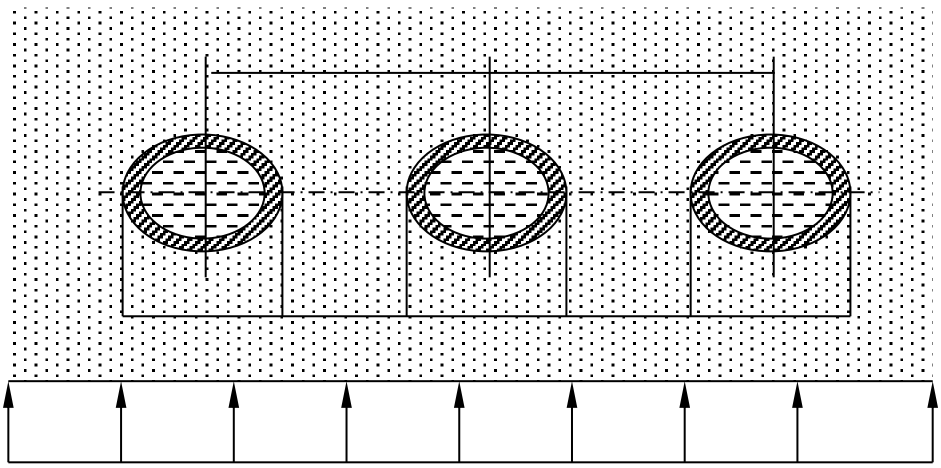
The input information includes the minimum necessary information: the elastic characteristics (E and ν) soil embankments and pipes; the density of the soil, pipe and fluid filling her; inner and outer radii of the tube; the predominant period of vibration of the soil particles; coordinates of the point in which the

VAT; seismic coefficient. With the help of special tags can count tubes filled with an ideal compressible liquid and empty. Calculation of cylindrical Bessel and Hankel functions performed by the known formulas. Solving systems of linear equations by Gauss made with the release of the main member.

Effect of distance between pipes. Table 1 shows the values of

$$\eta_{max}(\eta_{max} = |\sigma_{rr}| / (\lambda + 2\mu)\alpha^2 A$$

maximum radial earth pressure on the pipe at a different distance d between them in the event of a P - wave. It was assumed the wave number of P - wave α_r=1,0: the inner and outer radius of the tube R_0=0,8 m and R=1,0 m: the predominant period of vibration of the soil particles T=0,2 s. Characteristics of soil mound: Lame constants λ_1=8,9-MPa; μ_1=4,34 MPa; density ρ_1=1,74Кн s^2/m^4. Характеристики материала трубы λ_2=8690 MPa; μ_2=12930 MPa; ρ_2=2,55 Кн s^2/m^4.



$\varphi = Ae^{i(kx-\omega t)}$ **Figure 3. Estimated scheme.**

Table 4.1: The coefficient of dynamic concentration at different distances between the pipes for the case of P - wave

D/d	0,5	1,0	2,0	4,0
η_{max}	1,68	1,76	1,61	1,60

From Table 1 it follows that initially when the distance between tubes 0,5≤d/D≤1,0 coefficient η_{max} slightly increased by 5%, with a further increase in d/D>1,0 decreases more sharply by 10%. At d/D>2,0 value η_{max} stabilized, i.e. virtually unchanged, while l≤4,0 close to the value η_{max} for single pipe according to the calculations. Consequently, the mutual influence of concrete pipes installation of a multi-occurs when the distance between them d≤4,0D and increases the maximum dynamic soil pressure on them compared with a single tube. The effect of increasing the coefficient η_{max} associated with the combination of waves reflected more surfaces of a multi-tube. This non-monotonic increase in the coefficient max with decreasing distance between the pipes d/D due in our opinion to the phenomenon of interference imposed upon reflection waves. This phenomenon is extremely important for the practice of seismic design of underground pipelines multiline since It allows you to choose the optimal distance between the tubes, in which the dynamic pressure under seismic impact is minimal. For example, in Table 1 in such a distance d=0,5D.It is known, be noted for comparison that in the case of the static effects the opposite is true: the pressure on the soil of a multi-tube smaller than a single. In addition to the above, to analyze the effect of the distance between the tubes on their VAT must consider the relation (28) (so-called "slip point") at which there is a significant increase in the dynamic stresses in the vicinity of the tube - resonance. This phenomenon is well known from optics called Wood's anomaly is a feature of a multi-conduit and can not occur in a pipe arranged in a single thread. In terms of design practice, it is necessary to know how far you can stack the pipes to dangerous resonance phenomenon did not occur. The answer to this question is given by equation (27).

We analyze this relation in the case of the impact of P - and SV - seismic waves on the underground pipeline. Table 2 shows the dependence of the maximum distance between the centers of the light pipe d_{max}, wherein no resonance occurs, the angle of incidence of the seismic waves γ.

Table 2 The dependence of the distance D_{max} angle of incidence γ.

γ. hail	0	30	45	60	70	80	90
D_{max},M	5,0	5,36	5,86	6,66	7,45	8,52	10,0

From Table 2, it follows that the smaller the angle of incidence of the seismic wave on the pipe, the closer to each other is necessary to lay the pipe. Thus, the appearance of a multi-resonance pipes can be avoided by selecting an appropriate distance between them and thereby provide earthquake resistance of a pipeline. Influence of the type of the seismic action (P, SV-or SH-wave). Table 3 shows the values η_{max} maximum radial pressure on the soil in case of a fall pipe P- and SV - seismic waves at varying distances d between the pipes. It was assumed β_r=2. Analysis of the data table. 3 shows that when d/D<4,0 values of η_{max} values coefficient P-wave and SV-like are in antiphrasis, i.e. at l/D=1,0 seismic impact maximum P-wave is 27% higher than that of SV - wavelength at d/D=2,0 below 7%, while d/D=4,0 Again above, but only by 1%. With increasing distance between the tubes difference in these effects is reduced and d/D=4,0 virtually disappears altogether. In addition, we note that under the influence of SV - wave values η_{max} at various distances between the tubes is 2.5 times the variation (25%) than when exposed P - wave (10%). Thus, the phenomenon of "local resonance" appears more strongly to the seismic action as SV- wave.

Table 3 The coefficient η_{max} under seismic actions as P - and SV - waves at various distances d between the tubes

d/D	η_{max}	
	P – wave	SV - wave
1,0	1,76	1,29
2,0	1,61	1,72
4,0	1,60	1,51

Influence of fluid filling the pipe. Table 4 shows the values of the coefficient η_{max} in the case of the fall of P - waves on empty and water-filled tube at different distances d between the pipes. Liquid density assumed to be equal ρ_3=0,102 Кн. s^2/m^4.

Table 4 The coefficient η_{max} for the case of P - waves on empty and water-filled pipe

d/D	η_{max}	
	P - wave	SV - wave
1,0	1,76	1,89
2,0	1,61	1,78
4,0	1,60	1,90

From Table 4 it follows that the presence of water in the pipes increases seismic influence on them compared to empty tubes. Obviously, this is due to an increase in weight of the pipeline. The maximum dynamic pressure of soil on the pipe increases. For example: if d/D=1,0 the difference in the values of the coefficient d/D=2,0-10%, at d/D=4,0-19%.

In addition, we note that the coefficient of variation values η_{max} at various distances d tubes filled with water less (7%) than in the empty pipes (10%).

Effect of the length of the incident seismic waves. Table 4 shows the values of coefficient η_{max} different lengths l_0/l_0-$2\pi/\alpha$, p - wave incident on the tube blank located in the region *l*=1,0D from each other.

Table 5 The values of the coefficient η_{max} for different lengths l_0 P - wave.

l_0/D	3,0	5,0	10,0
η_{max}	1,76	1,52	1,20

From Table. 5 that the greater the length of the incident seismic wave; the denser the soil mound, the lower coefficient η_{max}. For reference, that relation l_0/D=5,0 – not a bulk sand, sandy and loamy soils; l_0/D=10,0 - clayey soils. Thus, the type of soil, and in particular its density significantly affects its dynamic pressure tube under seismic impact. It follows that in the construction of the embankment above the pipe must be carefully compacted backfill. Interestingly, good compaction and reduces the static pressure on the pipe. In addition, the calculations show that l_0>10,0D dynamic problem reduces to the quasi-static, which greatly simplifies the solution. Hence the important conclusion that the quasi-static approach is not applicable to the calculation of seismic impact on culverts.

Effect of pipe wall thickness. Table 6 shows the values of the coefficient η_{max} for a variety of wall thickness t of reinforced concrete pipe in the event of a P - waves on empty multiline pipes stacked multi-line pipe, arranged at a distance d=0,5.

Table 6 The coefficient η_{max} for varying the wall thickness t

d/D	0,08	0,1	0,15	0,2
η_{max}	1,60	1,66	1,66	1,68

From Table 6 it follows that the range of the wall thickness, virtually no effect on the dynamic pressure does not soil the pipes. This is apparently due to the fact that the harmonic wave does not pass into the concrete pipe sufficient stiffness to force the tube.

Conclusions.

1. When the seismic action the mutual influence of concrete pipes installation of a multi-occurs when the distance between them d>4,0D and increases the maximum dynamic earth pressure on them compared with a single pipe (the phenomenon of local resonance) 5-10%.

2.Poyavlenie multiline resonance pipes can be avoided by choosing the distance between the non-multiple seismic wave length of the incident. This resonance phenomenon is a characteristic of a multi-conduit and cannot occur in a pipe arranged in a single thread.

3.Yavlenie local resonance manifests itself more strongly to the seismic action in the form SV - waves than P - wave.

4.Nalichie water in the pipes increases seismic influence on them by 10-20%.

5.Chem denser soil mound, the lower the seismic impact on underground pipes. At l>10D dynamic problem reduces to the quasi-static.

6. Changes in wall thickness and concrete class does not affect the dynamic pressure on the ground reinforced concrete pipe under seismic impacts.

Also built a similar dependence when $\gamma=0$. It is interesting to note that in this problem, increasing the concentration of stress due to the proximity of other field gap is much larger when the wave falls from the side (i.e.$\gamma=0$) , that wave falls from above (i. e. $\gamma=\pi/2$).

7. The maximum dynamic pressure of the soil σ_{max} pipes, arranged in two lines in the region d<3,0D from each other by more than a single tube. This excess is 15%.

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